Environmental impacts of two snack foods in relation to their nutritional composition

A comparative life cycle assessment of Råggyberry and rice pudding

Michelle Rydow & Sam Hedblom

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Supervisor:	**Johan Karlsson, Swedish University of Agricultural sciences, Department of Energy and Technology**
Examiner:	Hanna Karlsson Potter, Swedish University of Agricultural sciences, Department of Energy and Technology

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Swedish University of Agricultural Sciences
Faculty of Natural Resources and Agricultural Sciences
Department of Molecular Sciences

Abstract

The rapid growth of the global food system has had a substantial negative impact on the environment. Simultaneously dietary habits in the west have continually degraded due to the increased availability of nutritionally inadequate and energy dense foods, often consumed as snacks. There is a need for both healthy and sustainable foods. Axfoundation has developed such a product, Råggyberry (RB), an alternative to the popular snack-food rice pudding (RP). The aim of this study was to assess the environmental impact of RB and compare it to the impact of RP while relativizing these impacts to each products nutritional content. This was done by the conduction of a nutritional life cycle assessment (n-LCA), using the Nutrient rich food index 11.3 (NRF11.3) as a nutritional indicator. The system boundaries for the assessment were cradle to ready-to-eat products (at production site). The results showed that RB had lower environmental impact than its conventional counterpart, both in general and especially in relation to its nutritional content. Moreover, the assessment showed that primary production was the production stage with the highest impact across all impact categories for both products. Although primary production and transportation in RB was more evenly distributed within the climate impact category due to the transportation of apples. In both products the dairy-based ingredients had the biggest impact on Climate impact and land use. The apples in RB, accounted for the biggest impact to water use, while for RP its the strawberries and rice. In conclusion, RB is both a healthier and more sustainable alternative to a conventional RP. However, given the fact RB is a niche product dependent on waste-streams and is produced at small scale, there might be challenges in upscaling production and reaching wide market success.

Keywords: Life cycle assessment (LCA), Nutritional LCA (n-LCA), snack-food, Råggyberry, Rice pudding, Nutrient rich food index (NRF), NRF11.3

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Abbreviations

NNR	Nordic nutritional recommendations
RB	Råggyberry
RP	Rice pudding
LCA	Life cycle assessment
NRF	Nutrient rich foods
FU	Functional unit
SFA	Swedish food agency
NPO	Non-profit organisation
HiG	Hidden in Grains
IC	Impact category
ISO	International Organization for Standardisation
n-LCA	Nutritional life cycle assessment
DRI	Dietary reference intake
MRI	Maximum recommended intake
CO_2-eq	Carbon dioxide equivalents
SAFAD	Sustainability Assessment of Foods and Diets

1. Introduction

The extensive growth of the global food system during the last century has had substantial negative impacts on our environment. The global food system is the largest driver for both land use change and freshwater depletion (Verschuuren 2022; FAO 2025a), while concurrently accounting for a third of global greenhouse gas emissions (Crippa et al. 2021). Although the size of the global food system has steadily been increasing, the quality of western diets has been decreasing due to the prevalence of food items with low nutritional value (Nylander. A, 2014). This has led to higher rates of overweight and obesity globally, which in turn increases the risk for non-communicable diseases e.g. type 2 diabetes and cardiovascular disease (*ibid.*).

The dietary habits in Sweden follow these global trends, and dietary guidelines are seldom followed (Folkhälsomyndigheten 2025a). While Swedes, according to the Nordic nutrition recommendations (NNR) should be eating a primarily a plant-based diet rich in fruit, vegetables, and pulses, they are often instead consuming calorically dense food rich in sugar, salt and saturated fats (Nordic Council of Ministers 2023), foods which are often consumed as a snack.

While a snack (meaning a small meal in between the main meals) can be an efficient way to maintain energy balance and supplement our diet with more fruits and vegetables, it is often the opposite (Livsmedelsverket n.d. ; Livsmedelsverket 2015). Nutritionally inadequate foods such as candy, chocolate, sugar-sweetened beverages, and potato chips, are often consumed as snacks, all of which can be related to weight gain and subsequent non-communicable disease (Hess et al. 2016). There is a need for, as well as a gap in the market for healthy snack-foods meaning there is potential for the development of such products (Ciurzyńska et. al 2019). Healthier versions of already established snack foods seem to be particularly popular among consumers (*ibid.*).

The commissioner of this study, the Swedish Non-profit organisation (NPO) Axfoundation, has done exactly this with the development of their product “Råggyberry” (RB), meant to be a healthier and more environmentally sustainable alternative to the popular rice pudding (RP) commonly sold under the brand name “Risifrutti”. Just like its conventional counterpart RB consists of a grain-based pudding and a fruit sauce. In RB´s case the pudding is made out of rye grains that have undergone hydrothermal treatment that increases the bioavailability of nutrients such as iron and zinc, and it also utilises waste flows by the inclusion of waste shreds from production of grill-cheese. However, no study has evaluated the environmental impacts of RB in comparison to conventional alternatives.

Since RB has been developed to be a healthier and more sustainable alternative, it is also relevant to evaluate the environmental impact in relation to its nutritional value. Life cycle assessment (LCA) is a widely used method to quantify and evaluate the environmental impacts of products along their life cycle (Nurjanov 2019). The most common way of conducting LCA is to evaluate the environmental impact in relation to weight, but by including the nutritional aspects of a food, it is possible to evaluate the environmental impact based on the value the food provides in terms of nutrition (McLaren, et al., 2021). To comprehensively capture the nutritional value of foods, indicators covering multiple nutrients have been developed (RISE, 2024) One such example is the Nutrient Rich Foods (NRF) index, which allows ranking and profiling foods based on their overall nutritional quality (Bianchi 2020). This index could then be used as a functional unit (FU) in an LCA, in order to evaluate the environmental impact in relation to the nutritional composition of foods.

1.1 Aim and objective

The aim of this study was to quantify and compare the environmental impact of RB to a conventional RP, by using LCA as a method. The chosen impact categories were Climate impact, water use, and land use, with one serving as a FU (170 g of product). The aim was also to include the aspect of nutrition in the assessment by performing a nutritional LCA where the environmental impacts of both products were related to their nutritional content by using NRF11.3 index as a complementary FU.

1.2 Background

The global food system has changed dramatically during the last 100 years, primarily in high income countries. Rapid industrialization and globalization have led to a big increase in both the production and availability of food, subsequently improving the living standard for those who have access to it (Nylander 2014). This has however also placed a greater strain on the environment through increased resource consumption, transportation, and waste (Finley et al. 2017).

Currently the food system is estimated to account for 25-42% of man-made greenhouse gas emissions (Crippa et al. 2021). It also acts as the biggest driver for land use change globally (Verschuuren 2022), while simultaneously being the largest consumer of the world’s freshwater resources (FAO 2025a). The agricultural stage of food supply chains generally stands for the largest share of impacts, while transportation, processing, packaging and waste contributes less, although these stages are growing in importance (Vermeulen et al. 2012).

Additionally, the increased global production and availability of food has fuelled overconsumption and the prevalence of foods with low nutritional value, primarily in high income countries (Nylander. A, 2014). As a result, there has been an increase in overweight and obesity, which in turn leads to a higher prevalence of non-communicable diseases such as type 2 diabetes and cardiovascular disease (ibid).

This trend is also evident in Sweden where the dietary habits have continually worsened (Folkhälsomyndigheten 2025a). The intake of foods such as fruit, vegetables, berries, and seafood has been decreasing in the past 10 years (ibid). This is in direct contradiction to the Swedish recommendations that state that we should consume more of these types of foods along with whole grains and plant-based fats, while intake of red meat, saturated fats, salt, and sugar should decrease (Folkhälsomyndigheten 2025b).

Dietary changes are necessary for the improvement of public health as well as sustainability within the food system. Adherence to dietary guidelines has the potential to significantly reduce mortality from lifestyle-related diseases, while reducing greenhouse gas emissions (Springmann et al. 2020). However, even if dietary advice were to improve some aspects of sustainability, it would not tackle all issues linked to the food system (ibid.). In order to further decrease emissions and take account of all sustainability issues linked to the food system, it's important to consider both nutritional aspects alongside environmental issues when developing dietary guidelines to identify the most sustainable way in which we should consume food.

1.2.1 Snacking and snack foods

A snack (mellanmål in Swedish) is defined as 'a meal eaten in between the main meals generally consisting of food that has not been cooked' (NE n.d .a). This term should not be confused with the Swedish word 'snacks' which refers to food items such as potato chips and salted nuts (NE n.d. b). According to the Swedish food agency (SFA) snacking can be a good way to maintain energy balance as a compliment to the main meals (Livsmedelsverket n.d.). This is especially true for children, given that the snack is nutritionally balanced (Livsmedelsverket, 2016).

The SFA suggests fruits and vegetables, unsweetened dairy products, and wholegrain sandwiches adequate food choices for snacking (Livsmedelsverket 2016; Livsmedelsverket 2015). However, the types of food often consumed as snacks does not reflect this recommendation, instead they often consist of food items such as candy, chocolate, potato chips, and high calorie beverages, and are usually consumed as part of hedonic eating patterns (Hess et al. 2016). Although being tasty and convenient, these types of food are associated with weight gain and associated non-communicable diseases (ibid), and consumption of them are recommended to be kept to a minimum (Nordic Council of Ministers 2023).

The market for convenient food products intended for snacking is oversaturated by these types of foods (Ciurzyńska et. al 2019). There exists a need and market space for food products that offer the same convenience but with higher nutritional quality and ingredients belonging to food groups that should be consumed more often (ibid.). Healthier alternatives to classic and familiar snack foods are especially appreciated among consumers, which opens up possibilities for the food industry to develop such products (ibid.). Nutrient insufficiencies within a population could be used as a basis for both snacking recommendations and the development of new innovative snack foods (Hess et al. 2016).

1.2.2 Råggyberry

Axfoundation is the commissioner of this master thesis. They are a Swedish NPO focused on sustainable development, particularly within the areas of future food and biobased materials. This is done through a multitude of projects and often in collaboration with actors from the private sector, seeing as one of Axfoundation's core beliefs is that business is a driving force for change (Axfoundation n.d.).

In 2024 Axfoundation started a project with the intent to develop a healthier and more sustainable snack-food. This resulted in the RB, a healthy and sustainable ready-to-eat snack-food (Axfoundation, 2025), which mirrors the popular snack-food Risifrutti.

Advertised as Sweden's most liked snack, the Risifrutti has been a staple product in Swedish grocery stores since the early nineties (Risifrutti n.d.a). The product is produced by Orkla in Örebro Sweden and consists of two components: a rice pudding made out of short grain rice, milk, and cream as well as a jam-like fruit sauce (Risifrutti n.d.b). Although Risifrutti is the most well-known brand, there are a multitude of companies producing this type of RP snack and sell them under different brand names.

Just like its conventional counterpart the RB consists of a grain- and dairy-based pudding as well as a fruit-based sauce. The basis for the pudding is hydrothermally treated rye grain, a process increasing the bioavailability of important minerals such as iron and zinc in the grain. This process is developed by the company Hidden in Grains (HiG), who are also collaborators on the RB-project. Other ingredients in the rye-pudding include yogurt, scrap pieces from the production of grill-cheese, and sugar, all of which have Swedish origin. The fruit sauce is based on apples and black currants.

