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Life Cycle Assessment of Argentinian dry bean flour

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INTRODUCTION & AIM

Dry bean (*Phaseolus* vulgaris sp.) is widely cultivated in Northwest of Argentina (NOA) (Fig 1). It is an excellent source of energy and nutrients, notable for its high protein, vitamins, and mineral contents (Fig 2). On the other hand, it is a short-cycle crop during rainy season, so it does not require irrigation. Furthermore, chemical fertilizers are not required since leguminous plants can fix nitrogen from the air.

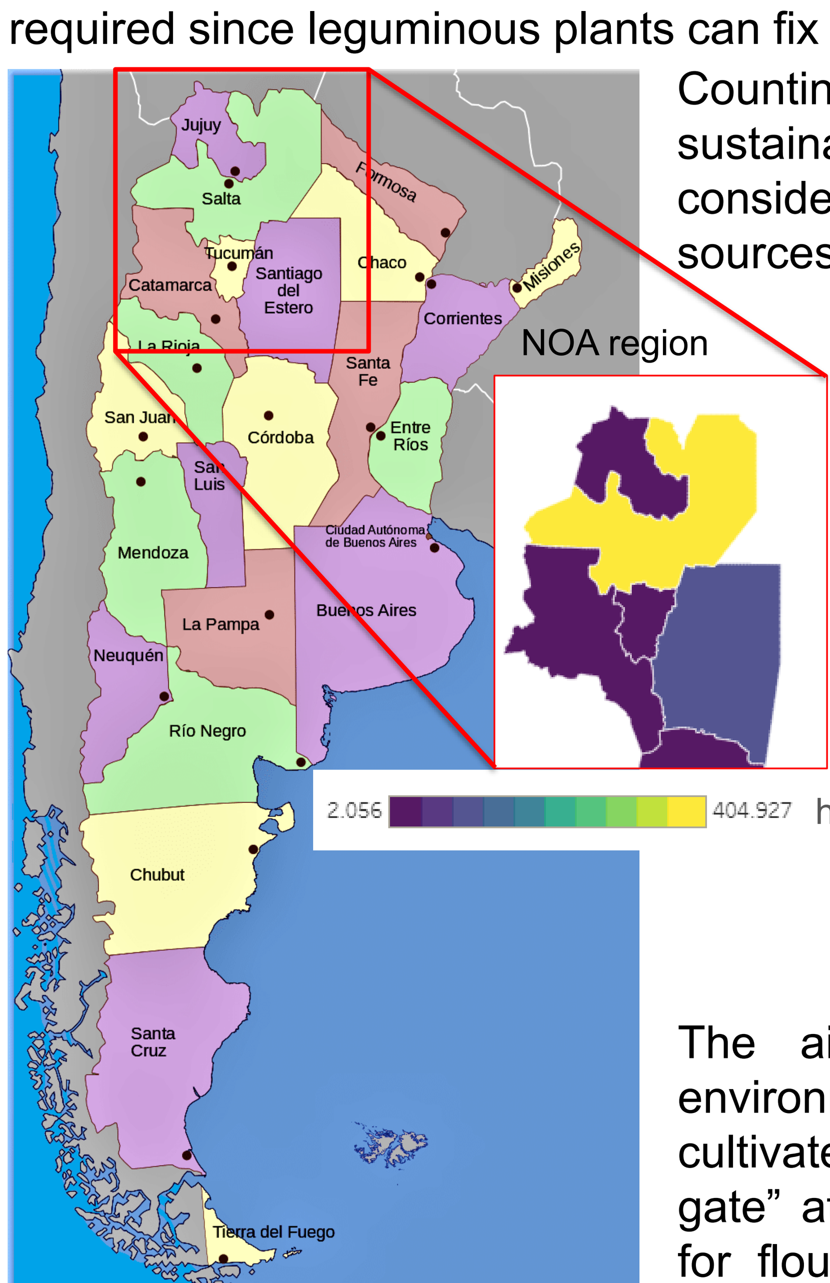

Figure 1 Argentinian dry bean cultivation area

Counting its multiple nutritional benefits and some sustainable agricultural management, dry beans are considered a potential food substitute for other protein sources. To increase legume consumption, some recipes were developed using the bean flour as an alternative ingredient [1].

