ARTICLE | **OPEN ACCESS**

Discovery Agriculture

Energy input-output analysis cost for tomato production in Turkey

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To Cite:
Ismailla IS, Miassi YE, Akdemir S, Dossa KF. Energy input-output analysis cost for tomato production in Turkey. *Discovery Agriculture* 2024; 10: e16da1581
doi: https://doi.org/10.54905/disssi.v10i22.e16da1581

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Peer-Review History
Received: 16 April 2024
Reviewed & Revised: 20/April/2024 to 25/June/2024
Accepted: 29 June 2024
Published: 03 July 2024

Peer-Review Model
External peer-review was done through double-blind method.

Discovery Agriculture
pISSN 2347-3819; eISSN 2347-386X

DISCOVERY SCIENTIFIC SOCIETY

ABSTRACT

This study, conducted in Elazig with the Turkish Ministry of Agriculture, aims to quantify the energy and costs associated with tomato production. This analysis aims to improve efficiency, reduce production costs, and improve production profitability. Data collection involved surveys and questionnaires, supplemented by focus groups to verify information. The study covers the entire tomato production process, highlighting the energy inputs and outputs associated with tomato cultivation. The results reveal that the energy inputs associated with tomatoes vary according to production altitude. At 30 m altitude, the energy input is 5914.83 MJda-1. The increases to 6982.62 MJda-1 at 75 m, 8414.48 MJda-1 between 75-150 m, and 9240.36 MJda-1 at 150 m and above. Irrigation is the most energy-intensive stage, accounting for 36.28% of total energy consumption. Other activities, such as sowing and transporting produce to market, also contribute significantly to energy consumption. The primary energy sources used in tomato production include 29% direct energy, 17.05% indirect energy, 18.31% renewable energy, and 35.63% non-renewable energy. Total production costs, including variable and fixed costs, vary with altitude, affecting the cost of production per kilogram and net income. Lower altitudes generally produce higher net revenues and benefit-cost ratios, indicating greater profitability. It is, therefore, vital to optimize irrigation methods to reduce energy consumption and production costs. Strategies such as efficient irrigation systems and alternative water sources can contribute to the sustainability and improved profitability of tomato cultivation.

Keywords: Elazig, Energy efficiency, Energy use, Sustainability, Tomato.

1. INTRODUCTION

Energy input-output analysis, often abbreviated as EIOA, is used to examine energy flows within an economy or system. It quantifies energy inputs and outputs across various sectors, shedding light on their energy utilization and efficiency. The expenses linked with EIOA studies can fluctuate based on factors like analysis scope, complexity, and data availability. Within agriculture, energy input-output analysis entails quantifying the energy inputs required and the energy outputs attained in production systems. It facilitates the evaluation of energy efficiency, sustainability, and the overall environmental impact of agricultural practices. However, there are associated costs when conducting energy input-output analysis in agriculture.

Energy input-output analysis cost for tomato production in Turkey involves assessing the energy consumption and associated costs throughout the production process, including land preparation, seedling production, planting, irrigation, fertilization, pest management, harvesting, and transportation. It also considers the energy needed to manufacture inputs like machinery, fuel, and fertilizers. The tomato sector plays a crucial role in Turkey's agricultural, making a high contribution to the economy. Tomatoes hold significant value in Turkey, cultivated and consumed locally and in export markets. The sector employs a substantial portion of the rural population, contributing to livelihoods and rural development. Turkey is among the top producers of tomatoes globally. According to the latest available data, Turkey produced approximately 12.8 million tonnes of tomatoes in 2022.

The total area dedicated to tomato cultivation in Turkey covers approximately 171,000 hectares, representing one of the largest single-crop areas in the country. The yield of tomato production in Turkey varies depending on the region and cultivation practices. On average, the yield is about 75 tonnes per hectare. This high yield results from the favorable climatic conditions, fertile soils, and advanced agricultural practices employed by Turkish farmers. Turkey is a significant exporter of tomatoes, supplying fresh and processed tomatoes to various countries worldwide. In 2022, Turkey exported over 500,000 tonnes of fresh tomatoes, generating considerable foreign exchange earnings. Major export destinations include European countries, Russia, and the Middle East. On the import side, Turkey imports a relatively small quantity of tomatoes, primarily to meet specific market demands or during off-season periods (Trade, 2023). Energy management is a critical aspect of tomato production in Turkey.

