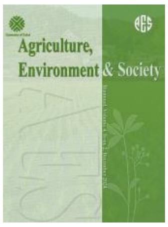
Agriculture, Environment & Society (2025) Volume 5, Issue 1, P. 45-57

Agriculture, Environment & Society

Journal homepage: www.aes.uoz.ac.ir



Unveiling the most sustainable date production systems in Mirjaveh, Iran: an emergy-based approach

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ARTICLE INFO

Article history:
Received: 9 May 2024
Accepted: 21 February 2025
Available online: 10 June 2025

Keywords:
Emergy value of money
Environmental inputs
Exchange
Export
Sustainable agriculture

ABSTRACT

This study aimed to identify the most sustainable production system for Mazafati and Rabbi date palm cultivars in Mirjaveh County, Iran, during 2022-2023. Data pertaining to cultivated area, date palm production and yield, export volume, as well as the environmental and economic inputs necessary for production, were gathered through documentary and survey methods. These data were then analysed for the two study systems. The input elements were subsequently transformed into emergy equivalents, sej. The data collected indicates that the total emergy needed to sustain the Mazafati and Rabbi date palm production systems was 3.33E+16 and 2.92E+16 sej/ha/yr, respectively. The majority of inputs for both the Mazafati and Rabbi date palm production systems came from purchased sources, making up 92.69% and 71.68% of the total inputs, respectively. The findings suggest that both systems impose substantial environmental burdens as a result of their lack of utilisation of renewable resources and heavy dependence on non-renewable inputs. Hence, it is imperative and inevitable to decrease the utilisation of these resources in both date palm systems. Based on the emegy exchane ratio and emergy to money ratio indices, the Mazafati date palm system demonstrated higher values, indicating greater economic sustainability compared to the Rabbi system. Conversely, the emergy yield ratio was higher for the Rabbi date palm, suggesting that this system is more sustainable than Mazafati date palm production in terms of product yield. Overall, the Mazafati date palm system demonstrated a slight edge in terms of economic, commercial, and ecological sustainability.

Highlights

- Mazafati dates use 3.33E+16 sej/ha/yr, Rabbi 2.92E+16 sej/ha/yr in Mirjaveh, Iran.
- Purchased inputs dominate: 92.69% for Mazafati, 71.68% for Rabbi dates.
- Mazafati excels in economic sustainability (EER 4.460) over Rabbi (3.391).
- Rabbi shows higher yield sustainability (EYR 1.455) than Mazafati (1.430).
- Both systems strain environment, need less non-renewable input reliance.

1. Introduction

Over the past few decades, scientists in the field of agriculture have become more focused on clean production and environmental protection as the foundation for sustainable development. This shift in attention is a result of the growing awareness of the environment and the demand for sustainable agricultural practices (Gheicari et al., 2021; Amiri et al., 2022). Given the circumstances, it is crucial to meticulously plan and oversee agricultural ecosystems, as sophisticated systems can guarantee both sustainable and desirable production (Fallahinejad and Armin, 2022). Due to the abstract nature of sustainability, it is not feasible to directly measure it. Therefore, simpler criteria are needed to assess agricultural and agroecosystem

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https://doi.org/10.22034/jelsa.2025.456534.1064

sustainability (Shahhoseini and Kazemi, 2022).

The impact of energy consumption on various aspects such as food security, agricultural sustainability, community health, and ecosystem functions and services is widely acknowledged (Kazemi et al., 2018; Kohkan et al., 2017). Indicators based on changes in capital value have been developed to assess and compare the sustainability of different agricultural systems. Indicators used to evaluate the sustainability of agricultural systems should fulfil specific criteria, as outlined by Brown and Ulgiati in 1997. Initially, it is imperative that they exhibit consistency and conformity with one another, while also adhering to predetermined objectives for the advancement of sustainable agricultural practices. Consistency and absence of contradictions are essential for ensuring the reliability of the indicators. Furthermore, it is crucial that the indicators are precise, effectively capturing the intricacies of sustainability in agricultural systems with an adequate level of specificity. In order to be practical, data collection for these indicators should be quantifiable, indicating that it can be easily and economically carried out. Ultimately, in order to achieve widespread acceptance, the indicators must possess user-friendly characteristics and be specifically crafted to facilitate unambiguous comprehension by farmers, policymakers, and all pertinent stakeholders. The foundation of all these characteristics is the necessity for data of superior quality. For the sustainability assessment to be valid, the calculations of indicators must rely on valuable and reliable input data.

An assessment of these indicators in various agricultural ecosystems allows for the identification and quantification of their environmental, economic, and sustainability effects. The outcomes of these evaluations can provide valuable insights for farmers and local decision-makers in determining the most effective strategies for optimising resource utilisation and promoting sustainable agriculture (Jafari et al., 2018). Emergy analysis has become a useful tool for developing environmental policies and evaluating resource quality in complex environmental and economic systems over the last thirty years (Brown and Ulgiati, 1997).

The numerous emergy measurement indicators offer a more comprehensive understanding of the extent of resource renewability, the proportion of renewable and non-renewable resources, and the impact of environmental and market inputs on the overall emergy of a system (Odum, 2000). Emergy indicators can be utilised to precisely evaluate the capacity, renewability, environmental stress, and overall sustainability of a system, considering both environmental and economic aspects. Emergy analysis is a useful tool for measuring the sustainability of various agricultural systems within a shared framework. It helps identify the most environmentally sustainable system (Asgharipour et al., 2020).

Several studies have employed emergy analysis to assess the sustainability of various agricultural systems. For instance, Asgharipour et al. (2021) evaluated the sustainability of four greenhouse vegetable production systems (cucumber, tomato, bell pepper, and eggplant) in Iran. They found that the cucumber production system was the most sustainable, primarily due to its efficient use of free environmental energy and lower reliance on non-renewable inputs. Similarly, Amiri et al. (2021) investigated the sustainability of different beef cattle production systems in the Sistan region of Iran. Their study highlighted the importance of balancing economic and environmental factors in agricultural production. They concluded that a semi-intensive production system for Sistani cattle could provide a sustainable and economically viable option for livestock farmers in the region.

