

An analysis of energy consumption and GHG emissions in some grafted and non-grafted horticultural crops seedlings production in greenhouse

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Abstract: In order to analyze and compare energy consumption and greenhouse gases (GHG) emissions in some horticultural grafted and non-grafted crops seedlings (watermelon, bell pepper, tomato and eggplant) production. This study was designed and carried out in a greenhouse located in Mohammadshahr, Alborz province of Iran. The results showed that total energy consumption for grafted seedlings of watermelon, bell pepper, tomato, and eggplant were 2753347, 2289304, 2261888, and 1958799 MJ per 1 million seedlings (MS⁻¹) and for non-grafted types were 415931, 365433.6, 413881.8 and 436663.81 MJ MS⁻¹, respectively. Average of consumed energy for grafted seedling production was 467.64% more than non-grafted type. The inputs of electricity, plastic and natural gas had the largest share in energy consumption in grafted seedlings production with 44.15%, 27.08% and 25.26%, and on the other hand, the inputs of natural gas, electricity and plastic had the largest share with 47.98%, 35.03% and 8.24%, respectively, in non-grafted seedlings production. The share of consumption of non-renewable energy resources increased from 84.28% for non-grafted seedlings to 96.93% in grafted seedlings due to the greater use of inputs such as plastic and natural gas. The GHG emissions in non-grafted watermelon, bell pepper, tomato, and eggplant seedlings production increased from 21538.61, 19549.72, 21441.77 and 22597.51 Kgco2eq MS⁻¹ to 133257.1, 109510.6, 108537.8 and 93891.4 Kgco2eq MS⁻¹, respectively. The average of GHG emissions in grafted seedlings production was 422.98% higher than non-grafted type.

Keywords: grafted seedling, energy consumption, GHG emissions

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1 Introduction

In order to supply agricultural products for the growing population demand, agricultural crops

production should be increased. Energy, as a driving factor in agricultural operations, has an important role among the inputs of agricultural crops production. Due to the limitations in resources, it is necessary to improve energy productivity in sustainable agriculture systems (Hosseini et al., 2014; Alamouti and Hosseini, 2014). Although the use of energy inputs in agriculture has developed rapidly and brought many benefits, these have negative effects on the environment (Soni et al., 2013). The agricultural

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sector affects the greenhouse gases (GHG) emission in two ways. First, due to the use of inputs (such as fertilizers, plastic, chemicals) based on fossil fuels, agricultural machinery, and burning crops residues, the agricultural sector ranks second with the emissions of about 21% of GHG. Second, the agricultural sector reduces some CO₂, which can reduce GHG emissions (Qiao et al., 2019). To increase energy productivity in agriculture, it is necessary to know and manage the types of energy inputs (Witney, 1988).

Nowadays, grafting technique is considered as an efficient method in increasing the productivity of vegetables and horticultural products. This technique has been used for many years in East Asia to overcome the problems related to intensive cultivation and the limitation of cultivated land in the vegetables production. As a result, many countries in Europe, the Middle East, North Africa, Central America, and other parts of Asia (other than Japan and Korea) have adopted the technology, and the areas introducing grafted plants have increased rapidly in the past three decades (Kubota et al., 2008). 1.2 Mt of watermelon has been produced in Iran in 2022 (FAO, 2023). Also, about 595 Kt of eggplants, about 5 Mt of tomatoes and more than 269 Kt of bell pepper are produced in Iran (Agricultural statistics, 2023). Part of this amount is produced by transplanting seedlings. Based on this, in 2022, more than 824 million seedlings have been produced in Iran, of which more than 94 million seedlings belong to Alborz province. This shows the high speed of grafting cultivation development in the world. The results of several studies show the benefits of using grafted seedlings in vegetables cultivations.

The yield of grafted sweet pepper in the open fields is about 11.5% higher than the non-grafted variety (Rizani et al., 2022). The yield of grafted sweet pepper is 39% higher than non-grafted type in greenhouse conditions (Ropokis et al., 2019).

