RESEARCH ARTICLE

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Energy balance and greenhouse gas (GHG) emissions of Sauceboat Pepper (*Capsicum annuum* L.) production in Türkiye

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Abstract

In this study, the efficiency of energy consumption and the amount of greenhouse gas emissions from the cultivation of sauceboat pepper were determined. The experiments and research data are based on the 2020 growing season and were conducted in the Karaisali district of Adana province, Turkey. The primary data used in this study, such as the financial system, labor efficiency, fuel consumption levels, weights of tools and machinery used in sauceboat pepper production, fertilizer, and seedling quantities, were obtained from existing calculations, previous studies, and various sources. The energy ratio, specific energy, energy productivity, and net energy in sauceboat pepper were calculated as 0.82, 0.98 MJ kg^{-1}, 1.02 kg MJ^{-1}, and -6845.51 MJ ha^{-1}, respectively. In the case of the sauceboat peppers, the energy of the fuel oil had the highest share of the total energy input, 31.65%. It was followed by energy for planting seedlings, energy for fertilizer, water energy for irrigation, energy for human labour, energy for spraying, and energy for machinery, with 21.55%, 19.64%, 12.55%, 8.59%, 4.45%, and 1.87%, respectively. Total GHG emissions were estimated as 3703.54 kgCO$_{2\text{-eq}}$ ha^{-1} for sauceboat pepper highest-quality production portion in human labour (31.18%). Human labour was followed by diesel fuel consumption (25.79%), machine (0.08%), seedling planting (15.90%), nitrogen fertilizer (15.88%), phosphate fertilizer (4.09%), herbicides (3.68%), fungicides (1.93%), calcium consumption (0.09%), magnesium application (0.08%) and iron (0.52%). In addition, the GHG value for the production of sauceboat peppers was calculated to be 0.096 kgCO$_{2\text{-eq}}$ kg^{-1}.

Keywords: Energy ratio, Sauceboat pepper, Greenhouse gas ratio, Greenhouse gas emissions

INTRODUCTION

Pepper is an indispensable vegetable consumed in many ways all over the world, and its consumption in the form of pastes, spices, pickled vegetables, or fresh vegetables is increasing day by day in parallel with the population. It is also used to make pickles, sauces, and dishes by roasting. Pepper has a very high nutritional value. Fresh green pepper has 29 calories per 100 g, 4.2 g carbohydrates, 1.1 g protein, 0.2 g fat, 93 g water and 1.4 g cellulose. Green peppers are rich in vitamins A, B1, B2 and C and also contain vitamins P and K and alkaloids. The oil content of pepper seeds is 25-28% (Keleş, 2007).

The motherland of pepper is South America, it belongs to the Solanaceae family and the most common variety is called *Capsicum annuum* L. (Keleş 2007). Capia pepper (*Capsicum annuum* L.) has a long, conical shape and is consumed as soon as it turns red. It is also called "sauceboat" or "oil pepper" (Azder et al., 2020).

12,000,000 tons of pepper is produced worldwide, of which about 23% are produced in China, 10% in Turkey, and 9% in Nigeria. Pepper is grown to varying degrees throughout Turkey. According to Turkstat data from 2021, 3.09 million tons of pepper was produced in Turkey. 46.75% of these are capia pepper for pastes, 34.44% are pointed pepper, 13.62% are bell pepper, and 5.19% are Charleston pepper (Turkstat, 2022). In recent years, Turkey's total pepper export was reported to be 97.31 thousand tons and import was 251 tons (Güvenç, 2020).

Although produced and consumed in large quantities, it suffers from yield and quality losses due to plant and soil nutrient deficiencies (Ortaş, 2012). Vegetative nutrient deficiencies are directly related to the plant and soil properties in which it grows (Sabbağ et al., 2015). Pepper (2013) suggested that soil health is equivalent to human health. Therefore, soil quality parameters should be determined in detail and sensitively in agricultural production.

Energy analysis of crop output is critical for describing and categorizing agricultural systems based on energy consumption. To increase efficiency and minimize inputs in production, inputs and outputs should be thoroughly studied (Sabah, 2010). Among agricultural inputs, it is emphasized that the highest price increase in terms of producers is in chemical fertilizers. However, agricultural production with fertilizer programs based on planning and soil analysis in agriculture prevents producers from being adversely affected by rising fertilizer prices (Bellitürk, 2019; Çelik et al., 2020; Kılbacak et al., 2021).