Developing countries prioritise achieving rapid economic growth, and exports are crucial in driving this growth and promoting economic prosperity (Frankel and Romer, 1999). Given the circumstances, it is crucial to implement export development strategies, specifically focusing on boosting non-oil exports. Agricultural exports make a substantial contribution to increasing farmers' incomes, alleviating poverty, and improving overall livelihood and economic well-being at the national level. Iran, being one of the leading exporters of dates worldwide, is encountering a notable obstacle in the form of a decreasing share of exports to the European Union market, which happens to be its most crucial export destination, despite its efforts to increase its presence in the global market.

The fluctuation in prices of agricultural products has consistently been a significant concern for agricultural economists and policymakers. According to Rafiei and MirBagheri (2017), a broader range of these fluctuations leads to more severe negative outcomes, resulting in significant losses primarily for farmers and ultimately for society as a whole. While certain economists highlight the notable effectiveness of exports, there have been concerns raised regarding the potential rise in energy consumption and subsequent environmental pollution linked to the expansion of exports. Hence, it is imperative to conduct a comprehensive empirical analysis of the correlation between exports and energy in order to develop suitable trade and environmental policies (Sadorsky, 2012).

Over the next 50 years, agricultural production in developing countries is expected to experience significant growth. This growth will result in a two- to threefold increase in the consumption of nitrogen and phosphorus, a doubling of water demand, and a tripling of pesticide use, as stated by Tilman et al. in 2001.

Iran confronts a multitude of environmental challenges, such as water scarcity, droughts, population growth, and rising demand for food production. Developing a more profound comprehension of sustainability among planners and policymakers is essential in effectively tackling these challenges. Assessing the level of sustainability and making informed choices to improve it are crucial for the country's long-term development (Nazarian et al., 2020).

The date palm is a prominent horticultural commodity in Iran, consistently ranking between third and sixth place in terms of export value in recent years. This product has substantial potential to generate foreign exchange for the country (Pejman, 2001). Nevertheless, a considerable proportion of date palm production and its derivatives in

Iran rely on conventional techniques and encounter multiple deficiencies throughout the production process and palm cultivation operations, resulting in a detrimental effect on the ultimate product's quality. In order to fully maximise food production capacities, it is crucial to effectively oversee the entire production chain, spanning from the initial production stages to the final consumption. This requires establishing the essential circumstances to optimise the country's capacity for food production (Alipour and Mahdavi, 2014).

Due to its favourable climatic conditions, Mirjaveh County in Sistan and Baluchestan Province is regarded as one of Iran's most suitable regions for date production. This region cultivates a wide variety of dates, such as Mazafati, Rabbi, Zardān, Piyū, Sang Shekan, Āshey, Shāhān, Helilī, and Dezk. Out of these different types, Mazafati and Rabbi dates are particularly esteemed for their exceptional quality. The provinces of Sistan and Baluchestan, specifically the counties of Saravan and Mirjaveh, are acknowledged as the primary cultivators of Mazafati dates in Iran. Furthermore, this particular region is the exclusive cultivator of the distinct Rabbi variety within the nation. Mazafati dates are highly sought after in the domestic market due to their exceptional quality and flavour.

They hold a prominent position in the overall production of Mazafati dates in the country. Rabbi dates, known for their distinct attributes including a chocolatey consistency, partial dryness, long shelf life, ability to be washed, deep and vibrant colour, elongated form, and small seed, are in high demand in international markets. Traders predominantly purchase and export the majority of this product to foreign countries (Mollazehi, 2013).

This study utilised an emergy-based methodology to accomplish the following aims: (a) Determine the most environmentally friendly date palm production system between the Mazafati and Rabbi cultivars grown in Mirjaveh County, Iran during the period of 2022-2023. The assessment of sustainability will involve a comprehensive evaluation of both environmental and economic factors. (b) Assess the environmental consequences of both systems by examining their dependence on renewable resources versus non-renewable inputs. (c) Assess the economic feasibility of each system using emergy yield ratio (EER) and emergy material ratio (EMR). The study aims to provide valuable insights for policymakers and date palm producers by accomplishing these objectives. The provided data can be utilised to advance sustainable methodologies and enhance the efficient utilisation of resources in the Iranian date palm industry. This will ultimately contribute to ensuring food security and improving environmental well-being.

2. Materials and Methods

2.1 Study Area

The objective of this study was to monitor the production of date palms in Mirjaveh County, located in Sistan and Baluchestan Province, throughout the cropping year of 2021-2022. Mirjaveh County is situated in the eastern part of Sistan and Baluchestan Province and shares a border that spans more than 350 kilometres with Pakistan. The county shares borders with Pakistan to the northeast, east, and southeast. It also borders Zaranj County to the north and west, and Khash County to the south and southwest. The county spans across an expansive area of more than 6,000 square kilometres and is situated at an elevation of 858 metres above sea level.

Mirjaveh is classified as one of the most arid regions in the country, with an average annual precipitation of only 30 millimetres. The climate in the central region of the county is characterised by high temperatures, low humidity, and a desert-like environment. Nevertheless, as a result of the significant altitude variation of more than 2,200 metres between the central part and the Ladiz section, this particular area experiences a more temperate climate and greater precipitation. The heights in the Ladiz section are sufficiently covered with snow during winter.

2.2 Data Collection

Data on various facets of date palm production in the region were gathered to carry out this research. This encompassed data regarding the acreage dedicated to cultivating date palms, the total output and productivity of dates, and the rate of exporting date products. In addition, information regarding the environmental and economic resources needed for date production was collected. The data were gathered through a combination of documentary research, analysis of existing records, and survey methods, which involved directly obtaining information from pertinent sources.

To ensure the robustness of our findings, we collected data from a representative sample of date palm orchards in Mirjaveh County. The sample size was determined based on statistical considerations and practical constraints. We aimed to capture the diversity of production systems and environmental conditions within the region. Specifically, we sampled 87 Mazafati date palm orchards and [insert number] Rabbi date palm orchards.

Initially, the inputs provided to the agricultural systems were transformed into emergy equivalents. Agricultural ecosystems can be classified into two distinct categories: purchased inputs and free environmental inputs. The purchased inputs encompass commodities such as electricity, fuel, agricultural machinery, fertilisers, pesticides, and other industrial products. On the other hand, environmental resources that are not restricted or limited are referred to as free environmental inputs. These include sunlight, soil, organic matter, wind energy, chemical energy, irrigation water potential, and rain.

