



Comparative life cycle assessment of retort pouch and aluminum can for ready-to-eat bean packaging

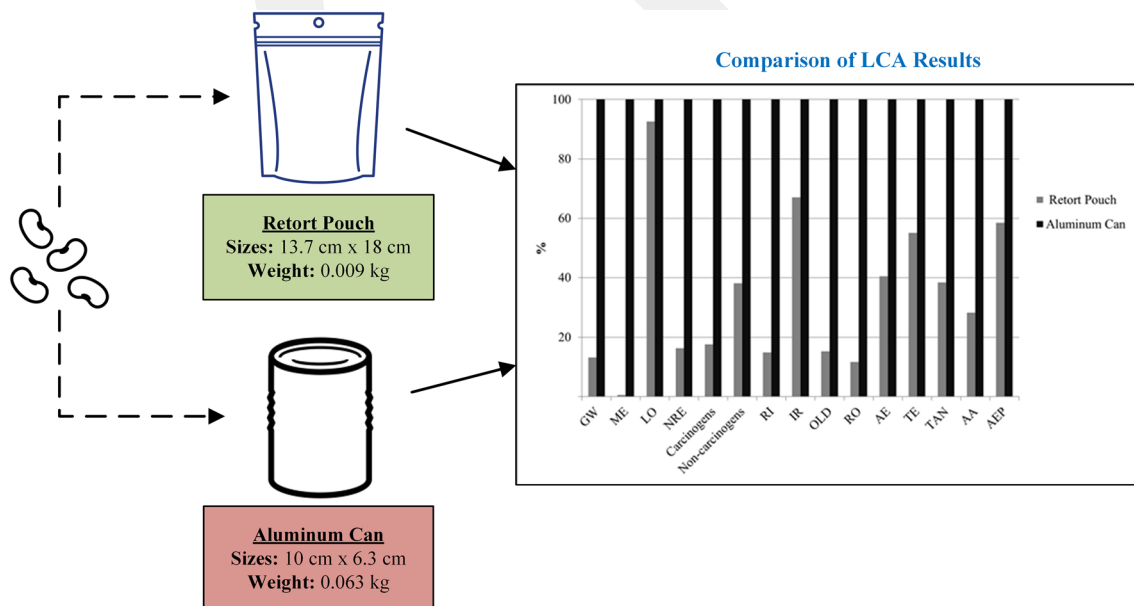
Sedat Gulcimen¹ · Ozlem Ozcan² · Selin Babacan Çevik³ · Kevser Kahraman⁴ · Nigmet Uzal¹

Received: 9 May 2022 / Accepted: 23 August 2023 / Published online: 12 September 2023
© The Author(s), under exclusive licence to Springer Nature Japan KK, part of Springer Nature 2023

Abstract

Since packaging contributes to severe environmental impacts in food production, alternatives of packaging materials that satisfy customer needs while minimizing environmental impacts in a cost-effective manner should be preferred for food product sustainability. This paper compares two different packaging materials (aluminum cans and retort pouches) with a life cycle approach to assess the environmental impacts of ready-to-eat bean packaging. The life cycle assessment (LCA) was used to define and compare the environmental performance of ready-to-eat beans in aluminum cans and retort pouches. The gate-to-gate approach was used in the LCA, with a functional unit of 1 kg of packaged ready-to-eat bean product. Inventory for packaging in retort pouch was created in collaboration with Duru Bulgur Company (Karaman, Turkey) and the data for ready-to-eat beans in the aluminum can were gathered from the literature. The findings show that ready-to-eat beans in retort pouches have lower environmental impacts than ready-to-eat beans in aluminum cans. The packaging and washing processes for both ready-to-eat beans packaged in aluminum cans and retort pouches had the greatest environmental impact. In ready-to-eat beans production, retort pouch provides 87% better environmental performance than aluminum can in terms of global warming (GW). Overall, the results demonstrated that replacing aluminum cans with retort pouches in ready-to-eat bean production can significantly reduce environmental effects in all impact categories.

Graphical abstract



Keywords Food packaging · Life cycle assessment · Ready-to-eat bean · Retort pouch · Aluminum can

Extended author information available on the last page of the article

Introduction

Food packaging protects food products from harmful physical, chemical, and biological influences, and thus has a direct impact on shelf life [1]. The right packaging material preserves product quality, reduces deterioration, and increases shelf life [2]. Although packaging technologies, processing innovations, and packaging materials provide significant advantages for ready-to-eat foods on the market, other factors such as material and energy costs, environmental impacts, and regulations must also be considered [2, 3]. Packaging is now under increasing pressure to become more sustainable in its production, use, and disposal, as these are linked to the direct environmental impacts of food products [4]. Sustainable packaging allows for the storage of food in a cost-effective manner that meets industry requirements as well as consumer desires, while maintaining food safety and reducing environmental impacts [2].

Glass, metals (aluminum, tinplate, tin-free steel, etc.), paper, paperboards, and plastics have conventionally been used in food packaging. Metal packaging materials are widely used because they have a unique combination of properties such as physical protection, ease of formation, decorative potential, and consumer acceptance. Steel, tin, chromium, and aluminum are the most common metals used in food packaging [5]. Aluminum is a silvery-white metal derived from bauxite ore and enriched with magnesium and manganese to improve its strength [1]. It also has a lightweight compared to other metals, extremely resistant to corrosion, and providing a great barrier to air, moisture, odors, and microorganisms, which makes it proper packaging material in the food market. On the other hand, its high cost compared with other metals like steel and its incapability to be welded are the main disadvantages of aluminum [2].

Even though metal cans are the major packaging materials in the bean packaging, recently the interest in retort pouches is increasing due to their prominent feature for different industrial processed food products [1]. The retort pouch term is utilized to depict a flexible package made of heat resistant multi-layer plastic, into which food products are put and sterilized at temperatures up to 121 °C [6]. In 1960s, the US Army Natick Laboratories and association of food-packaging companies brought out concept of using pouch as a container [3]. In time, heat-sterilized foods in pouches developed a new segment in food sector [7]. Nowadays, retort pouches made of different materials are commercially available on the market. They are hermetically sealed on three or four sides and produced from one or more layers of plastics or foil. Each layer of retort pouches possesses a specific functionality. Moreover,

retort pouches are made from either aluminum foil-based plastic laminates or foil-free plastic laminate films, which are suitable for microwave heating [2]. The selection of layers depends on the processing conditions, desired shelf life, and product type.

