Nutritional Assessment Focusing on Beta-carotene and Dietary Fibre of Fermented Grated Carrots

- Supplementary Life Cycle Assessment

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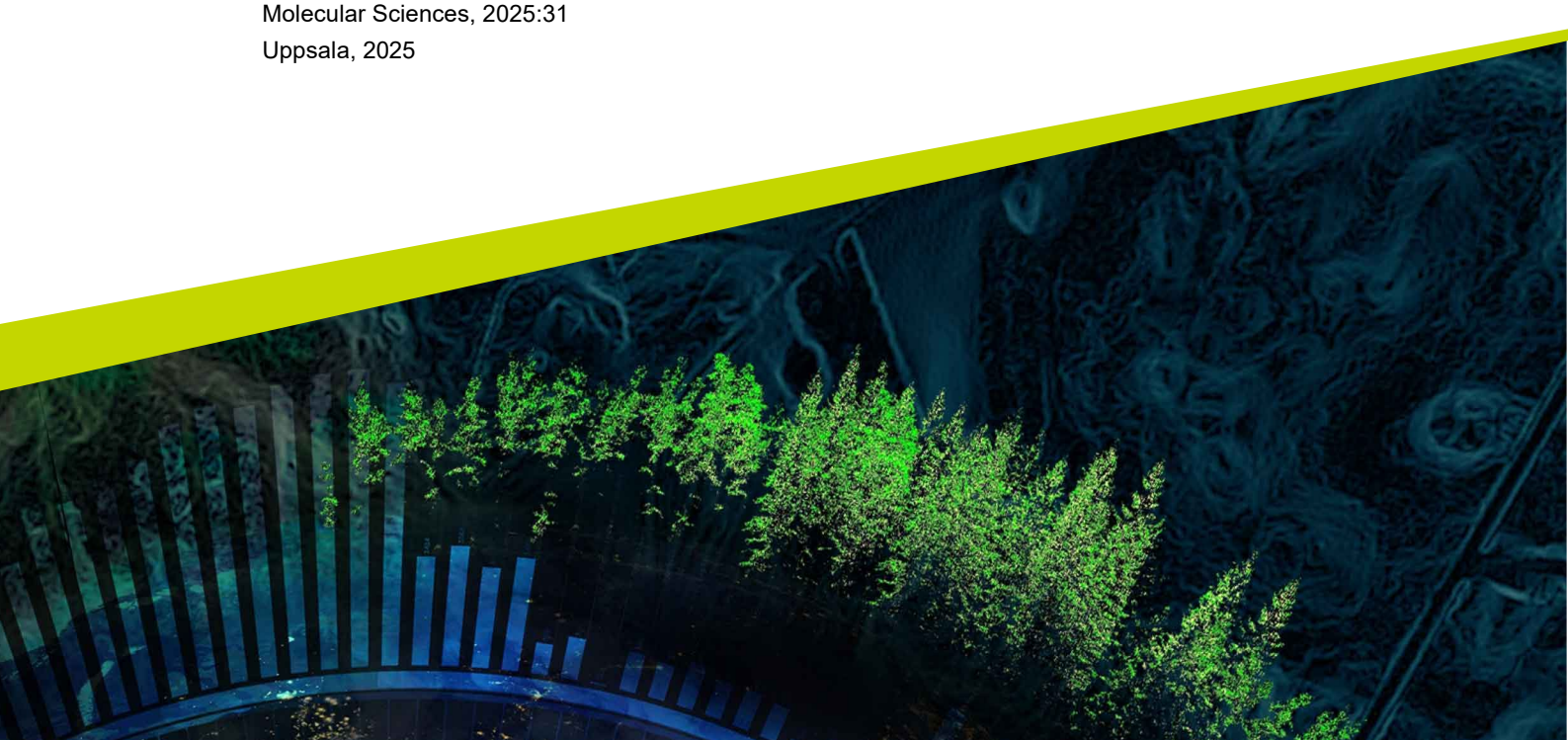

Nutritional Assessment Focusing on Beta-carotene and Dietary Fiber of Fermented Grated Carrots. Supplementary Life Cycle Assessment.

Näringsbedömning med fokus på betakaroten och kostfiber från fermenterade rivna morötter. Kompletterande livscykelanalys.

Linnea Andersson

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Abstract

This master's thesis was conducted in collaboration with Axfoundation and their initiative *Blood and Turnip*. A notable amount of carrots produced goes to waste and about a third of the carrots produced are not used as food. This thesis investigates the impact of lactic acid fermentation on the nutritional composition of one of Axfoundation's newly developed products, fermented, grated carrots from upcycled packhouse side streams mixed with a vegan mayonnaise. The primary objective was to assess the effects of fermentation on the content of beta-carotene and dietary fibre. Nutritional analyses were conducted by an external laboratory using established analytical methods.

Additionally, a life cycle assessment (LCA) was performed to estimate the carbon dioxide footprint of the final product using a standard methodology.

The results from the nutritional analysis indicated an increase in the detected levels of beta-carotene and fibre following fermentation. These findings were consistent with previous studies suggesting that fermentation may enhance the bioavailability of certain nutrients. The LCA resulted in a carbon dioxide value that was lower compared to similar products currently available on the market. However, this result should be interpreted with caution, considering factors such as the quality of raw materials and specific process parameters.

In conclusion, the study supports the hypothesis that fermentation may enhance the nutritional quality of vegetable-based food products. However, further research is required to isolate the specific mechanisms by which fermentation affects the nutrient availability, and to validate the results under varied conditions.

Keywords: Carrots, Fermentation, Lactic acid bacteria, Nutrients, Beta-carotene,Vitamin A, Dietary fibre, Carbon dioxide footprint, Food waste

Sammanfattning

Denna masteruppsatts är genomförd i samarbete med Axfoundation som en del av deras projekt *Blod och Rova.* En betydande mängd morötter som produceras blir svinn, och ungefär en tredjedel av de producerade morötterna används inte som livsmedel. Uppsatsen undersöker hur mjölksyrafermentering påverkar näringsinnehållet i en av deras nyutvecklade produkter, fermenterade, rivna morötter från återvunna sorteringsflöden, blandade med en vegansk majonnäs. Det huvudsakliga syftet var att utvärdera hur fermentering påverkar halten av betakaroten och kostfibrer. Näringsanalyser utfördes av ett externt laboratorium med etablerade analysmetoder.

Utöver detta genomfördes en livscykelanalys (LCA) för att uppskatta produktens koldioxidavtryck med hjälp av en standardiserad metod.

Resultaten från näringsanalysen visade en ökning i detekterat betakaroten och fiberinnehåll efter fermentering. Dessa resultat överensstämmer med tidigare studier som tyder på att fermentering kan öka biotillgängligheten av visa näringsämnen. LCA:n visade ett lägre koldioxidvärde jämfört med liknande produkter på marknaden. Detta resultat bör tolkas med försiktighet med hänsyn till faktorer som råvarornas kvalitet och processparametrar.

Sammanfattningsvis bekräftar studien hypotesen att fermentering kan förbättra den näringsmässiga kvaliteten hos vegetabiliska livsmedelsprodukter. För framtiden krävs ytterligare forskning för att isolera de specifika mekanismerna genom vilka fermentering påverkar näringstillgängligheten och för att bekräfta dessa resultat under varierande förhållanden.