Both systems were assessed for capital allocation and post-harvest product performance. The fair selling price of date palm products was determined using the emergy exchange ratio indicator. This method involves converting the flows associated with the sale of date palm products and the corresponding monetary transactions into emergy units, and then calculating their ratio. This ratio denotes the emergy transfer that occurs during a transaction or purchase. Furthermore, to assess the pros and cons in relation to the cost incurred for dates, the emergy of the money obtained from date sales was also computed.

2.3 Emergy Analysis

Step 1: Defining the Scope and Drawing Energy Diagrams

To begin the process of emergy analysis, it is necessary to establish the specific time and spatial limits for both systems being studied. Additionally, energy diagrams should be created to classify the inputs of the systems being assessed into categories such as renewable or non-renewable, environmental or imported sources (Odum, 2000). Energy diagrams are crucial for managing the connections between important system components and productive processes. They illustrate the environmental foundations of the system and the relationships between them.

Figure 1 displays the cumulative emergy flow diagram for the Rabbi and Mazafati date palm production systems. Agricultural systems derive inputs from two primary sources: environmental inputs and purchased inputs. The diagrams depict the extent of the production system, with environmental inputs on the left, purchased inputs at the top, and the beneficial output of the production systems on the right.

Step 2: Classifying Inputs

When analysing production systems, inputs are categorised into four distinct categories according to Lu et al. (2010).

Renewable environmental resources (R) encompass natural elements such as sunlight, wind, rain, and river water.

Non-renewable environmental resources (N) refer to resources that are not capable of being replenished, such as those related to soil erosion and the processes involved in soil formation and ground water.

Purchased renewable resources (FR): encompassing seeds, and organic fertilisers procured externally to the system.

Purchased non-renewable resources (FN): such as fertilisers, pesticides, machinery, etc.

The machinery's emergy consumption was determined by considering the quantity of steel employed, the machines' ideal lifespan, and the annual working hours (Asgharipour et al., 2019). The emergy of the consumed saplings was calculated using the emergy coefficient per unit of currency, as described by Jafari et al. (2018). The raw data was calculated in joules, grammes, or rials after estimating the input (U) and output (Y) flows for each production system, following the emergy standards in Iran (Amiri et al., 2019; Asgharipour et al., 2020).

Various emergy indices are used for emergy analysis, which is aimed at conducting environmental and economic assessments (Lu et al., 2010).

This study utilised various indices to assess different aspects of the system. These indices included the transformity (Tr), specific emergy (Se), percentage of emergy renewability (%R), emergy yield ratio (EYR), emergy investment ratio (EIR), environmental load ratio (ELR) and its modified version (ELR*), environmental sustainability index (ESI) and its modified version (ESI*), emergy exchange ratio (EER), emergy index of producti safety (EIPS), and the emergy to money ratio (EMR). Asgharipour et al. (2020) provided the descriptions and formulas for the emergy indices used in this research.

This study aimed to conduct a detailed analysis of the production and services carried out in both the Rabbi and Mazafati date palm production systems. To achieve this, all input and output values were multiplied by their respective conversion factors. This enabled the conversion of various units into a standardised unit, simplifying the computation of emergy ratios and indices.

Emergy indices serve as efficient tools for assessing the pressure and harm imposed on different systems. Furthermore, these indices have the ability to offer a thorough depiction of the functional attributes of the production system in terms of utilisation and sustainability (Campbell et al., 2005).

Choosing suitable indices for ecosystem evaluation is crucial. The chosen indices in this study are considered the most dependable indicators for assessing ecosystems (Cheng et al., 2017).

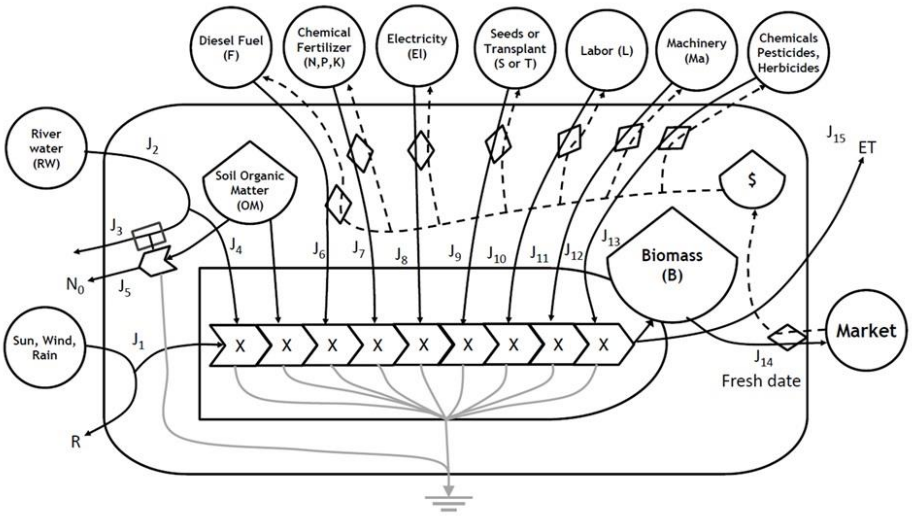

Figure 1. Emergy flow diagram of Mozafati and Rabi date production systems in Mirjaveh city

Table 1 displays the formulas and calculation methods of the emergy indices utilised for assessing the performance of research systems. By utilising these indices, it is possible to make a more precise comparison and analysis of the performance of the two production systems for Rabbi and Mazafati date palms.

