Carbon Footprint estimation of Japanese radish:
CFP reduction strategies and application possibility for environmental education

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Abstract : This study estimates the life cycle CO_2 (LC-CO_2) of the Japanese radish (variety: Aokubii Daikon) grown with the “tunnel cultivation method” in Choshi city, Chiba Prefecture, Japan. The highest emission stage and process of the LC-CO_2 were specified and the calculation processes and results were shown for their application in improving environmental education. The functional unit of a radish was calculated as the weight of CO_2 equivalent (CO_2eq), which has been converted to CO_2 from differed greenhouse gasses (GHGs)/kg of radish, otherwise known as its “carbon footprint (CFP)”. The life cycle of a radish is divided into five stages, which can be further divided into eight processes. The CFP is calculated as the total amount of CO_2 emitted from every process. The estimated CFP of a radish produced in Choshi city was 472.4 g-CO_2eq/kg. The highest contributors to the radish’s CFP were the cooking and field preparing processes, especially from the boiling water for cooking, which contributed to 44.9% of the total CFP, while the chemical fertilizer accounted for approximately 24.3%. Both consumers and producers should change their cooking and cultivating methods to reduce CO_2 emissions. Sharing the results of our research and other CFPs of local products as environmental education tools was shown to be effective in helping students recognize the important relationship between their daily life and the associated effects on the environment.

Keywords: radish; LC-CO_2; carbon footprint (CFP); environmental education; Choshi

Ⅰ. Introduction

A carbon footprint (CFP) is a CO_2 equivalent value (CO_2eq) that is converted to a CO_2 value based on the different greenhouse gases that are discharged from the producing and consuming processes of products, such as groceries and commodities, with the life cycle assessment (LCA) method. Displaying the CFP value on a product is an effective way to bring environmental awareness to consumers by helping them recognize how much CO_2 is discharged from a product throughout its life cycle. For producers, displaying a CFP on their products certifies their efforts against global warming, and helps consumers recognize the environmental burdens of their daily lives, thereby encouraging them to consider lifestyle changes. Previous my CFP researches regarding local agricultural products, such as cabbage[1), melons[2), canned mackerel[3), rice[4), and wind turbines[5), revealed exact environmental burdens. CFPs are essential values to consider when thinking about protecting the environment, such as mitigating global warming.

Choshi, a city in the Chiba prefecture, Japan is an area suited to cultivate agricultural products, especially the Japanese radish, because of its moderate oceanic climate. Choshi is the second largest producer of the Japanese radish, which is cultivated between October and May, after Miura city in the Kanagawa prefecture. Radish production here covers an area of 924 ha, and total amount of products is 51,900 t. The environmental impacts, such as exhaust CO_2 through the cultivating processes, of radishes in Choshi greatly effect both the local and global environment.

In this study, the author evaluate the CFP of radishes grown in Choshi and examine the CO_2eq emission rates from each producing process. This is because the author has considered CFP as hopeful index in order to reduce CO_2 emissions from each product's life cycle and determine the efficacy as environmental education tools.

Ⅱ. Methods

1. Target and system boundary

This study evaluated the Japanese radish (variety: Aokubii Daikon) cultivated by a typical farmer in Nojiri-chyo, Choshi city, Chiba prefecture, harvested from October 2017 to May 2018. The radishes were cultivated by the tunnel culture method, which is mainly supported with horseshoe-shaped struts, polypropylene (PP) films, and binding pins.

The life cycle of a radish is classified into five stages, which can be further divided into eight processes (Fig. 1).