On the other hand, more intensive energy use leads to significant environmental problems such as greenhouse gas (GHG) emissions that affect human health, so the efficiency of productive use of inputs becomes very important for sustainable agricultural production. Greenhouse gas emissions in agricultural production arise from the use of machinery, diesel fuel consumption, use of chemical fertilizers, and electricity consumption, and of course, an increase in energy use leads to an increase in greenhouse gas emissions.

To increase the energy-optimal strategy, either efficiency or input must be increased. In particular, the use of fuel, fertilizers, pesticides, machinery and tractors, which account for a large part of the total energy input, should be reduced. Within certain limits, it is possible to increase efficiency. But energy usage productivity value can be reduced by proper use of inputs (spraying, mechanization and fertilizers) (Çelen, 2016).

A number of studies have been conducted on peppers and some greenhouse products to determine the energy use efficiency, and these studies have evaluated the energy use efficiency of peppers (El-Helepi, 1997; Çanakçı and Akinci, 2006; Farani et al., 2012; Naderi et al., 2019); some greenhouse products (Özkan et al., 2004; Hedau et al., 2014; Nourani and Bencheikh,2017); onion and tomato (İbrahim and İbrahim, 2013); and greenhouse peppers (Çebi et al., 2017), lavender (Gokdogan 2016), plum (Baran et al.,2017), vetch (Baran, 2017), tobacco (Baran and Gokdogan,2015), mulberry (Gokdogan et al., 2017) and canola (Baran et al.,2014). Some other studies have also been conducted on agricultural products to determine the GHG emissions from the production of organic and conventional wheat (Meisterling et al., 2009), organic and diminished vegetable and fruit input practices (Clark et al., 2016), some vegetables (Maraseni et al., 2010), various fruits (Eren et al., 2019a), various field crop varieties (Eren et al., 2019b), and various medicinal aromatic plant varieties (Eren et al., 2019c), onion (Ozbek et al.,2021).

The aim of this study is to investigate the efficiency of energy consumption and greenhouse gas emissions in the production of sauceboat pepper in the Karaisali district of Adana in 2020.

MATERIALS AND METHODS

Explanation of the field of research

This research has been conducted in a farmer's field, 10 decares, that is located 4 km away from Karaisalı district of Adana. The dominant climate in Adana is Mediterranean and the annual average precipitation extending to long years is 644.6 mm and the average temperature is 19,1 °C (Anonymous, 2021b). In the study, the various input amounts used in the production of sauceboat pepper and the output values obtained were taken from different sources (Turkish Statistical Institute as well as previous related or similar studies), and the technical data of agricultural tools and machinery were taken from applications and catalogues in the region. The cultural and care practises employed in pepper production in Adana province are as follows.

Inputs Used in the Study

Pepper seedling planting norm ranges between 2500-5000 pcs/da depending on the type of pepper and the distances between rows. The seedling planting norm in this current study was 4000 pcs/da, the average weight of a seedling was 7.4 gr and yield were 3850 kg/da. The following have been used as fertiliser in the trial area; 10 kg/da pure nitrogen, 15 kg/da pure phosphor, 5 kg/da pure potassium, 3 kg/da pure calcium, 1 kg/da pure iron and 1kg/da pure magnesium. 2 fungicide and 7 insecticide applications have been performed against pest and diseases. In the experimental area, irrigation was done every 4-7 days, depending on the air temperature, sandiness of soil and water demand of the plant both before and after planting seedlings and first irrigation. Although it has been reported in the studies that the average annual water consumption of the pepper plant is between 600-900 mm (Şen, 2015), the average water consumption was calculated as 750 mm/ha. In pepper production, 1 driver was employed in soil cultivation, 1 driver and 1 assistant in bottom fertilization, and 1 worker was employed during irrigation operations. In the harvesting process, 16 workers were employed for an average of 1 ha field for picking peppers.