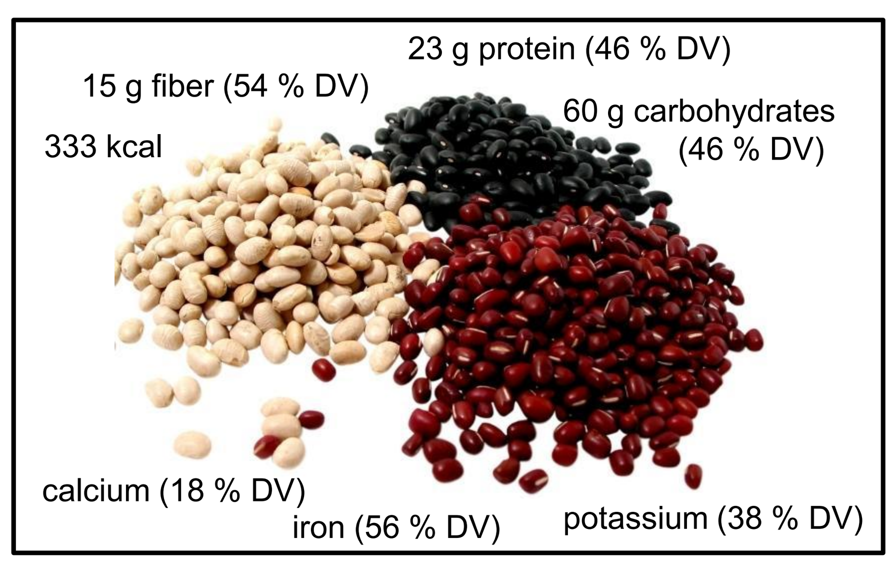

Figure 2 Dry bean nutritional facts (g /100 g and % dairy value (DV))

The aim of this analysis was to calculate the environmental footprint of flour produced from dry beans cultivated in NOA. The study considered the "cradle to gate" attributional life cycle scope. Grain pre-treatment for flour production was also considered to limit the negative effects of raw bean ingestion [2].

METHOD

Life Cycle Assessment (LCA) was performed following ISO standard 14040 and 14044 guidelines. The functional unit was 1 kg of bean flour (BF). Field stages included seed and grain cultivation. Industrial phase, grain transportation and sales at local market were also considered. Flour was prepared by three alternatives [2]: raw (R-BF), soaked (S-BF), and soaked and cooked (SC-BF) beans (Fig 3).