Nyckelord: Morötter, Fermentering, Mjölksyrabakterier, Näringsämnen, Betakaroten, Vitamin A, Kostfibrer, Koldioxidavtryck, Matsvinn

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Abbreviations

DF	Dietary fibre
IDF	Insoluble dietary fibre
SDF	Soluble dietary fibre
LAB	Lactic acid bacteria
LCA	Life cycle assessment
LOR	Limit of reporting
MU	Measurement uncertainty
NMR	Nuclear magnetic resonance analysis

1. Introduction

This thesis was conducted in collaboration with Axfoundation and their initiative, *Blood and Turnip*. Axfoundation collaborates with partners to identify and assess the potential of food ingredients previously classified as food waste, animal feed or biogas. At Axfoundation's test farm and development centre Torsåker Gård, new food products are developed based on raw materials and resources that are both safe and environmentally sustainable. The aim of the initiative *Blood and Turnip* is to contribute to safe, nutritious and enjoyable food for serving in the public sector (Axfoundation, 2025).

This report provides a deeper analysis of fermented, grated carrots, which is one of the products developed at Torsåker gård. The product consists of fermented, grated carrots, where a vegan mayonnaise, named Ärtonnaise, based on peas is added. Since the effects of fermentation vary between different vegetable (Knez et al, 2023), it is valuable to deepen the understanding of how fermentation affects the nutrients as more innovative and untested fermented products are being developed.

How the nutritional content of food changes after preparation is a valuable concern. Fermentation has been shown not only to extend shelf life of food but also improve its nutritional profile (Cagno et al, 2016). Microbial fermentation can enhance the bioavailability of nutrients by reducing or neutralizing tannins and phytates. Bacterial processing can also lead to increased antioxidant potential, which has been linked to the release of polyphenols
from complexes with anti-nutritional ingredients (Knez et al, 2023).

Food processing has the capacity to modify the microstructure of the cell wall and therefore improve the nutritional properties of a food product. Different forms of thermal processing are known to affect the integrity of the cell wall and by that the bio accessibility of nutrients in carrots (Ribas-Agusti et al, 2014). However, may lead to undesirable changes in the physical characteristics and chemical composition of the vegetable (Di Cagno et al, 2013). In contrast, the effects of fermentation on the nutritional content in carrots is a less evaluated area. Fermentation could potentially serve as a beneficial way to treat carrots to keep, and even increase, the bioavailability of nutrients.

Carrots are a rich source of essential nutrients like beta-carotene, a precursor to vitamin A and dietary fibre (Sharma et al, 2011). The focus in this thesis was on beta-carotene, vitamin A and dietary fibre. By evaluating the transformation of these nutrients during the fermentation process, this study aimed to contribute to

the understanding of how the fermented carrots with Ärtonnaise developed by Axfoundation could serve as a food to reduce food waste while at the same time promoting health.

1.1 Aim

The aim of this thesis was to conduct a nutritional- and life cycle assessment on a product consisting of fermented carrots and Ärtonnaise. Furthermore, the objective was to examine how the nutrients, more specifically beta-carotene and dietary fibre, were affected by fermentation as a process. Based on the result regarding the nutrient content, the study evaluated whether the product could qualify for nutrient claims.

2. Background

A notable amount of carrots produced goes to waste and about a third of the carrots produced are not used as food. Instead the carrots become animal feed, biogas or compost. Food losses of carrots accounted for around 26 percent of the total harvest (Olsson, 2023). Carrots are sensitive concerning influences by biotic and abiotic stress on quality characteristics. Carrots are exposed to biotic and abiotic factors during the whole production chain that may affect the quality in different ways (Seljåsen et al, 2013). Abiotic stresses includes extremes in e.g. temperature and drought while biotic stresses comprises attacks by pathogens like fungi, bacteria and herbivores (Gull et al, 2019).

The main reason for waste during carrot production is due to various defects such as the carrots being rotten or mouldy, too big or too small. The advantages of creating a product consisting of grated carrots is that the consumer does not see the possible defects or deviations that make the carrots unsellable in store (Olsson, 2023).

Carrots are a valuable vegetable around the world. They are rich in bioactive compounds like dietary fibers and carotenoids and are the most important source of dietary carotenoids in Western countries (Sharma et al, 2011). The body needs plant metabolites that provide antioxidants and protect from oxidative stress. Carotenoids are a vital bioactive compound which is a precursor to vitamin A (Boadi et al, 2021). The diverse functions and actions of carotenoids make them among the most significant nutrients in food (Sant'Ana a et al, 1998).

2.1 Beta-carotene

Fruits and vegetables contain mono- and disaccharides, dietary fibre, vitamins, minerals, phenolic compounds, and carotenoids (Wei et al, 2025). Carotenoids belong to the tetraterpenoids and are a class of natural pigments (Anand et al, 2022). Carotenes are a subgroup of carotenoids and carotenoids are further categorized into two classes; carotenes which contain carbon and hydrogen and xanthophylls which contain oxygen atoms in addition to carbon and hydrogen (Telegina et al, 2023). The most prominent member of the carotenoid group is beta-carotene (Xu et al, 2020). Beta-carotene, which are provitamin A carotenoids are the main source of vitamin A and its derivatives in the human diet (Lintig, 2012). Beta-carotene is a vital compound and serves as a plant pigment. It is beta-carotene that gives carrots their orange colour (Tufail et al, 2024). Beta-carotene is a fat-soluble compound (Kono & Arai, 2014) and provides different benefits to the body, including regulating lipid metabolism and reducing inflammation

caused by oxidative stress. Beta-carotene cannot be synthesized by the body and must therefore be obtained through the diet (Yang et al, 2024). The antioxidant properties and provitamin A activity, which are believed to play an important role regarding lowering the risk of certain diseases (Tufail et al, 2024) including different forms of cancer, cystic fibrosis and inflammatory diseases (Anand et al, 2022), are considered the most important health benefits of beta-carotene. (Tufail et al, 2024). The bioavailability of beta-carotene from natural sources varies and depends on the food matrix and individual response (Donhowe et al, 2014).

Beta-carotene is in the carrot chromoplasts and exists in crystalline form (Rodriguez-Concepcion & Stange, 2013). They can be associated with proteins and residual membranes. To be absorbed in the gut, because of the intracellular and membrane bound localization, beta-carotene needs to be released during food processing and during digestion. The release of beta-carotene might be affected by the cell walls. It was discovered that firmer carrots had lower bio accessibility of beta-carotene, whereas softer carrots had higher bio accessibility. This implies that using conventional processing methods may not be optimal for simultaneously achieving a firm texture and high level of bio accessible beta-carotene in carrots. Processing conditions should therefore be optimized to achieve an appropriate compromise between nutritional value and textural attributes (Lemmens et al, 2009).

The cellular structure and its complex combination with proteins give carotenoids some stability in vegetables. Various processing steps can affect the ultra-structure of carotenoids leading to damaged complexes. Multiple factors affect the stability during the different stages of processing. Factors that may influence the stability include carotenoid structure, oxygen availability, humidity content, acid and water activity, temperature and light exposure, presence of antioxidant and prooxidant (Rodrigues et al, 1998).

It is generally recognized that after consuming beta-carotene, both intact beta-carotene and its metabolite retinol appear in the bloodstream. In humans, the conversion of beta-carotene into vitamin A primarily occurs in the intestine and lesser conversion in other tissues. The relationship between the amount of beta-carotene consumed and the amount of vitamin A produced from it is referred to as the beta-carotene-to-vitamin-A conversion factor to the beta-carotene equivalent to vitamin A (Tang, 2010).