$$\text{Energy use efficiency} = \frac{\text{Energy output}\left(\frac{MJ}{ha}\right)}{\text{Energy input}\left(\frac{MJ}{ha}\right)} \quad \text{(Eq.1)}$$

$$\text{Energy productivity} = \frac{\text{Pepper output}\left(\frac{kg}{ha}\right)}{\text{Energy input}\left(\frac{MJ}{ha}\right)} \quad \text{(Eq.2)}$$

$$\text{Specific energy} = \frac{\text{Energy input}\left(\frac{MJ}{ha}\right)}{\text{Pepper output}\left(\frac{kg}{ha}\right)} \quad \text{(Eq.3)}$$

Net energy = Energy output (MJ ha^{-1}) - Energy input (MJ ha^{-1}) (Eq.4)

Table 1. Energy equivalents in agricultural production

Inputs	Energy Equivalent (MJ unit^{-1})	References
Human labour (h)	1.96	Davoodi and Houshyar, 2009 Mousavi Avval et al., 2011
Machine production energy (kg)		
Tractor	64.8	Sing, 2002; Özkan et al., 2004
Tillage equipment	62.7	Canakci and Akinci, 2006
Fuel (L)		
Diesel	35.69	Eren, 2011
Oil	6.51	Sabah, 2010
Fertilizers (kg)		
Nitrogen fertilizer	47.10	Kaltcshmitt and Reinhardt, 1997
Phosphate fertilizer	11.1	Hedau et al., 2014
Potassium fertilizer	6.7	Hedau et al., 2014
Calcium	8.8	Naderi et al., 2019
Magnesium	8.8	Naderi et al., 2019
Iron	33.00	Medina et al., 2006
Irrigation water	0.63	Özkan et al., 2004 Hedau et al., 2014
Spraying (kg)		
Insecticides	101.2	Erdal et al., 2007
Fungicides	216	Erdal et al., 2007
Plant material		
Pepper Seedlings	0.20	Bojacá et al., 2012
Output		
Pepper	0.8	Kaltcshmitt and Reinhardt, 1997

Table 2. GHG emission equivalents in agricultural production

Inputs	Unit	GHG emission equivalents (kgCO$_2$-eş unit^{-1})	References
Human labour	h	0.700	Nguyen et al., 2012
Machinery	MJ	0.071	Pishgar-Komleh et al., 2012
Diesel fuel	L	2.760	Clark et al., 2016
Nitrogen (N)	kg	5.88	Clark et al., 2016
Phosphorus (P2O5)	kg	1.010	Clark et al., 2016
Potassium(K2O)	kg	0.580	Clark et al., 2016
Calcium	kg	0.11	Clark et al., 2016
Magnesium	kg	0.30	Anonymous, 2021 b
Iron	kg	1.910	Anonymous, 2021 b
Herbicides	kg	23.100	Maraseni et al., 2010
Fungicides	kg	14.300	Maraseni et al., 2010
Pepper Seedling	kg	1.99	Clark et al., 2016

In this study, the inputs were identified to be human labour energy, equipment energy, fertilizer energy, diesel fuel energy, spraying energy, irrigation water energy, and pepper seedlings. The output was judged to be sauceboat pepper yield. The values of the pepper production inputs were calculated using the units indicated in Table 1. The energy equivalent coefficients were calculated using previous energy analysis research. By summing the energy equivalents of all inputs in MJ units, the total energy equivalent was calculated. "Energy use efficiency equation (1), energy productivity equation (2), specific energy equation (3), and net energy equation (4) were calculated by using the following formulates (Mandal et al., 2002; Mohammadi et al., 2008; Suha et al., 2019)" to determine the energy usage efficiency in sauceboat pepper production.

The units shown in Table 2 represent the inputs for pepper production. When determining the energy equivalent and Greenhouse Gas Emissions coefficients, previous energy balance and greenhouse gas emissions research were considered.

The following equation adopted from Hughes et al. (2011) has been used to determine GHG emission:

$$GHG_{ha} = \sum_{i=1}^{n} R(i) \times EF(i) \qquad \text{(Eq.5)}$$

Here;
$\sum R(i)$: The application rate of input, i ($unit_{input} ha^{-1}$),
EF (i) : The GHG emission coefficient of input i ($kg\text{-}CO_{2\text{-}eq} unit_{input}^{-1}$).