For better plant protection, grafted seedlings are usually cultivated in controlled climates such as greenhouse. While producing crops with grafted

seedlings increases energy productivity, more energy may be used to produce grafted seedlings compared to the non-grafted type. Fuel for greenhouse heating (natural gas or diesel fuel) has the largest share in energy consumption and GHG emissions for bell peppers production at greenhouse in the cold season (Naderi et al., 2019; Farani and Bahrami, 2013). The grafting technology can be effective to eliminate the effects of unfavorable climatic conditions. The yield of grafted bell pepper in Mediterranean conditions increased by 30% and 50% under non-shaded and shaded conditions, compared to the non-grafted type, respectively (López-Marín et al., 2013).

There are many studies, the results of which indicate an increase in the yield of grafted eggplant (in the greenhouse and in the open-field) compared to the non-grafted type (Musa et al., 2020; Khah, 2011; Gisbert et al., 2011).

Many studies have been conducted on the benefits of producing grafted crops, but there are still limitations in studies to determine energy indices these crops. The energy consumption in the healing and acclimatization stage of watermelon grafted seedling production in two conventional tunnel and vertical systems were compared. The results showed that the energy consumption in the conventional system is five times more than the vertical system. Of course, the results of this study only cover the after seedlings grafting (healing and acclimatization) stage and do not include the total energy consumption in the production of grafted seedlings (Moosavi-Nezhad et al., 2022).

Some of the factors affecting the energy consumption for seedlings production are the production method, region and climate, the type of seedlings and the level of technology used. The energy consumption for non-grafted (normal) tomato, melon and watermelon seedlings production in the Antalya region was measured as 0.28, 0.18 and 0.18 MJ per seedling, respectively (Canakci et al., 2005).

It is necessary to know the equivalent of different inputs (such as seeds, fertilizers, seedlings, electricity), for energy calculations and analysis in

agricultural systems. Due to the limitation in information on the energy equivalent of grafted seedlings, it is difficult or impossible to evaluate the energy indices in grafted crops production. Therefore, this study was planned and carried out to determine the energy consumption and GHG emissions of grafted seedlings of some horticultural crops cultivating (watermelon, tomato, bell pepper, and eggplant).

2 Materials and Methods

This study was planned and carried out to calculate and compare energy consumption and GHG emissions for grafted and non-grafted some horticultural crops seedlings production. The study was carried out in a greenhouse of Ide Pardazane Mazrae Sabze Pars Company, located in Imam Khomeini Higher Education Center and Mohammad Shahr, Alborz Province.

2.1 Specifications of the greenhouse

Scheduling and method of seedling cultivation can be effective in total energy consumption of seedling production. In this study, seedlings were cultivated in late winter and early spring as the region method. The dimensions of the greenhouse were 10 m × 50 m (width × length) of an arched type with a maximum height of 3 meters. The cover of the greenhouse was UV polyethylene. The heating system was a natural gas burner and fan, and its cooling system was fan and pad type. Temperature, relative humidity; heating, cooling and ventilation systems were controlled manually. The seedling production capacity of the greenhouse was 330,000 seedlings per each cultivation period (about 50 days). The scheduling and quantity of each type of cultivated seedling is shown in Table 1.

Table 1 Grafted and non-grafted seedlings cultivation scheduling in greenhouse

Plant	Cultivated seedling quantity			Seedlings cultivation scheduling						
				Grafted seedlings				Non-grafted		
	Rootstock	Scion	Non-grafted	Rootstock planting	Scion planting	grafting	Nursery period	Transfer to farm	Seed planting	Transfer to farm
Watermelon	19950	19950	65100	March, 11	March, 11	April, 4	8 days	April, 19	March, 18	April, 19
Tomato	19950	19950	23100	March, 11	March, 11	April, 4	8 days	April, 17	March, 11	April, 10
Bell pepper	19950	19950	23100	March, 11	March, 16	April, 15	7 days	May, 4	March, 16	April, 30
Eggplant	16800	16800	18900	March, 18	March, 11	April, 12	5 days	April, 21	March, 18	April, 21