The main factors that affect the bioavailability of food carotenoids and the bioconversion of food provitamin A carotenoids to vitamin A in humans are food matrices, food preparation and the fat content of a meal (Tang, 2010).

2.2 Vitamin A

Vitamin A can be obtained naturally through the diet (Tang, 2010) and is available in different forms. We obtain vitamin A from food in two main forms, either as preformed vitamin A in the form of retinol and retinyl esters found in food from animal origin, or by provitamin A, a precursor to vitamin A in the form of carotenoids, mainly as beta-carotene, found primarily in plant-based foods (Tang et al, 2005). Carrots are rich in provitamin A (Dias, 2014).

Provitamin A carotenoids can be converted into vitamin A in the body when needed. The total vitamin A content of foods from animal and plant sources is expressed as either retinol equivalents (RE) or as retinol activity equivalents (RAE). Both units are measures of the amount of biologically active vitamin A in the body after absorption and consider that absorption varies between different sources of vitamin A in the diet (Livsmedelsverket, 2023). About half of dietary provitamin A carotenoids are converted to retinol and around half are absorbed intact, despite the fact that the amount of conversion varies between individuals (Harrison, 2012). Provitamin A carotenoids are converted into vitamin A by the enzyme beta-carotene monooxygenase type 1 BCMO1 in the intestine (NIH, 2025).

The vitamin A concentration of a food has commonly been based on the amounts of preformed vitamin A and provitamin A carotenoids contained in that specific food. Still, considerable factors that affect the bioavailability of food carotenoids and the bioconversion of food carotenoids to vitamin A in humans depend on food preparation methods, fat content of the meal and the food matrix (Tang et al, 2005).

Different forms of vitamin A are dissolved into micelles in the intestine and absorbed by cells in the duodenum. Retinyl esters and provitamin A carotenoids are converted into retinol after being taken up from the lumen (in the case of retinyl esters) or absorbed (for provitamin A carotenoids). Retinol is then converted into retinal and retinoic acid, which are the primary active forms of vitamin A in the human body. The majority of the body's vitamin A is stored in the liver as retinyl esters (NIH, 2025).

2.3 Fibre

Fibres can be divided into two broad chemical classes. The first one is called non-alpha-glucan polysaccharides and includes cellulose, hemicelluloses and pectin. The other class consists of lignin (Kay, 1982). Dietary fibre (DF) refers to a wide range of food components that are not digestible. Studies have proven that DF plays a major role in gastrointestinal health by regulating the gut microbiota (Guan et al, 2021). Depending on their solubility in water, DF can be categorized into soluble DF (SDF) and insoluble DF (IDF) (Liu et al, 2019). Beta-glucan, pectin, arabinoxylan and inulin are the major constituents of SDF. IDF on the other hand is commonly composed of lignin, cellulose and hemicellulose (Li et al, 2022).

The sugar chains in cellulose, the most common and abundant form of IDF in nature, are connected through strong hydrogen bonds, creating a hydrophobic and crystalline structure that resists the breakdown by external glucosidases. Cellulose is a polysaccharide with high molecular weight made up of beta-glucose. It serves as the primary structural element of plant cell walls and typically combines with hemi-cellulose, pectin and lignin. SDF consists of different active substances with various structures. They are primarily composed of resistant oligosaccharides and viscous DF with a high molecular weight. The solubility can vary and depend on both the structures of the fibres and external factors like pH and temperature. Pectin solubility increases with the abundance of side chains (Guan et al, 2021).

Pectin is in the primary cell wall and intracellular layer of plant cells and is a variant of structural fibre (Mudgil, 2017). Pectin consists of galacturonic acid units joined by linkages, with neutral sugars and methanol forming side chains (Jafari et al, 2017). It is one of the main components in the middle lamella and primary cell wall of vegetables and fruits. As fruit and vegetables ripen, the pectin molecules break down and dissolve within cell walls. This causes a decrease in their molecular size and increases the fruit's solubility. The dissolved pectin continues to degrade, resulting in a lower overall pectin content (Wang et al, 2012).

2.4 Lactic Acid Bacteria Fermentation

Fermentation is the process in which microorganisms produce, mainly from sugars, carbon dioxide, alcohols and/or organic acids to generate energy. This is done primarily under anaerobic conditions. Apart from increasing shelf life of a product, fermentation has become associated with health benefits (Leeuwendaal et al, 2022). Fermented foods are rich in probiotic microorganisms, where lactic acid bacteria (LAB) are the main group. LAB induced fermentation often produces by-

products with bioactivity and health promoting effects such as anti-obesity-, anti-allergenic-, and antioxidant effects as well as protection against infectious agents and promotion of the bioavailability of vitamins and minerals (Mathur et al, 2020).

Nutrients and more specifically the sugars they contain make carrots useful for the growth of microorganisms. LAB are the native microorganisms in carrots. Their characteristics depend on growing conditions, climate and the quality of the vegetable. The fermentation process in carrots is mostly characterized by a sequence of hetero- and homo fermentative original LAB (Ramos-Andrés et al, 2021). Fermented vegetables can be defined as low acid vegetables and prone to the action of acid-producing microorganisms that will naturally reach and sustain a pH of 4.6 or below even without the addition of acid (Perez-Dias et al, 2013). Carrot is a low acid vegetable relatively rich in sugars and hence a suitable substrate for growth and metabolic activity of LAB (Xu et al, 2020).

Lactic acid fermentation is a simple way to maintain and enhance both the nutritional and sensory properties, as well as the shelf life, of vegetables (Di Cagno et al, 2013).

LAB can hydrolyse large molecules that are difficult to digest into small molecules that are easily absorbed by the human body, or can degrade and transform to produce new organic acids, phenolic substances, volatile substances, and other active substances. For example, LAB produce acidic metabolites during the fermentation process, which can protect active substances such as vitamins and phenols in plant-based materials, or convert into other polyphenols, such as catechins and anthocyanins, resulting in fermented products with enhanced antioxidant activity (Yang et al, 2024).

During fermentation substrates, primarily organic compounds, undergo non-respiratory metabolism through the action of enzymes or microorganisms. This leads to biochemical changes that significantly improve the food's quality (Behera et al, 2018). It is the formation of a range of microbial metabolites that contributes to the extension of shelf life. It is claimed that microorganisms can produce a wide range of antimicrobial compounds and proteinaceous substances which can inhibit undesirable flora in food products. There are several examples in which LAB inhibits spoilage and pathogenic bacteria (Ross et al, 2002). LAB can produce organic acids like acetic-, lactic- or propionic acid which serve as antimicrobial compounds (Ricci et al, 2019).

Salt, mainly NaCl, plays a major role in preservation and shelf-life of fermented vegetables. It helps to influence the type and extent of microbial activity and prevent softening of the tissue of the vegetable. Furthermore, salt is involved in disrupting the fruit membranes, enabling the transfer of different components into the cover brine solutions used by microbes for growth of metabolic processes (Perez-Dias et al, 2013).

Fermentation further contributes to the structural breakdown of plant cell walls, leading to release or synthesis of different antioxidant compounds (Zong et al, 2023).