The coefficients of GHG emissions of agricultural inputs are shown in Table 2. However, as adopted by Houshyar et al. (2015) & Khoshnevisan et al. (2014), an index is calculated to measure the quantity of released kg $C_{O2\text{-}eq}$ per kg yield.

$$I_{GHG} = \frac{GHG_{ha}}{Y} \qquad \text{(Eq.6)}$$

Here;
I_{GHG} : GHG ratio,
Y : The yield (kg per ha). as kg per ha.

Table 3. Energy Balance in Sauceboat Pepper Production

Inputs	Units	Input used per hectare (unit ha^{-1})	Energy values (MJ/ha)	Ratio (%)
Human Labour	(h)	1649.69	3233.40	8.59
Tillage		11.42	22.39	
Planting seedlings		358.27	702.21	
Harvest		1280.00	2508.80	
Machinery power	(h)	41.36	702.28	1.87
Tractor		20.68	267.37	
Tillage		11.42	189.64	
Planting seedlings		9.26	245.26	
Fuel + Oil	(l)	346.05	11915.75	31.65
Tillage		124.88	4299.96	
Planting seedlings		221.17	7615.79	
Fertilizers	(kg)	250.00	7392.00	19.64
Nitrogen		100.00	4710.00	
Phosphorus		150.00	1665.00	
Potassium		50.00	335.00	
Calcium		30.00	264.00	
Magnesium		10.00	88.00	
Iron		10.00	330.00	
Spraying	(kg)	10.90	1677.08	4.45
Fungicide		5.00	1080.00	
Insecticide		5.90	597.08	
Planting seedling	(piece)	40000.00	8000.00	21.25
Irrigation water	(m3)	7500.00	4725.00	12.55
Total Input	(MJ ha-1)		37645.51	
Output	(kg / ha)			
Sauceboat Pepper Yield		38500	30800.00	100
Total Output	(MJ ha-1)		30800.00	

Table 3 contains the energy balance results and related computations. Table 4 shows measures of energy balance in sauceboat pepper production. Each parcel's total fuel usage is calculated as l ha-1. The quantity of fuel utilized was calculated using the full tank approach (Göktürk, 1999; El Saleh, 2000; Sonmete, 2006). The total time spent in the trial area determines the labor yield of the area (ha h^{-1}). Sonmete (2006), Güzel (1986), and Özcan (1986) are examples of this. Chronometers are used to track the amount of time spent on various agricultural tasks.

In addition, the direct and indirect energy inputs in the manufacturing of sauceboat pepper were calculated separately. The energy value of gasoline and oil in the manufacturing of tomato paste consumed by agricultural tools and machinery are considered as direct energy input, and the energy values consumed for human labour, agricultural tools and machinery, fertilizer, pesticides and seeds are considered as indirect energy inputs Koçtürk et al., (2009). The pepper production level in Turkey in 2020 was 2 636 905 ton and pepper cultivation in Adana during the same year was 139 793 tons (Anonymous 2021a).

RESULTS AND DISCUSSION

Energy Use Efficiency

The energy balance of sauceboat pepper production in Adana is shown in Table 3 and energy use efficiency values in sauceboat pepper cultivation are listed in Table 4. As shown that in Table 3, 11915.75 MJ ha^{-1} of fuel-oil energy has been consumed and the ratio of this value to the total energy input was 31,65%, making it the highest input. Per 1 ha area, this was followed by seedling planting energy by 8000 MJ ha^{-1} and 21,25%, fertiliser energy input by 7392.00 MJ ha^{-1} and 19,64%, irrigation energy by 4725.00 MJ ha^{-1} and 12,55%, human labour by 3233,40 MJ ha^{-1} and 8.59%, pesticide energy input by 1677.08 MJ ha^{-1} and 4,45%, tool/machine energy by 702,284 MJ ha^{-1} and 1,87%. In sauceboat pepper production, agricultural energy input was calculated as 37645,51 MJ ha^{-1} and agricultural energy output has been calculated as 46400.00 MJ ha^{-1}.

As indicated in Table 4, the energy ratio in sauceboat pepper production in Adana has been calculated as 0.82. While the energy ratio found in this study was 0.82, Naderi et al., (2019) reported the energy rate in red pepper production as 0.004, Çanakçı et al., (2006) determined the energy rate in pepper production as 0.19 and Özkan et al. (2004) found the energy rate in pepper production as 0.99. In other studies, Nourani et al., (2017) reported that the energy ratio of tomato, eggplant, cucumber and pepper was 0.82 in their study in Algeria, and İbrahim and İbrahim found the energy ratio of tomato as 0.20 in their study in Nigeria and Çebi et al., (2017) found the energy ratio in greenhouse head salad as 2.29.