Table 1. Specifications and formulas of the emergy-based indicators used to evaluate Mozafati and Rabbi date production systems in Mirjaveh city (Asgharipour et al., 2020)

Index	Formula	Specifications	Reference
Renewable inputs from free local resources	R	Renewable environmental flows	By definition
Non-renewable environmental inputs	N	Non-renewable environmental flows	By definition
Renewable purchased inputs	F_R	Renewable flows from purchased resources	By definition
Non-renewable purchased inputs	F_N	Non-renewable purchased flows	By definition
Transformity	$Tr = U / AE$	Amount of emergy required to produce an output unit in joules. AE is the energy content.	(Brown and Ulgiati, 2004)
Special Emargy	$SE = U / PW$	Amount of emergy required to produce an output unit in grams. AE is the energy content.	(Brown and (Ulgiati, 2004)
Renewable emergy ratio	$\%R = R+F_R / U\times100$	Percentage of the renewable energy used by the system	(Odum, 2000)
Emergy yield ratio	$EYR = U / F_N+F_R$	Ability of a process to use renewable and nonrenewable environmental resources with economic resources as a capital	(Odum, 2000)
Emergy investment ratio	$EIR = F_R+F_N/R$	EIR is the ratio of emergy resources purchased from outside to all free environmental emergy in the system.	(Brown and Ulgiati, 2004)
Modified Emergy Investment Ratio	$= F_N+F_R /R\ EIR^*$	The adaptation rate of investment in product production is compared with environmental resources received for free.	(Amiri et al., 2019)
Environmental loading ratio	$ELR = N+F_N / R+F_R$	Environmental pressure produced by a process	(Lu et al., 2017)
Modified Environmental Loading Ratio	$ELR^* =F_N+N / R+F_R$	An inverse measure of sustainability	(Lu et al., 2017)
Emergy Sustainability Index	$ESI = EYR / ELR$	The dependence of the system output on the environment, the greater the value, the stronger the sustainability of the system	(Lu et al., 2017)
Modified Emergy Sustainability Index	$ELR^*\ ESI^* = EYR/$	Alternate sustainability index that focuses on the use of renewable resources with minimal pressure on the environment.	(Lu et al., 2017)
Emergy Exchange Ratio	$EER = U/YM$	Economic output (A system yield) traded with money in the market (YM) on total emergy input rate (U).	(Odum, 1996)
Emergy Money Ratio	$EMR = U/\text{net profit}$	Emergy investment per dollar of net profit	By definition
Emergy index of product safety	$EIPS=1 - [C/ (F_N + F_R)]$	It assesses the effect of chemical fertilizer, pesticide and herbicide use on product safety	(Xi and Qin, 2009)

3. Results and Discussion

3.1 Input Emergy Structure

Table 2 displays the movement of natural resources and purchased inputs within the production systems of Rabbi and Mazafati dates. The inputs listed in this table have been computed using coefficients associated with solar energy over the course of the year. Additionally, the inputs have been categorised as either renewable or non-renewable, depending on their renewability percentages. Furthermore, the total energy of the systems has been converted to solar energy (sej).

The total emergy input for the production systems of Mazafati and Rabbi dates in Mirjaveh county were 3.33E+16 and 2.92E+16 sej/ha/yr respectively (Table 3). The Mazafati date production system had a higher total emergy consumption compared to the Rabbi date production system. This was primarily because the Mazafati system used more non-renewable inputs that were purchased.

As a result, the Mazafati date production system consumed a greater amount of emergy compared to the Rabbi date production system. The seedlings accounted for the highest proportion of emergy in the Mazafati date production system, contributing 19.47 percent or 6.49E+15 sej/ha/yr. Nitrogen fertiliser was the second highest contributor, accounting for 14.83 percent or 4.94E+15 sej/ha/yr.

The study by Fallahinejad et al. (2021) reported the total supportive emergy for wheat production system as 2.32E+16, for barley as 1.91E+16, for sugar beet as 4.95E+16 sej/ha/yr. The supportive emergy for the production systems of wheat, garlic, and onion was 2.45E+16, 3.12E+16, and 4.73E+16 sej/ha/yr, respectively. As a result, the garlic production systems had an emergy consumption that was approximately 90 percent greater than the wheat production systems and 50 percent greater than the onion production systems (Yasini et al., 2020). Amiri et al. (2021) focused on comparing the sustainability of various shallot production systems, including a natural habitat, a mechanized system, and a conservation system. In contrast, our study aimed to compare the sustainability of two specific date palm cultivars, Mazafati and Rabbi, under different production systems.

The production systems of Mazafati and Rabbi dates in Mirjaveh county have been classified into four categories based on the types of inputs they receive: renewable environmental free inputs (R), non-renewable environmental free inputs (N), purchased inputs (FR & FN).

3.1.1 Renewable Environmental Inputs (R)

Renewable environmental resources encompass solar energy, wind energy, the chemical energy of precipitation, and freshwater from rivers. In the production systems for Mazafati dates, the inputs accounted for 0.21 percent of the total input energies, while for Rabbi dates, they accounted for 0.24 percent (Table 3). The proportion of these inputs was greater in the Rabbi date production system in comparison to the Mazafati date production system. The study conducted by Jafari et al. (2018) determined that in Nehbandan county, the renewable environmental inputs for date and pistachio production systems were estimated to be 13.8 percent and 10.4 percent, respectively. The study conducted by Moonilall et al. (2020) found no significant variation in the quantity of renewable environmental resource inputs across different maize cultivation production systems.

Table 2. Natural and economic flows of Mozafati and Rabbi production systems in Mirjaveh city

	Unit	Mazafati	Rabbi
Renewable environmental inputs			
Solar energy	J	3.6E+13	3.6E+13
Wind, kinetic energy	J	2.25E+09	2.25E+09
Rain, chemical	J	1.51E+09	1.51E+09
River water	J	1.15E+11	9.99E+10
Non-renewable environmental inputs			
Groundwater	J	2.89E+11	2.51E+11
SOM reduction	J	2.06E+10	2.06E+10
Soil erosion	g	1.82E+06	1.82E+06
Purchased inputs			
Human labor	J	4.88E+08	4.29E+08
Machinery	g	6.42E+03	6.42E+03
Fossil fuel and lubricant	g	3.21E+10	3.21E+10
Nitrogen fertilizer	g	1.60E+05	1.45E+05
Phosphorus fertilizer	g	1.25E+05	9.50E+04
Potash fertilizer	g	5.50E+04	3.50E+04
Micro fertilizer	g	2.50E+03	2.50E+03
Earth emergy	Rials	3.72E+15	3.72E+15
Organic fertilizer	g	2.00E+06	1.70E+06
Sapling	Rials	9.60E+07	7.15E+07
Outpu			
Economic yield	g	3.25E+06	3.75E+06
Economic yield	J	3.82E+09	4.41E+09

