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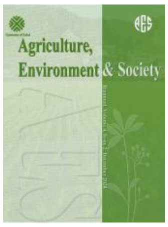

Environmental impacts of mung bean production systems based on life cycle assessment methodology and IMPACT 2002+ model

Amin Fathi[a,b], Kamran Kheiralipour*[a]

[a] Mechanical Engineering of Biosystems Department, Ilam University, Ilam, Iran
[b] Department of Agronomy, Ayatollah Amoli Branch, Islamic Azad University, Amol, Iran

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ABSTRACT

Environment is one of the key elements in sustainable production. The present study was conducted to investigate the environmental impacts of mung bean production systems in Dareh Shahr, Ilam, Iran. The required data were collected through questionnaires and face-to-face interviews with 78 mung bean farmers in 2022-2023. Inputs and output data were calculated and then environmental impacts were calculated using the life cycle assessment methodology and IMPACT 2002+ impact assessment model. The results showed that the mung bean production process in farms, potassium production in the factory, and seed production in the farm were the main contributors to almost all environmental indicators. Human health was the main indicator in mung bean production. Other main indicators were ranked as climate change, resources, and ecosystem quality. The total environmental damage of mung bean production was equal to 263.90 mPt. The results of the present research found hotspots in mung bean production which are useful to practically decrease environmental impacts via decreasing inputs and increasing output.

Highlights

- LCA shows mung bean production's total environmental damage is 263.90 mPt in Dareh Shahr, Iran.
- Human health tops environmental indicators, followed by climate change and resources.
- Farms, potassium, and seed production are key contributors to mung bean's eco-impact.
- Global warming potential of mung bean is 787.85 kg CO_2 eq./ton, higher than wheat.
- Biofertilizers and direct planting can reduce environmental burdens of mung bean.

1. Introduction

Sustainable production is a path considering economic, environmental, and social aspects, besides the technical perspective (Kheiralipour, 2022). To move on sustainable production path, environmental aspect is assessed via studying material, energy, and environmental indicators to reduce the consumption/use of different inputs and consequently decrease emissions (Kheiralipour and Sheikhi, 2021; Dekamin and Kheiralipour. 2023; Ramedani et al., 2024; Pourmehdi and Kheiralipour, 2024; Kheiralipour et al., 2024a). In this regard, environmental indicators of different production systems are studied using life cycle assessment (LCA) as a main research method (Kheiralipour et al., 2021).

Life cycle assessment is a method in which all environmental impacts associated with a product (including goods and services) are assessed throughout its life cycle, from the extraction or collection of raw materials to the consumption stage, and then recycling or disposal of the resulting waste. In this method, all resources used to produce the product and all emissions released into the environment are quantified and assessed (Pennington et al., 2004; Kheiralipour, 2020).

Life cycle assessment is a systematic and step-by-step process that consists of four phases: defining the purpose

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* Corresponding author.
E-mail address: k.kheiralipour@ilam.ac.ir

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and scope of the study (scope), inventory analysis, impact assessment, and interpretation (Guinee, 2002). The methodology has been applied to assess the environmental impacts of different production systems in industry (Kheiralipour et al., 2022; Jiang et al., 2023; Kheiralipour et al., 2024b), agriculture (Kheiralipour et al., 2017; Payandeh et al., 2017; Ramedani et al., 2019; Bamber et al., 2022; Kheiralipour et al., 2023), and agricultural processing plants (Pourmehdi and Kheiralipour, 2020; Gholamrezaee et al., 2021; Jalilian et al., 2021; Dominguez Aldama et al., 2023; Kheiralipour & Sheikhi, 2024).

Environmental impacts of different agronomic products such as canola (Kheiralipour et al., 2017), coriander (Dekamin et al., 2022), oat (Viana et al., 2022), and wheat (Pourmehdi and Kheiralipour, 2023) have been investigated. However, the goal of the present research is to investigate the environmental impacts of mung bean production systems. Studying the environmental impacts of this agronomic product is essential to take the first step in reducing its environmental burdens. Moreover, it finds environmental hotspots by ranking the environmental contributors to prioritize the management strategies in the reduction of the burdens.