Another advantage is the ease to carry, reheat, and serve together with lower weights and space-savings. In addition, plastic-based packaging materials may provide source reduction, allowing conservation of resources, protection of the environment, and prevention of greenhouse gas formation [8]. Lastly, used pouches are disposed of much easier than metal cans as they can be simply flattened. However, there are some challenges about retort pouches including the segregation of separate layers for recycling and their sensitivity to rupture during rapid cooling following a high-temperature process [9]

The negative environmental impacts of packing are primarily determined by the packaging process, material and waste generation. Packaging wastes have a considerable impact on the environment, which is significantly affected by their disposal method. Demetriou and Crossin conducted a life cycle assessment (LCA) of paper and plastic packaging waste in landfills, incinerators, and gasification-pyrolysis. Their findings indicate that various techniques should be considered for managing different types of recyclables [10]. Ferreira et al. used LCA to quantify the positive and negative environmental impacts of packaging waste management operations in Belgium. All the packaging waste management operations (refuse collection, selective collection, sorting, recycling, and burning) were analyzed using LCA, and the results show that incineration is the worst option [11]. A further disadvantage for the food business is deciding on packaging materials that would improve consumer satisfaction while reducing environmental impacts [12]. LCA studies have been used to quantify the environmental impacts of sustainable packaging technologies in the previous few decades [13–16]. Improving the environmental performance of food items requires assessing the sustainability of food-packaging techniques [17]. LCA is one of the most effective and comprehensive methods for analyzing environmental impacts across a product's or process's life cycle [18]. In the literature, several impact assessment methods such as Recipe Midpoint (H), IMPACT 2002+, CML and TRACI 2.1 are used for performing LCA of food production [18–20]. Costa et al. reviewed LCA studies on legume in the literature. They revealed that, although several impact methods are used for LCA studies of legumes, 66% of the reviewed studies state the results cross only one or two environmental impact categories. Their results also indicate that 50% of the studies only present global warming potential, in addition, eutrophication, acidification, ecotoxicity, ozone, and land use impacts are the most widely used categories [21].

The use of plastic in food packaging has grown thanks to its low cost and functional advantages (such as thermosealability, microwavability, optical characteristics, and infinite sizes and shapes) against conventional materials such as glass and metal [2]. However, the usage of plastic packaging has become a health and environmental concern due to issues such as the accumulation of microplastics [22]. Therefore, environmental impact assessments and comparisons of alternative food-packaging materials are crucial. The environmental impacts of food packaging have been studied and quantified in a number of studies [23–25]. However, there is a severe lack of research regarding the environmental sustainability of retort pouch packaging. [26, 27]. A study by Humbert et al. examined the environmental impact of baby food packaged in plastic pots and glass jars. Products packaged in plastic containers were shown to have lesser carbon footprints by 28–31% compared to those packaged in glass jars [28]. Compared to metal can and retort pouch systems for tuna goods, Poovarodom et al. discovered that retort cup systems reduced GHG emissions by 10% and 22%, respectively [29]. Del Borghi et al. studied the supply chain of legumes (peas, borlotti beans, steam-cooked peas, cannellini beans, and chickpeas) to compare environmental hotspots in their life cycle. They identified the GW of 1.166 kg CO₂ eq/kg of Borlotti beans and 0.98 kg CO₂ eq/kg of Cannellini beans. In addition, packing was identified as the main contributor of 70% of the total impacts [30]. Furthermore, to the best of our knowledge, no study has been conducted to assess the environmental impact of packaging in retort pouches during the production of ready-to-eat beans. As a result, it is critical to conduct retort pouch packaging studies that focus on potential environmental impacts during the manufacturing process. The purpose of this paper is to define and compare the environmental impacts of ready-to-eat bean production using two different packaging materials: (i) aluminum can and (ii) retort pouch. LCA method was used to assess the environmental performance of these two packaging materials. Since studies on the environmental performance of ready-to-eat bean products packaged in retort pouches are scarce in the literature, this study fills the gap by presenting the results of environmental performance analyses of ready-to-eat bean in retort pouch and aluminum can.

Materials and methods

Ready-to-eat bean production process description

The production processes of ready-to-eat bean can be generally described in the following main steps: washing, soaking, blanching, cooling, inspection, seaming of cans/retort pouch, the addition of brine, packaging, and heat treatment as shown in Fig. 1. The first processing operation is washing

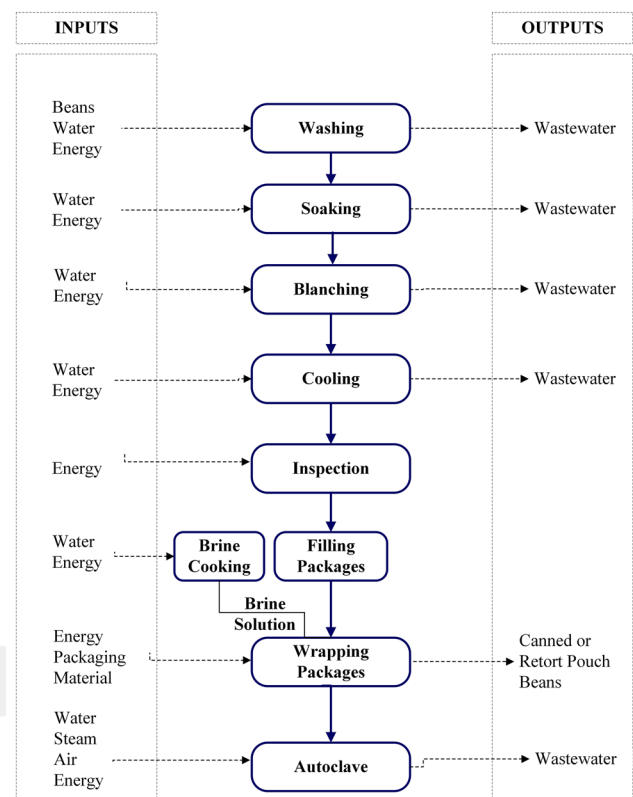


Fig. 1 Production processes of ready-to-eat bean

the raw beans in ready-to-eat bean production. The beans are then soaked into water for hydration. After removing the damaged and non-standard size beans and other impurities in the hydration step, the products are blanched in water at a temperature between 82 and 93 °C for 3–8 min, followed by cooling process for 30 min [31, 32]. After that, the processes are followed by the packaging stage in ready-to-eat bean production. The products are packed in aluminum cans or retort pouches for product preservation. After filling the beans in the package, brine is added to the packages. The basic formula of brine consists of a combination of 1.8–3.0% sodium chloride (NaCl), 3.6–5.4% sugar, and some chemicals such as; EDTA and calcium chloride (CaCl₂) to reduce the loss of product coloration [33]. Thermal processing is an important phase in the processing of ready-to-eat bean production as cooking and sterilization of the product occur in this phase. Heat treatment is carried out in pressurized containers (autoclaves), which provides heat transfer to the inside of the product by applying liquid water, steam water, or a mixture of these two. The time required for cooking and sterilization of the product is affected by some factors such as packaging material, the resistance of enzymes to heat, heating conditions, and food pH. The main difference in the application of two different packaging materials, metal can and retort pouch, for ready-to-eat bean production is the time required

for heat treatment [32]. When compared with the metal cans, one of the advantages of the retort pouches is the thin profile of the package (12–33 mm for 200–1000 g pouches), which provides lower retorting times to be decreased by up to 60% [5]. For sterilization, ready-to-eat beans are autoclaved for 10–15 min in retort pouch and 42 min in aluminum can at 120–130 °C. After the thermal treatment stage, packaged products are cooled down with water to 30–40 °C to protect against the deterioration induced by thermophilic bacteria [34].