Table 3. Emergency analysis and input structure in Mozafati and Rabbi production systems in Mirjaveh city (sej/ha/yr)

Items	Mazafati			Rabbi	
	Emergy/Unit	Emergy	%	Emergy	%
Renewable environmental inputs					
Solar energy	1.00E+00	3.60E+13	0.11%	3.60E+13	0.12%
Wind, kinetic energy	1.24E+03	2.79E+12	0.01%	2.79E+12	0.01%
Rain, chemical	2.34E+04	3.54E+13	0.11%	3.54E+13	0.12%
River water	3.61E+04	4.16E+15	12.48%	3.61E+15	12.34%
Subtotal	2.34E+04	7.14E+13	0.21%	7.14E+13	0.24%
Non-renewable environmental inputs					
Groundwater	2.34E+04	6.76E+15	20.29%	5.88E+15	20.13%
SOM reduction	4.27E+04	8.80E+14	2.64%	8.80E+14	3.01%
Soil erosion	1.27E+09	2.31E+15	6.93%	2.31E+15	7.91%
Subtotal		9.96E+15	29.87%	9.07E+15	31.05%
Purchased inputs					
Human labor	2.22E+06	1.08E+15	3.25%	9.52E+14	3.26%
Machinery	1.01E+10	6.48E+13	0.19%	6.48E+13	0.22%
Fossil fuel and lubricant	8.60E+04	2.76E+15	8.28%	2.76E+15	9.45%
Nitrogen fertilizer	3.09E+10	4.94E+15	14.83%	4.48E+15	15.33%
Phosphorus fertilizer	2.82E+10	3.53E+15	10.57%	2.68E+15	9.17%
Potash fertilizer	2.23E+09	1.23E+14	0.37%	7.81E+13	0.27%
Micro fertilizer	3.91E+09	9.78E+12	0.03%	9.78E+12	0.03%
Earth emergy	1.00E+00	3.72E+15	11.15%	3.72E+15	12.72%
Organic fertilizer	2.96E+08	5.92E+14	1.78%	5.03E+14	1.72%
Sapling	6.76E+07	6.49E+15	19.47%	4.83E+15	16.54%
FR		1.20E+15	3.60%	9.21E+14	3.15%
FN		2.21E+16	66.32%	1.92E+16	65.56%
Subtotal		2.33E+16	69.92%	2.01E+16	68.71%
Total		3.33E+16	100.00%	2.92E+16	100.00%

3.1.2 Non-Renewable Environmental Inputs (N)

The study considered non-renewable environmental inputs such as groundwater, loss of soil organic matter, and soil erosion. In the production systems for Mazafati dates, these inputs accounted for 29.87 percent, and for Rabbi dates, they accounted for 31.05 percent of the total input emergy (Table 3). The Rabbi date production system exhibits a greater rise in these values in comparison to the Mazafati date system, which suggests a higher level of soil erosion and loss of organic matter. Furthermore, the proportion of groundwater, which is the most substantial non-renewable resource, is noteworthy in both systems. It accounts for 20.29 percent of the total emergy input in the Mazafati date system and 20.13 percent in the Rabbi date system (Table 3). Implementing contemporary irrigation techniques can effectively decrease the utilisation of groundwater.

The study conducted on a maize farm in Kansas, USA, estimated that the proportion of non-renewable environmental inputs was 2.16E+13 sej/ha/yr (Martin et al., 2006). According to Shahhosini et al. (2020), the assessment of potato production in Golestan province revealed that the groundwater input for autumn and spring production systems was respectively 23.92 percent and 45.28 percent higher than other inputs.

The significant reliance on non-renewable resources, particularly groundwater, in both Mazafati and Rabbi date palm production systems highlights the need for sustainable management practices. Our findings corroborate those of Asgharipour et al. (2019), who also emphasized the importance of reducing reliance on non-renewable inputs in agricultural systems.

To mitigate the environmental impacts of date palm cultivation, several strategies can be implemented, such as adopting advanced irrigation systems like drip irrigation to reduce water consumption and improve water use efficiency, implementing sustainable soil management practices like cover cropping, crop rotation, and organic fertilization to improve soil health and reduce erosion, exploring the use of renewable energy sources like solar power to reduce dependence on fossil fuels and decrease greenhouse gas emissions, and developing policies that promote sustainable agricultural practices and provide incentives for farmers to adopt environmentally friendly technologies.

Future research should focus on quantifying the environmental and economic benefits of these strategies and exploring their long-term impacts on the sustainability of date palm production systems. Additionally, a more comprehensive assessment of the social and cultural factors influencing farmers' adoption of sustainable practices is needed.

3.1.3 Purchased Inputs (FN and FR)

The inputs Purchased consist of the labour force, machinery, fossil fuels and oils, chemical fertilisers (nitrogen, phosphorus, potassium, and micronutrients), land value, organic fertilisers, and consumed seedlings. The cumulative values of these inputs for the Mazafati date production systems were 2.33E+16 sej/ha/yr, while for the Rabbi dates, the total values were 2.01E+16 sej/ha/yr. The proportion of renewable resources purchased for the Mazafati date production system was 3.60 percent, and for Rabbi dates it was 3.15 percent. In contrast, the proportion of non-renewable resources purchased was 66.32 percent for Mazafati dates and 65.56 percent for Rabbi dates. The market inputs accounted for 69.92 percent of the total input emergy for Mazafati dates and 68.71 percent for Rabbi dates. These inputs were nearly equal for both date production systems, with no significant differences observed (Table 3).

The nitrogen fertiliser accounted for the largest proportion of purchased inputs in both the Mazafati and Rabbi date production systems, with 14.83 percent for Mazafati and 15.33 percent for Rabbi. This was followed by land value, which accounted for 11.15 percent for Mazafati and 12.72 percent for Rabbi. Seedlings had the third highest share, with 19.47 percent for Mazafati and 16.54 percent for Rabbi. Minimising the usage of these resources is crucial for reducing the proportion of externally purchased resources in these systems. The proportion of certain inputs was below one percent, specifically machinery (0.19 percent for Mazafati and 0.22 percent for Rabbi), potassium fertiliser (0.37 percent for Mazafati and 0.27 percent for Rabbi), and micronutrient fertilisers (0.03 percent for both types of dates) (Table 3).