Mung bean (*Vigna radiata* L.) belongs to the legume family (Lambrides & Godwin, 2007) and is one of the most important crops due to their high nutritional properties (Tong, 2020; Ganesan & Xu, 2018; Fathi & Kheiralipour, 2025). Although about 90% of the mung bean is produced in Asia, mostly in India, China, Pakistan, and Thailand countries, it is cultivated in Africa and Australia (Lambrides & Godwin, 2007). According to the importance of mung bean and protecting the environment, the novel goal of the present research is to assess the environmental impacts of the crop.

Different impact assessment models have been used to calculate environmental impacts including CLM-IA baseline (Kheiralipour et al., 2022; Kheiralipour et al., 2024c), ReCiPe 2016 (Shrestha et al., 2020; Jiang et al., 2021), and IMPACT 2002+ (Jolliet et al., 2003; Rybaczewska-Blazejowska & Jezierski, 2024). However, the goal of the present research is to investigate the environmental impacts of mung bean production systems in Dareh Shahr, Ilam, Iran, using the IMPACT 2002+ model.

2. Materials and methods

The present LCA study was conducted based on the ISO 14040 standard in four main phases (ISO, 2006). In the first phase of the life cycle assessment, the product, process, or activity is defined and described. The system under study, the system boundaries, and the functional unit are also identified (Guinee, 2002).

Defining the purpose and scope is the most important stage of life cycle assessment; because it is the most important leader for the next phase and the selection of the impact categories under study.

Life cycle assessment is a “cradle to grave” approach; however, it is possible to consider the system boundary as part of the entire process in order to focus on the processes. It is also possible to express the results based on the selected boundary and on a smaller scale (Kheiralipour, 2020). The goal of the present research was to investigate the environmental impacts of mung bean production systems via a gate-to-gate LCA study in Dareh Shahr, Ilam, Iran. The functional unit was 1 tone mung bean grain. The allocation process was neglected because the output in the farms was only mung bean grain. The boundary of the present research was considered to be included from tillage to harvesting operations and transportation, post-harvest processing, and distribution were excluded.

In the inventory analysis phase, all necessary resources in the system for the production of the product and all outputs and environmental emissions should be determined. This phase included calculating inputs and emissions. The data collection in the present research was based on the questionnaire method and face-to-face interviews.

The information about different inputs and their amounts and the amount of mung bean output was collected. The inputs were seed, fertilizers (nitrogen, phosphorous, and potassium), sprays (pesticide and herbicide), labor, machinery, fuel, oil, electricity, and water in different agricultural operations The data related to the input and output materials were randomly collected for the mung bean farms in Darreh Shahr, Ilam, Iran. The input and emissions were calculated per the functional unit. All emissions to air, soil, and water must be calculated or measured. The emissions related to input consumption/use were calculated according to the IPCC 14040 (IPCC, 2006).

As in agriculture, the Ecoinvent2.0 database is more used, the emissions related to input production were obtained from the available in the used software.

In the third phase, impact assessment, it must first be determined which impact categories should be considered and what method should be used to assess their impact. As in agriculture, SimaPro (PRé, 2006) is more used, this software was used to calculate the midpoint and endpoint environmental impacts of mung bean production in the characterization step. The IMPACT 2002+ model was applied to categorize the environmental impacts. Other steps in the third phase including normalization and weighting were done after characterization.

In the interpretation phase, the results of the impact assessment and the calculations are evaluated to identify the hotspots in the production path that have the most adverse environmental impacts. The options with less adverse impacts on the environment can be evaluated. In this phase, conclusions are drawn and an LCA report is prepared (Kheiralipour, 2021; Kheiralipour, 2023). In the last phase, the contributions of the process and all inputs were assessed in this phase.

3. Results and Discussion

3.1. Environmental indicators

The midpoint and endpoint environmental indicators and their values in mung bean LCA study based on the IMPACT 2002+ model were presented in Table 1 and 2, respectively.

Table 1. The values of the midpoint environmental indicators in mung bean production systems.