RB has not yet hit the Swedish grocery market on a wide scale. It is currently being produced by Urban Deli (an Axfood-owned company) and is being sold in their stores as well as a select few other Axfood-owned stores, all of which are located in the Stockholm area.

2. Technical framework

2.1 Life cycle assessments

LCA is a method used to evaluate and quantify the environmental impacts of a product or service during its lifetime. In an LCA emissions, energy use, waste generated, and resources used are quantified throughout the lifecycle after which characterization factors are applied to calculate different environmental impact categories (IC) such as Climate impact, water use, and land use. It can also help to identify impact hotspots throughout the product's life cycle (Hellweg & Canals 2014). Furthermore, this method can be used in order to (among other things) evaluate and increase resource efficiency from the extraction of raw materials, production, and final disposal (Azapagic 1999). The LCA method is a diverse tool and can be used in policymaking, product development and marketing (ibid.).

ISO-standard 14040:2006 serves as a guiding document for LCA-methodology and describes its core principles and framework in a manner that ensures consistency and transparency of LCA-studies (ISO 2006). This process is divided into four distinct stages namely: Goal and scope definition, inventory analysis, impact assessment, and interpretation (figure 1) (*ibid*.).

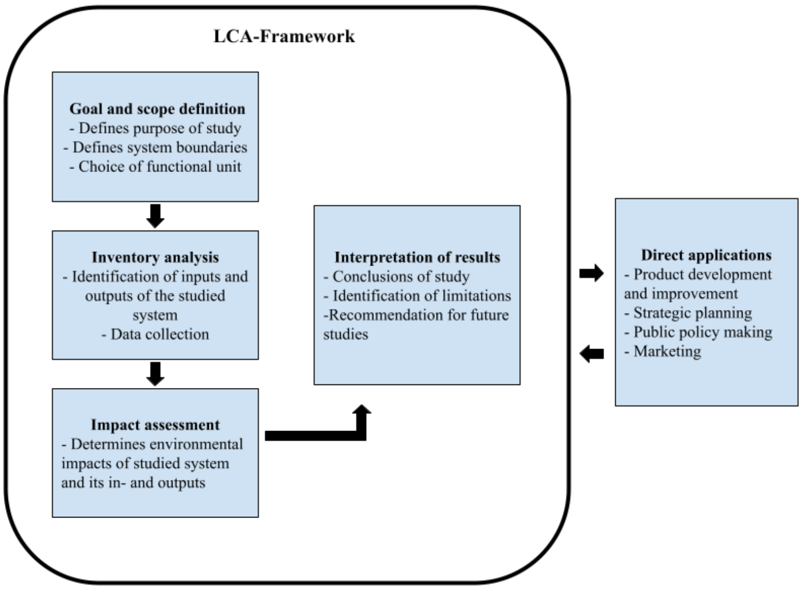

Figure 1. The 4 stages of LCA-studies is illustrated, adapted from ISO-standard 14040.

Production systems are often intricate with many processes resulting in one or several co-products. In such cases it is important to correctly divide the environmental impact of the system between the products. To address this issue ISO-standard 14040 suggests performing a system expansion or allocation. When performing a system expansion any co-products are considered alternatives to other products already available on the market, meaning that the impact of the replaced product can be subtracted when assessing the impact of the co-product. Impact of co-products can also be assessed using allocation most commonly by weight or costs of products, meaning that impact of the system is divided between co-products in accordance with their economic value or volume produced. It is important to note that ISO-standard 14040 suggests avoiding using allocation whenever possible and instead performing a system expansion.

2.2 Nutritional LCAs

While traditional LCA-studies are a useful tool to quantify the environmental impacts of a product or a system, it is not always applicable on the complex issues faced by the global food system. This is for example true in relation to nutritional aspects, to better include nutritional considerations in LCA-studies an extension of the method has been developed, namely n-LCA (McLaren et al. 2021).

n-LCAs account for a food item's nutritional composition in relation to its environmental impacts. When conducting an n-LCA it is important to consider whether or not the system boundaries have an effect on the nutritional quality of the product, e.g. whether or not degradation of nutrients happens during the product's shelf life (RISE 2024). The impact of processing steps such as cooking on the nutritional quality of the product should also be considered (Öhrvik et al. 2015). Furthermore, it is also important to consider the nutritional needs and dietary habits of the studied population (RISE 2024).

Although the framework detailed in ISO-14040 makes out the basis for an n-LCA there is no standardised method as to how nutritional aspects should be included. However, common approaches are inclusion of nutritional or health-related properties in the chosen IC, or using a nutrition-based FU instead of a mass-based FU, which is most common in traditional LCAs of food (RISE 2024.)

2.3 Nutritional indicators and functional units in LCAs

Nutritional FUs have become increasingly important in LCA studies of food. In these cases content of individual nutrients are usually used such as protein, fat or energy content (Bianchi, M, 2020). To better represent the entire nutritional value of food items, more complex indicators have been developed where several nutrients are considered to make it possible to rank and profile foods regarding their overall nutritional quality (Fulgoni et al. 2009).

As previously stated, there is no standardized methodology for n-LCA. Several nutritional indicators have been developed and applied in LCA studies, but they are all structured differently, making it difficult to compare results. In recent studies the NRF-index has been proposed as a robust method (Bianchi, M, 2020). The NRF index is a versatile method since it offers the possibility to include a variety of nutrients suitable for different study populations. The algorithm takes into account desirable as well as undesirable nutrients in relation to the dietary reference intake (DRI) and Maximum recommended intake (MRI) for the studied population (Hallström, E. 2009).

2.4 NRF11.3

More specifically, the NRF11.3 index has been suggested as a suitable index to be used in studies targeting the Swedish population, as it best reflects the dietary guidelines in the country (Bianchi 2020). The index includes the nutrients of public concern in Sweden, and includes 11 desirable nutrients and 3 undesirable (table 1).

Table 1. The desired and undesired nutrients included in the calculation of NRF 11.3-index.

Desired nutrients		Undesired nutrients
Protein	Calcium	Saturated fat
Fiber	Iron	
Vitamins: A, C, E, D	Magnesium	Sugar
Folate	Potassium	Natrium

The content of desirable nutrients in the studied food is divided by the DRI of these nutrients, while the undesirable nutrients are divided by the MRI which is then subtracted from the first division (equation 1). This calculation gives the food product an index score which is used to compare products with each other, as in this case in a life cycle assessment. As the score is rather abstract, it does not in itself provide any information if applied to a single food, but provides value when comparing different foods.

$$NRF11.3 \sum_{i=1-11} \frac{nutrient\ i}{DRI\ i} - \sum_{i=1-3} \frac{nutrient\ i}{MRI\ i} \qquad (1)$$

The nutrient density is calculated based on a defined quantity of food, known as the reference unit. Different reference units could be used when studying food items, for example the amount of nutrient in a portion size, per 100 kcal or 100 g. Portion size refers to the amount of food typically consumed during a meal, and is generally more intuitive and easier to communicate to the public. However, using portion size as a basis for analysis results in varying food quantities compared to standardized measures such as per 100 grams.

The choice of reference unit could have an effect on the results, When using 100 kcal as reference unit in relation to food items (such as eggs, berries or nuts), the nutrients are relativized in relation to the products energy density which favours products with low energy density, such as fruits and vegetables with high water content. Using portion size could instead promote both energy and nutrient dense foods such as salmon, venison or poultry (Bianchi, 2020).

Furthermore, weighting is a method applied when using a nutrient index in order to differentiate the relative contribution to the overall score. Weighting adjusts the importance of each nutrient based on population-level intake relative to the DRI, assigning greater weight to nutrients that are under-consumed and less to those that are sufficiently or excessively consumed (Hallström et al. 2018).

3. Methodology

An LCA was conducted for both RB and RP to quantify their environmental impacts using a mass-based FU of one serving (170g) as well as a FU that accounts for their nutritional composition, NRF11.3. For the purposes of this study, a portion size of 170 g was selected as the index reference unit, as it is more intuitive and easily understood than for example 100 kcal or 100 g. The following sections provide a detailed description of the LCA methodology.

3.1 Goal and scope definition

The system boundaries for the LCA were from 'cradle' up until production of the ready-to-eat product (at production facility) (Figure 2 and 3). As such, packaging and later stages in the lifecycle were excluded in this study, as these processes were assumed to be equivalent across the two products and would not influence the comparison. Packaging materials used for raw ingredients were also not included in the assessment nor was potential warehouse storage in between production facilities due to limitations in available data.

Despite current differences in production scale between the products, the assessment was conducted on a hypothetical large-scale production of RB to avoid that scale-dependent differences in e.g. processing energy use would influence the comparison between the two products. In practice this meant using the same energy inputs for the processing steps (blast freezing and cooking of components) as in the assessment of RP. Additional processing steps, such as peeling and coring apples or removing leaves from strawberries, were not included in the analysis.

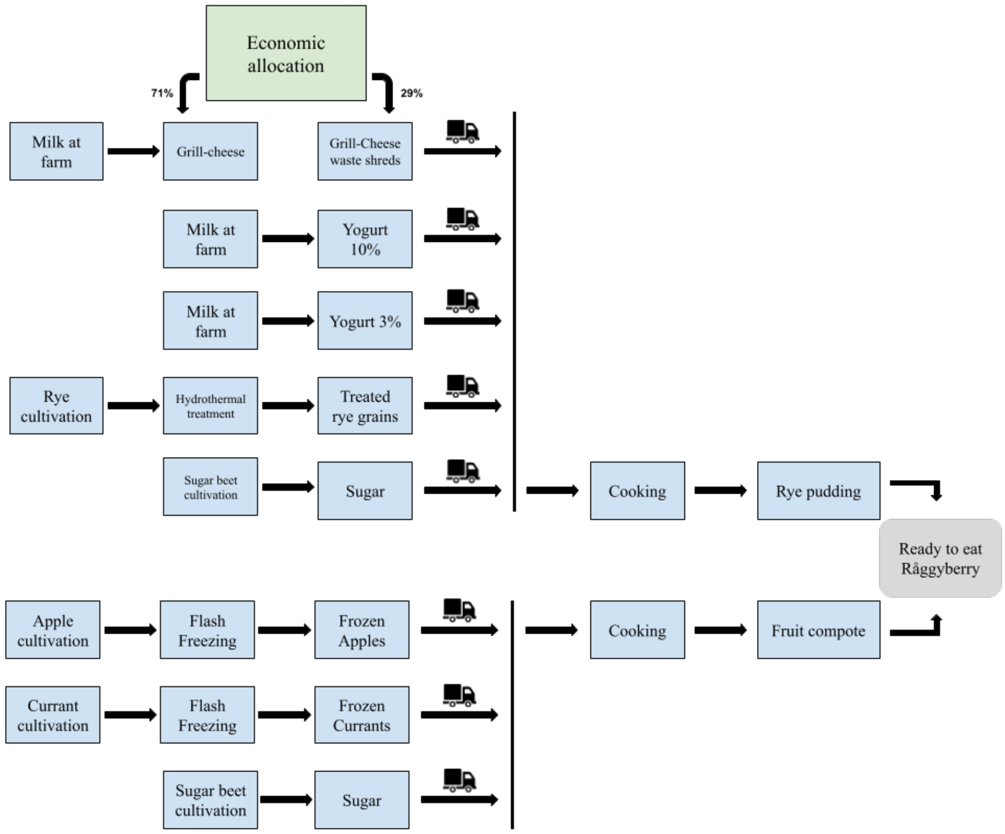

Figure 2. Illustrative flowchart of the system boundaries used in the LCA of Råggyberry and its ingredients.