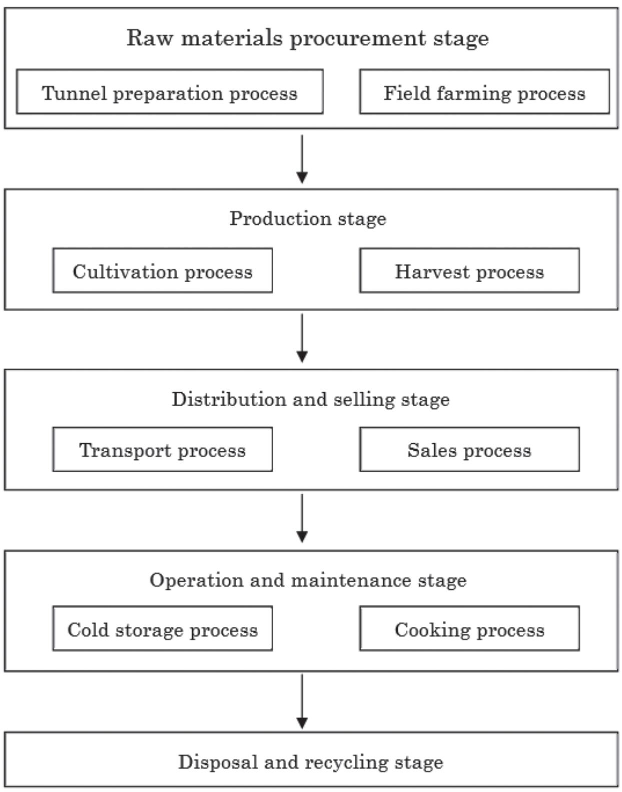

Fig. 1 Life cycle stages of the Japanese radish cultivated in Choshi city in the Chiba prefecture, Japan.

The CFP of a radish was calculated as the total amount of CO_2eq from each process, including: 1) the raw material procurement stage, which is divided into the tunnel preparation and field farming processes, 2) the production stage, which is divided into the cultivation and harvest processes, 3) the distribution and selling stage, comprising both the transport and sales processes, 4) the operation and maintenance stage, which is divided into the cold storage and cooking processes, and 5) the disposal and recycling stage.

2. Functional unit and collection method of inventory data

The functional unit of 1 kg of radish, which is expressed as the CFP, was set at 1 L of its volume. The data used for calculations were collected by interviewing a typical radish farmer, a local agricultural cooperative union called “JA”, and a regional supermarket in Choshi. The remaining data were taken from the national CFP[6] and CO_2 emission coefficient database for foods, which was provided by the Ajinomoto Corporation[7], a general-purpose LCA calculation software (JEMAI-LCA Pro Ver.2.1.2 with optional data pack), and previous CFP calculation case studies of agricultural products. The substantiated calculation procedures in this study followed the standards of the Product Category Rule (PCR: PA-BF-03) for "Vegetables and Fruits"[8].

Ⅲ. Results

The annual production of radishes was set to 9 ton/10 are (denoted as "a") of farming field. Input items, CO_2 basic units, and the calculation units used for estimating a radish’s CFP are shown in Table 1.

1. Raw materials procurement stage

a. Tunnel preparation process

The typical radish cultivation method in Choshi uses a "tunnel" with horseshoe-shaped struts, plastic films, and pins, which are used for fastening. The cropped and fertilized ridges are covered by PP films and then seeds are planted on top of it. The farming poly vinyl-chloride (PVC) tunnels with horseshoe-shaped struts and fastened pins are built by hand.

The amount of CO_2 discharged for the PP films over the course of a year was calculated to be 5.1 kg-CO_2eq/10a, for the iron horseshoe-shaped struts (input item: Steel bar, shown in Table 1), whose life cycle is ten years, was 98.1 kg-CO_2eq/10a, for the PVC films for their ten year life cycle was 1.3 kg-CO_2eq/10a, and for the fastened iron pins (input item: Steel bar) for ten years use, it was were calculated as 39.3 kg-CO_2eq/10a.

Table 1 Input items, CO_2 basic units, and calculation units used for estimating the carbon footprint (CFP) of Japanese radishes cultivated in Choshi city, Chiba prefecture, Japan.

Input items	Basic units (kg-CO_2eq)	unit
Steel bar (for horseshoe-shaped struts)	4.58	kg
Polypropylene (PP)	1.49	kg
Poly Vinyl-Chloride (PVC)	1.46	kg
Polypropylene film	2.46	kg
Combustion in boiler by light oil	2.74	L
Public electricity	0.479	kWh
Chemical fertilizer	7.1	kg
Compost	0.06	kg
Pesticide	4.14	kg
Fungicide	7.24	kg
Cardboard	1.13	kg
LPG basic unit for boiling: original	10.6	g-CO_2eq/min.
Transportation by lightweight truck with 0% of loading ratio	0.259	km
Transportation by lightweight truck with 25% of loading ratio	3.16	km
Transportation by 2-ton truck with full loading ratio	0.29	t・km
Cold storage transportation by 15-ton truck with full loading ratio	0.127	t・km
Incineration of general waste	0.0334	kg
Gasoline combustion	2.66	L