Efficient energy use can lead to substantial cost savings, improved productivity, and reduced environmental impact. Key areas where optimization of energy management can be focused include irrigation, greenhouse climate control, fertilization, and harvesting (Agricultural Production Report, 2023). Advanced irrigation methods like drip irrigation can notably decrease water and energy usage. Optimal water management ensures plants receive the precise quantity of irrigation needed, enhancing quality and yield while preserving water resources. In regions where tomatoes are cultivated in greenhouses, it is crucial to have efficient climate control systems. These systems manage temperature, humidity, and CO2 levels, ensuring optimal growing conditions. Energy-efficient climate control systems can reduce energy consumption and lower production costs (OECD, 2023). Precision agriculture techniques can optimize the use of fertilizers, reducing both energy input and environmental impact.

By monitoring soil nutrient levels and applying fertilizers only as needed, farmers can improve crop yield and quality while conserving energy. Mechanized harvesting can enhance efficiency and reduce labor costs. Energy-efficient machinery and equipment contribute to overall energy savings in the production process (World Bank, 2023). The tomato sector's contribution to the national economy through employment, income generation, and export earnings underscores its importance. Improving energy management can enhance the sector's profitability and sustainability. With growing concerns about climate change and resource depletion, optimizing energy use in agriculture is crucial. Efficient energy management can reduce the carbon footprint of tomato production and promote sustainable agricultural practices (OECD, 2023). This analysis provides a comprehensive understanding of tomato production's energy usage and costs, identifying opportunities to enhance efficiency.

Such analysis is crucial for developing sustainable agricultural practices that balance economic, social, and environmental aspects. Farmers and policymakers can make well-informed decisions by identifying the primary energy consumers and associated costs. These decisions may involve adopting more efficient production practices, integrating renewable energy sources, and formulating energy policies that promote sustainable agriculture. The study's primary objectives are to quantify the energy requirements at various stages of tomato production (e.g., land preparation, planting, irrigation, fertilization, pest control, harvesting, and transportation) and calculate the associated production costs to assess the economic viability of tomato cultivation in Turkey. Overall, this analysis offers valuable insights to agricultural decision-makers, enabling them to enhance system efficiency, reduce costs, and boost profitability.

2. METHODOLOGY

Elazig, situated in Eastern Anatolia, Turkey, is a province known for its diverse geography, featuring mountains, plateaus, and rivers (Figure 1). Specifically, it is located within the Kuzova region. The coordinates for Elazig are 38.6743° N latitude and 39.2233° E longitude.

Figure 1 Map of Elazig Province
Source: World map, 2022

The study was conducted at the Agricultural Experiment Station of the Turkish Ministry of Agriculture in Elazig Province, involving the participation of agricultural experts and engineers. Elazig's agricultural experimental site was chosen due to its prominence as one of the significant tomato-producing regions with exceptional performance records. Engineers and agronomy specialists overseeing the tomato production area at the experimental site were surveyed through a questionnaire totaling 35 participants. Additionally, we formed five focus groups, each comprising approximately seven engineers and specialists, to corroborate the data obtained from individual interviews. Tomato production experts then correlated this data with production statistics and the technical approaches adopted. The analysis encompasses the entire tomato production process from seed to harvest or a specific production stage.

Upon data collection, various energy inputs, including labor, fuel, fertilizer, pesticides, and electricity, along with their respective quantities, were documented. Standardize all input to energy units, such as megajoules (MJ). Additionally, energy outputs representing the energy content in the harvested tomatoes were calculated (Kaya and Kahraman, 2014). Energy inputs, such as seeds, fertilizers, pesticides, herbicides, and mechanical energy for tomato production, were quantified. Subsequently, the data is analyzed to determine the energy efficiency of the tomato production system. These studies provide a solid foundation for understanding the energy dynamics in agricultural production systems and offer methodologies that are applied to assess energy efficiency in tomato production (Ozkan et al., 2004; Gündoğmuş, 2006; Hatirli et al., 2006). Table 1 presents these sources and coefficients.