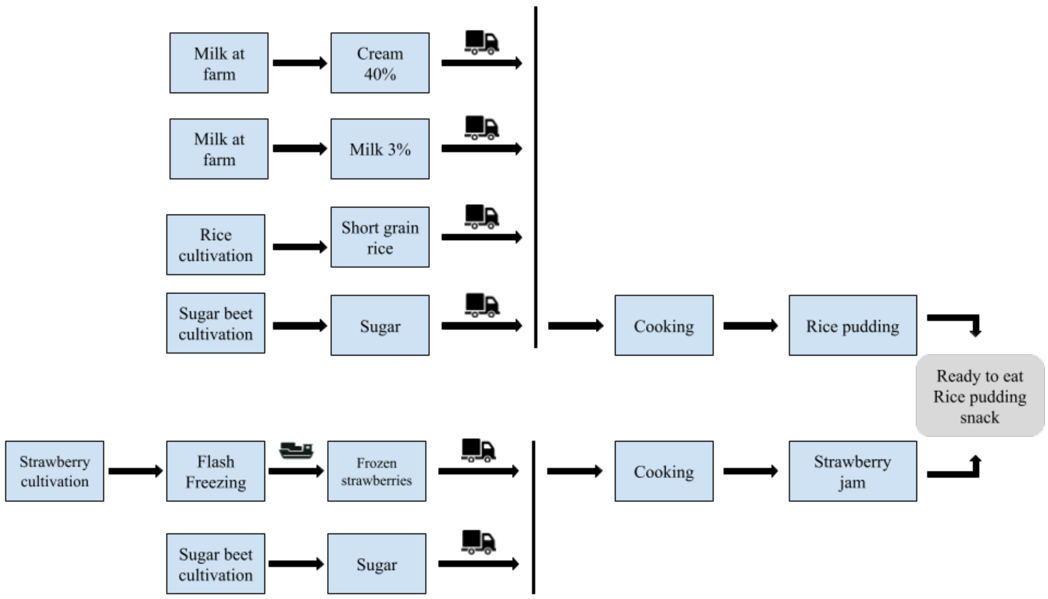

Figure 3. Illustrative flowchart of the system boundaries used in the LCA of rice pudding and its ingredients.

3.2 Impact categories

The LCA was conducted using the modelling software Simapro v.9.6.0.1. The method used for the impact assessment was ReCiPe 2016, midpoint (H) v1.09. The IC chosen for the study were climate impact, land use, and water use.

Climate impact is reported in kilograms of CO_2 equivalents (kg CO_2-eq), based on the Global Warming Potential over a 100-year time horizon (GWP100), using characterization factors from IPCC 2021. This metric reflects the amount of energy absorbed by the emission of 1 ton of a specific greenhouse gas over 100 years, relative to the energy absorbed by 1 ton of CO_2 (US EPA, 2016). Land use is expressed as the area of land transformed or occupied over time, measured in square meters multiplied by years ($m^2 \cdot yr$). Water use is quantified as the volume of freshwater consumed, expressed in cubic meters (m^3) of water.

3.3 Life cycle inventory

Data related to the ingredients and processing steps of both products were collected by various means. The RB-recipe (Table 2) was shared in detail by Axfoundation and UrbanDeli, while information regarding the hydrothermal treatment of the rye grains was shared directly by HiG through e-mail correspondence.

The RP-recipe (Table 3) was estimated by analyzing the nutritional information and ingredient lists of three commercially available products, Risifrutti (Orkla), Rismellis (Coop) and Rismål (ICA). This estimate was then compared and validated with a percentage-based recipe provided by a product developer from one of Sweden's largest dairy producers, which also markets a RP product. The developer could not disclose the exact recipe, but shared an independent estimate. As the two estimates were almost identical, the recipe derived from our analysis was adopted for use in the study.

As both products assessed contain a multitude of ingredients a cut-off point at 2% of the total weight of the product was used. This allowed for the inclusion of the main components of the recipe, while excluding ingredients such as preservatives and aromas, which have little to no nutritional contribution and likely have a marginal contribution to total environmental impacts.

The origin for each ingredient included in RB (Table 2) was shared by Axfoundation, while estimates had to be made for the ingredients included in RP (Table 3), except for milk and sugar which are declared to be of Swedish origin on the Risifrutti website (Risifrutti n.d. b). Trade-data suggested strawberries primarily were imported from Spain, while Cambodia was the largest importing country of rice to Sweden in 2023 (FAO, 2025b). But since there was no specification on short-grain rice or whether the strawberries were fresh or frozen an assumption was made that the available data referred to fresh strawberries and long-grain rice or an average of all rice and strawberry-types imported. Instead, a market assessment was conducted by comparing multiple brands and retailers to identify the most probable origin of the rice and strawberries used in RP. Across all major retailers the short grain rice typically used for porridge had Italian origin. Even though Asian countries are the largest exporters of rice globally, it is primarily linked to long-grain rice (USDA 2025). Since Italy is the largest producer of rice in Europe (Sustainable EU Rice n.d.), and primarily short-grain (risotto/parboiled) (Tesio et al. 2014) it seems reasonable that the rice in RP would be of Italian origin.

In the case of frozen strawberries, Morocco was the most commonly occurring country of origin in the market assessment. Trade-data indicated that there was no import of strawberries from Morocco, which seems unlikely given the market assessment done. This could be due to imports from non-EU countries might be hidden in the import data (Jordbruksverket 2025a). This could be explained by the fact that food products imported from outside Europe to other European countries and then further transported to Sweden are counted as imports from that country rather than the country of origin (*ibid.*). It may also be related to the fact that the trade-data refers to fresh strawberries.

Table 2. The ingredients used in Rågգyberry (%) and its origins.

	Percentage in recipe	**Origin**
Ingredient		
Hydrothermally treated rye, cooked	30,8%	Sweden
Apples, peeled	19,5%	Poland
Yogurt, 3% fat content	18,5%	Sweden
Yogurt, 10% fat content	12,3%	Sweden
Grill-cheese, shredded	5,9%	Sweden
Black currants	4,7 %	Poland
Water	4,1%	Sweden
Sugar, from sugar beets	4,1%	Sweden

Table 3. The ingredients used in Rice pudding (%) and its origins.

Ingredient	Percentage in recipe	Origin
Milk 3% fat content	66,8%	Sweden
Short grain rice, dried	8,6%	Italy
Strawberries	6,9%	Morocco
Sugar, from sugar beets	6,9%	Sweden
Water	5,8%	Sweden
Cream, 40% fat content	4,7 %	Sweden
Other ingredients	2,2%	Not included in assessment.

Data on energy consumption connected to the preparation of the fruit sauce and rice pudding was collected from previous LCA-studies made on jam and rice pudding (Başaran et al. 2020, Sharma et al. 2018). The preparation methods for the components of RB were assumed to be similar to those in RP, and were therefore treated as equivalent.

Through email correspondence with Ivo van Houten[1], a representative of a company producing frozen Moroccan strawberries (Messem international), information about the freezing process as well as the typical shipment route of the strawberries was shared. We assumed that all products other than strawberries were transported by lorry as this is the usual shipping method in Europe. To calculate the transportation distance for each product 'transportmeasures.org/ntmcalc' was used for lorry-transportation, and 'ports.com' for ferry-transportation.

[1] Ivo van Houten, sales representative, Messem international, email correspondence 2025-02-18

Data used to model each process in Simapro were primarily derived from databases included in the software, namely Agri-Footprint and Ecoinvent 3.11. Primary production data for Swedish dairy and Polish black currants were derived from Sustainability Assessment of Foods and Diets (SAFAD) because of limitations in above databases (For detailed information about Datasets used see appendix X).The data collected from SAFAD concerned the use of cropland, which may pose some limitations as the land use IC includes all types of land use, e.g. grasslands, wetlands, forests, etc. Most likely the use of these land types are not so high for these types of products, but it is important to consider when using data from several databases.

3.4 Allocation

Scraps from grill-cheese is one component in the RB-recipe where it was necessary to allocate. Although the ISO-standard recommends using system expansion if possible, it was not feasible in the case of the grill-cheese scraps. This is due to the fact that the scraps are used elsewhere in food production if not included in RB. Since the producer would not share the information on what type of product the waste shreds are used in or what it is replaceing in the other food product system expansion is not feasible, as such economic allocation was applied.

The total impacts of grill-cheese production were allocated between the scraps and the main grill-cheese product based on their economical value. The allocation factors were calculated from business-to-business bulk prices provided by Axfoundation. Due to confidentiality, only the percentage differences in price are presented in this study. Furthermore, this method aligns with the allocation used in the underlying databases.

Data on the Swedish dairy products used in both RB and RP was derived from SAFAD. In this case, raw milk data were included along with processing parameters for finished products such as yogurt, grilled cheese and cream, which allowed us to calculate the amount of milk used in each product and the corresponding economic allocation factors. Specific data are presented in appendix 3.

3.5 Nutiritional indicators

The NRF11.3-index was used as a nutritional indicator with one serving of product (170g) being used as the basis of calculation. The content of relevant nutrients in one serving of each product was calculated using data from the SFA’s food database, while DRI and MRI were derived from NNR (2023). The NRF11.3 was calculated according to equation 2, the calculation is based on the amount of nutrient i per serving of each product. Weighting was applied using Swedish intake data derived from Riksmaten (2012). This resulted in one index score for each product. The assessment results using the mass-based FU were then divided by these index scores. Details on the amount of nutrients in each product and the weighting factor are available in appendix x.

$$NRF11.3_{170g} \sum_{i=1-11} \frac{nutrient\ i}{DRI\ i} - \sum_{i=1-3} \frac{nutrient\ i}{DRI\ i} \quad (2)$$

3.6 Nutritional considerations

The Swedish nutritional recommendations were used to establish DRI and MRI for the NRF11.3 index. The DRI for protein, as well as the MRI for sugar and fats, is expressed as a percentage of an individual's energy requirements, which varies based on age, sex, and energy expenditure. The population for this study was set to individuals between 18-50 years, moderately active and an average between men and women. When collecting the weighting data, the age span was set to 18-44 years.

Dairy products sold on the consumer market in Sweden are required to be fortified with vitamin-D. But for dairy products sold within the industry there is no such requirement (Livsmedelsverket 2024a). This means that dairy products used in products such as RP and RB are usually not fortified. When assessing the nutritional content of the dairy products included in both products, fortification was not considered. A retention factor for cooked foods was used for the calculation of micronutrients, for the vitamins and minerals that have an available retention factor, as shown in Appendix 2.