Therefore, the total amount of discharged CO_2 from the tunnel preparation process was calculated to be 143.8 kg-CO_2eq/10a. Therefore, by recalculating the value, we can determine that for every 1 kg radish, the discharged CO_2 is 16.0 g-CO_2eq.

b. Field farming process

The amount of CO_2 discharged from fuel for the trucks that transport workers and materials (input items: transportation by light truck with 0% and 25% of loading ratio) was calculated to be 52.4 kg-CO_2eq/10a. For the light oil tractor used for cultivation (input item: combustion in boiler by light oil) the value was 27.4 kg-CO_2eq/10a, and for the chemical fertilizer (Ecolet 866), which has a small amount of compost (poultry manure) fertilizer, it was 1032.0 kg-CO_2eq/10a.

The total amount of discharged CO_2 from the field farming process was 1111.8 kg-CO_2eq/10a, meaning that the CFP is 123.5 g-CO_2eq/kg.

2. Production stage

a. Cultivation process

The amount of CO_2 discharged from electricity usage (input item: public electricity) for pumping water from a well was 68.9 kg-CO_2eq/10a, for pesticide and fungicide, it was 0.3 kg-CO_2eq/10a, and for the gasoline of the cultivator and insecticide (input item: gasoline combustion) it was 19.0 kg-CO_2eq/10a.

Therefore, the total amount of discharged CO_2 from the cultivation process was 82.2 kg-CO_2eq/10a, which simplifies to 9.8 g-CO_2eq/kg.

b. Harvest process

In the harvesting process, cropped radishes were washed by a special washing machine, then spread out in yellow colored plastic cases to dry and packed into cardboard boxes, where one box fit six of the same size radishes to ship to the market.

The amount of CO_2 discharged for the washing machine electricity usage was calculated to be 86.2 kg-CO_2eq/10a, for the yellow colored plastic cases (PP), which have a life cycle of ten years, and the cardboard boxes, the total was 360.6 kg-CO_2eq/10a, for the fuel required for transportation to the market by a 2-ton truck, the CO_2 discharged was 29.8 kg-CO_2eq/10a. Finally, some consumable goods, such as packaging tapes and plastic bands (both PP), totaled to 1.5 kg-CO_2eq/10a.

Overall, the total amount of discharged CO_2 from the harvesting process was 478.1 kg-CO_2eq/10a, which is equivalent to 53.1 g-CO_2eq/kg.

3. Distribution and selling stage

a. Transport process

The radishes grown in Choshi city are transported to different areas, including Tokyo, Tohoku, and Hokuriku, via cold storage. According to the shipping data from the local JA office, the radishes are transported to more than 20 markets in these areas. In this study, the average distance for shipping was set to a one-way distance of 197.7 km using a 15-ton truck (maximum loading capacity) with cold storage. The amount of CO_2 discharged from this transportation (input item: cold storage transportation by 15-ton truck with full loading ratio) was calculated to be 27.0 g-CO_2eq/kg. Furthermore, the average round-trip transportation distance from market to retail by a 2-ton truck with full loading was 20 km and the corresponding calculated CO_2 was 6.4 g-CO_2eq/kg.

Thus, the total amount of discharged CO_2 from the transport process was 34.3 g-CO_2eq/kg.

b. Sales process

In this study, sales were determined at a typical rural supermarket, which has 2574 m^2 of selling space. The total amount of electricity usage in this supermarket, including its storage room, was estimated to be 166,445 kWh. The area ratio between total selling space and space for radishes only was estimated to be 0.08%. In a year, based on an interview with the store manager, the total weight of radishes sold was 202.5 t.

Subsequently, the total amount of discharged CO_2 from the sales process was determined to be 3.1 g-CO_2eq/kg.

4. Operation and maintenance stage

a. Cold storage process

The average chilled storage period of 1 kg of radish in a refrigerator (345 L in size) was set to 2d, and its occupied volume was estimated to be 0.3% based on the interviews of home managers.