A mathematical model was employed to calculate energy efficiency, computed by dividing the energy output by total energy inputs. A cost analysis was conducted, converting input quantities into corresponding costs using market prices. The findings from both the energy input-output analysis and cost analysis served to identify opportunities for improving energy efficiency and reducing costs. Environmental aspects, such as greenhouse gas emissions and water consumption, were considered, and potential strategies for mitigation were evaluated. In addition, the energy input-output analysis for tomato production in Turkey involved quantifying the energy required to produce a specific tomato yield. Inputs encompassed labor, fertilizers, pesticides, irrigation, machinery fuel, and other materials.

Outputs were measured in energy units, such as joules or calories, and in monetary terms by assessing input costs and tomato yield revenue. Energy inputs are categorized as direct and indirect, renewable and non-renewable. The energy resources employed in agricultural production are calculated using the parameters detailed in (Table 2). Once they determined the energy quantities for each farming operation, they calculated the economic performance indicators, drawing inspiration from (Akdemir et al., 2023; Ozkan et al., 2004; Houshyar et al., 2017). This process included calculating gross output value, net revenues, and production profit-cost ratios, for which the following equations:

$$\boldsymbol{Total\ production\ value} = \boldsymbol{Corn\ yield}\ (\boldsymbol{kgda^{-1}}) \times \boldsymbol{Corn\ price}(\ \$\boldsymbol{kg^{-1}})$$

$$\boldsymbol{Net\ return} = \boldsymbol{Total\ production\ value}\ (\ \$\boldsymbol{ha^{-1}}) - \boldsymbol{Total\ production\ cost}\ (\ \$\boldsymbol{ha^{-1}})$$

$$\boldsymbol{Benefit - cost\ ratio = Net\ return\ (\$ha^{-1})\ /Total\ production\ cost\ (\$ha^{-1})}$$

These calculations provided insights into the economic viability and efficiency of tomato production.

Table 1 Energy equivalents of inputs and outputs

Items	Unit	Energy content (MJunit-1)	Reference
Human labor	h	1.96	Houshyar et al., (2017) ; Akdemir et al., (2023)
Machinery			
Tractor 50 kw	h	41.4	Khoshnevisan et al., (2014)
Plough	h	22.8	
Sprayer	h	23.8	
Wagon	h	71.3	
Pump	h	2.3	
Fertilizers			
N	Kg	60.60	Singh, (2002)
P	kg	11.1	
K	Kg	6.7	
Insecticides	Kg	278	Dalgaard et al., (2001)
Fungicides	Kg	276	Graefe et al., (2013)
Farmyard manure (dry matter)	Kg	0.3	Mohammadi et al., (2014)
Diesel	1	56.31	Dyer and Desjardins, (2006); Pimentel and Pimentel, (2007)
Electricity	kwh	11.93	Mandal et al., (2002)
Water for irrigation	m3	0.63	Houshyar et al., (2017)
Fruit	Kg	2.4	Strapatsa et al., (2006)

Table 2 Energy forms

Energy forms	Inputs	References
Direct energy	Human, diesel, electricity	Akdemir et al., (2023); Ramesh et al., (2022)
Indirect energy	Fertilizers, chemicals, machinery, seeds	
Renewable energy	Human, seeds	
Non-renewable energy	Diesel, electricity, chemicals, fertilizers, machinery	

3. RESULTS AND DISCUSSION

Table 3 illustrates the energy requirements for tomato cultivation in Turkey at varying altitudes. The energy equivalents in MJ per decare (da) were calculated for each input, such as plowing, sowing, fertilizing, hoeing, spraying, irrigating, harvesting, and transporting to market. The results reveal that energy consumption in the farms under scrutiny varies with altitude, measuring 5914.83 MJda-1 at 30m, 6982.62 MJda-1 at 75m, 8414.48 MJda-1 at 75-150m, and 9240.36 MJda-1 at 150m and above. An indicates a direct correlation between altitude and energy demand for grain production. Specifically, energy requirements per decare for tomatoes were

5914.83 MJda-1 at 30 meters, 6982.62 MJda-1 at 75 meters, 8414.48 MJda-1 at 75 to 150 meters, and 9240.36 MJda-1 at 150 meters and above. According to, the primary energy-intensive process is irrigation, with energy demands at altitudes of 150 meters or more exceeding those at 30 meters by over double.