2.2 Seedling cultivation

105-hole seedling trays were used to produce seedlings. A mixture of coco peat and perlite (as seed and plant bed) was filled in the holes of the trays by the labores. The seeds were planted manually in the seedling trays according to the schedule shown in Table 1. The trays were immediately irrigated daily after planting. Only in the healing and acclimatization (nursery) stage of grafted seedlings cultivation, the irrigation operation was stopped. Seedlings were grafted manually and using the Splice Grafting method when the size of seedlings were suitable for grafting. The grafted seedlings grew with

conventional tunnel system (CTS) in high relative humidity and moderate temperature climate as a nursery period.

The inputs, including human labor, seeds, fertilizers, biocides, water for irrigation, coco peat, perlite, polystyrene (seedling tray), polypropylene (grafting clips, sticks, green shade), nylon, electricity, and natural gas, were measured and recorded for each seedling type separately.

2.3 Energy consumption

The data was inverted to equivalent energy based on MJ MS⁻¹. Table 2 was used to determine the equivalent energy.

Table 2 Energy equivalent of agricultural inputs

Type of energy	unit	Energy equivalent (MJ unit ⁻¹)	Reference
Human labor	h	1.96	(Singh and Mittal, 1992)
Natural gas	m ³	49.5	(Kitani, 1999)
Biocide			
Insecticide	Kg	115	(Kitani, 1999)
Fungicide	Kg	295	(Kitani, 1999)
Fertilizers			
Nitrogen	Kg	66.14	(Nabavi-Peesaraci et al., 2014)
Phosphate (P ₂ O ₅)	Kg	12.44	(Nabavi-Peesaraci et al., 2014)
Potassium (K ₂ O)	Kg	11.15	(Nabavi-Peesaraci et al., 2014)
Calcium	Kg	8.8	(Moghimi et al., 2014)
Chemicals	Kg	120	(Namdari, 2011)
Microelements	Kg	120	(Rostami et al., 2018)
Plastic	Kg	11.9	(Azizpanah et al., 2020)
Watermelon seed	Kg	1.9	(Rostami et al., 2018)
tomato seed	Kg	1	(Ozkan et al., 2004)
Bell pepper seed	Kg	1	(Ozkan et al., 2004)
eggplant seed	Kg	1	(Ozkan et al., 2004)
Electricity	Kw h	11.93	(Ozkan et al., 2004)
Water for irrigation	m ³	1.02	(Moosavi-Nezhad et al., 2022)
polystyrene	Kg	44	(Moosavi-Nezhad et al., 2022)
perlite	lit	2.96	(Moosavi-Nezhad et al., 2022)
polypropylene	Kg	12	(Moosavi-Nezhad et al., 2022)
nylon	Kg	60	(Moosavi-Nezhad et al., 2022)
Sterilizers	Kg	120	(Kitani, 1999)
Coco peat	Kg	18.6	(Moosavi-Nezhad et al., 2022)

Energy resources in agriculture are divided into two categories, direct and indirect. Direct energy resources (DE) that are used in the production process and include human labor, electricity and natural gas. Indirect energy (IDE) energy consists of energy used for the inputs production and transportation and includes biocides, fertilizers, plastic, seed, water for irrigation, polystyrene, perlite, polypropylene, sterilizer and cocopeat. On the other hand, renewable energy resources consist of human labor, seed and

cocopeat, and non-renewable energy resources includes natural gas, biocides, fertilizers, plastic, polystyrene, perlite, polypropylene, sterilizer, and electricity (Alamouti et al., 2024).

2.4 GHG emissions

In order to compare the pollution resulting from two seedling type (grafted and non-grafted) production, their GHG emissions were measured by the CO₂ emission coefficients of agricultural inputs Table 3.