No.	Indicator	Unit	Value
1	Carcinogens	kg C_2H_3Cl eq.	18.23
2	Non-carcinogens	kg C_2H_3Cl eq.	8.96
3	Respiratory inorganics	kg PM2.5 eq.	0.79
4	Ionizing radiation	Bq C-14 eq.	4386.18
5	Ozone layer depletion	kg CFC-11 eq.	5.87×10^{-5}
6	Respiratory organics	kg C_2H_4 eq.	0.21
7	Aquatic ecotoxicity	kg TEG water	260421.70
8	Terrestrial ecotoxicity	kg TEG soil	8361.43
9	Terrestrial acidification/nutrification	kg SO_2 eq.	74.13539
10	Land occupation	m2org.arable	67.85
11	Aquatic acidification	kg SO_2 eq.	24.69
12	Aquatic eutrophication	kg PO_4 P-lim	0.593042
13	Global warming	kg CO_2 eq.	787.85
14	Non-renewable energy	MJ primary	11891.05
15	Mineral extraction	MJ surplus	14.11

Table 2. The values of the endpoint environmental damages of mung bean production.

Indicator	Unit	Value
Human health	DALY	6.32×10^{-4}
Ecosystem quality	PDF*m^2×yr	230.27
Climate change	kg CO_2 eq.	787.85
Resources	MJ primary	11905.16

Pourmehdi and Kheiralipour (2023) calculated the environmental impacts of dryland and irrigated wheat production systems based on the CML Baseline model. As ozone layer depletion and global warming indicators are the same in IMPACT 2002+ and CML Baseline models, their values can be compared. The value of the global warming indicator in mung bean was 787.85 kg CO_2 eq./ton which was higher than the corresponding values of dryland (588 kg CO_2 eq./ton,) and irrigated (308 kg CO_2 eq./ton) wheat. The value of global warming in the production of 1 ton of wheat flour was 693 kg CO_2 eq (Pourmehdi and Kheiralipour, 2020), However, the value of the global warming indicator for mung bean was lower than that of coriander seed (897.38 kg CO_2 eq., Dekamin et al., 2022), chicken (5782.38 kg CO_2 eq., Payandeh et al., 2017), turkey bird (3630 kg CO_2 eq., Kheiralipour et al., 2017), and ostrich production (16800 kg CO_2 eq., Ramedani et al., 2019). Also, ozone layer depletion of mung bean had a higher value (5.87×10^{-5} kg CFC-11 eq./ton) than the corresponding values of dryland and irrigated wheat production systems (3.54×10^{-5} and 1.90 $\times10^{-5}$ kg CFC-11 eq./ton, respectively).

3.2. Normalized indicators

The normalizing step was done using the IMPACT 2002+ model. The highest to lowest endpoint indicators were ranked as human health, climate change, resources, and ecosystem quality. The values of the indicators were 8.92×10^{-2}, 7.96×10^{-2}, 7.83×10^{-2}, and 1.68×10^{-2}, respectively (Figure 1).

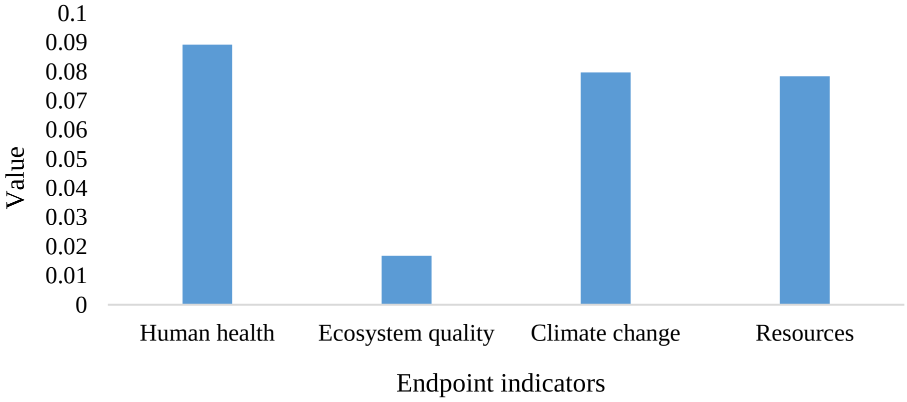

Figure 1. The normalized endpoint environmental damages of mung bean production.