4. Results

This section presents the results for each individual product and their respective impacts on climate impact, water use and land use. The total impacts are also disaggregated by life cycle stage (primary production, processing and transportation) and raw ingredients. The analysis is then linked to the NRF index, which integrates the environmental impact with the nutritional quality of the products. Finally, the contribution of each nutrient to each product's NRF index is presented, providing an insight into the relationship between the nutritional composition of the two products and their index scores.

4.1 Environmental impacts

The relative environmental impact per product and IC using 1 serving (170 g) as a FU is presented in figure 4. These findings indicate that RB had a lower impact across all studied IC compared to RP.

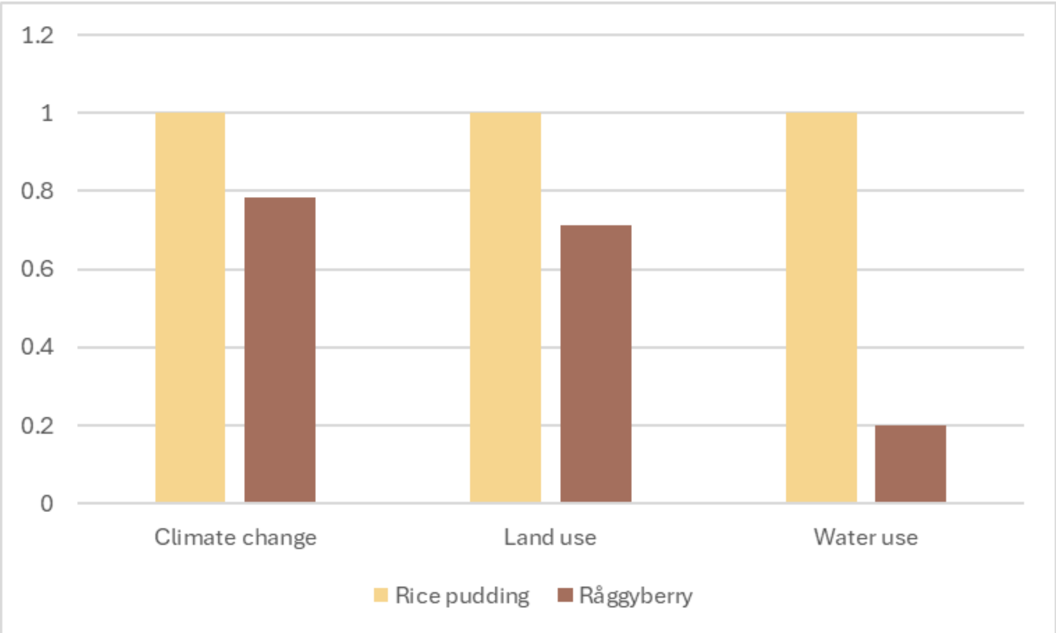

Figure 4. The relative impact of RB in comparison to RP is shown using one serving (170g) as a functional unit.

4.2 Impact of production stages

Across all IC for both products, primary production is the production stage with the largest environmental impacts. The impact on climate impact of primary production and transportation is more evenly divided in RB due to the cold-chain logistics used for the frozen apples (Figure 5). The impact of transportation is also higher for RB compared to RP, with an impact of 0.074 and 0.033 kg CO2eq/170g, respectively. Primary production accounted for 0.095 and 0.19 kg CO2eq/170g for RB and RP, respectively (Table 4). The processing stage has a small impact in comparison to primary production and transportation in all IC for both products.

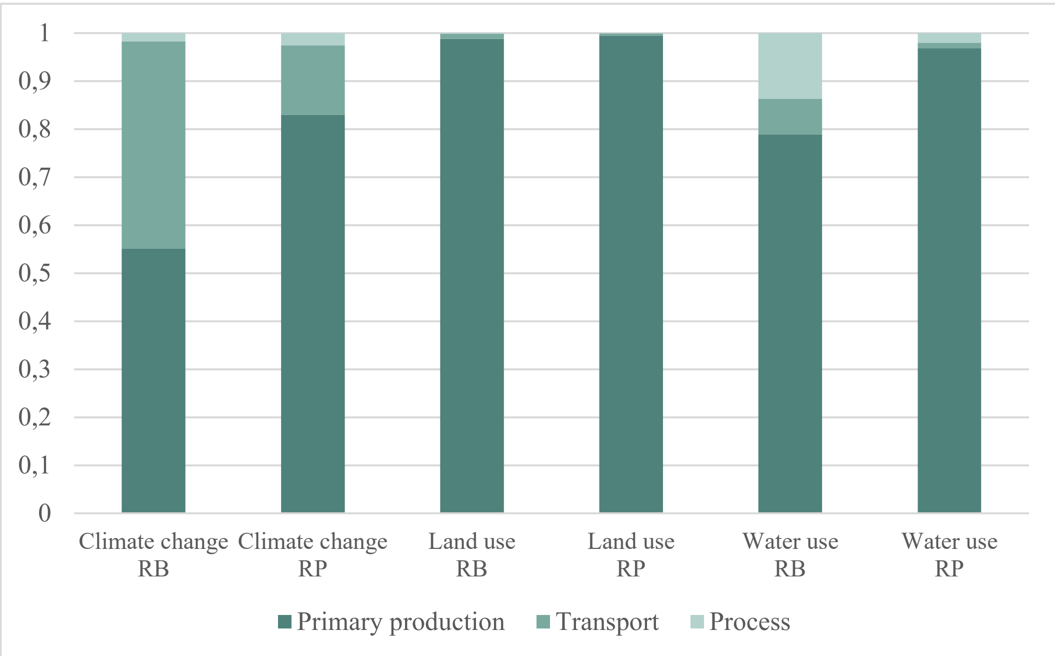

Figure 5. The contribution of processing stages: primary production, transportation and processing is shown, across all impact categories, climate impact, land use and water use for both products Råggyberry (RB) and rice pudding (RP), relative to the product's total impact.

Table 4. The contribution of each product Råggyberry (RB) and rice pudding (RP) per serving (170 g), on all impact categories disaggregated on the different lifecycle stages: primary production, transportation and processing.

Production stage		Climate impact (kg CO2 eq.)		Land use (m^2.)		Water use (L)	
	Product	*RB*	*RP*	*RB*	*RP*	*RB*	*RP*
Primary production		0.095	0.19	0.194	0.28	1.5	5.2
Transportation		0.074	0.033	0.0022	0.0011	0.14	0.63
Processing		0.0071	0.0066	0.00034	0.00030	0.26	0.12
Total		0.18	0.23	0.20	0.28	0.002	5.4

4.3 Impact per ingredient

When looking at the environmental impacts of the different ingredients, milk accounts for more than half of the environmental impact of RP in terms of both Climate impact and land use (Figure 6). While rice contributes less to these specific IC, it has a more significant impact on water use, to which strawberries also have a significant impact.

The ingredients with the highest overall environmental impact RB are yogurt and apples (Figure 7). Yogurt contributes most significantly to Climate impact and land use impacts, while apples, although also contributing to these categories, have the greatest impact on water use. For exact numbers see Table 5.

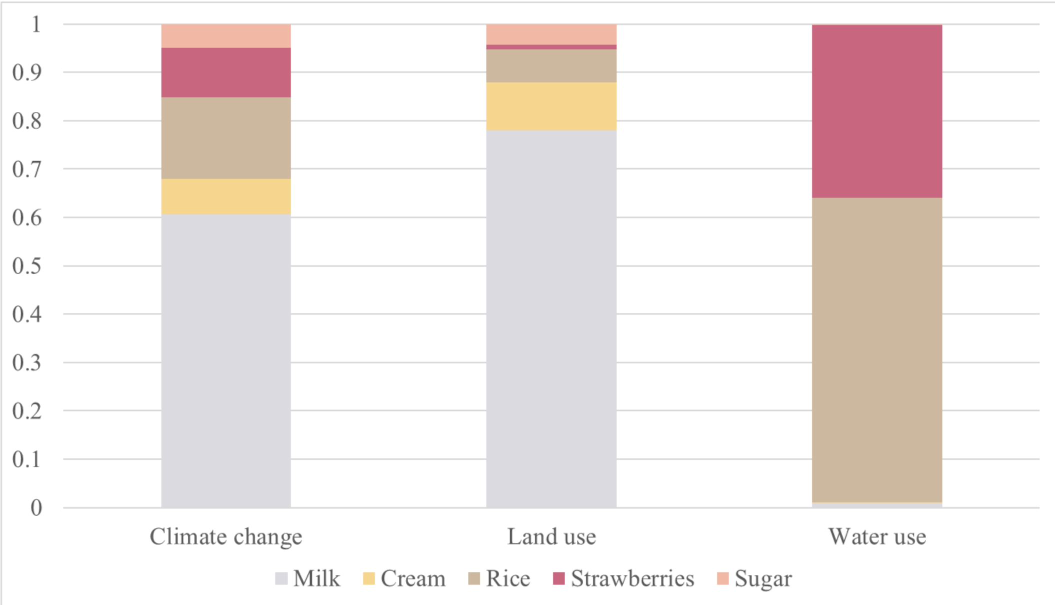

Figure 6. The relative impact of each ingredient per serving (170) of Rice pudding divided per impact category: Climate impact, land use, water use.

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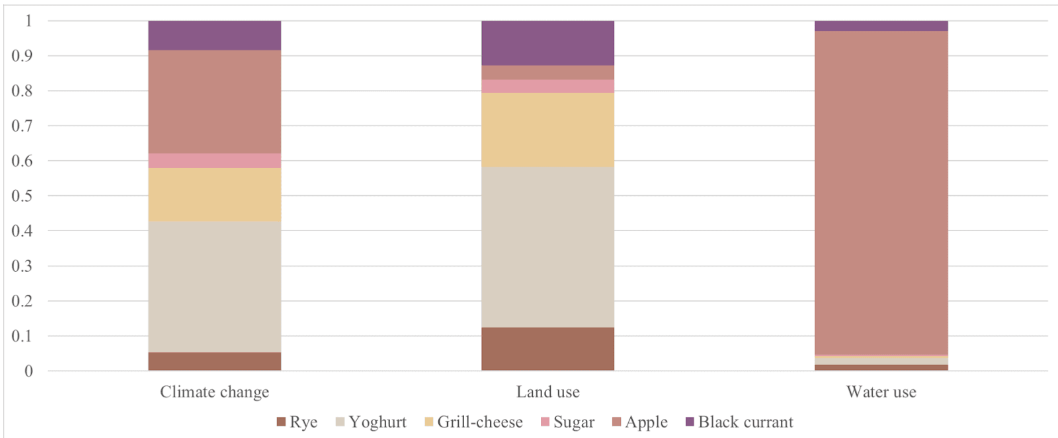

Figure 7. The relative impact of each ingredient per serving (170) of Rånggyberry divided per impact category: Climate impact, land use, water use.