Table 3 GHG emission coefficients of seedling production inputs

inputs	unit	GHG Coefficient (Kg CO _{2eq} Unit ⁻¹)	Reference
Human labor	h	0.001	(Pishgar-Komleh et al., 2012)
Biocide	Kg	5.1	(Lal, 2004)
Electricity	Kw h	0.608	(Nabavi-Peesaraci et al., 2014)
Phosphate (P ₂ O ₅)	Kg	0.2	(Lal, 2004)
Nitrogen	Kg	1.3	(Lal, 2004)
Potassium (K ₂ O)	Kg	0.2	(Lal, 2004)
Calcium	Kg	2.02	(Liu et al., 2014)
Chemical inputs	Kg	3.28	(Chen et al., 2019)
Plastic	Kg	2.093	(Sinha and Kutnar, 2012)
Natural gas	m ³	2.00	(Kirschen et al., 2009)
poly propylene	Kg	1.97	(Sinha and Kutnar, 2012)
Polystyrene	Kg	3.49	(Sinha and Kutnar, 2012)
Polyvinylchloride	Kg	2.00	(Sinha and Kutnar, 2012)
perlite	lit	10.51	

3 Results and discussion

The total energy consumption for grafted seedlings of watermelon, bell pepper, tomato, and

eggplant were 2753347, 2289304, 2261888, and 1958799, and for non-grafted were 415931, 365433.6, 413881.8, and 436663.81 MJ MS⁻¹, respectively (Figure 1).

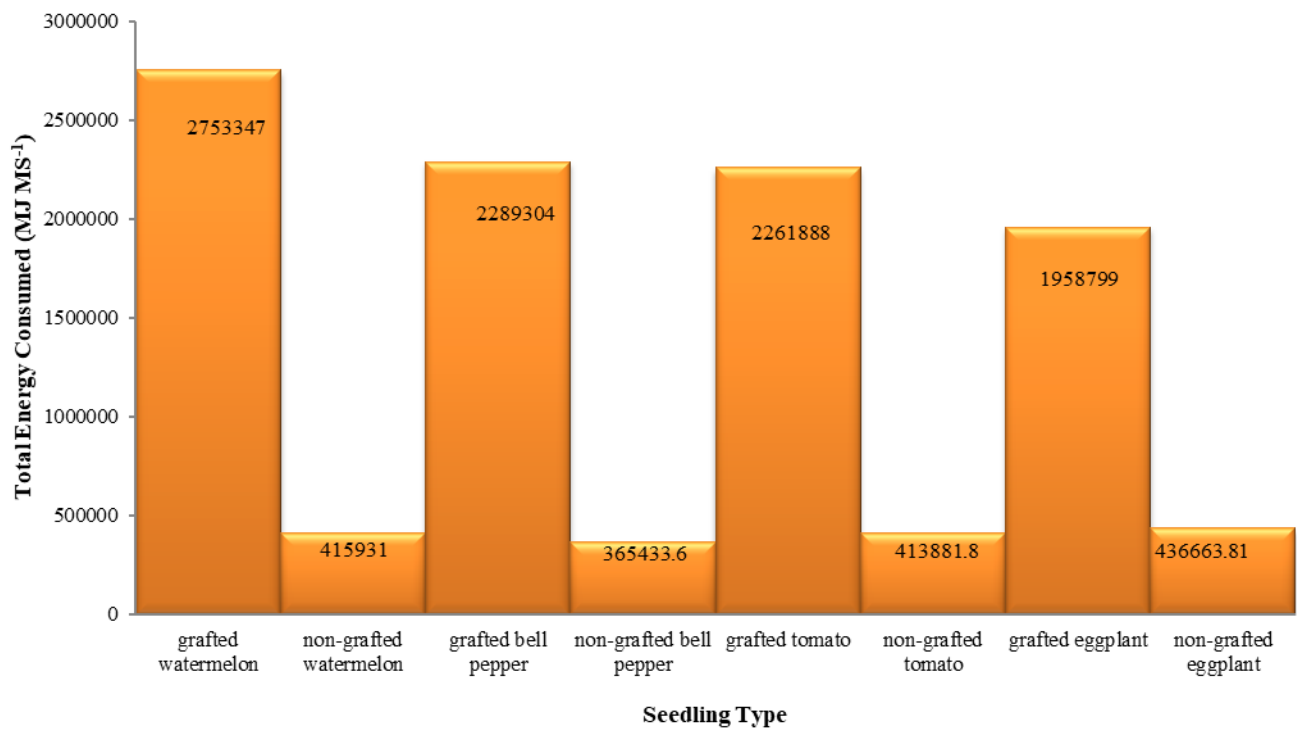


Figure 1 Total energy consumed for some crops seedlings production (MJ MS⁻¹)