2.5 Life Cycle Assessment and Environmental Claims

Life cycle assessment (LCA) is a crucial tool to assess environmental impact (SLU, 2022). Environmental considerations need to be integrated into different sorts of decisions given the current trajectory of climate change and environmental threats. LCA is used to determine the environmental impact and resources used throughout a product's life cycle. Different phases during the life cycle of a product are measured from raw material to processing, distribution and waste management (Finnveden et al, 2009).

Many natural resources are used in different food systems. Understanding which types of food, production methods, ways of processing, packaging, and distribution have higher environmental impact than others is vital. LCA helps to understand in which part of the food system the major impacts occur. The LCA method includes a specific framework consisting of four phases set by a standard, ISO14040. The first phase is objective/scope definition, followed by inventory analysis, impact assessment and interpretation (Literature 1). Functional unit is a fundamental concept of LCA. It should be a measure of the purpose of the operation and depends on what is measured, e.g. one kilo of something, one kWh or square metre living area. System boundary refers to the delimitation of the study. This involves both temporal and geographical boundaries, as well as the point at which you discontinue tracking different resource flows (SLU, 2022).

2.5.1 LCA Implemented on Fermented Carrots with Ärtonnaise

This thesis conducted a LCA on a product with fermented carrots with Ärtonnaise from raw material to finished product. The analysis included the process from cultivation to finished product ready for distribution to consumers. At the time of the study, the specific distribution channels and serving formats for the product had not yet been fully determined. However, the preliminary idea involved serving the product within schools and other public sector institutions.

The shelf life of the product had not yet been established, as it is influenced by multiple factors including storage conditions and handling of the product once opened. Consequently, it was difficult to account for consumer-led consumption and waste of the final product, as these factors had not yet been fully defined or measured. The focus was on climate impact, kg CO_2e/kg, created by the product. A more detailed LCA was made on the carrots while existing kg CO_2e/kg values for the other ingredients were taken from different databases.

3. Method

This study used a combined methodology, including a comprehensive literature review to identify existing research and information regarding the subject as well as data collection and laboratory analysis.

This study includes a literature review, processing of data obtained from the laboratory and processing of data used for the LCA. The literature review was conducted using academic databases including ScienceDirect, MDPI and NIH. Most of the referenced studies were published between 2010 and 2025. However, due to limited availability of current research and data on this subject, sources published prior to 2000 have also been incorporated to enrich the analysis and provide broader perspectives. Only peer-reviewed journal articles and reputable scientific reports have been included in this study.

3.1 Nutritional Analysis

The nutritional analysis began with a literature review, during which a range of scientific papers on the subject were examined to gain an understanding of previous research. Based on the findings from these studies, several hypotheses were formulated regarding the expected nutritional outcomes of the fermented carrots with Ärtonnaise.

3.1.1 Laboratory Analysis of the Fermented Carrots with Ärtonnaise

The fermented carrots with Ärtonnaise were produced and sent from Torsåker Gård to the ALS laboratory in Danderyd for analysis to determine their nutrient composition. The analysis focused on providing information regarding beta-carotene content and fibre content, both soluble and insoluble fractions. Information about the method and equipment used in the lab was taken from the laboratory protocol received by ALS. One sample of the product was analysed in triplicate.

The determination of DF was done according to an internal method employed by the ALS laboratory. The analysis was performed with enzyme degradation and gravimetry. The first incubation step was 30 minutes without the addition of HCI. Enzyme degradation and gravimetry are often used together to determine the DF content in foods. Enzymatic analysis uses enzymes to imitate the human digestive process with the objective of removing the components which would be broken

down in the small intestine. The remaining fibre components represent the fraction that reaches the large intestine. After the enzymatic treatment the sample consists of soluble and insoluble fractions of DF. Gravimetry is used after enzymatic treatment to weigh the remaining material. This provides a quantitative analysis of the DF content. This method is a recognized standard in nutritional analysis.

Beta-carotene was determined with HPLC-UV detection according to a standard operating procedure. The limit for beta-carotene was 0.05 mg/kg. HPLC was used to determine which substances were present in the sample and in what quantities. A standard procedure for HPLC includes extraction of the sample where it is mixed with an organic sample, then centrifuged and filtered before HPLC analysis (Berg et al, 2019). Organic molecules absorb UV light at specific wavelengths and can thereby be measured using a standard curve with specified concentrations. Beta-carotene has a strong UV/Vis absorption which makes it suitable for UV detection (Popescu et al, 2022). In a classic HPLC, a detector that monitors the absorbance of the eluate at a particular wavelength is placed directly after the column (Berg et al, 2019).

The other nutrients were detected with internal methods employed by ALS laboratory and measurements performed with gravimetry and NMR.

A pH measurement of the fermented carrots with Ärtonnaise was conducted at Torsåker.

3.1.2 Method for Isolating the Nutritional Value of Carrots in the Fermented Carrots with Ärtonnaise

The nutritional values for 100 grams of raw carrot were obtained from a report published by the Swedish Food Agency and used as a reference for comparison with the analysed fermented carrots with Ärtonnaise.

Since the aim was to compare raw carrots with fermented carrots it was necessary to exclude the other ingredients from the analysis, as the finished product did not consist solely of carrots. To enable a comparison between the nutrient content of the fermented carrots with Ärtonnaise and that of raw carrots, calculations were performed to determine the proportion of the final product that consisted of carrots. When receiving the recipe, the amount of each ingredient was converted to grams to simplify when calculating the amount of carrot in relation to the other ingredients.

The following calculation was used to determine the proportion of carrots in the fermented carrots with Ärtonnaise:

*Equation 1: 1000g (carrot) / 3020g (total product) = 0.33 * 100 = 33%.*

The laboratory results for beta-carotene and DF content were divided respectively by the proportion of carrots in the fermented carrots with Ärtonnaise (33%). Contribution of beta-carotene and DF from other ingredients were assumed to be low and thereby not accounted for.

Equation 2. Beta-carotene: 3160 / 0.33 = 9576 µg/100g.

Equation 3. Total fibre: 2.7 / 0.33 = 8.2g / 100g.

The results from the calculations enabled a comparison between the nutrient content of raw carrots and the fermented carrots within the fermented carrots with Ärtonnaise.

Finally, the results from beta-carotene as retinol equivalents and DF were compared against the values required to make nutritional claims.

3.2 LCA Method

The LCA commenced with the definition of the aim and scope including functional unit and system boundary. The system boundary included stages from cultivation to the finished product (fermented carrots with Ärtonnaise). Emission factors were determined for each input covering the impact in terms of carbon dioxide equivalents (CO_2e).

A flowchart was developed (Figure 1) to provide a visual overview of the life cycle stages of carrots included within the system boundary. The diagram also identified where potential waste could occur. Waste during cultivation, after harvest, and during sorting/packaging was included. To quantify resource use and emissions during cultivation (e.g. soil, water, fertilizers and chemicals), data was sourced from a report published by the Swedish Environmental Institute. To evaluate the waste from the production chain, data was obtained from a report by Jordbruksverket. According to the report losses after harvest accounted for 26%, and additional 26% of losses occurred during sorting and packaging.