LCA methodology

The study was performed following the ISO 14040 and ISO 14044 standards [35, 36], based on four main phases (i) goal and scope, (ii) life cycle inventory (LCI), (iii) life cycle impact assessment (LCIA), (iv) interpretation and described below. SimaPro 8.4 PhD version was used to characterize and normalize the environmental impacts of the products.

Goal and scope

The main goal of this study is to define and compare the environmental impacts of ready-to-eat bean production with two different packaging materials: aluminum cans and retort pouches. Ahmad et al. (2019) have reviewed and analyzed recent (published from 2010 to 2018) LCA studies on food production. They revealed that recent studies are more focused on the cradle-to-grave and cradle-to-factory gate approach [37]. The system boundaries are identified by considering the gate-to-gate approach as indicated in Fig. 1, which covers the phases from the washing process to packaging with a functional unit of 1 kg of the packaged product. The cultivation phase, use-phase, and packaging disposal are excluded from boundaries. Products are packaged in 400 g (drained weight of 220 g) retort pouches and 400 gr (drained weight of 280 g) aluminum cans. Packaging sizes are 13.7 cm × 18 cm for retort pouch and 10 cm (diameter) × 6.3 cm (height) for aluminum can. The weight of the packaging is 0.009 kg for retort pouch and 0.063 kg for aluminum can.

Life cycle inventory

Inventory data for ready-to-eat beans in retort pouch were compiled directly from Duru Bulgur Company (Karaman, Turkey) and the data for ready-to-eat beans in aluminum can is retrieved from the Ecoinvent database v.3 (Table S5) [38] of SimaPro 8.4 and the authors' literature search (Table S1–S4). This study utilized secondary data from the Ecoinvent database v.3 for energy inputs. To compare ready-to-eat beans in retort pouch and aluminum can, the same secondary data was used for both of them. For electricity

and steam, the following country/region-specific data were preferred: “electricity, high voltage (TR) market for Conseq, S” and “process steam from natural gas, heat plant, consumption mix, at plant, MJ, EU-27, S.”

Life cycle impact assessment (LCIA)

In this study, IMPACT 2002+ method is used for assessing the environmental impacts of ready-to-eat bean production to compare two different packaging materials (aluminum cans and retort pouches). As an attractive method in the comparative evaluation, the IMPACT 2002+ method is feasible for the implementation of a combined midpoint impact and damage approach by linking 15 midpoint categories to 4 damage categories [39]. The method covers the following midpoint impact categories; carcinogens, non-carcinogens, respiratory organics (RO), respiratory inorganics (RI), ionizing radiation (IR), ozone layer depletion (OLD), aquatic ecotoxicity (AE), terrestrial ecotoxicity (TE), terrestrial acid/nutritional (TAN), aquatic eutrophication (AEP), aquatic acidification (AA), land occupation (LO), global warming (GW), non-renewable energy (NRE), and mineral extraction (ME).

Results and discussion

The environmental impacts of aluminum can

The environmental impacts of production steps of ready-to-eat beans packaged in aluminum can are shown in Fig. 2. The packaging step contributes significantly to 13 environmental impact categories (GW, ME, NRE, carcinogens, non-carcinogens, RI, IR, OLD, RO, AE, TAN, AA, and AEP) with higher than 50% share among the total 15 impact categories. It shows the highest impacts in ME with 99% of the total impact due to the high amount of aluminum consumption for can production. As a result, aluminum cans as a packaging material have a significant negative impact on the ME impact category of natural resource extraction. Extraction of alumina, used in the production of aluminum, is an extremely energy-intensive process. Consistent with earlier study, GW was found as the other major environmental effect category associated with the manufacture of ready-to-eat canned beans. For instance, Del Borghi et al. studied on the environmental sustainability of a group of legumes (i.e., peas, beans, and chickpeas) produced in Italy and packaged in glass bottle or tin can. GW, non-renewable cumulative energy demand, water scarcity index and toxicity potentials were found as most significant environmental impact categories [30]. Similarly, in case of ME, the packaging process contributes significantly (85%) to the category

Fig. 2 The environmental impacts of the production steps of ready-to-eat beans packaged in aluminum can (IMPACT 2002+ method: V2.14/characterization) *GW* global warming, *ME* mineral extraction, *LO* land occupation, *NRE* non-renewable energy, *RI* respiratory inorganics, *IR* ionizing radiation, *OLD* ozone layer depletion, *RO* respiratory organics, *AE* aquatic ecotoxicity, *TE* terrestrial ecotoxicity, *TAN* terrestrial acid/nutria, *AA* aquatic acidification, *AE* aquatic eutrophication

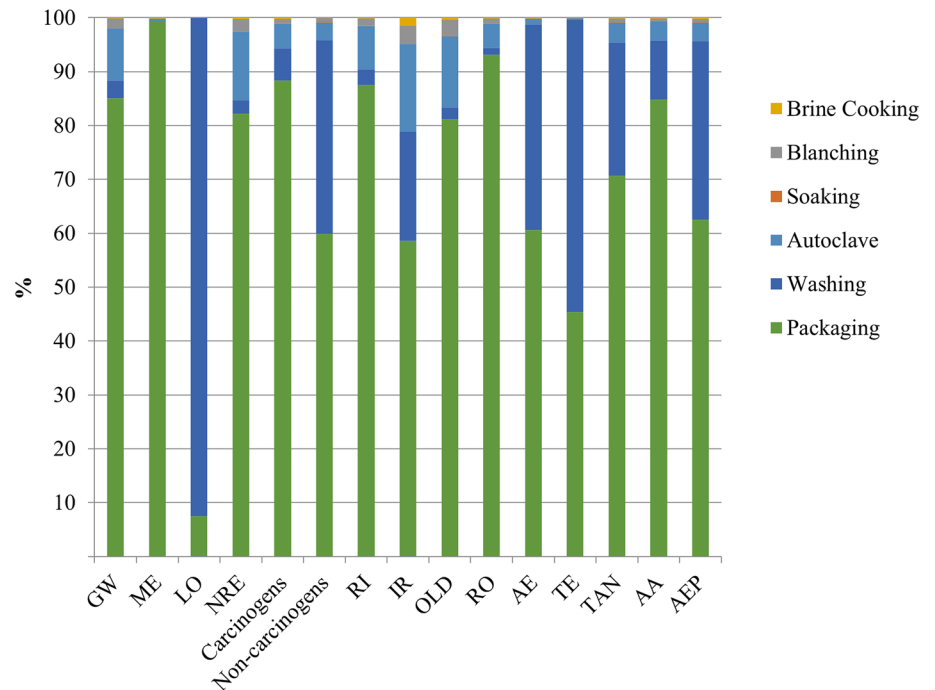


Table 1 The environmental impact category values production steps of ready-to-eat beans packaged in aluminum can (IMPACT 2002+ method: V2.14/characterization)