The highest shares of energy for grafted seedlings production are related to electricity, plastic and natural gas with 44.15%, 27.08% and 25.26%,

respectively, while for non-grafted seedlings production, natural gas, electricity, and plastic are 47.98%, 35.03% and 8.24%, respectively (Figure 2).

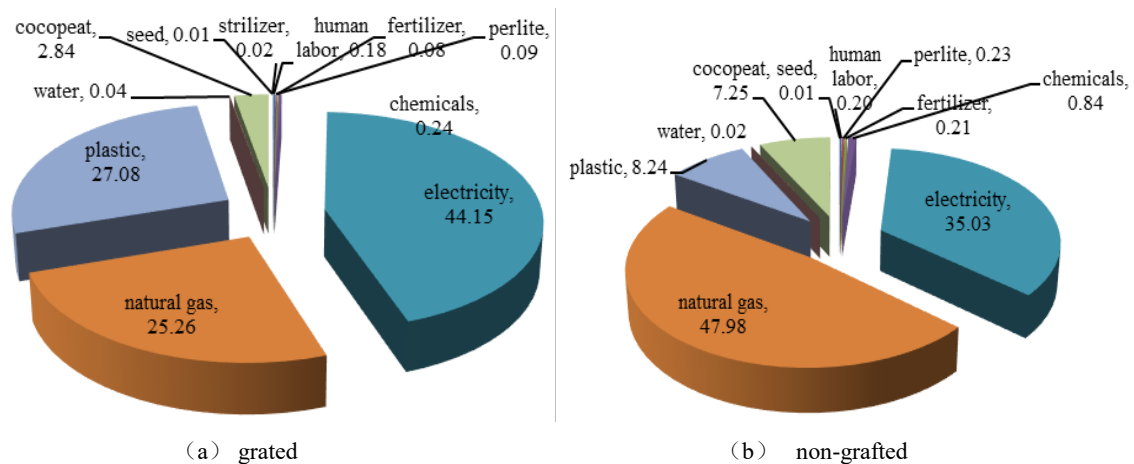


Figure 2 Average share of energy sources in seedling production (%)

Due to the healing and acclimatization stage in grafted seedlings and the need to use a Humidifer to increase relative humidity, the share of electrical energy has increased compared to non-grafted seedlings. Because different methods of healing and acclimatization have different energy consumption, for example, in the CTS, it is five times more than the

vertical system (Moosavi-Nezhad et al., 2022), using more efficient methods of healing and acclimatization systems such as vertical systems can be effective in reducing electricity consumption.

Natural gas was used only to heat the greenhouse. Therefore, the use of efficient heating systems, greenhouse covers with a low heat transfer coefficient,

and seedlings production in non-cold seasons can reduce natural gas energy consumption. In grafted seedlings production, more plastic energy is consumed compared to the non-grafted seedlings production, because plastic devices (such as grafting clips, grafting sticks, and green shade) are used in the grafting and nursery stages. In general, a large part of the energy consumed in greenhouses is related to the heating system and fuels (natural gas or diesel). Therefore, the use of efficient heating systems or the

use of alternative renewable energy resources can reduce energy consumption (Naderi et al., 2019).

The total energy consumption in grafted seedlings production was 69.59% as direct and 30.41% indirect energy. In the non-grafted seedlings production, the share of direct energy was 83.21% and indirect energy was 16.79% (Figure 3). Since in the grafted seedlings production, more inputs were used for grafting operation, compared to the non-grafted seedlings, the share of indirect energy has increased.