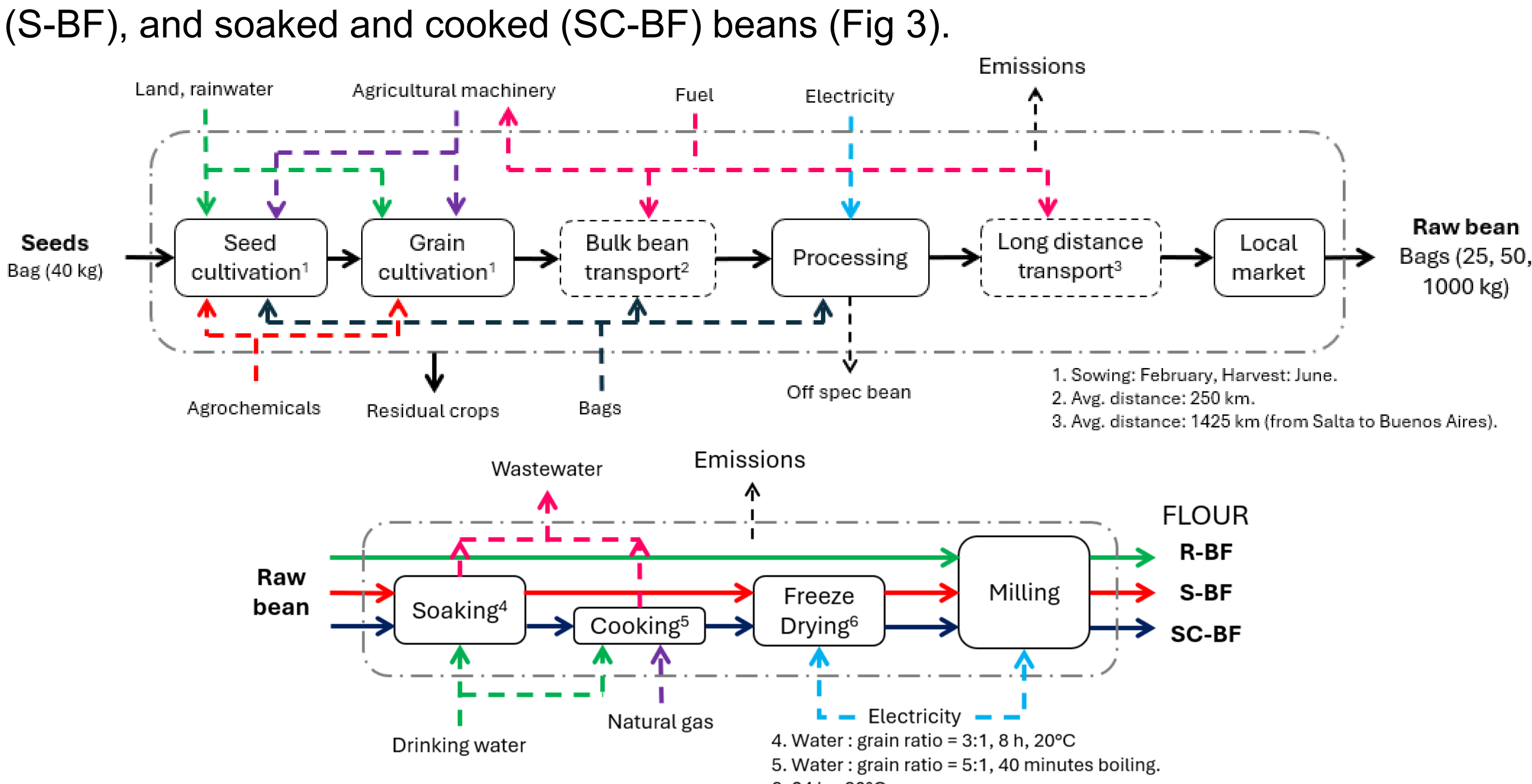

Figure 3 Process block diagram of LCA of bean flour (BF)

Primary data were collected for main stages (Table 1) and free databases were used to estimate inventory for secondary phases. ReCiPe Midpoint (H) multicategory methodology was applied to performed the Life Cycle Impact Assessment (LCIA), with focus on global warming potential, acidification, ecotoxicity, eutrophication, non-renewable resources scarcity, land use and water consumption.

Table 1 Source data for Life Cycle Inventory (LCI)

Phase	Source data
Seed cultivation	Porosem S.R.L
Grain cultivation	INTA (2023 harvest)
Processing	Alimar S.A.
Flour preparation	Laboratory scale CIDCA
Electricity generation	CAMMESA S.A (2023)
Natural gas	ENARGAS

Some notable results from inventory analysis were:

- Flour yield: 0.968 (R-BF), 0.794 (S-BF) and 0.743 (SC-BF) kg/kg packaged bean.
- Processing discard: 9% weight of inlet grain.
- Planting density: 105 kg seed / hectare.
- Grain cultivation yield: 1100 kg bean / hectare.

RESULTS & DISCUSSION

The LCIA (Table 2) showed that for LU, TEc and FWEc, the impact value increased by 1.2 to 1.4 times for S-BF and SC-BF with respect to R-BF, while the differences were up to 1.8 times for MRS, FWEu and TA. In the case of SOD, FRS, GWP, and WC, the differences in impact values of S-BF and SC-BF relative to R-BF were notable, from 3 to 8 times greater. The first influence of this increase was the grain yield in the flour inventory and its impact on the agricultural phases. This meant that all impact categories increased by at least 22 and 30% for S-BF and SC-BF relative to R-BF.

Table 2 Impact category values for 1 kg bean flour (ReCiPe 2016 midpoint (H))

Impact category	Abbreviation	Unit	R-BF	S-BF	SC-BF
Global warming potential	GWP	kg CO_2 eq	0.7838	3.1394	3.3423
Stratospheric ozone depletion	SOD	kg CFC11 eq	2.96E-07	9.21E-07	1.01E-06
Freshwater ecotoxicity	FWEc	kg 1,4-DCB	0.1255	0.1632	0.1745
Terrestrial ecotoxicity	TEc	kg 1,4-DCB	19.1099	24.1965	25.8311
Freshwater eutrophication	FWEu	kg P eq	1.49E-04	2.32E-04	2.51E-04
Terrestrial acidification	TA	kg SO_2 eq	2.70E-03	4.27E-03	4.77E-03
Fossil resource scarcity	FRS	kg oil eq	0.2708	1.2145	1.4125
Mineral resource scarcity	MRS	kg Cu eq	4.20E-03	6.46E-03	6.95E-03
Land use	LU	m^2a crop eq	11.7096	14.2923	15.2608
Water consumption	WC	m^3	0.0081	0.0594	0.0678

Considering categories highly influenced by field phases, in the case of LU, 88,2% of total impact value was due to grain cultivation area, while 11,5% was due to seed cultivation. Pesticides use was responsible for 71,6% and 57,9% on average of the FWEc and TEc values, respectively. Agriculture machinery accounted for 38,6% and 59,4% on average of the total value of FWEu and MRS. Grain transportation and glyphosate production also had a significant burden in both categories. For TA, grain transportation stood out as the most important process (36.4% on average), followed by fuel use (22.5%) and agricultural machinery use (17.9%).

In the case of GWP, SOD, FRS, and WC, the burden of production flour was particularly relevant for S-BF and SC-BF (Fig 4). The energy demand for freeze drying (electricity) was primarily responsible for the increase, followed by cooking (natural gas).