Impact category	Unit	Total	Washing	Soaking	Blanching	Brine	Autoclave	Packaging
Global warming	kg CO ₂ eq	4.161	0.137	0.002	0.076	0.005	0.402	3.539
Mineral extraction	MJ surplus	0.471	1.43E-04	3.45E-05	3.66E-04	0.001	0.002	0.468
Land occupation	m ² org.arable	1.479	1.368	4.60E-06	7.53E-05	7.78E-05	0.001	0.110
Non-renewable energy	MJ primary	51.169	1.300	0.021	1.227	0.097	6.456	42.068
Carcinogens	kg C ₂ H ₃ Cl eq	0.102	0.006	7.39E-05	0.001	2.31E-04	0.005	0.090
Non-carcinogens	kg C ₂ H ₃ Cl eq	0.180	0.065	1.11E-04	0.001	1.61E-04	0.006	0.108
Respiratory inorganics	kg PM _{2.5} eq	0.007	2.03E-04	8.89E-06	8.79E-05	7.81E-06	0.001	0.006
Ionizing radiation	Bq C-14 eq	3.576	0.726	0.007	0.118	0.049	0.579	2.097
Ozone layer depletion	kg CFC-11 eq	3.2E-07	6.96E-09	7.77E-10	8.81E-09	1.47E-09	4.23E-08	2.60E-07
Respiratory organics	kg C ₂ H ₄ eq	0.001	1.56E-05	3.36E-07	1.05E-05	2.01E-06	5.73E-05	0.001
Aquatic ecotoxicity	kg TEG water	406.120	154.955	0.059	0.583	0.482	3.749	246.292
Terrestrial ecotoxicity	kg TEG soil	258.877	140.254	0.014	0.144	0.148	0.881	117.438
Terrestrial acid/nutri	kg SO ₂ eq	0.078	0.019	2.48E-05	0.001	9.66E-05	0.003	0.055
Aquatic acidification	kg SO ₂ eq	0.023	0.003	8.56E-06	1.38E-04	2.89E-05	0.001	0.020
Aquatic eutrophication	kg PO ₄ P-lim	0.001	2.61E-04	4.74E-07	4.37E-06	2.09E-06	2.72E-05	4.92E-04

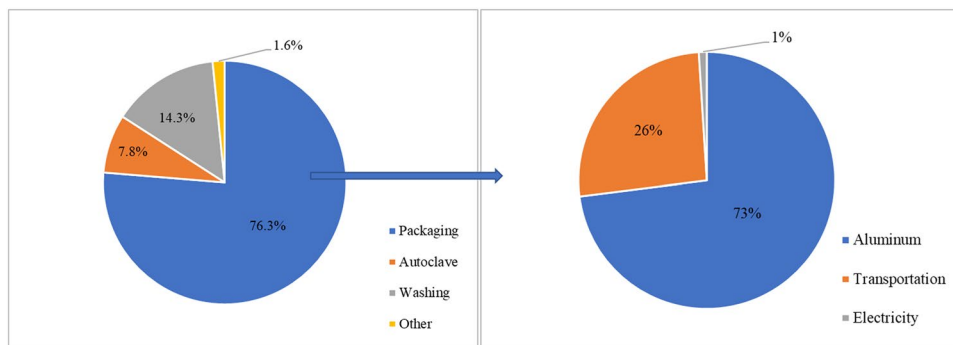
of GW impact for ready-to-eat beans packaged in aluminum cans.

The environmental impacts category values for production steps of aluminum can packaged ready-to-eat beans are shown in Table 1. The packaging process added 0.468 MJ surplus to the total ME value of ready-to-eat beans in an aluminum can, bringing the total ME value to 0.471 MJ surplus. Besides, the total GW value of ready-to-eat beans packaged in an aluminum can was calculated to be

4.161 kg CO₂ eq. Moreover, the packaging process had contributed to 3.539 kg CO₂ eq, and the autoclaving contributed 0.402 kg CO₂ eq of the total GW. In addition to GW and ME, the main sources of energy used in the production of NRE were packaging (42.068 MJ), autoclaving (6.456 MJ), and washing (1.30 MJ).

The distribution of environmental impacts by production steps and sub-components of packaging for ready-to-eat beans packaged in aluminum can is shown in Fig. 3. It

Fig. 3 The distribution of environmental impacts by production steps and by sub-components of packaging of ready-to-eat beans packaged in aluminum can (IMPACT 2002+method: single score)



was found that for ready-to-eat beans packaged in aluminum cans, the packing step had the highest environmental impact, accounting for 76.3% environmental impact. Following the packing process, the washing and autoclave steps take 14.3% and 7.8%, respectively.

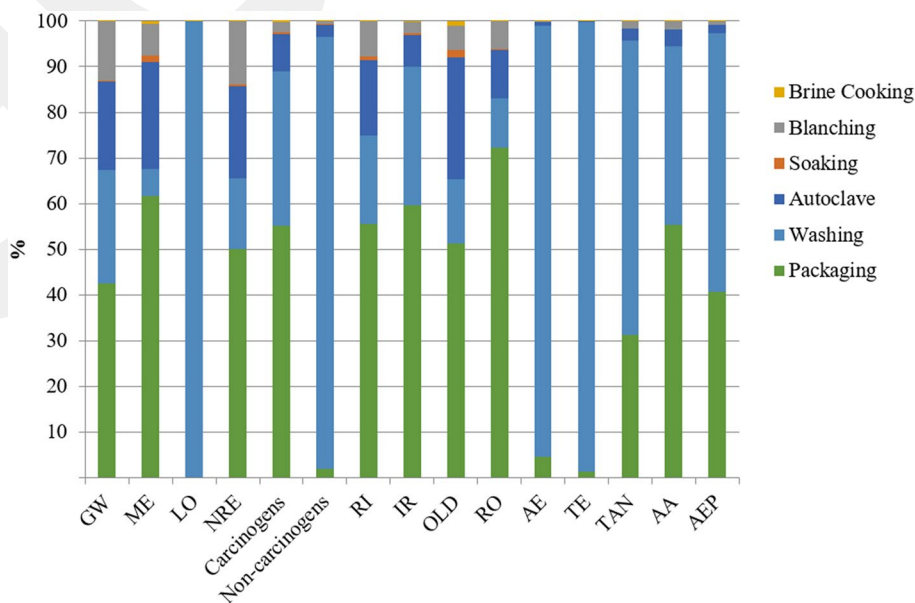
The main contributor component is found as material of aluminum used in aluminum can with 73% of the total packaging impact. This is mostly related to the energy consumption based on fossil fuels during the production process of aluminum cans. Peng et al. found that greenhouse gas (GHG) emissions and energy consumption of aluminum were 14.77 kg CO₂ eq/kg and 144.6 MJ/kg, respectively [40]. Yang et al. stated that the GHG emissions coefficient of aluminum varied between 4.91 kg CO₂ eq/kg (Al) and 21.8 kg CO₂ eq/kg (Al) depending on the energy sources. They also revealed that primary energy demand, water use, GW, and freshwater eutrophication potential were the primary environmental impact categories for aluminum production [41]. Similarly, GHG emissions and energy consumption of the aluminum production which is used as secondary data from Ecoinvent database v.3 [38] in this

study is 17.9 kg CO₂ eq/kg and 180 MJ/kg, respectively. The transportation of the packing materials is the second main hotspot (26%) for the packaging process in ready-to-eat beans production packaged in aluminum can as indicated in Fig. 3.