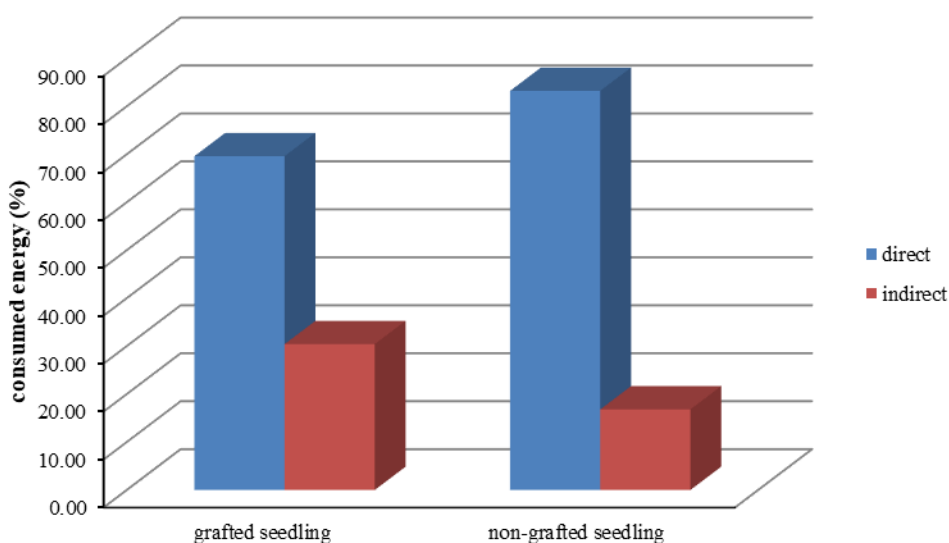


Figure 3 Comparison of direct and indirect energies in the two types of seedlings cultivation (%)

In the non-grafted seedlings production, 7.48% of energy consumption was renewable and 84.28% was non-renewable, while in the production of grafted seedlings, the share of renewable and non-renewable energy was 3.07% and 96.93%, respectively (Figure

4). The most important reason for increasing the share of non-renewable energy in the grafted seedlings production is the use of plastic inputs for seedlings grafting.

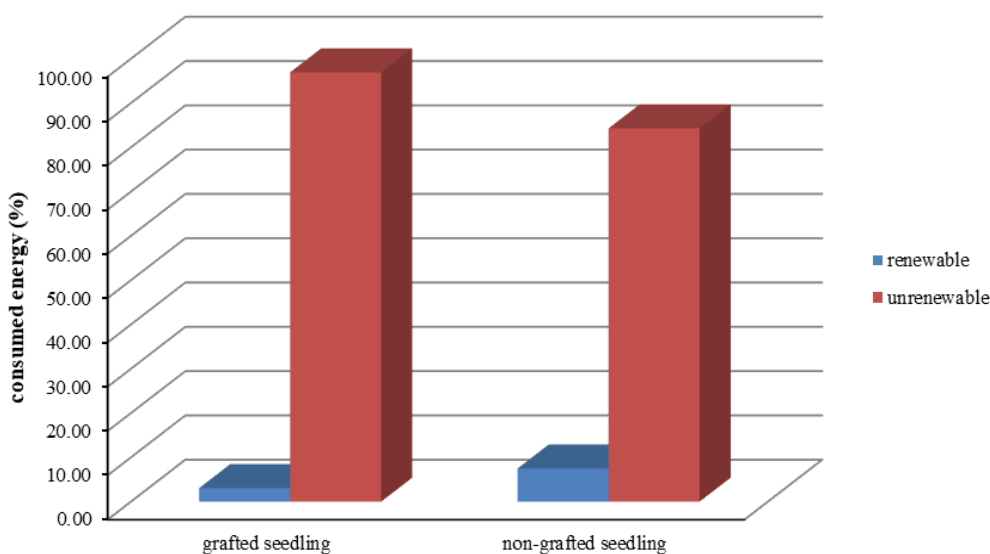


Figure 4 Renewable and nonrenewable energy shares in grafted and non-grafted seedlings production (%)

Since both the amount of energy consumed and the share of non-renewable energy in grafted seedling production increased, GHG emissions were much higher compared to non-grafted seedling production. The GHG emissions in the grafted and non-grafted seedlings production are illustrated in Table 4. In the

grafted seedlings production, due to the fact that the rootstock and scion seedlings are cultivated separately and then grafted, the consumption inputs have increased more than twice compared to non-grafted seedlings, and this has increased their GHG emissions.