The purchased inputs for the commercial rapeseed production system amounted to 1.80E+16 sej/ha/yr, while for the subsistence rapeseed production system it was 1.61E+16 sej/ha/yr. The evaluation of purchased resources in commercial and subsistence rapeseed systems reveals minor variations in the overall emergy of purchased resources between the two systems, however, there were notable disparities in the composition of these resources. As an illustration, the amount of energy required for labour in the subsistence system was almost twice as much as that in the commercial system. In the subsistence system, the amount of emergy consumed by organic fertilisers was 3.55E+15 sej/ha/yr, whereas in the commercial system, it was completely absent. In the commercial system, the combined emergy consumption for herbicides, electricity, and the establishment of the irrigation system amounted to 2.08E+15 sej/ha/yr, while it was completely absent in the subsistence system. The emergy consumed by agricultural machinery and fossil fuels in the commercial system was three times greater than that of the subsistence system, while in the subsistence system it was six times greater. The energy consumed by chemical potassium fertilisers in the commercial system was approximately three times greater than that in the subsistence system (Amiri et al., 2019). In the wheat production system, nitrogen, phosphorus, and potassium fertilisers made up 97 percent of the non-renewable resources that were bought (Hoshyar et al., 2018). According to Zhang et al. (2012), nitrogen fertiliser and labour were the inputs with the highest emergy in wheat production.

3.2 Emergy-Based Indices

Emergy analysis takes into account all available environmental resources, such as human labour and ecosystem services, which are often disregarded in other approaches. This aids in ascertaining appropriate strategies for the sustainable management of agriculture (Yue et al., 2016; Houshyar et al., 2018).

3.2.1 Transformity (Tr) and Specific Emergy (SpE)

These indices aid in assessing the efficiency of product output in terms of emergy (Brown and Ulgiati, 2004). The transformity is a measure of the profitability of a production process. A high level of this index indicates low performance and productivity in long-term environmental and economic competition (Odum, 2000). Specific emergy (SpE) is a fundamental concept in emergy studies that quantifies the amount of emergy needed to produce a single unit of biomass. The amount of supportive emergy required for each unit of biomass produced is determined by the unit of mass, either in grammes or kilogrammes (Odum, 2000; Chen et al., 2009; Li et al., 2010; Zhang et al., 2012).

The production systems of Mazafati and Rabbi dates in Mirjaveh county had transformities of 8.72E+06 and 6.63E+06 sej/J, respectively (Table 4). The emergy requirements for the production systems of Mazafati and Rabbi dates were 1.03E+10 and 7.79E+09 sej/g, respectively (Table 4).

The Mazafati date production system exhibited a lower efficiency in transformity compared to the Rabbi date system. However, when considering SpE calculation, the Rabbi date system demonstrated lower efficiency. Based on the acquired values, it can be concluded that there is a minor disparity in the transformity between the two systems, but there is a notable discrepancy in the calculated values for SpE.

The transformity for the commercial rapeseed production system was calculated as 3.08E05 sej/J, while for the subsistence rapeseed production system it was calculated as 9.48E+05 sej/J (Amiri et al., 2019). The transformity for dates in Nehbandan county was reported as 1.71E+09 sej/J, while for pistachios it was reported as 1.47E+09 sej/J. The specific emergy for date production system was 1.37E+10 sej/g, and for pistachio production system it was 2.02E+05 sej/g (Jafari et al., 2018).

Table 4. Emergy-based indices of the production systems of Mozafati and Rabbi date in Mirjaveh city

	Mazafati	Rabbi
Transformity	8.72E+06	6.63E+06
Specific emergy	1.03E+10	7.79E+09
R%	3.81%	3.40%
EYR	1.430	1.455
EIR	2.325	2.196
EIR*	326.433	281.212
ELR	139.568	127.213
ELR*	2.802	3.327
ESI	0.010	0.011
ESI*	0.510	0.437
EER	4.460	3.391
EIPS	0.945	0.963
EMR	5.86E+06	6.23E+06

3.2.2 Emergy Renewability Ratio (R%)

Production systems that have a higher proportion of renewable resources compared to those that rely more on non-renewable inputs are more likely to succeed and be sustainable in economic competition. This is because non-renewable resources are becoming increasingly scarce over time (Asgharipour et al., 2019). The production systems of Mazafati and Rabbi dates had a dependency on renewable resources of 3.81 percent and 3.40 percent, respectively, as shown in Table 4. The sustainability index of both systems is almost identical, although the Mazafati date production system is marginally more sustainable than the Rabbi date system.

The R% for shallot production in mechanised, traditional, conservation, and natural habitat systems were reported as 18.60%, 26.30%, 25.30%, and 16.30%, respectively (Amiri et al., 2021). The emergy renewability ratio for traditional rice production and intensive vegetable cultivation in China was estimated to be 52.66 percent and 12.30 percent, respectively, according to Su et al. (2020). The proportion of renewable resources in the total production resources for the rice production system in Mazandaran was documented as 8.26 percent (Amini et al., 2020).

3.2.3 Emergy Yield Ratio (EYR)

This EYR assesses the dominance of a system based on the emergy costs it incurs, serving as a sustainability indicator that encompasses both the environment and the environmental economy. It possesses the capacity to recognise agricultural ecosystems (Fallahinejad et al., 2021). The EYR is widely acknowledged as a crucial indicator in the analysis of various systems (Amiri et al., 2021). The EYR for the production systems of Mazafati and Rabbi dates were 1.430 and 1.455 respectively, as shown in Table 4.

Based on the results, the production systems of Mazafati and Rabbi dates exhibit almost identical stability. Nevertheless, the estimated EYR for Mazafati dates is marginally inferior to that of Rabbi dates, primarily because of the higher reliance on purchased emergy resources in the former system. Hence, it is imperative for farmers to prioritise the utilisation of available environmental resources, as minimising reliance on purchased resources enhances the EYR in production systems.