The environmental impacts of retort pouch

The environmental performance of ready-to-eat beans in the retort pouch varies depending on the processing steps used to make products (washing, soaking, blanching, brine cooking, autoclaving, and packaging). Figure 4 shows the environmental impacts of the various stages of production for ready-to-eat beans packaged in retort pouch. Hotspots in the production of ready-to-eat beans packaged in retort pouch are primarily associated with the washing and packaging processes. The packaging step significantly contributes to 8 environmental impact categories (ME, NRE, Carcinogens, RI, IR, OLD, RO, AA) with a higher than 50% share among the 15 impact categories. It is the factor that has the greatest impact on RO, accounting for 72% of the total. In addition,

Fig. 4 The environmental impacts of production steps of ready-to-eat beans packaged in retort pouch (IMPACT 2002+method: V2.14/characterization). GW global warming, ME mineral extraction, LO land occupation, NRE non-renewable energy, RI respiratory inorganics, IR ionizing radiation, OLD ozone layer depletion, RO respiratory organics, AE aquatic ecotoxicity, TE terrestrial ecotoxicity, TAN terrestrial acid/nutria, AA aquatic acidification, AEP aquatic eutrophication



the process of washing has a significant impact on 4 of the environmental impact categories (LO, non-carcinogens, AE, and TE), accounting for more than 90% of the total among all 15 categories of environmental impact. The autoclaving process also plays an important role for OLD (26%) as well as NRE (20%), and ME (23%) in terms of environmental performance.

The environmental impact category values of production steps of ready-to-eat beans packaged in retort pouch are shown in Table 2. The packaging process has highest impact on RO and added 1.06E−04 kg C₂H₄ eq to the total RO value of ready-to-eat beans packaged in retort pouch, bringing the total RO value to 1.46E−04 kg C₂H₄ eq. Besides, the washing process has highest impact on LO and TE environmental impact categories and added 1.368 m² org.arable and 140.254 kg TEG soil to the total LO and TE value of ready-to-eat beans packaged in retort pouch, respectively. The total LO and TE value of ready-to-eat beans packaged in retort pouch was calculated as 1.370 m² org.arable and 142.651 kg TEG soil, respectively.

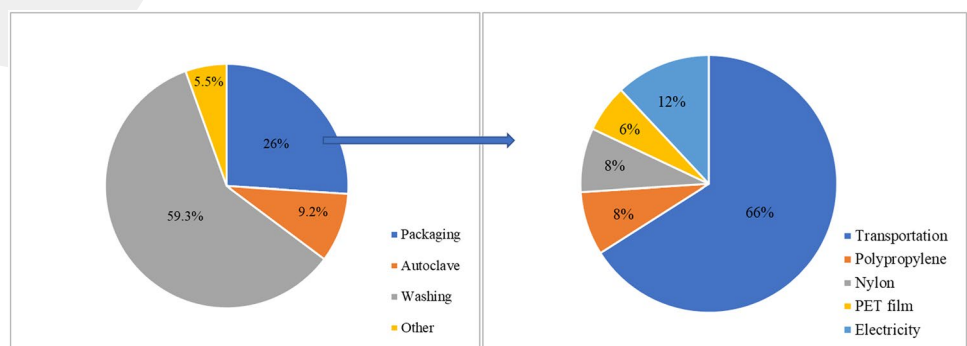
In addition, the major contributor process for GW was packaging with a 42% share of total (0.233 kg CO₂ eq), followed by washing with a 25% share (0.137 kg CO₂ eq). The outcomes are in line with previous research on the environmental sustainability of food throughout its life cycle. Del Borghi et al. studied on LCA of 13 tomato-based products, and it was found that the environmental hotspot of entire supply chains of these products is the packaging stage, which resulted in the life cycle assessment with the highest effect in all considered categories. It was also presented that packaging contributes about 50% for GW [42].

The distribution of environmental impacts by production steps and sub-components of packaging for ready-to-eat beans packaged in retort pouch is indicated in Fig. 5. It clearly shows that washing step has the highest environmental impacts with 59.3% of the total environmental impacts for ready-to-eat beans packaged in retort pouch. After washing step, packaging and autoclave steps follow with 26% and 9.2%, respectively.

Table 2 The environmental impact category values of production steps of ready-to-eat beans packaged in retort pouch (IMPACT 2002+ method: V2.14/characterization)

Impact category	Unit	Total	Washing	Soaking	Blanching	Brine	Autoclave	Packaging
Global warming	kg CO ₂ eq	0.550	0.137	0.002	0.071	3.79E−04	0.107	0.233
Mineral extraction	MJ surplus	0.002	1.43E−04	3.45E−05	1.69E−04	1.62E−05	0.001	0.001
Land occupation	m ² org.arable	1.370	1.368	4.60E−06	4.45E−05	2.53E−06	1.60E−04	0.001
Non-renewable energy	MJ primary	8.362	1.300	0.021	1.160	0.006	1.694	4.182
Carcinogens	kg C ₂ H ₃ Cl eq	0.018	0.006	7.39E−05	4.15E−04	2.68E−05	0.001	0.010
Non-carcinogens	kg C ₂ H ₃ Cl eq	0.069	0.065	1.11E−04	3.84E−04	7.01E−05	0.002	0.001
Respiratory inorganics	kg PM2.5 eq	0.001	2.03E−04	8.89E−06	7.98E−05	6.66E−07	1.72E−04	0.001
Ionizing radiation	Bq C-14 eq	2.397	0.726	0.007	0.061	0.005	0.169	1.430
Ozone layer depletion	kg CFC-11 eq	4.91E−08	6.96E−09	7.77E−10	2.62E−09	5.07E−10	1.31E−08	2.51E−08
Respiratory organics	kg C ₂ H ₄ eq	1.46E−04	1.56E−05	3.36E−07	8.76E−06	1.40E−07	1.57E−05	1.06E−04
Aquatic ecotoxicity	kg TEG water	164.072	154.955	0.059	0.363	0.018	1.159	7.518
Terrestrial ecotoxicity	kg TEG soil	142.651	140.254	0.014	0.084	0.005	0.270	2.025
Terrestrial acid/nutri	kg SO ₂ eq	0.030	0.019	2.48E−05	4.60E−04	5.86E−06	0.001	0.009
Aquatic acidification	kg SO ₂ eq	0.007	0.003	8.56E−06	1.17E−04	1.70E−06	2.33E−04	0.004
Aquatic eutrophication	kg PO ₄ P-lim	4.60E−04	2.61E−04	4.74E−07	3.49E−06	7.17E−08	8.41E−06	1.87E−04

Fig. 5 The distribution of environmental impacts by production steps and by sub-components of packaging of ready-to-eat beans packaged in retort pouch (IMPACT 2002+ method: single score)



The transportation of packaging component is found as the main contributor with 66% of the total packaging impact. Electricity consumption in the packaging process has the second highest impact (12%) of the total packaging impact. According to Johannes Remmele of Südpack, a packaging manufacturer, multi-layer packaging can contain up to 11 ultra-thin layers, each with its unique set of features such as oxygen barriers. While offering optimal food protection, extending shelf life, and reducing food waste, these packaging solutions reduce packing volume, raw material consumption, and CO₂ emissions [43]. The environmental impact of three-layer retort pouch packaging comprised of polypropylene, nylon, and PET film is assessed in this study. As shown in Fig. 5, the main contributors in packaging materials are polypropylene and nylon, which account for 8% of overall packaging impacts, and PET film, which accounts for 6% of total packaging impacts.