Table 4 Comparison of GHG emissions in grafted and non-grafted seedlings production

Seedling Typs	GHG emissions (KgCO ₂ eq MS ⁻¹)		Difference (%)
	grafted	Non-grafted	
wtermelon	133257.1	21538.61	518.68
bellpepper	109510.6	19549.72	460.16
tomato	108537.8	21441.77	406.19
eggplant	93891.4	22597.51	315.49
Average	111299.23	21281.9	422.98

The GHG emissions in the grafted seedlings production (average of watermelon, bell pepper, tomato and eggplant seedlings) was 422.98% higher than that of non-grafted types (Table 4). The average GHG emissions of human labor, perlite, fertilizer,

chemicals, electricity, natural gas and plastic for grafted seedlings the production were 405.63%, 122.22%, 122.23%, 63.95%, 615.55%, 198.85% and 949.6% higher than non-grafted seedlings, respectively (Figure 5).

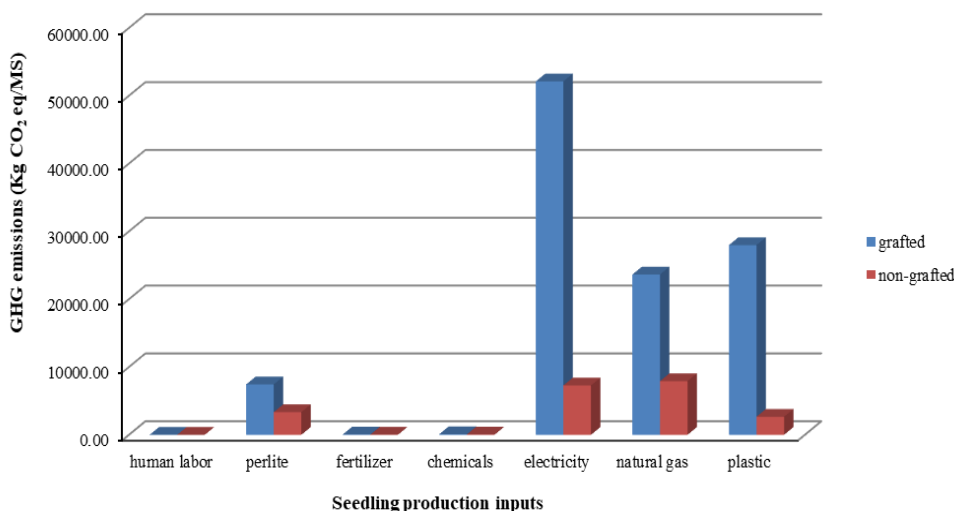


Figure 5 Comparison of the average GHG emission of inputs for the grafted and non-grafted seedlings production (Kg CO₂ eq MS⁻¹)

The most shares in GHG emission for the grafted seedlings production were electricity, plastic and natural gas with 46.82%, 25.13% and 21.24% respectively (Figure 6a). While in the non-grafted

seedlings production, natural gas, electricity and perlite had the highest shares of GHG emissions with 37.16%, 34.22% and 15.71% respectively (Figure 6b).