This highlights that a significant portion of the energy required for high-altitude tomato cultivation is due to irrigation. Higher-altitude tomato farming's elevated energy input can potentially lead to increased production costs. However, it's crucial to consider factors like yield, water accessibility, and market prices in the cost-benefit analysis. In a study by the total energy input for tomato production per hectare was 89,548 MJda-1with irrigation and fertilizers being the most energy-consuming components. The estimated total production cost per hectare was $4,764. Similarly, reported a total energy input of 45,733.55 MJda-1 for tomato production, with irrigation and fertilizer application being the dominant energy consumers. It's worth noting that these findings contrast with study on greenhouse cucumber production, which reported a significantly lower total energy input of 16,079 MJda-1, with electricity being the primary energy-consuming factor. The total production cost was 946.09 $/ha, with labor costs being the highest.

Moreover, investigated apple production, revealing a total energy input of 22,718.6 MJ/ha, with diesel fuel as the primary energy expenditure. The total production cost was 5070.58 $/ha, with fertilizer costs being the most significant. In a separate study, Tipi et al., (2009) found that wheat production had a total energy input of 11,307 MJda-1, with diesel fuel as the primary energy consumer. The total production cost was 872.14 $/ha, with labor costs being the highest. Lastly, conducted a cost and profitability analysis of tomato production in Antalya province, Turkey, revealing a total production cost of 7019.20 $/ha, with labor costs as the most significant expense. The average profit per hectare for tomato production was 3345.75 $/ha. These results demonstrate methods for evaluating agricultural production economically and energetically across different contexts. The mean energy input for tomato production is 7200 MJda-1. This indicates that tomato production requires a significant amount of energy input, particularly in irrigation.

Table 3 Energy use of tomato production

Energy equivalent (MJda-1)					
Input		**30m**	**75m**	**75-150m**	**150m+**
Plowing	1	315.46	315.46	315.46	315.46
	2	157.73	157.73	157.73	157.73
	3	157.73	157.73	157.73	157.73
Sowing	Machinery Rent + labor	297.46	297.46	297.46	297.46
	Seed	29.75	29.75	29.75	29.75
	Fertilizer (DAP)	640.56	640.56	640.56	640.56
Top Fertilization	Machinery Rent + labor	8	8	8	8
	Fertilizer (NPK)	654.2	654.2	654.2	654.2
Hoeing	Machinery Rent + labor	105.15	105.15	105.15	105.15
	Labor	13.06	13.06	13.06	13.06
Spraying	Machinery Rent + labor	31.66	31.66	31.66	31.66
	Drug Value (Insecticides)	528.2	528.2	528.2	528.2
Irrigation Cost+ (Fuel or Energy) + Labor		1189.95	2257.74	3689.6	4515.48
Harvest	-	556.84	556.84	556.84	556.84
Carrying to Market		1229.08	1229.08	1229.08	1229.08
Total	-	5914.83	6982.62	8414.48	9240.36
Energy means	-	7200	-	-	-

Table 4 illustrates that irrigation is the most energy-intensive stage, representing 36.28% of the total energy consumption, on average, across all altitudes, following closely sowing (13.04%) and transporting goods to market (16.56%). At all altitudes, such as hoeing, spraying, top fertilization, and harvesting collectives, contribute to less than 10% of the total energy consumption, notably, the distribution of energy usage shifts with altitude. At higher altitudes, a more significant portion of the energy is allocated to irrigation, while sowing and transporting goods to market consume relatively less energy. The highlights that irrigation is the primary energy-demanding process in tomato production that varies with altitude. The findings from Table 2 underscore the importance of enhancing irrigation methods to reduce energy consumption in tomato cultivation. For decrease, potential strategies might involve implementing more efficient irrigation systems or exploring alternative water sources. Additionally, improving the efficiency of activities such as transportation to markets and sowing can further reduce energy consumption and production costs in the tomato industry.

Table 4 Tomato production energies Equivalent

Energy equivalent (MJda-1) (%)					
Input	**30m**	**75m**	**75-150m**	**150m+**	**Mean**
Plowing	10.66	9.03	7.49	6.82	8.50
Sowing	16.36	13.85	11.5	10.47	13.04
Top Fertilization	11.19	9.48	7.86	7.16	8.92
Hoeing	2.04	1.73	1.45	1.32	1.63
Spraying	9.46	8.01	6.65	6.05	7.54
Irrigation	20.11	32.33	43.84	48.86	36.28
Harvest	9.41	7.97	6.61	6.02	7.50
Carrying to Market	20.77	17.6	14.6	13.3	16.56
Total	100	100	100	100	100