The dairy products in RB have a lower impact than RP for both Climate impact (0.093 vs 0.15 kg co2 / serving) and land use (0,13 vs 0,27 m2*yr / serving), for water use the impact is similar. The apples have a higher impact on Climate impact (0.52 g CO2 eq /serving) than for example strawberries (0.025 g CO2 eq / serving) used in RP.. While black currants (0.015 g co2 eq / serving) has a similar impact as the strawberries. When looking at the water use for apples (1.7 L/serving) is slightly lower than for strawberries (1.9 L/serving). When looking at rye grains compared to rice, the impact on Climate impact (0.0093 vs 0.041 co2 eq / serving) and water use (0,031 vs 3,4 L / serving) is much higher for rice, while land use is slightly higher for rye (0,024 vs 0,019 m2*yr). Rice has the highest impact on water use compared to all ingredients, while dairy products have the highest impact on both Climate impact and land use.

Table 5. The impact of each ingredient per serving (170 g) of each product Råggyberry (RB) and rice pudding (RP). Impacts of each ingredient is thus related to the amount used in each product.

Ingredient (Product)	**Amount used in product (g)**	**Climate impact (kg co2 eq.)**	**Land use (m^2*yr)**	**Water use (L)**
Rye (RB)	17	0.0093	0.024	0.031
Yogurt (RB)	52	0.066	0.090	0.036
Grill-cheese (RB)	10	0.027	0.041	0.010
Sugar (RB)	7	0.0073	0.0074	0.0082
Apple (RB)	33	0.052	0.0082	1.7
Black currant (RB)	8	0.015	0.025	0.055
Milk (RP)	117	0.14	0.22	0.051
Cream 40% (RP)	5	0.017	0.028	0.0044
Rice (RP)	15	0.041	0.019	3.4
Strawberries (RP)	12	0.025	0.0029	1.9
Sugar (RP)	12	0.012	0.012	0.013
Dairy products (RP)	122	0.15	0.24	0.056
Dairy products (RB)	62	0.093	0.13	0.046

4.4 Nutritional index

The environmental impact of RB and RP in relation to its nutritional composition using the NRF11.3 index is presented in figure 8. Furthemore, the index score is presented for both products illustrating the contribution of each nutrient to the index which is presented in figure 9.

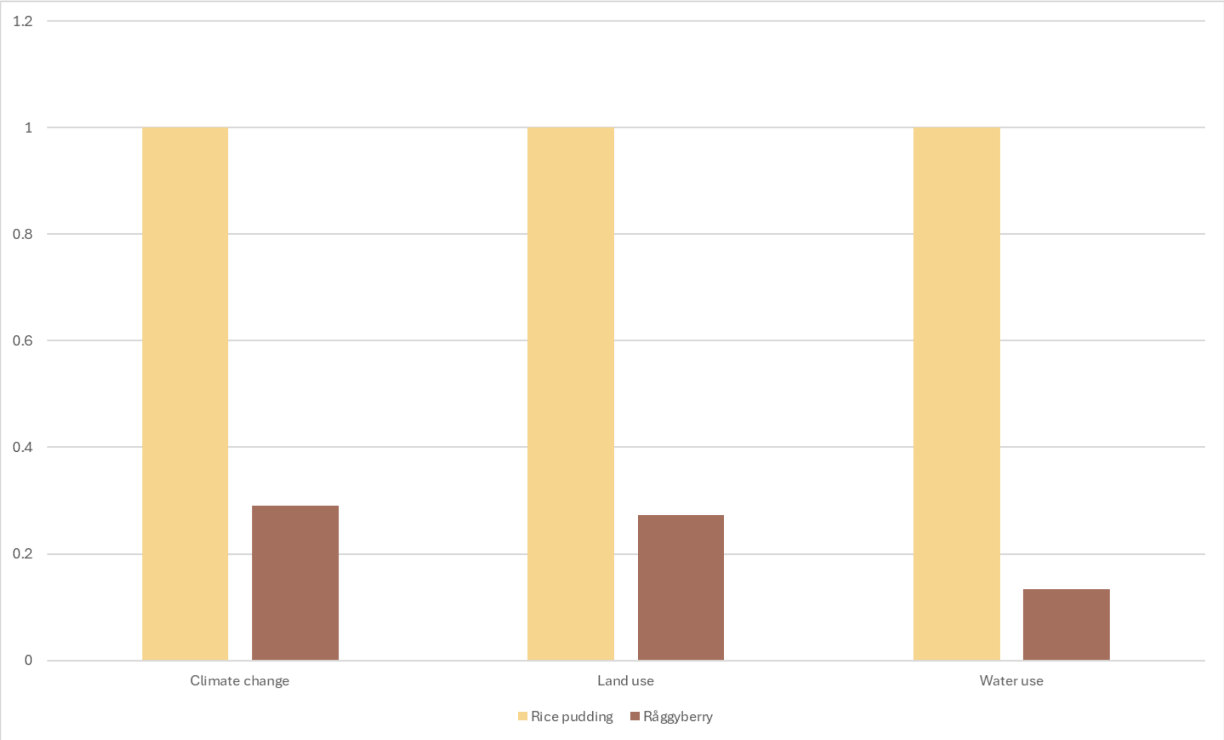

Figure 8. Relative impact of a serving (170 g) of Råggyberry in comparison to rice pudding with the NRF11.3-score as a functional unit.

The most significant contributions of the desired nutrients were calcium and fiber for RB, while calcium was the largest contributor to RP. Calcium had a similar contribution to both products. Sugar and saturated fats were the undesired nutrients with the largest impact on RP, while salt, saturated fats and sugar had an equivalent impact on RB. The contribution of saturated fat and sugar was greater in RP than in RB, while salt had a greater contribution to RB.

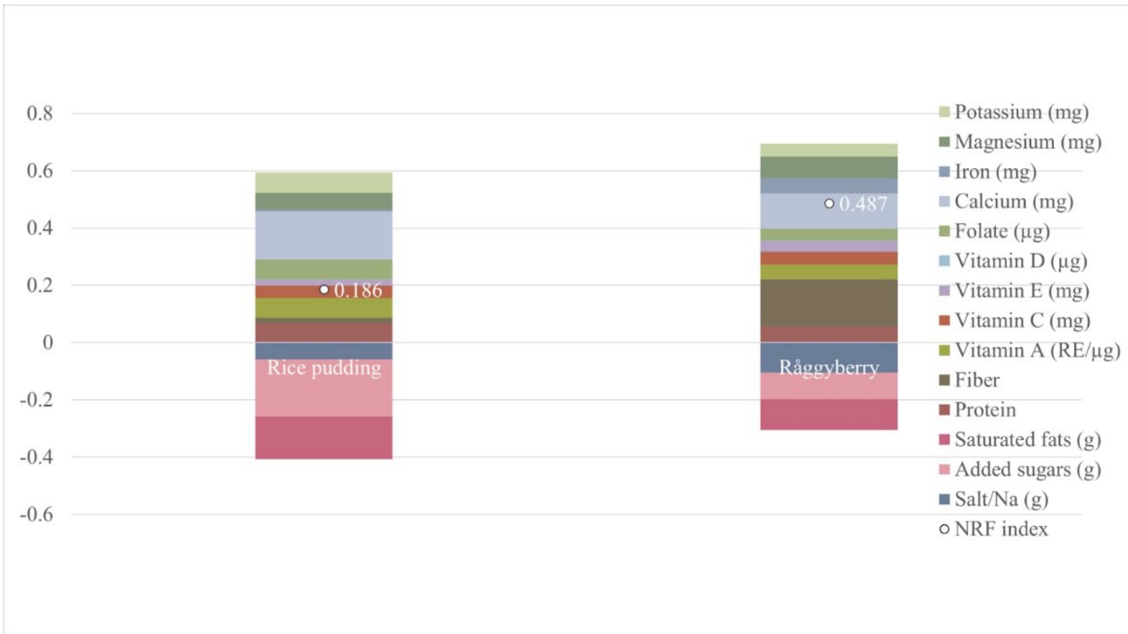

Figure 9. The contribution of each nutrient included in the NRF11.3 index to the overall NRF scores of Råggyberry and rice pudding.

The environmental impacts of the two products using NRF11.3 as FU increased the impacts per product, in all IC: Climate impact, land use and water use, by 5, 2 and 3 times for RP compared to when using mass-based FU, When looking at RB the impacts increased by 2 times for all IC (table 6). This demonstrates that all impacts increased more for RP than for RB, further widening the gap between environmental impacts.

Table 6. The environmental impact of a serving (a 170g) of RB and RP using a mass based and NRF-index as functional units is displayed, disaggregated per impact category. Data in brackets shows how the impact increased from a mass based to NRF index.

Functional unit		**Climate impact (kg CO2 eq.)**		**Land use (m^2a crop eq.)**		**Water use (m^3)**	
	Product	*RB*	*RP*	*RB*	*RP*	*RB*	*RP*
Mass-based		0.18	0.23	0.20	0.28	0.002	0.01
NRF-index		0.37(2)	1.24 (5)	0.42(2)	1.50(5)	0.004(2)	0.03(3)

4.5 Sensitivity analysis

The sensitivity analysis examines the sensitivity of the results to modeling changes related to the reference unit used in the NRF11.3 index and the allocation method for the grill-cheese.

The results were not sensitive to the choice of reference unit as the relation between RB and RP did not change considerably in any of the IC when changing the reference unit (Table 7). The ratio of RP to RB stayed at 25% in the water use IC when shifting between serving, 100 kcal, 100 g and 1 kg. For 100 g, there was a small change in Climate impact from 30% to 29% and for land use there was a small change from 28% to 27%.

Table 7. Illustrates how the choice of reference unit for the NRF index influences the results across impact categories and between products. Values in brackets display the relation between rice pudding and Råggyberry in %.

	Rice Pudding			**Råggyberry**		
	Climate impact	**Land use**	**Water use**	**Climate impact**	**Land use**	**Water use**
	Co2 eq	**m2*year**	**m3**	**CO2 eq**	**m2*year**	**m3**
Serving(170g)	1.52	1.83	0.04	0.45 (30)	0.52 (28)	0.01 (25)
100 kcal	1.52	1.84	0.04	0.45 (30)	0.52 (28)	0.01 (25)
100 g	1.56	1.88	0.04	0.45 (29)	0.51 (27)	0.01 (25)
1 kg	1.58	1.90	0.04	0.47 (30)	0.54 (28)	0.01 (25)

Changing the allocation method from economic allocation to an allocation based on milk solids had a significant effect on the results. When an economic allocation is applied to the grilled cheese used in RB, the environmental impact in all IC is lower than for RP (table 8). However, when using an allocation method based on milk solids, (mass based allocation method recommended by the international dairy federation). The influence on the IC climate impact and land use is higher for RB than for RP, while the influence on water use remains unaffected.

Table 8. Illustrates how the choice of allocation factor on the grill-cheese used in Råggyberry influences the results in each impact category.

	Råggyberry		Rice Pudding
Grill-cheese	*Economic allocation*	*Milk solids allocation*	
Climate impact	0.18	0.24	0.23
Land use	0.20	0.31	0.28
Water use	0.002	0.002	0.01

5. Discussion

The impact of RP is higher than the impact of RB when using both a mass-based index and NRF index as FU. When applying the NRF index, which takes into account the nutrient density of the two products, the gap increases even more, meaning that the RP has an even higher environmental impact in relation to its nutritional content.