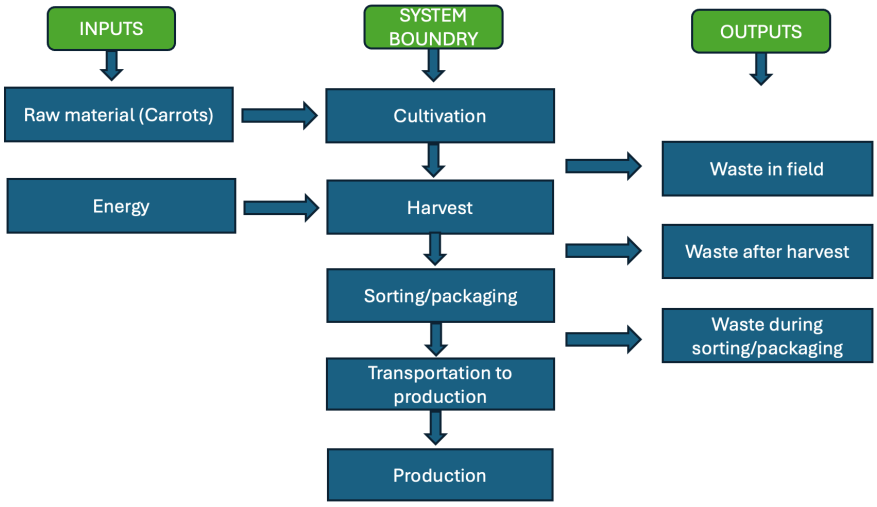

Figure 1. Flowchart of the parameters included in the LCA.

Thereafter, a literature review was conducted to identify suitable data sources used for the remaining ingredients included in the fermented carrots with Ärtonnaise. The carbon footprint data (CO_2e/kg) for these ingredients was obtained from the RISE climate database, CarbonCloud and the Swedish Environmental Institute. The kg CO_2e/kg values for mustard seeds, salt and Ärtonnaise were obtained from CarbonCloud using the same LCA methodology across the ingredients. The system boundary applied for these ingredients was from cradle to stage of delivery and included mechanisms regarding packaging, transportation and distribution, food processing and agricultural mechanisms. The kg CO_2e/kg from onion and sugar, obtained from the Swedish Environmental Institute using the same LCA methodology as for the carrots, excluded the updated values for waste and transportation.

The carrots used for the fermented carrots with Ärtonnaise were transported from cultivation sites in Skåne, a region where Sweden's largest carrot producers are located (Från Sverige, 2025). To estimate an approximate distance from cultivation to production, Löddeköpinge was used as the location for cultivation. Once the fermented carrots with Ärtonnaise are brought to market, production will take place in Hässleholm. That makes the distance approximately 90 kilometres from cultivation to production (Google maps, 2025). To estimate the diesel consumption during transportation from the carrot cultivation sites to the production facility Transportmeasures were applied. An interview with a representative at Swerock was also conducted to obtain approximate shipment weights and information on the type of truck typically used for transporting carrots.

Regarding packaging, the fermented carrots with Ärtonnaise were stored in jars during the fermentation process and thereafter sealed using vacuum packaging. Since the fermentation process did not include heating, cooling or any other process that requires a lot of energy, the amount of energy used for the fermentation was not considered. Additionally, the fermented carrots were stored at room temperature, which means that energy needed for refrigeration has not been included. It is only when the fermented carrots are combined with the Ärtonnaise that the product requires cool storage.

Once all relevant data had been obtained, life cycle calculations were performed using Excel. The Excel template provided by the Swedish Environmental Institute was used to input the data and perform the calculation. After receiving the kg CO_2e/kg for the carrot, the other ingredients were added to the value to get the final CO_2e/kg for the fermented carrots with Ärtonnaise. To obtain a correct value referring to the functional unit, the recipe was recalculated to corresponded to one kilogram of the fermented carrots with Ärtonnaise.

The final calculated value was subsequently evaluated and discussed to determine whether it constituted a scientifically valid result. This included a comparison with similar products on the market. A sensitivity assessment was also conducted to identify the limitation of the analysis and to evaluate the consistency of the results.

4. Previous Studies and Hypothesis

There is limited research regarding how specifically beta-carotene and DF in carrots are affected by fermentation. Previous studies have investigated other raw materials to evaluate how beta-carotene and DF are affected by fermentation and other processing treatments. Nevertheless, such studies may be useful for comparing how beta-carotene and DF are affected by fermentation of the fermented carrots with Ärtonnaise analysed in this thesis.

4.1 Previous Studies on Beta-carotene

In a previous study, alfalfa has been used to observe how beta-carotene changes during the fermentation process. The result indicated that certain lactobacilli had the potential for beta-carotene production demonstrating that some lactobacillus species have the capacity to biosynthesize beta-carotene. The beta-carotene concentration decreased during the first few days, followed by an increase. With more days of fermentation, the beta-carotene content increased due to the interaction between the bacteria in the middle and late phase of fermentation. High pH and high propionic acid content were unfavourable factors in terms of preserving beta-carotene in fermented alfalfa. This indicates that fermentation with specific bacteria and additives may improve the beta-carotene content of products. However, beta-carotene in vegetables is sensitive to oxidation, which results in apparently lower beta-carotene content in conserved materials compared to fresh materials (Zong et al, 2023). Fermentation is an anaerobic process; therefore, the risk of oxidation is unlikely to represent a significant issue within the context of this thesis.

Another study confirming the hypothesis regarding the increase in bioavailability of beta-carotene after fermentation has been done with tomatoes and carotenoid content. It showed that treatment with LAB breaks down the tomato cell matrix and makes the carotenoids, including beta-carotene more available, resulting in higher levels of total carotenoids. (Xu et al, 2020).

Similar outcomes may potentially be observed in the fermented carrots sample. The carrot cell wall is composed of pectin, cellulose, lignin, and hemicellulose. Carrots have tough cellular walls which means that the body can convert less than 25% of their beta-carotene into vitamin A. However, cooking and treatment partially dissolves the cellulose-thickened cell walls, releasing nutrients by breaking down the cell membranes (Sharma et al, 2011). A hypothesis would therefore be that if the bioavailability of beta-carotene is found to be higher in the

fermented carrots with Ärtonnaise analysed in this study, fermentation may have facilitated modifications of the cell walls of carrots.

During fermentation, the components of the original food matrix are converted into a range of new metabolites by the activity of endogenous and microbial enzymes. Many bioactive compounds which are present at low concentrations in unfermented material are increasing their concentration during fermentation because of the action of the microorganisms. Fermentation of vegetables generally improves the bioavailability of micronutrients, including beta-carotene (Xu et al, 2020).

Blanching caused a decrease in beta-carotene content because of thermal degradation. A compelling loss of beta-carotene was also observed after drying. Samples that were subjected to lower drying temperatures indicated higher loss of beta-carotene content. This might be due to the longer drying time required to get the product to the desired final moisture content (Chantaro, 2008). Fermentation may therefore be a good alternative since it does not involve high temperatures or drying that might affect the beta-carotene in a negative way.

Previous studies analysing the effect of fermentation of vegetables where carrots were included indicated slightly different changes in the case of beta-carotene. The bioavailability decreased in comparison with the unprocessed raw material in some of the fermented vegetables samples analysed. However, the fermented carrots had a higher level of beta-carotene (increase of 30%) (Kiczorowski, 2022).

Variable effects of fermentation of vegetables on the level of these compounds have been reported. Fermentation of Chinese cabbage has shown the ability to induce an apparent increase in the content of beta-carotene after two weeks of storage. A noticeable increase in the content of beta-carotene ranging from 30% to 40% was observed. These results could be explained by the enhanced release of beta-carotene from the cell matrix of the carrots during processing and even storage. Furthermore, fermentation increased the beta-carotene content in carrots. This highlights that changes in the bioavailability of beta-carotene during fermentation are greatly variable and depend on the plant material and fermentation conditions. Both losses and an increase might occur depending on the raw material and bacteria occurring naturally in fermented vegetables. (Kiczorowski, 2022).