Table 5 presents the breakdown of energy input for tomato production. It reveals that 29% of this energy is derived directly, while 17.05% comes indirectly. Additionally, renewable energy accounts for 18.31%, while non-renewable energy makes up 35.63%. Non-renewable energy sources include human labor, farmyard manure, seeds, equipment, diesel fuel, chemical fertilizers, biocides, and irrigation water. To improve sustainability and reduce dependence on non-renewable energy, increasing the use of renewable energy sources. The main contributor to energy use accounts for 29% of the total direct energy. Among direct energy sources, non-renewable energy dominates, constituting 35.63% of the overall energy consumption.

Renewable and indirect sources contribute 18.31% and 17.05%, respectively, to the total energy consumption. This study reveals a slightly lower percentage of direct energy use and a higher share of renewable energy compared to the findings of (Ozkan et al., 2004). Additionally, the energy input distribution in Hatirli et al., (2006) is similar, although their study reported a slightly higher percentage of direct and renewable energy. It is imperative to reduce reliance on non-renewable energy sources and promote the adoption of renewable alternatives to enhance sustainability in tomato production.

Table 5 Energy forms used in tomato production.

Energy forms	**30m**		**75m**		**75-150m**		**150m+**		
	MJda-1	**%**	**MJda-1**	**%**	**MJda-1**	**%**	**MJda-1**	**%**	**Mean**
Direct energy	1381.69	23.35	1901.15	27.22	2637.2	31.34	3150.22	34.1	29
Indirect energy	1178.7	19.92	1356.67	19.45	1302.06	15.47	1235.98	13.4	17.05
Renewable energy	1272.31	21.53	1450.28	20.76	1395.64	16.6	1329.09	14.4	18.31
Non-renewable energy	2082.13	35.2	2274.52	32.57	3079.58	36.59	3525.07	38.2	35.63
Total	5914.83	100	6982.62	100	8414.48	100	9240.36	100	100

Table 6 presents the input costs in ($/da) for various planting distances. The total input cost encompasses plowing, sowing, fertilization, hoeing, spraying, irrigation, harvesting, transportation to the market, other expenses, general administration expenses, and field rent. The highest input cost occurs with a 150m+ planting distance, totaling 182 $/da, while the lowest is at 30m, amounting to 138 $/da. Similarly, the findings of Esengun et al., (2007) indicated that input costs were influenced by planting density, with more intensive planting increasing costs due to higher input requirements. These parallels the higher input costs observed at the 150m+ planting distance in tomato cultivation. This disparity primarily results from the increased irrigation cost, which is imperative for more considerable planting distances.

As planting distances expand, so does the demand for irrigation, causing a significant hike in irrigation costs. Moreover, other expenses and general administration expenses rise correspondingly. Conversely, field rent expenses decrease as planting distance increases. These costs are tied to farm management and land utilization, which increase with greater planting distances. The cost analysis indicates that input costs per decare increase with planting distance, mainly because of higher irrigation costs. Notably, the cost of plowing 1 surpasses that of plowing 2 and 3 due to the initial deep plowing. However, input costs for sowing, fertilization, hoeing, spraying, harvesting, and transportation to the market remain nearly consistent across all planting distances.

Table 6 Cost analyzes input cost.

Input cost ($/da)					
		30m	**75m**	**75-150m**	**150m+**
Plowing	1	6	6	6	6
	2	3	3	3	3
	3	3	3	3	3
Sowing	Machinery Rent + labor	8	8	8	8
	Seed Cost	37.5	37.5	37.5	37.5
	Fertilizer Cost	13.6	13.6	13.6	13.6
Top Fertilization	Machinery Rent + labor	0.4	0.4	0.4	0.4
	Top Fertilizer Cost	8.48	8.48	8.48	8.48
Hoeing	Machinery Rent + labor	2	2	2	2
	Labor	16	16	16	16
Spraying	Machinery Rent + labor	1.6	1.6	1.6	1.6
	Drug Value (Insecticides)	7.6	7.6	7.6	7.6
Irrigation Cost+ (Fuel or Energy) + Labor		18	35	44	70
Harvest		28	28	28	28
Carrying to Market		24	24	24	24
Other expenses		3.54	3.88	4.06	4.58
General Administration Expenses		3.61	3.96	4.14	4.67
Field Rent (Field Rent)		30	26	24	22
Total		138	151	158	182