Comparison of aluminum can and retort pouch

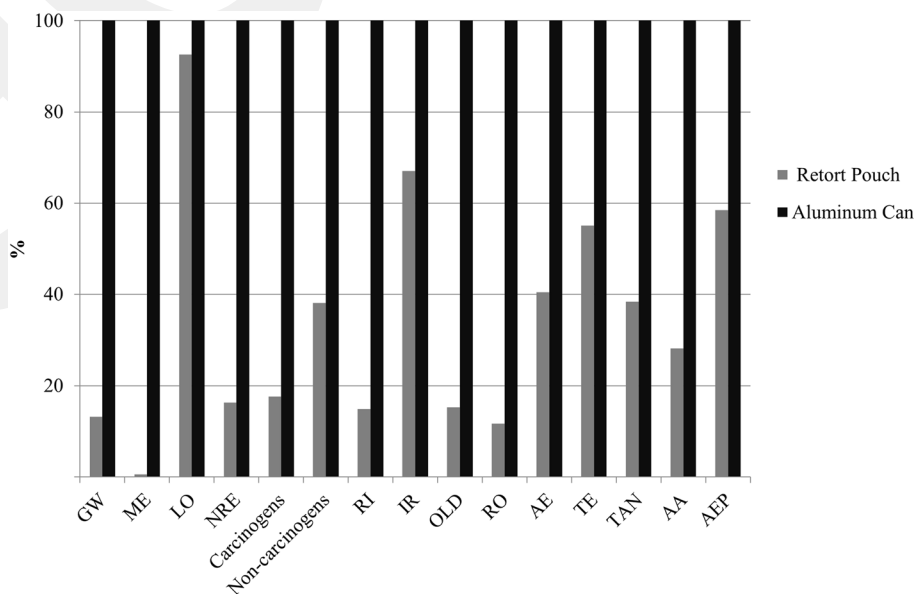
As mentioned in the goal and scope, the LCA analysis was performed for the comparison of environmental impacts of ready-to-eat bean production using aluminum cans and retort pouches. LCA analysis consists of 15 impact categories calculated using IMPACT 2002+ method and the effect of packaging type on the environmental performance of ready-to-eat bean production was compared. Comparison of the environmental impacts of ready-to-eat beans packaged in aluminum can and retort pouch are shown in Fig. 6. All impact category values of ready-to-eat beans in retort pouch were lower than ready-to-eat beans in aluminum can.

The highest difference was obtained for ME of impact category, while the retort pouch has 99% lower impact than

aluminum can in ready-to-eat bean production. The main reason of this difference is the high amount of mineral consumption for aluminum can production. Farjana and Mahmud studied on impacts of aluminum production using LCA methodology and they revealed that aluminum production is based on bauxite mining which causes environmental burdens for mineral extraction. Their results also indicate that aluminum smelting and refining have high environmental load due to electricity consumption in aluminum production [44]. Similarly, this paper revealed aluminum production as the leading contributor (56%) to the total impact of ready-to-eat bean production in aluminum can due to high electricity and mineral consumption. In this study, the country-specific data for Turkey were utilized as secondary data from the Ecoinvent database for electricity. The lowest difference was obtained for LO impact category. Ready-to-eat beans in retort pouch have 7% lower LO than ready-to-eat beans in aluminum can. While total LO of retort pouch was 1.370 m² org.arable, similarly, total LO of aluminum can was 1.480 m² org.arable in ready-to-eat bean production.

The results of the study revealed that the packaging phase was the primary environmental hotspot for environmental impacts of ready-to-eat food production. These results were also coherent with the literature on food-packaging applications. Del Borghi et al. studied on LCA for eco-design of product and package systems in the food industry. LCA of a set of legumes (i.e., peas, beans, and chickpeas) produced in Italy and packaged in glass bottles or steel tin cans were investigated to identify environmental hotspots under a cradle-to-grave approach. In that study, results indicated that about 90% of the contribution to non-renewable energy demand comes from packaging due to the production of energy-intensive primary packaging materials. It is stated

Fig. 6 Comparison of the environmental impacts of ready-to-eat beans packaged in aluminum can and retort pouch (IMPACT 2002+ method: V2.14/characterization). *GW* global warming, *ME* mineral extraction, *LO* land occupation, *NRE* non-renewable energy, *RI* respiratory inorganics, *IR* ionizing radiation, *OLD* ozone layer depletion, *RO* respiratory organics, *AE* aquatic ecotoxicity, *TE* terrestrial ecotoxicity, *TAN* terrestrial acid/nutria, *AA* aquatic acidification, *AEP* aquatic eutrophication



that packaging is thus the main contributor phase for global environmental effects [30]. Similarly, Perez-Martinez et al. performed an LCA study to evaluate the environmental performance of two ready-to-eat canned meat products with cradle to grave approach which includes stages from meat production to final disposal. They revealed that meat production and food processing including packaging step as well for both products, pork lean and meatballs with peas are the stages with the highest environmental impacts. Their findings also show that due to the use of electricity and steam in the food processing steps, packing and can sterilization have the greatest environmental impact potential [23].

Although past research has shown that the packaging stage has a significant impact on the environmental performance of processed foods, there are little data on the environmental performance of ready-to-eat beans packaged in retort pouches [45–48]. Humbert et al. compared the environmental load of plastic pots and glass jars for baby food products. They discovered that items with plastic pots had 28–31% smaller carbon footprints than glass jars [28]. Del Borghi et al. investigated the supply chain of legumes (peas, borlotti beans, steam-cooked peas, cannellini beans, and chickpeas) to compare environmental hotspots in their life cycle. They found that GW of 1.166 kg CO₂ eq for Borlotti beans and 0.984 kg CO₂ eq for Cannellini beans per kg of legume. In addition, packaging was found as a primary hotspot which accounts 70% of the total impacts [30]. Poo-varodom et al. revealed that retort cup systems decreased the overall GHG emissions by 10% and 22% when compared metal can and retort pouch systems for tuna products [29]. In our study, the GW of ready-to-eat bean production was calculated as 4.161 kg CO₂ eq and 0.550 kg CO₂ eq for packaged in aluminum can and retort pouch, respectively. In other words, retort pouch package provides 87% better environmental performance than aluminum can package in terms of GW.