3.3. Weighted indicators

The results of the weighting stage of endpoint environmental damages of mung bean production based on the Impact 2002+ model have been shown in Table 3. The first endpoint indicator in mung bean production systems was human health with a weighted value of 89.18 mPt. The second to fourth indicators were climate change, resources, and ecosystem quality, with values of 79.57, 78.34, and 16.81 mPt, respectively.

The advantage of the IMPACT 2002+ model is calculating the total damage impact of production systems, compared to the CML Baseline impact assessment model. The total damage impact of 1 ton of mung bean production in the present research has been estimated as 263.90 mPt.

Table 3. The values of the weighted endpoint environmental damages of mung bean production.

Indicator	Unit	Value
Human health	mPt	89.18
Ecosystem quality	mPt	16.81
Climate change	mPt	79.57
Resources	mPt	78.34
Total	mPt	263.90

3.4. Environmental contributors

The contributions of each factor in the midpoint and endpoint environmental indicators have been presented in Tables 4 and 5. The main contributor to all midpoint and endpoint indicators was the process (mung bean production in the farms). The second contributor to carcinogens, non-carcinogens, ionizing radiation, ozone layer depletion, respiratory organics, terrestrial ecotoxicity, non-renewable energy, and mineral extraction was potassium fertilizer. The corresponding factor for respiratory inorganics, terrestrial acid/nutria, aquatic ecotoxicity, aquatic acidification, aquatic eutrophication, and global warming indicators was seed input. Also, the second contributor to human health, ecosystem quality, and climate change endpoint indicator was seed. Lack of the information about seed production in databases was a limitation of the present research. This caused over estimating the contribution of seed in environmental impacts in mung bean production because instead of that, soybean seed was selected in SimaPro software.

Table 4. The values of each factor corresponded to the midpoint environmental indicators of mung bean production. *Process means the mungbean production in the farms.

Factor	Carcinogens	Non-carcinogens	Respiratory inorganics	Ionizing radiation	Ozone layer depletion	Respiratory organics	Aquatic ecotoxicity	Terrestrial ecotoxicity
Process	18.23009	8.96194	0.792738	4386.178	5.87E-05	0.205981	260421.7	8361.432
Seed	0	0.225506	0.550479	0	0	6.7E-05	226901.3	1020.824
Machinery	0.09114	-0.05328	0.010341	37.80238	7.53E-07	0.003149	-1559.16	-1511.17
Fuel	0.054364	-0.04274	0.00215	0	2.44E-08	0.003596	-283.19	0.47252
Lubricant	0.126524	0.200749	0.021211	1491.041	8.57E-06	0.054833	2198.17	560.6722
Nitrogen	0.028634	0.030902	0.001314	33.86752	6.28E-07	0.013798	203.6656	53.36281
Potassium	4.733545	5.351907	0.143139	1852.379	3.07E-05	0.061239	16258.02	5051.77
Phosphorous	0.229937	0.370029	0.010974	130.0214	1.72E-06	0.003903	1274.854	453.1436
Herbicide	0.095148	0.147634	0.009158	78.40036	6.06E-07	0.001387	500.6477	187.5579
Insecticide	0.183464	0.357923	0.010165	517.5986	1.58E-06	0.002998	4117.104	1458.821
Electricity	0.073605	0.147295	0.003867	199.4702	4.89E-07	0.001034	1750.717	627.9045

Factor	Terrestrial acid/nutria	Land occupation	Aquatic acidification	Aquatic eutrophication	Global warming	Non-renewable energy	Mineral extraction
Process	74.13539	67.84896	24.69323	0.593042	787.848	11891.05	14.10772
Seed	66.67962	0	22.97163	0.537317	312.251	0	0
Machinery	0.230248	56.92684	0.044106	0.006384	5.947096	68.92205	0.22634
Fuel	0.081681	0	0.014615	0.000498	13.00472	147.7827	0.224088
Lubricant	0.503183	0.234474	0.130386	0.003663	21.35105	2934.953	0.154229
Nitrogen	0.023565	0.019246	0.007655	0.000361	1.147453	66.28975	0.052515
Potassium	5.112735	6.748269	1.066944	0.027805	223.0732	4756.395	11.97614
Phosphorous	0.427686	0.555062	0.079403	0.002351	14.41521	249.9917	0.802822
Herbicide	0.176668	0.646204	0.12616	0.007944	5.38705	94.10621	0.26757
Insecticide	0.182964	1.769509	0.055369	0.003929	16.50746	335.7808	0.207067
Electricity	0.068512	0.870361	0.020876	0.001576	5.556864	116.9086	0.08029