Another study further confirmed that fermentation induced changes in beta-carotene were found to depend on substrate and fermentation conditions. For

instance, spontaneous fermentation reduced beta-carotene levels in broccoli, cucumber, and pepper but promoted their concentrations in carrot and beetroot (Wei et al, 2025).

Carotenoids exist in the trans configuration in nature making them more stable. Still, the cis isomers might be present and may increase during different cooking methods or industrial processing. The difference between the two isomers is of considerable importance from a nutritional point of view as the cis configuration indicates less efficiency. This, in turn, may lead to a reduction in the activity of vitamin A. The study presented by Sergio et al demonstrated that both cooking time and temperature are important aspects for carotenoid degradation. Less cooking time and lower temperatures are crucial to avoid greater losses (Rodrigues et al, 1998). These findings further support the hypothesis that fermentation may serve as a viable alternative to treat carrots to keep and increase nutrient bioavailability. Different kinds of treatment such as cooking, pureeing and chopping might result in smaller particle size and plant cell disruption, contributing to carotenoids becoming more available in the intestinal lumen for absorption (Sergio et al, 2013).

Cis isomers of carotenes are more polar, less prone to crystallization and have higher solubility compared to trans isomers. Therefore, they are more easily absorbed and transported into cellular compartments. However, cis isomers are less potent as vitamin A precursors (Telegina et al, 2023).

The increase in beta-carotene in fermented plants might be connected to structural changes induced by fermentation that may increase the ability to extract carotenoids. Reports have also indicated losses of carotene during the fermentation process of vegetables. Authors have asserted that LAB preserves beta-carotene more easily compared to other technologies of food processing like blanching, drying or steaming. Fermentation leads to a decrease in water content in plant tissues. This, in turn, contributes to an increase in bioavailability of nutrients, except for energy and crude fat (Kiczorowski, 2022).

As mentioned above, the bioavailability of beta-carotene is affected by multiple variables, including the properties of the food source, its interactions with other components in the diet and the individual characteristics of the subjects involved. The uptake and absorption of carotenoids can also be influenced by the carotenoid’s location within the plant, e.g. if it's part of the pigment-protein complexes in chloroplasts or in a crystalline form in chromoplasts (Rock et al, 1998).

The beta-carotene in carrots is in the form of crystals in chromoplasts. Studies have shown that carrot beta-carotene crystals in chromoplasts are more easily released during digestion in the gastrointestinal tract than e.g. spinach beta-carotene found in chloroplasts. By observing if carrots are effective sources to vitamin A, the conversion has been studied. A carrot beta-carotene to vitamin A conversion factor of 15 to 1.50 g carrots that contain 3.2 mg beta-carotene would provide about 200 µg retinol, which is a significant amount for a relatively small amount of carrot (Tang et al, 2005).

The structure of the cell wall and the interactions inside the polysaccharide network might regulate the extent to which it acts as a barrier to the release of carotenoids from inside cells. Results from a previous study indicated that the properties of the barrier cell wall polysaccharide network in carrots can be impaired by thermal processing and thereby affect the carotenoid bio accessibility (Ribas-Agusti et al, 2014).

According to findings from previous studies, the beta-carotene bioavailability and detection of beta-carotene is likely to be higher in fermented carrots compared to raw, unfermented carrots.

4.2 Previous Studies on Fibre

Regarding how the fibre content gets affected by LAB fermentation, there are limited studies that evaluate the effects of fermentation on fibre content in carrots specifically. A previous study has been done with a food waste mixture where the effects of LAB on physical and chemical properties of the mixture were determined. The result indicated an increase in fibre during non-anaerobic storage and anaerobic results showed that LAB inoculants induced compelling breakdown of fibre into soluble carbohydrate (Yang et al, 2006). The food waste mixture in the study mentioned used heat-treated waste, which might affect the fibre in another way compared to the fermented carrots with Ärtonnaise analysed in this study.

Another study analysed beans and the effect of LAB fermentation on total DF, IDF and SDF fractions, respectively. The different processing treatments resulted in a significant reduction in the SDF content, while no notable changes were observed in the IDF content of the processed beans. The activity of microorganisms played a key role in the varying degradation of the bean cell wall, breaking down the protein-carbohydrate interaction and thereby decreasing the solubility of DF (Martin-Cabrejas et al, 2004).

It is referred to the synergistic effect of the combination of LAB and cellulase on fermentation because cellulase was able to break down DF to supply sugars to LAB (Zong et al, 2023). The synergistic effect derives from two agents that together can produce an effect greater than the sum of their individual effects (Liu et al, 2017).

It is hypothesized that changes in pectin are the primary cause of the variations in beta-carotene bioavailability since it is a cause of cell wall degradation. More research is required to confirm this hypothesis and investigate novel processing technologies that could better balance texture and nutritional value (Lemmens et al, 2009).

Another study indicated a decrease in pectin fraction in the vegetable cell wall during fermentation. The reduction of pectin fraction in the cell wall led to enhanced binding capacity of cell wall material of vegetables after lactic acid fermentation, when fermented 24 hours or more. The loss of pectin during fermentation in the vegetable pomace from the study mentioned promotes the exposure of binding sites (Duan et al, 2025). This could be a possible explanation for the results obtained in this thesis. If the bioavailability of beta-carotene is higher in fermented carrots compared to non-fermented, this may be attributed to a reduction in pectin content, which contributes to the release of other compounds.

During storage, ripening and processing, tissue firmness decreases in the plant cell wall. Studies on processed carrots have indicated that different kinds of heat treatments give rise to changes in pectin solubility, size and charge density (Greve et al, 1994).

Fermentation of wheat bran leads to production of SDF, where different strains drive varying effects on the improvement of DF. A previous study indicated that *E.cristantum* (probiotic fungus) (Lu et al, 2022) fermentation increased the SDF to IDF ratio from 6.59% to 16.74% in wheat bran. This is due to xylanase release during fermentation, which causes hydrolysis of hemicellulose into monosaccharides and oligosaccharides by destroying ester bonds (Fan et al, 2024).

A study has been done on pectin degrading bacteria on the quality of cigar fermentation. Throughout fermentation, pectin and cellulose in the tobacco leaves are degraded which give rise to changes in the leaf tissue structure. The fermentation process also helps to break down pectin into different molecular compounds with low weight (Su et al, 2024). Since carrots are rich in DF like

pectin and cellulose, the same process is presumed to occur in the fermented carrots analysed in this thesis as in the tobacco leaves.

The integrity of the plant cell wall is crucial for the physical properties and action of DF. Treatments like LAB fermentation might adjust the structure of both cell wall and storage polysaccharides by altering the integrity of tissue structure and disrupting the protein-carbohydrate interactions through microbial activity and thereby decreasing the solubility of DF (Martin-Cabrejas et al, 2004).

A previous study investigated how different fermentation affects the cell wall degradation of pectin in wheat bran. A solid fermentation was made with LAB and incubated at 37°C for 36 hours. The results indicated that SDF increased (Fan et al, 2024). Pectin is a partially SDF and is the main DF in carrot cell walls. Therefore, it would be reasonable to assume that the proportion of SDF in carrots increases following fermentation.