The assessment of the individual production stage's contribution to the overall environmental impact of both products showed that primary production had the biggest impact. This is a result that mirrors what has previously been stated about environmental hotspots in food production (Vermeulen et al. 2012). There are however ingredients contributing more to specific IC, such as dairy having a large impact on Climate impact and land use, while rice, strawberry and apple have a large impact on water use, apples also has an unanticipated impact on Climate impact.

5.1 Climate impact

The dairy-based ingredients included in both products had the largest contribution to climate impact (RP 64% and RB 53%), alongside the rice used in RP (17%) (table. 5). This outcome is consistent with existing research, as both dairy and rice are recognized as emission-intensive products (Bačėninaitė et al., 2022). Their high emission levels are primarily attributed to substantial methane emissions from their production systems, with methane having a global warming potential 28 times greater than that of carbon dioxide over 100 years (European Commission, n.d.).

In the dairy sector, the emission of methane can be primarily attributed to the enteric fermentation of the cattle alongside manure degradation (Bačėninaitė, et al. 2022). In the rice sector these emissions are due to the use of "flooding" as an irrigation method which creates an anaerobic environment in which methanogenic bacteria thrive (ibid.).

Furthermore, it should be noted that the high emissions associated with dairy production are also attributed to emissions of nitrous oxide, which are the result of manure management as well as the production of feed used for the dairy cattle (Jayasundara S. et al. 2016).

Although both rice and dairy products are associated with large greenhouse gas emissions, there is considerable variation depending on the production region, with generally lower emissions in western production systems (FAO 2019; Maraseni, T.N. et al 2018), which is where the ingredients in both RB and RP are sourced.

Interestingly, apples were also a significant contributor towards Climate impact in RB, despite generally being considered a low emission-intense food (Le Féon et al. 2023). Here it is the transportation of apples which contributes to the ingredient's relatively large impact towards Climate impact. This is due to the apples being frozen at the production facility, which require them to be shipped under cold conditions. Although necessary, cold-chain logistics are energy-intensive which leads to higher emissions compared to transportation that is not as temperature-dependent (Hung-Jui, L. et al 2025). This alongside the fact that apples by weight is one of the biggest ingredients in RB resulted in the large contribution to Climate impact and also explains why the distribution between transportation and primary production was much more evenly divided in RB. The same principle can be applied to the strawberries in the RP, which are shipped from Morocco, despite the longer shipping distance, the impact on Climate impact is lower partially due to the small amount used in the recipe. It is also influenced by the fact that the strawberries are mostly shipped by container ship, which is a more efficient shipping method than truck transportation. Yet the total impact on Climate impact was lower for RB than it was for RP.

5.2 Water use

The ingredients that contributed most to water use were rice, strawberries and apples (Table 5). In rice production, flooding is an efficient method of irrigation, where the field is covered with water, improving plant conditions and increasing growth and yield (Nurjanov 2019), but this also results in a high use of freshwater resources. In addition, water losses through seepage and pre-location are also a concern, this is influenced by soil quality and water table depth (i.e. the distance from the soil surface to the water table) and can vary between 25-85% of the added water (Chauhan et al. 2017). Water use in rice production can therefore vary greatly depending on the local conditions. In this study, Italian rice was used, which requires continuous water supply through irrigation systems due to the soil and climatic conditions in Italy (Giuliana et al. 2024).

The water used to produce Moroccan strawberries is mainly attributable to covering the strawberries with polyethylene or glass during cultivation, which is done to ensure a quality that meets market requirements (Lillywhite et al. 2010). As strawberries grown in protected production systems cannot rely on rainfall, irrigation systems using freshwater resources are required (Wanders et al. 2023). Freshwater use varies greatly between different production systems and regional climate conditions. In this study, global data for strawberries were used as an approximation for Moroccan strawberries in the absence of any other suitable equivalent. According to Lillywhite et al (2010), Moroccan strawberries grown in macro tunnels require about 169 l/kg (2.0 l/serving RP), which is similar to the results 158 l/kg (1.9 l/serving RP) reported in this study.

Apple orchards require a consistent water supply, which is typically maintained through irrigation systems (Hong et al., 2022). However, water consumption from these systems can vary significantly depending on regional climatic conditions (ibid.). In this study, Italian apples were used as a proxy for Polish apples, since data on polish apples were not available. This likely influenced the results, as environmental conditions differ significantly between Italy and Poland.

According to SAFAD data, Italian apples show a significantly higher water use of 42 l/kg (1.4 l/serving) compared to Polish apples, which require only 0.94 l/kg (0.030 l/serving). If SAFAD data had been used for Polish apples in the modeling instead of data for Italian apples from the EcoInvent 3 database, the relative contribution of apples to water use in the RB recipe would have decreased from 92% to 18%. This would have been a more accurate picture of the apple's contribution to water use.

The Swedish dairy products used in the recipes have relatively low water usage compared to the other ingredients (table 5). Water use in milk production can vary significantly across different production systems, with differences of up to 14 times depending on various factors (Sultana et al. 2014). Water use in milk production is primarily influenced by the type of feed, whether cows are fed concentrate, roughage, or are grazed, as well as by the location and conditions under which the feed is produced. Moreover, milk yield and feed efficiency are important factors affecting overall water use (ibid.). Since milk production conditions in Sweden are favorable, with cattle primarily fed with rain-fed grass silages (Krizsan et al. 2021) the water use for the dairy products was relatively low. Swedish dairy cows also rely on other supplementary feeds to achieve high milk yields (Ibid.) Based on our results, despite the large amount of milk used in the recipes, the water use in milk production seems to be low compared to the other raw materials in the analyzed products, which could be explained by the fact that milk products are Swedish.

5.3 Land use

Dairy products are the main contributors to land use in both RB and RP (table. 5). Although they make up the largest share of the product composition, they are also inherently land-demanding (Krizsan et al. 2021). As with water use, land use is mainly driven by the production of feed for livestock, which is further influenced by factors such as feed efficiency and milk yield (ibid.).

The calculation method used in this assessment, ReCiPe2016 midpoint H, expresses land use in m2 annual crop land equivalents. Land use expressed in this metric is calculated relatively straightforward and is easy to grasp (Ran et al. 2024). However, agriculture encompasses much more than area used, and there are more sophisticated indicators to consider such as land productivity or scarcity of land related to geographical location (ibid.) Furthermore, soil degradation and loss of biodiversity due to land conversion are important sustainability indicators (ibid) that are not considered in the metric used for this assessment. A soil quality index was considered as an IC in this study, the index accounts for a multitude of soil quality indicators and biotic production (De Laurentiis et al. 2019). The index is also based on country-specific conditions, but when no regional data are provided, it is based on global data. Since the data retrieved from SAFAD is based on cropland, and limitations in incorporating the regional information, which is already incorporated in the databases when modeling in simapro. It was decided that the results would be misleading and that land use was a more appropriate IC for this study. In practice this means that both RB and RP have environmental impact due to land use beyond what is expressed in this assessment, which is important to consider as well as a motivation for a future study expansion.

5.4 Allocation

An economic allocation was performed on the waste-shreds of the grill-cheese included in RB to separate the environmental impacts attributable to this waste-stream from those attributable to the main product. This was done despite the recommendation of ISO-standard 14040, which is to avoid allocation whenever possible and instead perform a system expansion.

For a biological waste product, such as food waste, it is common for it to be composted or anaerobically digested (Avfall sverige 2023), therefore it would have been a reasonable assumption that this would be the case for the waste-shreds of grill-cheese as well. However, communication with the producer of the grill-cheese revealed that this was not the case, and instead waste-shreds that were not used in the production of RB were instead used elsewhere in the food industry, since further information on the product was not shared, system expansion would not be applicable in this study.

Moreover, the International dairy federation recommends allocation based on the content of milk solids, for dairy products and their co- and by-products (IDF 2015). When this type of allocation is applied on grill-cheese scraps the allocation factor is 1 for both the grill-cheese and the scraps since they contain the same amount of milk solids.

The economic allocation factor applied to the grill-cheese scraps was 0.29, meaning that the emission for grilled cheese was allocated 29% of the actual emission based on its economic value. As seen in the sensitivity analysis the choice of allocation method had a significant influence on the overall impact of RB, adjusting Climate impact from 0,24 to 0,18 CO_2 eq/170 g and land use from 0,31 to 0,20 m^2*yr (table 8). If the allocation were to be based on milk solids, RB would have a greater impact than RP when mass is used as the FU, as the impact of RP was 0.23 CO2 eq/170 g and 0.28 m^2*year, but when applying the NRF index, RP would still carry the greatest environmental impact.

Since the grill-cheese is the economic driver for production it can be argued that economic allocation is a reasonable approach in this context. However, since the choice of method poses such a large difference in the results, this is important to highlight.

5.5 Evaluation of the NRF index as a functional unit

When the NRF-index is used as the FU, the difference between the two products increases, ultimately leading to RP having an even higher environmental impact (Figure 8).

Portion size was used as a reference unit because of its intuitive nature, but looking at the sensitivity analysis choosing another reference unit would not affect the results. This contrasts the findings from studies where single food items are evaluated, using 100 g as a reference unit could potentially underestimate the nutritional contribution of energy-dense foods and overestimate foods with a low energy density (Drewnowski et al. 2009). While it seems like 100 kcal and portion size are relatively similar in terms of promoting foods that are in line with what we should eat, 100 kcal seems to give advantages to some foods that we should eat less of (ibid.).

But since RB and RP have a similar composition the reference unit would not impact the results. Which implies that when evaluating meals or dietary patterns, the reference unit plays a minor role, while studying single food items it's more important to consider which reference unit to choose and how it will affect the results.

The weighting of nutrients in the NRF index affected our results by slightly reducing the difference between the environmental impacts of products. Although the effect was modest, this suggests that weighting can play a role when applied to the NRF index. This is consistent with Bianchi (2020), who reported that weighting influenced the results, although the effects were small.

This study does not account for the bioavailability of minerals such as iron and zinc due to methodological challenges in estimating and integrating it into the NRF index. Taking bioavailability into account could have provided valuable insights, especially in terms of how such considerations can be integrated into LCA methods. However, such an approach would be more relevant when assessing whole diets rather than individual food products or meals, as bioavailability is very complex and highly dependent on what else an individual consumes during the day to meet recommended nutrient intakes (Hallberg & Hulthén 2000). Furthermore, bioavailability is not accounted for in current dietary recommendations, which is important to at least have in mind when applying bioavailability to tools such as the NRF index, as these recommendations are integrated into its algorithm. Moreover, in the future dietary recommendations could be developed to integrate bioavailability.

5.6 Nutritional assessment of Råggyberry compared to ricepudding

The nutritional index score of RB (0,472) was almost 40% higher compared to RP (0,186). Some of the differences in nutritional content stands out and can be attributed to the fiber content and the lower amount of sugar in RB, but it is actually the overall nutritional composition of RB that gives the higher result.