Machinery was the second contributor to the land occupation indicator. The potassium fertilizer was the third main factor for respiratory inorganics and aquatic ecotoxicity, terrestrial acid/nutria, land occupation, aquatic acidification, aquatic eutrophication, and global warming indicators. The third main factor for ionizing radiation, ozone layer depletion, respiratory organics, and non-renewable energy was lubricant oil, for carcinogens, non-carcinogens, and mineral extraction was phosphorous fertilizer, and for terrestrial ecotoxicity was insecticide. Also, the third contributor to human health, ecosystem quality, and climate change endpoint indicator was potassium fertilizer.

According to Pourmehdi and Kheiralipour (2023), the main contributor for almost all indicators in wheat production was nitrogen fertilizer except for eutrophication and acidification indicators which the wheat production process in farms was the main contributor for them.

Managing the different operations in mung bean production causes a reduction in inputs and an increase in output and consequently decreases the environmental impacts and climate change mitigation. Sustainable agriculture practices such as increasing biodiversity cause to decrease the environmental impacts. Governmental programs such as education, incentives, and fines can be effective in this regard. The consumption of biofertilizers leads to a decrease in the application of chemical fertilizers (Sharifi and Kheiralipour, 2025) and using direct planting equipment causes reduced machinery use and fuel and oil consumption. These strategies lead reduction in environmental impacts of mung bean production.

Table 5. The contribution values corresponded to each factor in the endpoint environmental damages of mung bean production.

Factor	Human health	Ecosystem quality	Climate change	Resources
Process	6.32×10^{-4}	230.27	787.85	11905.16
Seed	3.86×10^{-4}	88.81	312.25	0.00
Machinery	7.36×10^{-6}	50.26	5.95	69.15
Fuel	1.55×10^{-6}	7.45×10^{-2}	13.00	148.01
Lubricant	1.62×10^{-6}	5.32	21.35	2935.11
Nitrogen	1.12×10^{-6}	0.48	1.15	66.34
Potassium	1.29×10^{-4}	53.45	223.07	4768.37
Phosphorous	9.40×10^{-6}	4.70	14.42	250.79
Herbicide	7.11×10^{-6}	2.40	5.39	94.37
Insecticide	8.75×10^{-6}	13.87	16.51	335.99
Electricity	3.37×10^{-6}	6.07	5.56	116.99

4. Conclusions

Environmental impacts of mung bean production systems were assessed in the present research. The environmental impacts were investigated in characterization, normalization, and weighting steps. The total damage impact of the production was 263.90 mPt. The contribution of mung bean production process in the farms and all inputs to all indicators were studied to find the environmental hotspots.

Decreasing inputs and increasing output cause decreasing environmental impacts of mung bean production. Based on the results of the present research, different attempts must be made to decrease the environmental impact of mung bean production by focusing firstly on the hotspots and then the other contributing factors. Application of biofertilizers in the farms instead of chemical fertilizers, pest control using biological agents, and using new technologies and methods to manage different operations such as direct planting and new irrigation systems are recommended. Governmental programs can be useful in educating the farmers to better manage operations, crop rotation, and biodiversity and consequently move on the sustainable production path. These suggestions not only can decrease inputs, increase output, and reduce environmental impacts, but also can decrease production costs and increase economic profits in mung bean production. The limitation of the present research was the lack of mung bean seed production in the LCA databases. This caused over estimating the contribution of seed in environmental impacts in mung bean production because instead of that, soybean seed was selected in SimaPro software. So, the results of the present research can be used in the future by providing environmental impacts of mung bean.

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