A study has been made with carrot juice and how fermentation with *Lactobacillus gasseri* affects its nutrient content. The study highlighted that lactobacillus strains synthesized fructosyltransferase enzymes during fermentation which further led to conversion of simple sugars primarily into polysaccharides. A significant increase in total polysaccharide content was observed with an expansion from 25% to 77% (Xu et al, 2020). This strengthens the hypothesis that an increase in the DF content in the fermented carrots with Ärtonnaise analysed in this thesis may be observed.

Most of the studies reviewed investigate how nutrients are affected by various thermal processing methods including heat treatment, drying, and blanching. How fermentation affects the concentration and bioavailability of nutrients is an area with limited data. In summary, it can be concluded that if the bioavailability of beta-carotene and fibre increases, it is most likely due to the fermentation process creating changes in the cell wall, leading to a release of nutrients.

It is important to have in mind that the fermented carrots with Ärtonnaise contains fat from the Ärtonnaise. This could explain the results that differ from the hypothesis and previous studies since fat is a factor that can affect the bioavailability of food carotenoids and the bioconversion of beta-carotene to vitamin A (Tang et al, 2005).

5. Result

The following chapter presents the findings of the study, including both the nutritional aspects of the fermented carrots with Ärtonnaise and environmental impact of their production. The primary nutritional results focus on the beta-carotene and DF (SDF and IDF) content. These are complemented by an extensive overview of the total nutrient composition of the product. To be able to compare the nutrient content in the fermented carrots with Ärtonnaise, to raw, unprocessed carrots, a table with nutrient content in raw carrots is also presented.

In addition to the nutritional analysis, this chapter also includes the result of the LCA made on the fermented carrots with Ärtonnaise. The result of the LCA is presented in kg CO_2e/kg, showing the carbon dioxide footprint.

5.1 Nutrient Content

The laboratory results provided insights into the nutrient content of the fermented carrots with Ärtonnaise. Table 2 shows the total nutrient content, Table 1 displays the content of beta-carotene and fibre content, both soluble and insoluble fractions in the fermented carrots with Ärtonnaise.

The measurement uncertainty for each parameter is given as ± an uncertainty value, based on a coverage factor (k) of 2. This indicates that the uncertainty intervals correspond to a 95% confidence interval, which in statistical terms means that the true value is expected to lie within the given interval with 95% probability. Due to absence of further clarification from the laboratory regarding information about the MU, the reported values should be interpreted with caution.

Table 1. Soluble, insoluble, and total fibre content (g/100g) in the fermented carrots with Ärtonnaise. Beta-carotene content (µg/100g) in the fermented carrots with Ärtonnaise.

Parameter	Concentration
Fibre, soluble	1.7
Fibre, insoluble	1.0
Total fibre	2.7
Beta-carotene	3160

Table 2. Nutrient content (g/100g) in fermented carrots with Ärtonnaise including MU. Values for MU were received from the laboratory.

Parameter	Concentration	MU	LOR
Energy (kJ/100g)	1200	± 84	50
Energy (kcal/100g)	288	± 20	12
Fat	27.9	± 1.4	0.10
Carbohydrate	9.00	± 0.63	0.30
Protein	1.13	± 0.056	0.060
Water	60.0	± 0.60	0.10
Ash	1.90	± 0.057	0.060

Table 3. Nutrient content (g/100g) in raw carrot with values obtained from a report published by Swedish Food Agency (Pearson et al, 2013).

Parameter	Concentration
Energy (kJ/100g)	146
Energy (kcal/100g)	35
Carbohydrate	6.3
Protein	0.7
Water	89.9
Ash	0.6
Fibre	2.3
Soluble fibre	0.8
Insoluble fibre	1.5
Beta-carotene (µg/100g)	9220

By applying the calculation methodology described in the method section, the content of beta-carotene and fibre from the fermented carrots was obtained. When comparing the nutrient values of raw carrot with those of the fermented carrots in the fermented carrots with Ärtonnaise (Table 4), it can be observed that both the beta-carotene and fibre content have increased.

Table 4. Comparison between the carrots in the fermented carrots with Ärtonnaise and raw carrots in relation to beta-carotene (µg/100g) and fibre (g/100g) (soluble and insoluble).

Parameter	Concentration (Raw)	Concentration (fermented carrots)
Beta-carotene	9220	9576
Total fibre	2.3	8.2
Soluble fibre	0.8	5.2
Insoluble fibre	1.5	3.0

The pH analysis of the fermented carrots with Ärtonnaise showed a value of 3.6, which is considered low.

5.2 LCA

After completing the steps for LCA described in the method, a final value was obtained. Given the complexity and variability in LCA methodologies, the climate values associated with the fermented carrots with Ärtonnaise should be regarded as approximate estimates of climate impact. The climate values for a specific food item can vary between different producers based on growing conditions, production methods etc. Access to representative LCA analyses varies between the different ingredients, hence affecting the quality of the climate value for the fermented carrots with Ärtonnaise.

Result of the carbon dioxide footprint of the product: 1.4 kg CO_2e/kg.

6. Nutritional Claims and Requirements

To set a nutrient claim for a food product, specific and strongly regulated requirements must be followed and considered. This is to ensure a safe and reliable product for the consumer.

Claims about nutrition and health should be based on generally accepted scientific facts about the relationship between dietary habits and health. When establishing nutritional profiles, the content of various nutrients and substances with a nutritional or physiological effect (fat, sugars, vitamins, minerals, dietary fibres) should be considered (EG nr 1924/2006).

The substance to which the claim refers must be present in the final product in sufficient quantities to ensure that the claim is scientifically valid and compliant with regulatory standards. Additionally, the body must be able to absorb or utilize the substance, and if needed, a significant amount of the substance that will produce the claimed nutritional or physiological effect must be obtainable from such an amount of the food that will reasonably be consumed (EG nr 1924/2006).

The recommended daily intake of vitamin A varies depending on age and gender. The human body can store vitamin A as retinyl esters. The stored amount of vitamin A can be used by the body at later stages if intake of vitamin A is insufficient. It is only if the diet does not cover the daily requirements the body uses the stored vitamin A. With a balanced diet, vitamin A deficiency is rare (Livsmedelsverket, 2023).

A large intake of preformed vitamin A may lead to acute and chronic toxicity. The condition defined by exalted levels of vitamin A in the body is referred to as hypervitaminosis A. It is relatively rare to get hypervitaminosis and it usually derives from large intake of supplements or medication. The main cause of toxicity is the consumption of significant quantities of vitamin A through dietary supplements. The absorption of provitamin A can vary and be regulated by feedback mechanisms, therefore it is unlikely to cause toxicity even at high intake (Olson et al, 2023).

The UL (tolerable upper intake level) for adults is 3 000 µg/day of preformed vitamin A (EFSA, 2024). For women within the age group 18 to 70 the RDI is 700 µg retinol equivalents/day and for men 800 µg retinol equivalents/day (Livsmedelsverket).

For vitamins, as a rule, the following values should be considered when deciding what constitutes a significant amount: 15% of the reference value for the nutrient content per 100 g. The reference value for vitamin A is 800 µg.

Table 5. Nutrient requirement regarding fibre content.

Nutrient claims for high fibre content	Terms of use	Comments
Dietary fibre source	➢ 3 g/100g	
High dietary fibre content	➢ 6 g/100 g	Twice as much as the "source of"

Table 6. Nutrient requirement regarding vitamins.