The EYR for rice was 5.13, as reported by Amini et al. (2020). The EYR values for cucumber, tomato, bell pepper, and eggplant production systems were documented as

1.025, 1.015, 1.014, and 1.012 respectively. The cucumber production system exhibited a greater value compared to the other three systems (Asgharipour et al., 2020).

The EYR for the Yaghuti grape production system in Sistan was reported to be 1.02, according to Koohkan et al. (2017).

3.2.4 Standard Investment Ratio (EIR) and Modified Investment Ratio (EIR*)

The EIR assesses the level of investment, economic growth, and availability of unrestricted environmental resources, as well as the agricultural system's reliance on the environment. A lower EIR value indicates that a system relies more heavily on environmental resources, incurs lower economic costs, and has a higher output dependence on environmental resources (Odum, 2000). Furthermore, the EIR* is calculated by dividing the amount of inputs purchased by the amount of renewable environmental inputs. Amiri et al. (2019) suggest that conducting a more principled comparison of production costs and competitive strength in the market is advisable. The EIR index for the production systems of Mazafati and Rabbi dates were 2.325 and 2.196, respectively, as shown in Table 4. The EIR* values for Mazafati dates were 326.433, while for Rabbi dates they were 281.212 (as shown in Table 4).

The Mazafati date production system demonstrates greater economic development as evidenced by its higher EIR and EIR* compared to the Rabbi date production system. This is attributed to a larger utilisation of market inputs, such as nitrogen fertiliser and saplings, which have contributed to the increase in these indices. Hence, by decreasing market inputs in the Mazafati date production system, it is possible to reduce these indices and enhance production efficiency.

The EIR values for different production systems of shallot, including mechanised, traditional, conservation, and natural habitat systems, were 7.721, 12.665, 23.223, and 0.785, respectively. Similarly, the EIR* indices for these systems were 21.872, 25.308, 40.932, and 3.708, as reported by Amiri et al. in 2021. A research conducted on the sustainability of the Huanjiang forest-grassland region in China revealed a consistent upward trend in the EIR index over a span of 16 years. The index value escalated from 0.12 in 2000 to 0.71 in 2015 (Zhan et al., 2020). The EIR, as reported by Zhao et al. (2019), varied from 4.15 to 7.18 across different wheat-growing regions with varying climates. The EIR for oat and wheat production systems in China was calculated as 2.94 and 1.30, respectively, according to Zhai et al. (2017).

3.2.5 Standard Environmental Load Ratio (ELR) and Modified Environmental Load Ratio (ELR*)

The ELR quantifies the environmental strain caused by the utilisation of non-renewable energies that are within human jurisdiction. Greater environmental pressure is indicated by higher ELR values, particularly when this index surpasses 10 (Su et al., 2020). The ELR is determined by dividing the total non-renewable and purchased emergy inputs by the renewable inputs. On the other hand, ELR* specifically examines the ratio of non-renewable resources to renewable resources (Ortega et al., 2002). Typically, ELRs that are less than 2 indicate a minimal impact on the environment, ELRs between 2 and 10 suggest a moderate impact, and ELRs above 10 indicate a significant strain on the environment (Brown and Ulgiati, 2004; Cavalett et al., 2006).

The ELR was calculated as 139.568 for the production system of Mazafati dates and 127.213 for the production system of Rabbi dates. In addition, the ELR for the same systems were 2.802 and 3.327 respectively, as shown in Table 4. Systems with high ELR values indicate a substantial amount of environmental pressure, mainly because they heavily rely on non-renewable environmental resources like groundwater and contribute to soil erosion. Nevertheless, the significant disparities between the ELR and ELR* values indicate that both systems impose a moderate burden on the environment.

The ELR index values for wheat, barley, sugar beetroot and saffron were reported as 63.56, 66.06, 23.56, and 79.63 respectively (Fallahinejad et al., 2021). The ELR for subsistence cultivation of rapeseed was 19.75, while for commercial cultivation it was 12.68. The ELR* for subsistence cultivation was 17.85, and for commercial cultivation it was 4 (Amiri et al., 2019). According to Wang et al. (2014), the ELR for wheat production systems was 10.59, while for maize it was 0.47.

3.2.6 Standard Environmental Sustainability Index (ESI) and Modified Environmental Sustainability Index (ESI*)

The ESI is a comprehensive measure of environmental sustainability. It is calculated by dividing the EYR index by the ELR. The assessment quantifies the advantages gained from a system in relation to the amount of space occupied (Brown and Ulgiati, 1997). The ESI and ESI* assess the ability of a process to achieve high performance while minimising its impact on the environment (Odum, 1996). A production system with an ESI value below 1 signifies a significant environmental pressure, whereas values ranging from 1 to 10 indicate a relatively sustainable production system (Su et al., 2020).

The research calculated the ESI and ESI* for the Mazafati date production system as 0.010 and 0.011 respectively. For the Rabbi date production system, the values were 0.510 and 0.437 respectively (Table 4).

The study found that both agricultural systems had environmental sustainability indices below one, which suggests a very low level of sustainability and a high degree of environmental pressure. Both the Mazafati and Rabbi date production systems heavily rely on non-renewable environmental resources.

The index for the autumn and spring potato cultivation systems was calculated as 0.05 and 0.07 respectively (Shah Hoseini et al., 2021). The environmental sustainability of the conventional forage maize production system in Denmark was reported as 0.24 (Ghaley et al., 2018). The index for dates and pistachios was computed as 0.93 and 1.30 respectively, according to Jafari et al. (2018).

Furthermore, the index for the potato production system was calculated to be 0.03, as determined by Zhai et al. (2017).

3.2.7 Emergy Exchange Ratio (EER)

The EER, a metric developed by Azizi et al. (2021), quantifies the efficiency of emergy by comparing the total emergy consumed in production to the emergy obtained from sales in the market. This index is determined by the efficiency of the product in relation to its area and assesses the emergy gain from product sales. Furthermore, it evaluates the equilibrium between the economic output traded for currency in the market (YM) in megajoules per unit area and the overall emergy input to the system (U). An EER value greater than one signifies a high level of system efficiency in converting monetary emergy into product and reflects significant purchasing power in the market (Amiri et al., 2019). The EER values for the Mazafati and Rabbi date production systems were 4.460 and 3.391 respectively, as shown in Table 4. The fact that the index is greater than one for both systems indicates their high production efficiency.