Table 4. Energy use efficiency values in sauceboat pepper cultivation

Indicators	Unit	Values
Energy Ratio	-	0.82
Specific Energy	MJ kg-1	0.98
Energy Productivity	kg MJ-1	1.02
Net Energy Efficiency	MJ ha-1	-6845.51

Net energy efficiency (MJ ha^{-1}) is defined as the difference between the total amount of energy obtained after production and the total amount of energy utilized in production operations (Baran et al., 2016). Energy efficiency, expressing the amount of product yield per energy use per unit area, was found to be 1.02 kg / MJ, while specific energy, expressing the amount of energy used per product, was found to be 0.98 MJ / kg (Table 4). In other similar studies; Kuswardhani et al., (2013) determined the energy efficiency in open lettuce production as 0.69 kg / MJ and specific energy as 1.45 MJ / kg, Çebi et al., (2017) figured out energy efficiency as 2,86 kg/MJ and specific energy as 0.35 MJ/kg in greenhouse lettuce cultivation, while Razavinia et al., (2015) determined energy efficiency as 1.67 kg/MJ and specific energy as 0.595 MJ/kg in lettuce cultivation. With regards to sauceboat pepper production under Adana conditions, net energy efficiency has been estimated as 8754.49 MJ ha^{-1}, when only number of seeds taken from unit cultivation area (ha) was taken into consideration.

Table 5. Energy inputs for sauceboat pepper production

Indicators	Energy input (MJ ha^{-1})	Ratio (%)
Direct energy[a]	15149.15	40.24
Indirect energy[b]	22496.36	59.76
Total	37645.51	100.00
Renewable energy [c]	11233.40	29.84
Non-renewable energy [d]	26412.11	70.16
Total	37645.51	100.00

[a] Human labour energy, fuel-oil energy;
[b] Seed energy, chemical fertilizer energy, pesticide energy, machine energy;
[c] Human labour energy, seed energy;
[d] Fuel-oil energy, agricultural insecticide energy, chemical fertiliser energy, machine energy

Table 5 depicts the distribution of inputs utilized in the manufacturing of sauceboat pepper according to direct, indirect, renewable, and non-renewable energy categories. The distribution of direct energy in total energy was found to be 40.24%, the indirect energy component of total energy was determined to be 59.76 percent. Renewable energy sources are inexhaustible energy sources and their most important feature is that they are energy sources that do not harm the nature. Non-renewable energy sources, on the other hand, are limited, energy resources that can be exhausted, and the vast majority of them harm the environment (Çebi et al., 2017). In the research area, renewable energy accounted for 29.84 percent of total energy used in pepper production, whereas non-renewable energy accounted for 70.16 percent of total energy. Due to the limited usage of machinery in

Table 6. Total GHG emissions in sauceboat pepper cultivation

Inputs	Unit	The input used per area (unit ha^{-1})	GHG Emissions (kg CO_2-eş ha^{-1})	Ratio (%)
Human Workforce	h	1649.69	1154.78	31.18
Machine	MJ	41.36	2.94	0.08
Diesel Fuel	l	346.05	955.09	25.79
Nitrogen (N)	kg	100.00	588.00	15.88
Phosphorus (P_2O_5)	kg	150.00	151.50	4.09
Potassium	kg	50.00	29.00	0.78
Calcium	kg	30.00	3.30	0.09
Magnesium	kg	10.00	3.00	0.08
Iron	kg	10.00	19.01	0.52
Herbicide	kg	5.90	136.29	3.68
Fungicide	kg	5.00	71.50	1.93
Seedling	kg	296	589.04	15.90
TOTAL	-	-	3703.54	100.00
GHG Ratio (per kg)	-	-	0.096	

pepper production and low energy consumption from non-renewable energy sources, the renewable energy ratio in total energy is low.