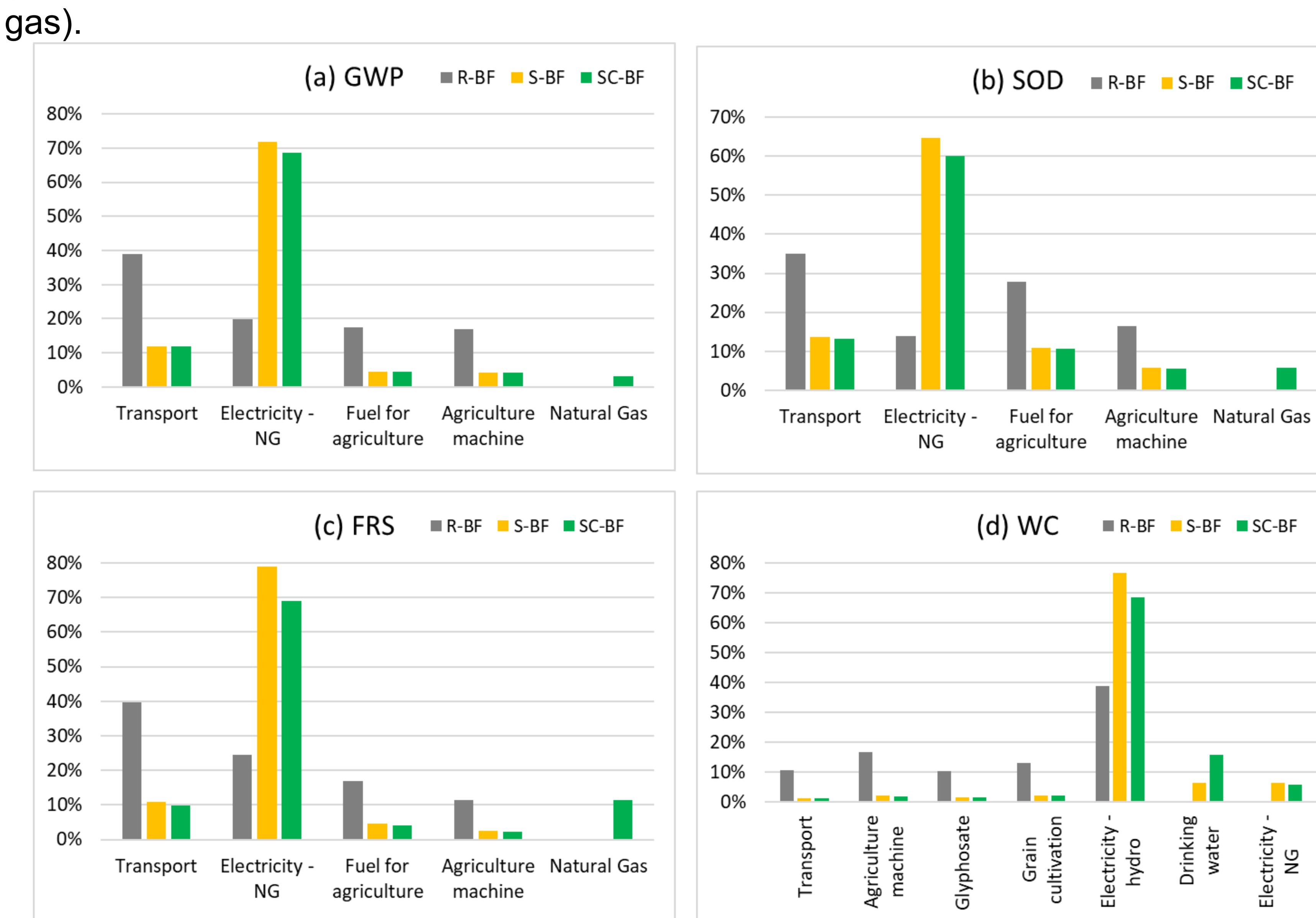

Figure 4 Percentage of total burden of processes for (a) GWP, (b) SOD, (c) FRS and (d) WC

CONCLUSION

Regarding regional implications, although dry bean cultivation does not require fertilization, the use of agrochemicals (fallow land and phytosanitary treatment) had a significant impact on ecotoxicity. In terms of global effects, impacts such as GWP, SOD, and FRS were remarkable influenced by energy consumption (electricity and natural gas) during production flour; therefore, the differences between pretreatment grain compared to raw beans were the greatest.

FUTURE WORK / REFERENCES

To mitigate the impact of energy consumption during the flour production stages, other ways of cooking and dehydration are being analyzed. It is suggested to reuse of wastewater of cooking and soaking to reduce the impact on water consumption.

[1] Nagai et al. (2025) Int J Gastron Food Sci 41, 101239.
[2] Nagai et al. (2024) ACS Food Sci Technol 4 (7), 1747-1755.