The EERs for cucumber, tomato, bell pepper, and eggplant production systems were documented as 0.72, 0.54, 0.46, and 0.33 respectively, according to Asgharipour et al. (2020). The EER values for these systems, which are below one, indicate their low efficiency. The EER index for commercial rapeseed systems was 0.94, while for subsistence rapeseed systems it was 0.31. The rapeseed production systems are considered inefficient because their EER values are less than one (Amiri et al., 2019).

3.2.8 Emergy Index of Product Safety (EIPS)

The EIPS evaluates the level of safety in agricultural product outputs by considering the contributions of chemical fertilisers and herbicides as inputs. According to Xi and Qin (2009), there is a positive correlation between the EIPS value and the security and health of the crops. In other words, as the EIPS value increases, the crops are more secure and healthy. The production safety index for the Mazafati date production system was determined to be 0.945, while for the Rabbi date system, it was found to be 0.963. The assessment of production safety for both systems yielded almost identical results (Table 4).

Nevertheless, the safety index of the Rabbi date system was marginally superior to that of the Mazafati dates. Thus, it can be asserted that the Rabbi date production system yields a more wholesome product. However, in order to augment this index, it is imperative to decrease the overall utilisation of fertilisers for both systems. The EIPS values for mechanised, traditional, conservation, and natural shallot habitat systems were 0.883, 0.906, 1.00, and 1.00 respectively (Amiri et al., 2021). The EIPS for three different models of goose farming in cornfields, conventional corn and wheat-chickpea rotation were determined to be 0.97, 0.91, and 0.94, respectively, according to a study conducted by Guan et al. (2016). According to Sha et al. (2015), the index for two production models of goose farming in cornfields and conventional corn cultivation in the southeastern region of Tibet were 0.86 and 0.70, respectively.

3.2.9 Emergy-Money Ratio (EMR)

The EMR establishes a connection between the economic attributes and the environmental inputs to an ecosystem. This indicator quantifies the monetary value of environmental flows and purchased inputs that enter the system as a result of the production of goods (products and services) at a specific point in time (Lu and Campbell, 2009). Within the realm of emergy indices, there is a requirement for an index that effectively conveys the economic worth of system outputs from an emergy standpoint. This index is known as EMR, as described by Chen et al. (2017). EMR is a measure of the amount of energy invested per unit of profit. It is calculated by dividing the emergy investment by the net profit. This concept was introduced by Zhang et al. (2012).

The EMR values for the production systems of Mazafati dates and Rabbi dates were determined to be 5.86E+06 and 6.23E+06, respectively. The analysis of EMR values in this study reveals that the Rabbi date production system has a greater emergy flow per unit of net profit compared to the Mazafati date production system (Table 4). The emergy analysis of four systems, namely corn farming, duck breeding, mushroom cultivation, and fish farming, yielded EMR values of 1.36E+13, 8.22E+13, 5.04E+13, and 4.78E+13 emrial, respectively.

The EMR values of the assessed systems demonstrate that the agricultural system (specifically maize production) has a lesser amount of emergy flow per dollar earned in comparison to the animal husbandry (duck breeding), horticulture (mushroom production), and aquaculture (fish farming) systems. Put simply, the agricultural system had a lower emergy-to-dollar ratio compared to the other systems. The fish farming system had a more favourable energy-money ratio compared to the animal husbandry and horticulture systems, primarily because of its semi-natural state. According to Zhang et al. (2012), if two systems have the same net income, the one with a lower emergy inflow would be more sustainable. The EMR values for mechanised, traditional, conservation, and natural habitat systems of shallot were determined as 1.67E+13, 1.86E+13, 1.72E+13, and 8.6E+12, respectively, according to Amiri et al. (2021).

4. Conclusion

This study aimed to implement a production system that maximises efficiency and economic-ecological productivity for two export products, Mazafati and Rabbi dates, in the Mirjaveh county from 2022 to 2023. Agricultural ecosystems are considered complex biological systems because of their diverse forms and functions. Hence, it is crucial to assess the sustainability of agricultural systems in order to identify appropriate production patterns, as part of a comprehensive and scientific approach. Emergy analysis has the ability to evaluate the environmental, economic, product quality, and social aspects of different systems. The primary objective of this research was to generate a premium and nutritious product with optimal financial gain, given that dates are the predominant crop grown in Mirjaveh county. The Mazafati and Rabbi varieties dominate the cultivation area in the palm groves of Mirjaveh among the different types of dates. The chosen indices for this research were diverse and capable of measuring ecological, economic, market dimensions, and product quality.

The results obtained from emergy-based indices for these export products showed variations in the calculated values of the transformity with specific emergy. The calculation of the transformity revealed that the efficiency of the Mazafati date production system was lower than that of the Rabbi date system. Conversely, when considering the SpE calculation, the efficiency was lower for the system specific to Rabbi dates. When analysing indices in the Mazafati date production system, it was found that higher R% and EER values, as well as lower EIPS, ELR*, and EMR values, provided a slight advantage. However, the Rabbi date production system demonstrated greater sustainability in terms of higher EYR, lower EIR and EIR*, and lower ELR compared to the Mazafati date production system. However, the calculated values of these indices must not ignore the extra strain that both production systems place on the environment. Date farmers must prioritise this matter and enhance the quality of their product and the surrounding environment by optimising the utilisation of natural resources and substantially decreasing the reliance on non-renewable environmental resources and purchased inputs. Nevertheless, when considering the economic, commercial, and ecological aspects, the Mazafati date system exhibited a slight superiority compared to the Rabbi date production system.

Acknowledgement

The authors would like to express their sincere gratitude to University of Zabol for the financial support provided for this research through Grant No. IR-UOZ-GR-6673. We are also grateful to the Department of Agriculture of Mirjaveh County and the Jihad Keshavarzi Organization Jihad Organization of Sistan and Baluchestan Province for their valuable assistance in providing data and facilitating the collection of field data .The researchers also extend their appreciation to the date palm farmers who participated in the study for their time and for providing the necessary information.

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