Dairy products contribute most to the nutritional index, mainly due to their high calcium content, but they also contain saturated fatty acids which contribute to the undesirable nutrients. RP contained higher levels of saturated fat and added sugars compared to RB, whereas RB contained a greater amount of salt. The salt content in RB can be attributed to the inclusion of grilled cheese. Although RP included a larger quantity of dairy products (122 g versus 62 g in RB), the calcium content in RB remained comparable, likely due to the grilled cheese being processed from approximately eight times more milk. The higher saturated fat content in RP can be explained by the higher amount of dairy used. Additionally, RP contained more added sugar (12 g) than RB (7 g). The most pronounced nutritional difference between the two products lies in fibre content, which was substantially higher in RB due to the presence of whole rye grains.

5.7 Råggyberry as part of a sustainable diet

Although RB demonstrates a lower environmental impact compared to RP, specific hotspots have been identified, the dairy components and the transportation of frozen apples used in the sauce. Although RB shows strengths in terms of both nutritional quality and from an environmental perspective compared to RP, the following section evaluates RB for its suitability as part of a healthy and sustainable diet.

5.7.1 Environmental aspects

A key ingredient in RB is organically cultivated rye, a crop well suited to Swedish agricultural conditions. For example, it is tolerant to both cold weather and droughts (Saltåkvarn, 2015) and can be grown on nutrient-poor and light soils which is difficult to cultivate on (Jordbruksverket, 2011). Additionally, it has beneficial impacts on soils, due to its deep root systems and nitrogen fixation properties, preventing leaching and making the nitrogen available for subsequent crops (Snapp & Surapur 2018). The rye used in RB is also organically grown, which supports ecosystem services and biodiversity.

Except for the apples and blackcurrants all ingredients in RB are of Swedish origin, supporting the resilience within the country. According to the results in our study RB (0.18 CO2 eq) is a suitable snack option in relation to WWF food guide one planet plane, which says that snacks (mellanmål) should not go over 0.2 CO2 eq per meal (WWF, 2018). All ingredients used in RB meet the criteria set by the WWF's One Planet Plate (WWF 2021), which requires foods to receive a green light in the WWF's Meat Guide; a traffic light system for assessing the sustainability of foods. The grilled cheese included in RB is listed in the Meat Guide with a green light classification. Cereal components, such as rye, are expected to contribute to biodiversity, for example by being organically produced. Furthermore, no ingredients listed in the Veggie Guide should have an orange light, as this indicates foods to be avoided. While apples are categorized with a green light, blackcurrants are not included in the guide, making their sustainability assessment uncertain. However, by analogy, none of the berries included in the guide are marked with orange light, suggesting that blackcurrants can reasonably be assumed to meet the sustainability criteria.

5.7.2 Nutritional aspects

The Swedish Food Agency recommends a daily intake of 90 grams of whole grains due to their higher nutritional content, RB contributes 17 grams per serving toward this goal (Livsmedelsverket, 2025). Whole grains are rich in fiber, which helps regulate blood sugar levels, support healthy blood lipids, and promotes a longer-lasting feeling of fullness, benefits not provided to the same extent by refined grains such as the white rice used in RP (Livsmedelsverket, 2025). RB contains 0.5 grams of salt per 170-gram serving (equivalent to 0.29 g per 100 g), which aligns well with the Swedish Food Agency's recommendation to keep total salt intake below 6 grams per day.

The rye grain in RB has undergone hydrothermal treatment, a process that enhances the bioavailability of essential nutrients like iron and zinc (Hidden in Grains, n.d.). Iron is a key concern in the shift toward more plant-based diets, as the body absorbs plant-based iron less efficiently (Cohen & Powers 2024). Given that iron deficiency is particularly prevalent among adolescents and young women, this dietary shift may pose additional challenges for these groups (ibid.). In this context, RB may serve as a beneficial alternative to RP or other snacks, especially for individuals at risk of iron deficiency.

5.7.3 Product development

The production of grilled cheese, which requires large quantities of milk, would significantly increase the emissions and land use associated with RB if allocation were based on milk solids instead of economic value. Although replacing grilled cheese, possibly with a plant-based alternative could be considered in the perspective of dietary recommendations of increasing plant-based alternatives, the grill-cheese has a functional role by utilizing residual streams and providing beneficial nutritional properties. Dairy products are an important source of protein, calcium, B12 and iodine, dairy products with a fat content of 3% or higher also contribute to vitamin D intake, while products with a lower fat content need to be fortified (Livsmedelsverket 2024a). Generally, plant-based alternatives contain lower amounts of energy, saturated fats and sugar compared to dairy products which could contribute positively to the NRF index (Moshtaghian et al. 2024). But they also contain lower amounts of protein, with exception of some soy-based alternatives, and negligible amounts of micronutrients, this means that these alternatives need to be fortified to match the nutritional composition of dairy (ibid.). Not all plant-based alternatives on the market are fortified, but in Sweden, 70% of plant-based milk and yogurt alternatives sold directly to customers are fortified with vitamin D, Calcium and B12 (ibid.). If plant-based alternatives were to be used in products like RB a requirement should be that the products used in the industry are also fortified to meet the nutritional composition of the dairy products used. This could further decrease RB contribution to all IC without compromising with the nutritional value.

The apples account for a significant share of the emissions, primarily due to the emissions associated with chilled transportation. To reduce these emissions, Polish apples could be substituted with locally produced Swedish apples, thereby eliminating the need for chilled long-distance transport. In terms of water use, when looking at SAFAD data, Swedish and Polish apples contribute similarly, which can be explained by the comparable climatic conditions. If the apples and blackcurrants in RB, both from Poland, were to be replaced with fresh, locally produced alternatives would eliminate the need for freezing and long-distance transport, thereby reducing the climate impact. To further lower the environmental impact and promoting biodiversity the fruit and berries should ideally be organically or KRAV-certified (KRAV 2024). Finally, increasing the share of locally and sustainably produced ingredients contributes not only to reducing climate impact but also to strengthening national food security and system resilience, which are key priorities in the transition to a more sustainable food system (Jordbruksverket, 2025b).

5.8 Råggyberry as a niche product

Despite RB currently being produced on a small scale local to the Stockholm area, the LCA was performed on a hypothetical large-scale production of the product. This was done as it's the ambition of Axfoundation to have RB produced and sold at a larger scale, it also made for an easier comparison to the conventional RP which is already produced at such a scale. This is what could be defined as a prospective LCA according to Arvidsson et al. (2017), meaning an assessment of an emerging technology (in our case a food product), modelled after a more developed future stage such as large-scale production. There are a multitude of benefits to prospective LCA studies, they can for example provide early insights into the environmental hotspots of the product (ibid). Such insights provide stakeholders with information that enables proactive decision making that can improve the upscaling process (ibid.).

It should be noted that prospective LCA's have its restrictions especially in relation to assumptions on future scenarios and technologies. This could include incomplete life-cycle inventory data, and difficulties predicting potential issues in regard to operational difficulties in the upscaling process (ibid.). In the case of RB such uncertainties could relate to the availability of certain ingredients. The waste-shreds of grill-cheese and the hydrothermally treated rye are two ingredients included in RB that are not necessarily available on the conventional market, given that one is a waste product, and the other is still produced at a relatively small scale. HiG, the company producing the treated rye grains, are relatively small and seeing as the rye is a niche product, it is hard to assess its upscaling possibilities. Given the currently low production volumes of RB, the availability of side streams such as grill-cheese and hydrothermally treated rye may become a limiting factor in scaling up production. In the case of waste shreds shortage, if instead regular pieces of grill-cheese were used the climate impact of RB would be significantly higher, as shown by the sensitivity analysis (table 8). And should the hydrothermally treated rye be replaced with conventional rye grains, the amount of bioavailable nutrients would decrease. This would not impact the results of this study as the increased bioavailability of nutrients could not be accounted for due to limitations in available methodology. However, the increased bioavailability is still one of the benefits and selling points of RB and is important to note. These are potential issues that should be taken into consideration would there be an upscaling in RB’s production.

From the perspective of product development and the Swedish food market, RB is arguably both an innovative and a niche product. While previous studies have indicated that some consumers are likely to look for a healthy alternative to their favorite snack foods (Ciurzyńska et. al 2019) there are also consumers who are considerate of how their food choices may impact the environment. Despite these positive trends in some consumers' attitudes there are still hurdles present in the upscaling of innovative and sustainable products (Augenstein et al. 2020). For one, if the party responsible for the innovations isn’t the same party responsible for the upscaling process there can be issues in the transition of agency of the product. This is especially true if there is heterogeneity in the parties’ organizational size, structure, and purpose (Meier 2020). An example of this would include the transition from a NPO to a commercial institution (such as a large-scale producer of food), which would be the case for RB. Furthermore, commercial interests are a potentially inhibitory factor to innovation, as changes might have to be made to a product to ensure commercial viability. This would mean that despite RB being more environmentally sustainable and nutritionally adequate compared to its conventional counterpart, its success is more dependent on monetary considerations.

5.9 Study population

The reference population used to calculate the NRF11.3 index score for both products was Swedish adults between the ages of 18-50, with a moderate activity level. This choice was motivated by available information such as DRI and MRI derived from NNR (2023), as well as nutrient intake data from Riksmaten (2011), and recommended energy intake (Livsmedelsverket).

Although the recommendations and intake-data were varied within this group, they were similar enough to justify the usage of average values. The recommended energy intake and nutritional needs within other age groups (children and elderly) were too varied to include in an average without risking skewing the results.

Children were planned to be included as a secondary study population, but due to limitations in the weighting data, they were ultimately not included. Children are however a relevant study population regarding both RB and RP, as it can be argued that both products at times are marketed towards children (Axfood 2024; Risifrutti n.d. c).

A similar study performed with Swedish children as the chosen population is a suggestion for future research and would be particularly interesting given the nutritional qualities found in RB. Adolescents in Sweden are currently consuming too little fibre, too much sugar and saturated fats, which are primarily consumed by snacking (Livsmedelsverket, 2018), and a snack like RB could therefore be a suitable replacement.

It should be noted that intake data of Swedish children and adolescents are limited, and constrained to specific age groups, 8th graders and second year high school students (Livsmedelsverket 2018) and 1,5- and 4-year-olds (Livsmedelsverket 2024b). This combined with large varieties regarding recommended energy intakes for children complicates choosing them as a study population.

5.10 Data limitations

When conducting the life cycle inventory, it became clear that no single database contained all relevant input-data needed for the assessments. As such, data from three different databases was used to perform the assessments, namely, EcoInvent 3, Agri-footprint, and SAFAD. While it is possible to combine data from several databases, it is generally recommended to use one to avoid deviations and general inconsistencies of inventory-data which may affect the results of the LCA (Kalverkamp & Karbe 2019). One such discrepancy noted in this study was the fact that SAFAD uses cropland for land use modelling while Ecoinvent3 and Agri-footprint incorporate a more extensive amount of land use categories in their modelling. These inconsistencies in the input-data should be considered while interpreting the result of this study in relation to land use.