Greenhouse Gas (GHG) Emission

The outcomes of GHG emissions of regarding the productions of sauceboat pepper are given in Table 6. Total greenhouse gas emission is calculated as 3703.51 kg$CO_{2\text{-eq}}$ ha^{-1}. The highest share of total GHG emissions belongs to human workforce (31.18%). Human workforce is followed by diesel fuel consumption (25.79%), seedling planting (15.90), nitrogen fertilizer (15.88%), phosphate fertilizer (4.09%), herbicide (3.68%), fungicide (1.93%), potassium (0.78%), calcium (0.09%) and magnesium (0.08%). The GHG ratio (per kg yield) is determined as 0.096 kg$CO_{2\text{-eq}}$ kg^{-1}. In other similar studies, Yousefi et al. (2013) has reported the total greenhouse gas emission in pepper cultivation as 14390.85 kg$CO_{2\text{-eq}}$ ha^{-1}, Tongwane et al. (2016) reported the total greenhouse gas emission in tomato cultivation as 34.251 kg$CO_{2\text{-eq}}$ ha^{-1} and the ve GHG ratio as 1.65 kg$CO_{2\text{-eq}}$ kg^{-1}, and they reported it as 165.368 kg$CO_{2\text{-eq}}$ ha^{-1} in potato cultivation and GHG ratio as 1.48 kg$CO_{2\text{-eq}}$ kg^{-1}, Elhami et al. (2016) have reported the total greenhouse gas emission in chickpea as 6884.14 kg$CO_{2\text{-eq}}$ ha^{-1} and GHG ratio as 3.03 kg$CO_{2\text{-eq}}$ kg^{-1}, while Eren et al. (2019) reported the following GHG emission values in different types of fruits; GHG emission in organic grape 1452.75 kg$CO_{2\text{-eq}}$ ha^{-1} and GHG ratio 105 g$CO_{2\text{-eq}}$ kg^{-1}, GHG emission in apple as 3722.33 kg$CO_{2\text{-eq}}$ ha^{-1} and GHG ratio as 0.092 kg$CO_{2\text{-eq}}$ kg^{-1}, GHG emission in watermelon as 1402.01 kg$CO_{2\text{-eq}}$ ha^{-1} and GHG ratio as 0.077 kg$CO_{2\text{-eq}}$ kg^{-1}, GHG emission in cantaloupe as 1141.24 kg$CO_{2\text{-eq}}$ ha^{-1} and GHG ratio as 0.041 kg$CO_{2\text{-eq}}$ kg^{-1}, GHG emission in plump as 930.20 kg$CO_{2\text{-eq}}$ ha^{-1} and GHG ratio as 0.146 kg$CO_{2\text{-eq}}$ kg^{-1}, GHG emission in pomegranate as 438.33 kg$CO_{2\text{-eq}}$ ha^{-1} and GHG ratio as 0.146 kg$CO_{2\text{-eq}}$ kg^{-1} and GHG emission in organic strawberry as 8226.35 kg$CO_{2\text{-eq}}$ ha^{-1} and GHG ratio as 0.783 kg$CO_{2\text{-eq}}$ kg^{-1}.

CONCLUSION

In this research, sauceboat pepper production energy usage efficiency and GHG emission were calculated in the 2020 production season in Karaisalı district of Adana province. The energy ratio in enterprises engaged in the production of sauceboat pepper production was found to be 0.82. As a result of the calculations, it is seen that fuel-oil energy has the highest share among the production inputs, followed by seedling planting, irrigation, fertilizer, human, medicine and machine labour energies, respectively. Total GHG has been defined. The highest energy consumption in fuel-oil input is seen in soil tillage, cultivation and other processes. In addition, seedling planting took the second place and fertilizer energy took the third place in energy consumption. For this reason, it is thought that different and alternative tillage methods and fertilization methods should be investigated for the reduce of the fuel oil input and fertilizer energy in sauceboat pepper production. Another important conclusion to be drawn from this study is that fertilization programs must be applied according to soil analysis in order to make the correct fertilization. Such research discloses crucial results in terms of both the scientific world and agricultural production in terms of protecting farmers from being negatively affected by price rises in production inputs, which are mostly caused by oil prices.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest

The authors declared that for this research article, they have no actual, potential or perceived conflict of interest.

Author contribution

The contribution of the authors to the present study is equal. All the authors read and approved the final manuscript. All the authors verify that the Text, Figures, and Tables are original and that they have not been published before.

Ethical approval

Ethics committee approval is not required.

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Data availability

Not applicable.

Consent for publication

Not applicable.

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