Therefore, the total amount of discharged CO_2 from the cold storage process was determined to be 5.6 g-CO_2eq/kg.

b. Cooking process

For the cooking scenario, our values were determined for the energy required to boil 0.5 kg of radish in 2 L of water when heated by liquid propane gas (LPG) for 20 min. The LPG basic unit for boiling water was estimated by an original measurement fitted to the above boiling condition.

The total amount of discharged CO_2 from cooking process (input item: LPG basic unit for boiling: original data) was 217.6 g-CO_2eq/kg.

5. Disposal and recycling stage

The disposal and recycling parameter were fixed, determining that 45% of 1 kg of radish was residual based on the "product category rule". This radish residue and other wastes, such as films and tapes derived from the other processes, were incinerated as general waste.

The total amount of discharged CO_2 from the disposal and recycling process (input item: incineration of general waste) was 15.0 g-CO_2eq/kg.

6. CFPs of the Choshi radish

The following are the results obtained for the five life cycle stages of a Choshi radish (Table 2). The CFP and ratio from each stage and subdivided process are shown in Fig. 2. 1) The raw materials procurement stage: 139.5 g-CO_2eq (component ratio: 29.5%), 2) the production stage: 62.9 g-CO_2eq (13.3%), 3) the distribution and selling stage: 37.4 g-CO_2eq (3.2%), 4) the operation and maintenance stage: 217.6 g-CO_2eq (46.1%), and 5) the disposal and recycling stage: 15.0 g-CO_2eq (2.6%). The estimated result of the total CFP of a radish produced in Choshi was 472.4 g-CO_2eq/kg.

Ⅳ. Discussion

1. Reduction of CO_2 emission strategy

The highest CO_2 emission from all of the life cycle processes was the cooking process, which was 212.0 g-CO_2eq/kg (44.9% in total). We experimented with microwave cooking in an attempt to reduce CO_2 emissions in this process. A 0.5 kg radish, which was prepared in the same method of the previous cooking process, was

Table 2 The corresponding carbon footprint (CFP) and ratio for each stage and subsequent process of the Japanese radish from Choshi city, Chiba prefecture, Japan.

Stage (Process)	g-CO_2eq /kg	Stage% (Process%)
Raw materials procurement stage (A)	139.5	29.5
Tunnel preparatory process ①	16.0	3.4
Field farming process ②	123.5	26.1
Production stage (B)	62.9	13.3
Cultivation process ③	9.8	2.1
Harvest process ④	53.1	11.2
Distribution and selling stage (C)	37.4	7.9
Transport process ⑤	34.3	7.3
Sales process ⑥	3.1	0.7
Operation and maintenance stage (D)	217.6	46.1
Cold storage process ⑦	5.6	1.2
Cooking process ⑧	212.0	44.9
Disposal and recycling stage (E)	15.0	3.2
Total	472.4	100

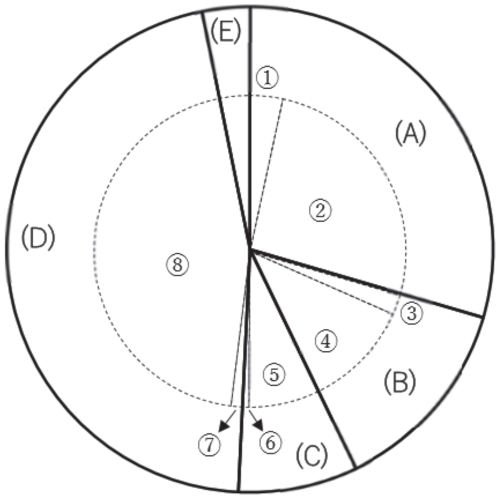

Fig. 2 The CO_2 emission ratios of the Japanese radish' s carbon footprint (CFP) as cultivated in Choshi city, Chiba prefecture, Japan. (a) The raw materials procurement stage divided into tunnel preparation (①) and field farming (②) processes, (b) the production stage divided into cultivation (③) and harvest (④) processes, (c) the distribution and selling stage divided into transport (⑤) and sales (⑥) processes, (d) the operation and maintenance stage divided into cold storage (⑦) and cooking (⑧) processes, and (e) the disposal and recycling stage.

heated in a microwave (SHARP Co., Ltd, RE-TDl) for 3 min as pre-cooking, then boiled in 2 L of water by LPG for 10 min. Here, the electricity usage was 0.06 kWh, which is equal to 25.5 g-CO_2eq/kg. The total CO_2 from this hybrid method was 131.5 g-CO_2eq/kg, which is a 28% reduction of the CO_2 emissions. In addition, this method reduced the cooking time by 35%.