While the recipe for RB was provided in detail by Axfoundation, the recipe for RP had to be estimated as well as the origin of its ingredients, which can introduce some inaccuracies in the result. Furthermore, data on Italian apples from Agri-fooprint were used as a proxy for Polish apples. This was done on the assumption that data on European apples would not vary much between regions. Upon further research however, it came to our attention that the water usage differed significantly between Polish and Italian apples due to regional differences in climate. As this revelation was discovered in the later phases of this study there were time constraints which did not allow us to redo the assessment with data on Polish apples. As such the estimated water usage for RB is most likely smaller than what our assessment shows, and these results should be interpreted with consideration to this.

Retention factors were used to obtain information on the actual amount of nutrients in the products after processing (Eneroth & Mattisson 2017). The available retention factors were applied to rye grains and the berries and fruits used in the berry sauce. It was not clear whether the retention factors were based on dilution of nutrients during boiling and straining of water or whether it was due to nutrient degradation or an average value. The largest losses of minerals is due to leaching (Brugård Konde 2017), if the retention factor is primarily based on leaching it should not have been applied to the minerals in the fruits and berries used in the products, as everything was cooked into a sauce. For rye, it can be assumed that it is cooked in water that is strained out both in the hydrothermal process and during cooking when preparing the products and the retention factor should be applied.

Moreover, weighting data is based on a report where individuals have self-reported intake of different foods. A challenge with studies relying on self-reported intake is that individuals often tend to overestimate the consumption of healthy foods and underestimate the intake of foods perceived as unhealthy, which could potentially influence the results of this study (Kowalski et al. 2025). Riksmaten data is based on data collected in 2010-2011, as the dietary intake of the Swedish population is continuously changing and seems to be in a continued negative trend, this may skew the results (Folkhälsomyndigheten 2025a).

6. Conclusions

In conclusion RB is a more environmentally sustainable and nutritionally adequate alternative in relation to a conventional RP. The differences between the products' environmental impact were especially pronounced when relativized to their nutritional content using the NRF11.3 index. The nutritional index score was almost 40% higher for RB compared to RP, although the high fiber content stands out it's RBs overall nutritional composition that results in the high score. In both products, calcium was a major contributor to the score, especially in RP where it was the largest.

For both products the primary production was the largest contributor to their environmental impact, however for RB it was more evenly divided between primary production and transportation due to the cold-chain transportation of the apples, this can be attributed to the large quantity of apples used in the recipe. The dairy-products had the largest impact on Climate impact and land use for both RB and RP, while rice had the second largest impact on Climate impact for RP and apples for RB. Rice and strawberries accounted for the largest impact on water use in RP, while apples accounted for the largest impact in RB. This impact would have been significantly smaller if data on polish apples would have been used instead of Italian apples as a proxy for polish ones. The sensitivity analysis showed that the RBs small environmental impact is heavily dependent on the use of grill-cheese waste streams. Should the production of RB be upscaled the availability of such products should be considered.

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Popular science summary

The rapid growth of the global food system has had major negative impacts on the environment. It currently accounts for a third of global greenhouse gas emission while simultaneously being the biggest driver for land use conversion and depletion of freshwater resources. While the growth of the global food system has given more people access to food it has also increased the prevalence of foods with low nutritional value. This is primarily prevalent in western diets, increased rates of obesity and subsequent non-communicable diseases.

Modern lifestyles demand quick and accessible food options, currently these types of convenient foods are usually lacking in relation to nutritional content and are high in energy. There is a need for healthier and more sustainable snack foods, which are convenient and could be consumed on-the-go. The Swedish non-profit organisation Axfoundation has created Råggyberry, a rye-based pudding served with a fruit sauce, similar to the popular rice pudding snacks. Råggyberry is aiming at being a more sustainable and healthier alternative to current ones available on the market. The product is developed in collaboration with Hidden in grains, a company which has developed hydrothermally treated grains, a process that makes nutrients easier to absorb for the body. Råggberry also uses waste streams in the form of waste shreds of grill-cheese production.

The aim of this study was to quantify the environmental impact of Råggyberry and compare it to the impact of a conventional rice pudding, and to evaluate these impacts relative to each product's nutritional composition.

The results showed that Råggyberry had a lower environmental impact than a conventional rice pudding, along with a more favorable nutritional profile. Overall, the results show that Råggyberry is a more environmentally sustainable and nutritionally balanced option. The differences in environmental impact were particularly evident when related to the nutritional composition of the products.

Appendix 1

Appendix 1 compiles a list of included datasets, their source, and what they were used to model.

Table 9. Compilation of Datasets used in lifecycle assessments.

Nr.	Source	Dataset name	Used to model	Input (U) per serving (170 g)	Comment
1	Agri-Footprint	Rye grain, dried, at storage {SE} Economic, U	Swedish Rye	17 g	
2	EcoInvent 3	Lactic acid {RER} | Production of lactic acid | Cut-off, U	Lactic acid, hydrothermal treatment	0,01 g	
3	EcoInvent 3	Sugar, from sugar beet, at processing {DK} Economic, U	Swedish sugar	7 g	Danish sugar was equated with Swedish sugar.
4	EcoInvent 3	Apple {IT}| apple production | Cut-off, U	Polish apples	33 g	Italian apples were equated with Polish apples.
5	Agri-Footprint	Rice, dried, at storage {IT} Economic, U	Italian short-grained rice	15 g	
6	EcoInvent 3	Strawberry {RoW}| strawberry production, open field, macro tunnel | Cut-off, U	Moroccan strawberries	12 g	
7	SAFAD	A.05.04.010. | Currants (Red, black and white) | PL	Polish black currants	8 g	
8	SAFAD	A.08.01.001.002 | Cow milk, Raw milk off cattle | SE	Swedish dairy products		SAFAD parameter-files contained data for milk % in each product and allocation-factors

9	EcoInvent 3	Biogas {RoW}| market for biogas | Cut-off, U	Gas usage, hydrothermal treatment	0,3 kg	
10	EcoInvent 3	Electricity, high voltage {SE}| electricity production, wind, >3MW turbine, onshore | Cut-off, U	Electricity usage, hydrothermal treatment	5 kJ	
11	EcoInvent 3	Transport, freight, sea, container ship with reefer, cooling {GLO}| market for transport, freight, sea, container ship with reefer, cooling | Cut-off, U	Transportation of frozen strawberries by sea	0.037 tkm	Frozen strawberries - Larache, Morocco to Vlissingen, The Netherlands (3097 km)
12	EcoInvent 3	Transport, freight, lorry with refrigeration machine, 3.5-7.5 ton, EURO6, carbon dioxide, liquid refrigerant, cooling {GLO}| market for transport, freight, lorry with refrigeration machine, 3.5-7.5 ton, EURO6, carbon dioxide, liquid refri(...)_5 | Cut-off,	Lorry transportation of chilled/frozen goods	0.019 tkm	Frozen strawberries - Vlissingen, The Netherlands to Stockholm, Sweden (1603)
				0.069 tkm	Frozen Apples - Grocheck, Poland to Stockholm, Sweden (2108 km)
				0.015 tkm	Frozen Currants - Skierniewice, Poland to Stcokholm, Sweden (1896 km)
				0.019 tkm	Yoghurt - Falköping, Sweden to Stockholm (379 km)
				0.004 tkm	Grill-cheese waste shreds - Falköping, Sweden to Stockholm, Sweden (379 km)
				0.044 tkm	Milk - Falköping, Sweden to Stockholm, Sweden (379 km)
				0.002 tkm	Cream - Falköping, Sweden to

					Stockholm, Sweden (379 km)
13	EcoInvent 3	Transport, freight, lorry >32 metric ton, EURO6 {RER}| market for transport, freight, lorry >32 metric ton, EURO6 | Cut-off, U	Lorry transportation of dried goods	0.002 tkm	Treated Rye - Skölding, Sweden to Stockholm, Sweden (129 km)
				0.033 tkm	Rice - Turin, Italy to Örebro, Sweden
				0.005 tkm	Sugar- Örtofta, Sweden to Örebro, Sweden (466 km)
				0.004 tkm	Sugar - Örtofta, Sweden to Stockholm, Sweden (577)
14	EcoInvent 3	Electricity, low voltage {PL}| market for electricity, low voltage | Cut-off, U	Blast freezing of polish produce	13 kJ (Apples)	Inputs were equated with freezing of strawberries
				3 kJ (Currants)	
15	EcoInvent 3	Electricity, low voltage {MA}| market for electricity, low voltage | Cut-off, U	Blast freezing of Moroccan strawberries	5 kJ	
16	EcoInvent 3	Electricity, low voltage {SE}| market for electricity, low voltage | Cut-off, U	Cooking of grain-puddings	56 kJ	Energy inputs were equated for both products
17	EcoInvent 3	Electricity, low voltage {SE}| market for electricity, low voltage | Cut-off, U	Cooking of fruit-sauces	54 kJ	Energy inputs were equated for both products

Appendix 2

The retention factors for calculating the nutritional value of food items after boiling is presented (Eneroth & Mattisson 2017). The factor is derived from SFA, and was used in the assessment of both RP and RB.

Table 10. Retention factors for nutrients in boiled foods which were applied in the nutritional calculations of NRF11.3.

Nutrient	**Retention factor**	
	Fruits and berries	Cereals
Vitamin C	0,4	-
Folate	0,5	0,6
Potassium	0,6	0,65

Appendix 3

The factors used to calculate the quantity of milk and the corresponding economic allocation factors for each dairy product used in the products, based on data obtained from SAFAD.

Table 11. Allocation factors and processing factor for each dairy product included in both the råggyberry and rice pudding recepies.

Ingredient	**Processing factor (amount of milk)**	**Allocation factor**
Milk, 3% fat content	1	1
Yogurt, 3% fat content	1,25	0,73
Yogurt, 10% fat content	1,25	0,73
Grill-cheese, shredded	8	0,94

Appendix 4

The quantity of nutrients included in NRF 11.3 equation in both RP and RB per serving (170 g product) and the weighting factors applied per nutrient.

Table 12. Content of nutrients included in NRF 11.3 in both råggyberry and rice pudding per serving (170 g product) and the weighting factors applied per nutrient.

	Råggyberry	**Rice Pudding**	
Nutrient (unit)	**Amount per serving**	**Amount per serving**	**Weighting factor[2]**
Protein (g)	5.7	5.3	1.1
Fiber (g)	3.8	0.4	1.6
Vitamin A (RE/µg)	47	49.6	1.0
Vitamin C (mg)	4.7(1)	3.6[1]	1.2
Vitamin E (mg)	0.57	0.2	0.9
Vitamin D (µg)	0.0	0.0	1.4
Folate (µg)	12(1)	16.7[1]	1.4
Calcium (mg)	137	149.9	1.1
Iron (mg)	0.69	0.1	1.2
Magnesium (mg)	30	18.7	1.0
Potassium (mg)	169(1)	208.8[1]	1.2
Salt/Na (g)	0.54	0.2	1.4
Saturated fats (g)	3.2	3.5	1.1
Added sugars (g)	7.0	12	1[3]

(1) Retention factor was applied, see appendix x. (2) Data derived from Riksmaten 2016, calculation details can be found in appendix x. (3) Capping was used and set to 100% since the intake was lower than MRI, according to Bianchi (2020) recommendations.

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