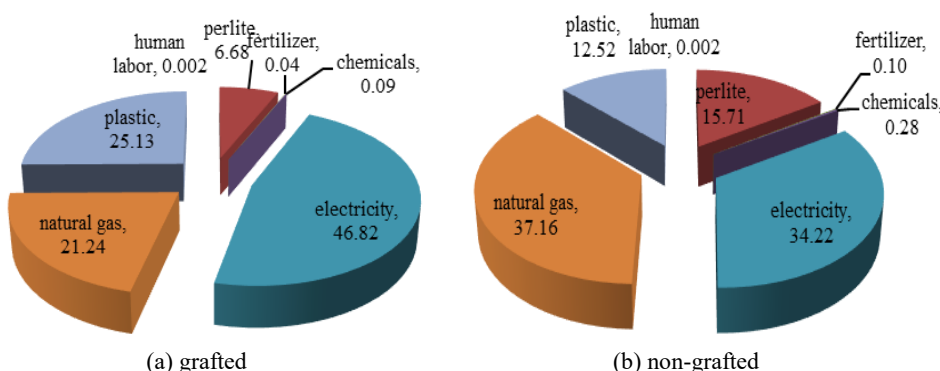


Figure 6 Comparison of the average inputs of GHG emission in the seedlings production (%)

4 Conclusion

In order to calculate and compare the energy consumption and GHG emissions in the grafted and non-grafted seedlings production of watermelon, bell pepper, tomato and eggplant, this study was planned and carried out in a seedling production greenhouse located in Mohammad Shahr, Alborz Province, Iran, at the end of winter and beginning of spring. The results of the study were summarized as follows:

The total energy consumption for grafted seedlings of watermelon, bell pepper, tomato, and eggplant were 2753347, 2289304, 2261888, and 1958799 MJ MS⁻¹, respectively. The total energy consumption in the non-grafted seedlings production of watermelon, bell pepper, tomato and eggplant were 415931, 365433.6, 413881.8 and 436663.81 MJ MS⁻¹, respectively. The average energy consumption in the grafted and non-grafted seedlings production were 2315834.66 and 407977.55 MJ MS⁻¹, respectively, which for grafted seedling production was 467.64% more than non-grafted type.

Although the use of grafted seedlings increases energy efficiency in agricultural crops production compared to non-grafted seedlings, the energy consumption for grafted seedlings production is currently much higher than non-grafted types. The use of more inputs in the healing and acclimatization stage, as well as the cultivation of more seedlings (both rootstock and scions) in grafted seedlings production, are the main reasons for the increase in energy consumption and GHG emissions compared to non-grafted seedlings. Efficient systems of healing and adaptation, such as the vertical system in grafted seedlings production, reduce energy consumption. The inputs of electricity, plastic and natural gas had the largest share in energy consumption in grafted seedlings production with 44.15%, 27.08% and 25.26%, and on the other hand, the inputs of natural gas, electricity and plastic had the largest share with 47.98%, 35.03% and 8.24%, respectively, in non-grafted seedlings production.

The most direct energy used for grafted seedlings production was 55.73% (total natural gas 25.26% and part of electricity 30.46%) to control the climate (temperature and relative humidity) of the greenhouse, and for non-grafted seedlings production was 49.2% (total natural gas 47.98% and part of electricity 1.21%). Therefore, solutions such as producing seedlings in the season (if possible) or regions with moderate temperature, using efficient climate control systems (cooling, heating, ventilation and humidifier systems), using renewable energy resources (such as solar, biomass, wind), the use of suitable greenhouse cover, and compliance with technical points in the design and construction of protected environments (greenhouse, plant factory, etc.) can reduce energy consumption and GHG emissions in seedling production (whether grafted or non-grafted).

The share of consumption of non-renewable energy resources increased from 84.28% for non-grafted seedlings to 96.93% in grafted seedlings due to the greater use of inputs such as plastic and natural gas. Therefore, the GHG emissions in non-grafted watermelon, bell pepper, tomato, and eggplant seedlings production increased from 21538.61, 19549.72, 21441.77 and 22597.51 Kgco2eq MS⁻¹ to 133257.1, 109510.6, 108537.8 and 93891.4 Kgco2eq MS⁻¹, respectively. The average of GHG emissions in grafted seedlings production was 422.98% higher than non-grafted type. Electricity, plastic and natural gas inputs had the largest share in GHG emissions for grafted seedlings production with 46.82%, 25.13% and 21.24%, respectively, while natural gas, electricity and perlite inputs had the largest share in GHG emissions in non-grafted seedlings, respectively.

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