The second highest CO_2 emission was from the chemical fertilizer, which contained a small amount of organic compost, at 114.7 g-CO_2eq/kg (24.3%). Changing the fertilizer to organic compost completely would effectively reduce the CO_2 emission. This is because, unlike the chemical fertilizer, which has a high CO_2 basic unit (7.1 kg-CO_2eq/kg), the basic unit of organic compost is a comparatively negligible value (0.06 kg-CO_2eq/kg). Moreover, changing the fertilizer is not only useful for reducing production energy but also effective in reducing organic waste from a farmer's own facilities.

CO_2 reduction of each process can be highly influenced by decisions and actions not only by producers but also consumers. Visualizing a CFP is important to encourage such reductions.

However, it goes without saying that there are compositional and efficacious differences between chemical fertilizers and organic compost. So, it is necessary to consider not only environmental aspects, but also agricultural management aspects, such as costs and sustainable usage of farmland.

2. CFP applications for environmental education

Environmental education, which is designed to teach students the life cycles of local, especially agricultural, products, provides insight to students on how they impact the environment.

For example, when the CFPs of local agricultural products are shared as an environmental education tool, students can easily understand the direct environmental impacts of goods and how CFPs can vary based on geological and geographical features.

When the CFPs of local agricultural products are shared as an environmental education tool, students can simulate experience of their life cycle through its calculation processes. Then students can easily understand the direct environmental impacts of goods and how CFPs can vary based on geological and geographical features. For example, the calculation of transport process shows real discharged CO_2 quantity from truck, and the calculation of field farming process shows how much discharged CO_2 from chemical fertilizer. Consequently, students were able to understand the meaning of "local production for local consumption", and learned the necessity of reducing chemical fertilizers, from the viewpoint of reducing CO_2. And other important factors for protecting environment, such as saving energy and reducing garbage, were able to understand easily when students calculate CFP from whole life cycle of products.

One of my previous research[9] showed that CFP was powerful environmental education tool for understanding the connection between their life style and its associated impacts both locally and globally, which can be difficult to learn.

Since CFP environmental education program which proposed in this article involves the view point of Sustainable development Goals (SDG's), this program could be applied to ESD education tools.

Ⅴ. Conclusions

The CFP of a radish from Choshi city, Chiba prefecture was estimated in this study. The estimated CFP of a radish produced in Choshi city was 472.4 g-CO_2eq/kg. The following are the results obtained for each life cycle stage: 1) The raw materials procurement stage: 139.5 g-CO_2eq/kg (component ratio: 29.5%), 2) production stage: g-CO_2eq/kg (13.3%), 3) distribution and selling stage: 37.4 g-CO_2eq/kg (3.2%), 4) operation and maintenance stage: 217.6 g-CO_2eq/kg (46.1%), and 5) the disposal and recycling stage: 15.0 g-CO_2eq/kg (2.6%).

The top CO_2 emission process was the cooking process, which comprised 44.9% of the total CFP. This was primarily a result of the boiling water required to heat the radish. Our comparison experiment showed that precooking with a microwave was effective in reducing energy usage, accomplishing a decrease of approximately 30% compared to boiling the water with gas.

The material with the highest CO_2 emission value was the chemical fertilizer at 26.1%. Changing the fertilizer to organic compost was effective in reducing CO_2 emissions. Chemical fertilizer has a high CO_2 basic unit because it needs a lot of energy for production. Meanwhile, organic compost is not only useful for reducing production energy but also effective in reducing the organic waste materials discharged from a farmer's own facilities.

Furthermore, using the CFPs of local products as an environmental education tool is highly recommended as it encourages students to evaluate products carefully and make informed decisions that are good for the environment.

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