Table 7 displays the cost analysis and benefit-cost ratio for tomato production across different field altitudes. The price per kilogram is 0.16 $/Kg, with an expected yield of 3000 kg/da. Variable costs, encompassing expenses for irrigation, fertilization, hoeing, spraying, and other inputs like plowing and sowing, are influenced by the field's altitude. The variable costs are as follows: 180.72 $/da (30m), 198.06 $/da (75m), 207.24 $/da (75-150m), and 233.76 $/da (150m+). General administration expenses remain minimal, ranging between $3.61 and $ 4.67. The cost of renting the agricultural land per $/da for each production unit. It accounts for the expense incurred in leasing the land for agricultural purposes. Fixed costs, which include field rent, machinery depreciation, and interest charges, these decrease as field elevations decrease, ranging from 33.61 $/da to 26.67 $/da.

The highest cost corresponds to the largest field with the highest altitude. Total production costs, encompassing variable and fixed costs, fluctuate between 214.33 $/da and 260.43 $/da. The cost of production per kilogram varies from 0.072 $/Kg to 0.086 $/Kg, with the highest cost linked to the highest elevations of the more significant field. Net income, which represents the disparity between production value and total production costs, ranges from 265.55 $/da to 219.56 $/da, with lower field altitudes yielding the highest net income. The benefit-cost ratio, which indicates the relationship between net income and total production expenses, varies from 1.23 to 0.84. A benefit-cost ratio exceeding one implies that the benefits surpass the costs, indicating the profitability of tomato production at different altitudes.

This finding contrasts with the results of Akdemir et al., (2023), who reported that the benefit-cost ratio is less than one for all field altitudes. That indicates that production costs exceed the revenue generated, rendering the production unprofitable. The table indicates that as the field altitude rises, the revolving fund interest, total production costs, production cost per kilogram, and benefit-cost ratio tend to increase, while net income decreases. That suggests that higher altitudes may incur higher costs and lower profitability than lower altitudes for tomato production under these specific conditions.

Table 7 Cost analysis and benefit-cost ratio

	Unit	**30m**	**75m**	**75-150m**	**150m+**
Yield	(kg/da)	3000	3000	3000	3000
Price	($/Kg)	0.16	0.16	0.16	0.16
Production Value	($/da)	480	480	480	480
Revolving Fund Interest	-	9.03	9.90	10.36	11.68
Total changing costs	($/da)	180.72	198.06	207.24	233.76
General Administration Expenses	($/da)	3.61	3.96	4.14	4.67
Field Rent (Field Rent)	($/da)	30	26	24	22
Total fixed costs	($/da)	33.61	29.96	28.14	26.67
Total production costs	($/da)	214.33	228.02	235.38	260.43
Production cost	($/Kg)	0.072	0.076	0.078	0.086
Net Income	($/da)	265.55	251.97	244.61	219.56
Benefit-cost ratio	-	1.23	1.10	1.03	0.84

4. CONCLUSION

The findings support the assumption that tomato production at higher altitudes involves more energy used for irrigation. In contrast, energy consumption for sowing and transportation to the market is comparatively lower. Improving irrigation techniques and other inputs could help reduce energy consumption and production costs. The primary energy source in tomato production is direct energy, accounting for 35.63% of total energy use. To improve sustainability and reduce reliance on non-renewable energy sources, increasing the utilization of renewable energy sources is essential. Additionally, ensuring that irrigation techniques in tomato production suit the local climate and altitude is crucial for adequate water consumption. This study offers valuable insights into the energy efficiency and cost-effectiveness of tomato production in Turkey, guiding future strategies to lower energy consumption and production costs.

Acknowledgment

We thank the participants who all contributed to the study.

Author Contributions

Ismailla IS: Data collection and analysis, Writing - original draft, Writing - review & editing; Miassi YE: Writing - review & editing, Sampling & investigation; Akdemir S: Data collection, Writing - review & editing, material support, guides; Dossa KF: Writing - review & editing, Sampling & investigation.

Informed consent

Written & Oral informed consent was obtained from individual participants included in the study.

Conflicts of interests

The authors declare that there are no conflicts of interests.

Ethical approval

Not applicable.

Funding

The study has not received any external funding.

Data and materials availability

All data associated with this study are present in the paper.

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