Conclusions

In the present study, LCA was used to compare the environmental performance of ready-to-eat bean production utilizing two alternative packaging materials. Using the IMPACT2002+ method, the gate-to-gate methodology was utilized to compare the environmental impacts of ready-to-eat beans packaged in aluminum cans versus retort pouches. According to the obtained results, the following conclusions can be drawn:

- In the production of ready-to-eat soybeans, the retort pouch surpassed the aluminum can in all environmental impact categories.

- GW contribution of aluminum can and retort pouch was found as 4.161 kg CO₂ eq and 0.550 kg CO₂ eq, respectively.
- GW of retort pouch was 87% lower than aluminum can in ready-to-eat bean production.
- AE of retort pouch packaging was 60% lower than aluminum can in ready-to-eat bean production.
- For ready-to-eat bean packaged in retort pouch, main process contributing to GW was packaging with 42% share of total (0.233 kg CO₂ eq) and then washing process follows with 25% contribution (0.137 kg CO₂ eq).
- The packaging process had the highest effect on GW with 85% share of total (3.539 kg CO₂ eq) and then the autoclave process follows it with 10% contribution (0.402 kg CO₂ eq) for ready-to-eat bean production packaged in aluminum can.
- Due to the usage of fossil fuel in this process, the autoclaving process was another significant source of GW, as well as non-renewable energy and mineral exploitation.
- The washing step had the highest environmental impact in terms of LO and TE for both aluminum can and retort pouch in ready-to-eat bean production.

To summarize, the usage of various packing materials resulted in varying environmental performance, which is dependent on the manufacturing steps and their applications. Our study revealed that in the production of ready-to-eat beans, retort pouches were more environmentally friendly than aluminum cans. Furthermore, ready-to-eat beans in retort pouches outperformed metal cans across the board in terms of all environmental impact categories. Since the sustainability of packaging materials has not been extensively investigated in the literature, the study's findings can be regarded noteworthy for food packing. As a further idea for future research is to adopt a cradle-to-grave approach to evaluate the environmental sustainability of ready-to-eat food manufacturing in a more comprehensive manner.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s10163-023-01791-9>.

References

1. Coles R, McDowell D, Kirwan MJ (2003) Food packaging technology. Blackwell, CRC Press, Boca Raton
2. Marsh K, Bugusu B (2007) Food packaging—roles, materials, and environmental issues. *J Food Sci* 72:R39–R55. <https://doi.org/10.1111/J.1750-3841.2007.00301.X>
3. Bindu J, Ravishankar CN, Gopal TKS (2012) Packaging of retort-processed seafood, meat and poultry. *Adv Meat Poult Seaf Packag*. <https://doi.org/10.1533/9780857095718.3.331>
4. Accorsi R, Cholette S, Manzini R, Tufano A (2018) A hierarchical data architecture for sustainable food supply chain management and planning. *J Clean Prod* 203:1039–1054. <https://doi.org/10.1016/J.JCLEPRO.2018.08.275>

5. Robertson GL (2005) Food Packaging: principles and Practice, 2nd edn. CRC Press, Boca Raton
6. Walsh H, Kerry JP (2012) Packaging of ready-to-serve and retail-ready meat, poultry and seafood products. In: Advances in meat, poultry and seafood packaging, pp 406–436. <https://doi.org/10.1533/9780857095718.3.406>
7. Bindu J, Mallick A, Gopal TK (2014) Thermal processing of fishery products in flexible and rigid containers. *Fish Technol* 51:137–148
8. Agency UEP (2002) Solid waste management: a local challenge with global impacts. Washington DC, USA
9. Deshwal GK, Panjagari NR (2020) Review on metal packaging: materials, forms, food applications, safety and recyclability. *J Food Sci Technol* 57(7):2377–2392
10. Demetriou A, Crossin E (2019) Life cycle assessment of paper and plastic packaging waste in landfill, incineration, and gasification-pyrolysis. *J Mater Cycles Waste Manag* 21(4):850–860. <https://doi.org/10.1007/s10163-019-00842-4>
11. Ferreira S, Cabral M, De Jaeger S, Da Cruz NF, Simões P, Marques RC (2017) Life cycle assessment and valuation of the packaging waste recycling system in Belgium. *J Mater Cycles Waste Manag* 19(1):144–154. <https://doi.org/10.1007/s10163-015-0383-x>
12. Notarnicola B, Tassielli G, Renzulli PA, Castellani V, Sala S (2017) Environmental impacts of food consumption in Europe. *J Clean Prod* 140:753–765. <https://doi.org/10.1016/J.JCLEPRO.2016.06.080>
13. Chiellini E (2008) Environmentally compatible food packaging. Elsevier, Amsterdam
14. Dilkes-Hoffman LS, Lane JL, Grant T, Pratt S, Lant PA, Laycock B (2018) Environmental impact of biodegradable food packaging when considering food waste. *J Clean Prod* 180:325–334. <https://doi.org/10.1016/J.JCLEPRO.2018.01.169>
15. Geueke B, Groh K, Muncke J (2018) Food packaging in the circular economy: overview of chemical safety aspects for commonly used materials. *J Clean Prod* 193:491–505. <https://doi.org/10.1016/J.JCLEPRO.2018.05.005>
16. Kan M, Miller SA (2022) Environmental impacts of plastic packaging of food products. *Resour Conserv Recycl* 180:106156. <https://doi.org/10.1016/J.RESCONREC.2022.106156>
17. Mattsson B, Sonesson U (2003) Environmentally-friendly food processing. Woodhead Publishing, Sawston
18. Perez-Martinez MM, Noguerol R, Casales BI et al (2018) Evaluation of environmental impact of two ready-to-eat canned meat products using life cycle assessment. *J Food Eng* 237:118–127. <https://doi.org/10.1016/J.JFOODENG.2018.05.031>
19. Cabral CFS, Elabras Veiga LB, Araújo MG, de Souza SLQ (2020) Environmental life cycle assessment of goat cheese production in Brazil: a path towards sustainability. *LWT* 129:109550. <https://doi.org/10.1016/J.LWT.2020.109550>
20. Ghamkhar R, Hartleb C, Wu F, Hicks A (2020) Life cycle assessment of a cold weather aquaponic food production system. *J Clean Prod* 244:118767. <https://doi.org/10.1016/J.JCLEPRO.2019.118767>
21. Costa MP, Chadwick D, Saget S, Rees RM, Williams M, Styles D (2020) Representing crop rotations in life cycle assessment: a review of legume LCA studies. *Int J Life Cycle Assess* 25:1942–1956. <https://doi.org/10.1007/S11367-020-01812-X>
22. Fadare OO, Wan B, Guo LH, Zhao L (2020) Microplastics from consumer plastic food containers: are we consuming it? *Chemosphere* 253:126787. <https://doi.org/10.1016/j.chemosphere.2020.126787>
23. Simon B, Ben AM, Földényi R (2016) Life cycle impact assessment of beverage packaging systems: focus on the collection of post-consumer bottles. *J Clean Prod* 112:238–248. <https://doi.org/10.1016/J.JCLEPRO.2015.06.008>
24. Siracusa V, Ingrao C, Lo Giudice A, Mbohwa C, Rosa MD (2014) Environmental assessment of a multilayer polymer bag for food packaging and preservation: an LCA approach. *Food Res Int* 62:151–161. <https://doi.org/10.1016/J.FOODRES.2014.02.010>
25. Abejón R, Bala A, Vázquez-Rowe I, Aldaco R, Fullana-i Palmer P (2020) When plastic packaging should be preferred: life cycle analysis of packages for fruit and vegetable distribution in the Spanish peninsular market. *Resour Conserv Recycl* 155:104666. <https://doi.org/10.1016/J.RESCONREC.2019.104666>
26. Leadley C, Tucker G, Fryer P (2008) A comparative study of high pressure sterilisation and conventional thermal sterilisation: quality effects in green beans. *Innov Food Sci Emerg Technol* 9:70–79. <https://doi.org/10.1016/J.IFSET.2007.06.005>
27. Rodríguez JJ, Olivás GI, Sepúlveda DR, Warner H, Clark S, Barbosa-Canovas GV (2003) Shelf-life study of retort pouch black bean and rice burrito combat rations packaged at selected residual gas levels. *J Food Qual* 26:409–424. <https://doi.org/10.1111/J.1745-4557.2003.TB00256.X>
28. Humbert S, Rossi V, Margni M, Joliet O, Loerincik Y (2009) Life cycle assessment of two baby food packaging alternatives: glass jars vs. plastic pots. *Int J Life Cycle Assess* 14:95–106. <https://doi.org/10.1007/s11367-008-0052-6>
29. Poovarodom N, Ponnak C, Manatphrom N (2012) Comparative carbon footprint of packaging systems for tuna products. *Packag Technol Sci* 25:249–257. <https://doi.org/10.1002/PTS.975>
30. Del Borghi A, Strazza C, Magrassi F, Taramasso AC, Gallo M (2018) Life cycle assessment for eco-design of product–package systems in the food industry—the case of legumes. *Sustain Prod Consum* 13:24–36. <https://doi.org/10.1016/J.SPC.2017.11.001>
31. Walters KJ, Hosfield GL, Uebersax MA, Kelly JD (1997) Navy bean canning quality: correlations, heritability estimates, and randomly amplified polymorphic DNA markers associated with component traits. *J Am Soc Hortic Sci* 122:338–343. <https://doi.org/10.21273/JASHS.122.3.338>
32. Schoeninger V, Coelho SRM, Bassinello PZ (2017) Industrial processing of canned beans. *Ciência Rural* 47:5. <https://doi.org/10.1590/0103-8478CR20160672>
33. Wang CCR, Chang SKC (2002) Effect of selected canning methods on trypsin inhibitor activity, sterilization value, and firmness of canned navy beans. *J Agric Food Chem* 36:1015–1018. <https://doi.org/10.1021/JF00083A028>
34. White BL, Howard LR (2012) Canned whole dry beans and bean products. *Dry Beans Pulses Prod Process Nutr*. <https://doi.org/10.1002/9781118448298.CH7>
35. ISO (2006) ISO 14040: environmental management, life cycle assessment, principles and framework. Geneva, Switzerland
36. ISO (2006) ISO 14044: environmental management, life cycle assessment, requirements and guidelines. Geneva, Switzerland
37. Ahmad S, Wong KY, Ahmad R (2019) Life cycle assessment for food production and manufacturing: recent trends, global applications and future prospects. *Procedia Manuf* 34:49–57. <https://doi.org/10.1016/J.PROMFG.2019.06.113>
38. Ecoinvent Database (2013) <https://ecoinvent.org/>. Accessed 13 Apr 2022
39. Joliet O, Margni M, Charles R et al (2003) IMPACT 2002+: a new life cycle impact assessment methodology. *Int J Life Cycle Assess* 8:324–330. <https://doi.org/10.1007/BF02978505>
40. Peng T, Ou X, Yan X, Wang G (2019) Life-cycle analysis of energy consumption and GHG emissions of aluminium production in China. *Energy Procedia* 158:3937–3943. <https://doi.org/10.1016/J.EGYPRO.2019.01.849>
41. Yang Y, Guo YQ, Zhu WS, Huang JB (2019) Environmental impact assessment of China's primary aluminum based on life cycle assessment. *Trans Nonferrous Met Soc China* 29:1784–1792. [https://doi.org/10.1016/S1003-6326\(19\)65086-7](https://doi.org/10.1016/S1003-6326(19)65086-7)

42. Del Borghi A, Gallo M, Strazza C, Del Borghi M (2014) An evaluation of environmental sustainability in the food industry through life cycle assessment: the case study of tomato products supply chain. *J Clean Prod* 78:121–130. <https://doi.org/10.1016/j.jclepro.2014.04.083>
43. Matthews C, Moran F, Jaiswal AK (2021) A review on European Union's strategy for plastics in a circular economy and its impact on food safety. *J Clean Prod* 283:125263. <https://doi.org/10.1016/J.JCLEPRO.2020.125263>
44. Farjana SH, Huda N, Mahmud MAP (2019) Impacts of aluminum production: a cradle to gate investigation using life-cycle assessment. *Sci Total Environ* 663:958–970. <https://doi.org/10.1016/J.SCITOTENV.2019.01.400>
45. Biswas WK, Naude G (2016) A life cycle assessment of processed meat products supplied to Barrow Island: a Western Australian case study. *J Food Eng* 180:48–59. <https://doi.org/10.1016/J.JFOODENG.2016.02.008>
46. Calderón LA, Iglesias L, Laca A, Herrero M, Diaz M (2010) The utility of life cycle assessment in the ready meal food industry. *Resour Conserv Recycl* 54:1196–1207. <https://doi.org/10.1016/J.RESCONREC.2010.03.015>
47. Hanssen OJ, Vold M, Schakenda V, Tufte PA, Moller H, Olsen NV, Skaret J (2017) Environmental profile, packaging intensity and food waste generation for three types of dinner meals. *J Clean Prod* 142:395–402. <https://doi.org/10.1016/J.JCLEPRO.2015.12.012>
48. Hospido A, Vazquez ME, Cuevas A et al (2006) Environmental assessment of canned tuna manufacture with a life-cycle perspective. *Resour Conserv Recycl* 47:56–72. <https://doi.org/10.1016/J.RESCONREC.2005.10.003>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.

Authors and Affiliations

Sedat Gulcimen¹ · Ozlem Ozcan² · Selin Babacan Çevik³ · Kevser Kahraman⁴ · Nigmet Uzal¹

✉ Kevser Kahraman
kevser.kahraman@agu.edu.tr

✉ Nigmet Uzal
nigmet.uzal@agu.edu.tr

¹ Department of Civil Engineering, Abdullah Gül University, Kayseri 38080, Turkey

² Department of Material Science and Mechanical Engineering, Abdullah Gül University, Kayseri, Turkey

³ Duru Bulgur, Organized Industrial Zone, Karaman 70100, Turkey

⁴ Department of Nanotechnology Engineering, Abdullah Gül University, Kayseri 38080, Turkey