Nutrient claims for high content of vitamins	Terms of use
Source of vitamin A	➢ Significant amount
High content of vitamin A	➢ Twice as much as significant amount

7. Discussion

7.1 Nutrient Content

Previous research on the effect of fermentation has reported both increases and decreases in beta-carotene and fibre content. However, most of the studies suggest that an increase in both detected beta-carotene and fibre is the more likely outcome. By evaluating the results from the laboratory, the data indicated an increase of beta-carotene content from 9220 µg to 9575 µg corresponding to an increase of approximately 3.85 %. The fibre content exhibited an increase from 2.3 g/100g to 8.2. g/100g. The observed increase in detected fibre is notably high, therefore the result should be interpreted with caution. The result may be influenced by the analytical method used, interactions with the other ingredients, as well as the concentration applied. Since the carrot cell wall is composed of pectin, cellulose, lignin and hemicellulose, the increase in both fibre and beta-carotene may be due to changes in these fibres. This will be further discussed in the following section.

Since the fermented carrots contains Ärtonnaise, which increases the fat content of the product and exerts a dilution effect, the nutrient content may be affected, and this must be taken into consideration when comparing with raw carrots.

The measured pH-value is expected, as carrots are classified as low acid vegetables and therefore can facilitate the activity of acid producing microorganisms which are capable of naturally reaching and sustaining a pH below 4.6 without the addition of acid.

Salt facilitates membrane degradation during fermentation as mentioned by Perez-Dias et al., 2013 and thereby enhances the release of intracellular components. Therefore, it is reasonable to hypothesize that the observed increase in detected beta-carotene may also be attributed to the effect of salt.

7.1.1 Beta-carotene Content

Previous research suggests that the increase of beta-carotene may be attributed to various processes caused by fermentation. LAB are known to synthesize carotenoids as a protective mechanism to prevent oxidative stress (Xu et al, 2020).

Beta-carotene in vegetables is sensitive to oxidation, which makes it favourable to use an anaerobic process such as that employed in this fermentation process.

As noted in the section reviewing previous research, carrots have tough cellular walls making beta-carotene less available. Carrot cell wall contains beta-carotene, and the breakdown of these cell wall membranes facilitates the release of nutrients making more beta-carotene available for detection. Therefore, the results regarding beta-carotene are expected.

The increase of beta-carotene depends on the raw material, fermentation conditions and bacteria occurring naturally in raw carrots. The increase observed following the analytical assessment may be attributed to the activity of microorganisms. LAB break down cell matrix, making beta-carotene more available and easier to detect. Some lactobacilli can biosynthesize beta-carotene by interactions between bacteria in the middle and late stages of fermentation. The lactobacilli active in the fermented carrots with Ärtonnaise are unknown. The reason for the increased detection of beta-carotene may be attributed to the interactions between the bacteria contributing to biosynthesis of beta-carotene.

A decrease in beta-carotene content was observed in previous studies when different thermal processing methods were used such as drying and blanching. As previously discussed, beta-carotene is sensitive to oxidation. During different kinds of thermal processing, oxygen can interact with beta-carotene causing oxidative damage and reduce the amount of intact beta-carotene. Based on the results obtained, fermentation appears to represent a valuable contribution to enhance or preserve the beta-carotene content since low temperature is crucial to prevent greater losses. Thermal processing is often used to preserve foods but with the risk of losing important nutrients (Dutta et al, 2006). Fermentation also acts as a preserving method but with the possibility of preserving and simultaneously increase the bioavailability of nutrients like beta-carotene. The fermentation also prevents loss through leaching. Boiling and blanching can cause leaching of water-soluble nutrients. Despite beta-carotene being a fat-soluble vitamin, leaching might still occur in the food matrix.

The pH is a critical parameter, as high pH levels are not favourable for preserving beta-carotene. The pH level measured in the fermented carrots with Ärtonnaise was 3.6, indicating a low-acid environment favourable for preserving beta-carotene. The increase in detected beta-carotene may, therefore, be attributed to the low pH environment which supports the preservation of beta-carotene.

Another aspect worth discussing is the isomer configuration. Cis isomers increase during different cooking times and methods making the isomers less stable. Different isomers have different retention times due to their variation in shape and polarities. As a result, they can be separated and detected easily. Cis isomers are less stable which mean that they degrade more easily and therefore induce losses of beta-carotene during certain thermal treatments. How fermentation affects the trans- and cis configuration remains undetermined. However, fermentation may affect isomer configuration and facilitate a transformation from trans configuration to cis isomers.

Since interactions with fatty acids can enhance the stability of cis isomers, the fat from the Ärtonnaise in the product studied may interact with the isomers. A possible reason for the increased detection of beta-carotene could be that the fermentation has caused the formation of cis isomers that are more polar, less prone to crystallization and have higher solubility compared to trans isomers. The cis isomers degrade more easily, which contributes to a loss in beta-carotene. However, since fatty acids can help to promote the stability of the cis isomers, it is possible that the presence of fatty acids are advantageous for preserving the cis isomers. Further, this makes the soluble cis isomers of beta-carotene easier to detect, thereby contributing to the increase observed in the analytical results.

The increase in beta-carotene content may also be due to its solubility in the fat coming from the Ärtonnaise. Beta-carotene is a fat-soluble compound which means that it is better absorbed and more bioavailable when consumed together with fat. The fat in the Ärtonnaise could potentially help to dissolve and enhance the absorption of beta-carotene from the carrots. When dissolving into the fat the beta-carotene may be easier to detect, hence the increased concentrations detected in the analysis.

When comparing the results with the values for nutritional claims and regulatory requirements, it can be observed that the fermented carrots with Ärtonnaise meet the criteria to be classified as a source of vitamin A. “Contains vitamin A or “rich in beta-carotene” could therefore be written on the product label. Since beta-carotene cannot be synthesised by the body and must be ingested through the diet, the fermented carrots with Ärtonnaise could be a favourable way to include beta-carotene in the diet.

7.1.2 Fibre Content

A large increase in DF content was observed. The SDF content is higher compared to the IDF content. This result is anticipated given pectin, which is the primary dietary fibre in carrot, is a partially soluble fibre. It is therefore not surprising that the detected SDF content is higher compared to the detected IDF content.

The fermented carrots with Ärtonnaise analysed in this thesis have undergone an anaerobic process. Anaerobic conditions from a previous study indicated that LAB inoculants induced breakdown of fibre into soluble carbohydrates. The synergistic effect gives rise to breakdown of fibre to supply sugars to LAB by cellulase intrudes with LAB. LAB can degrade cellulose to monosaccharides or oligosaccharides (Zhao et al, 2021).

Smaller molecules like simple sugars or short-chain oligosaccharides have lower molecular weight compared to larger molecules like cellulose which is a long-chain polysaccharide. The smaller molecules have fewer intramolecular hydrogen bonds making them easier to disperse in water. As previously mentioned in this thesis, cellulose forms tight crystalline structures and has strong internal hydrogen bonding between chains. When LAB hydrolyses cellulose, it helps to degrade cellulose to smaller molecules and therefore gives rise to the result obtained in this report.

Fermentation weakens cell wall structure, contributing to more soluble polysaccharides being released into the matrix. The acidic environment created by microbial metabolism may further solubilize pectin and hemicellulose promoting detection of SDF. Fermentation facilitates the breakdown of pectin into different molecular compounds and LAB adjusts the structure of both cell wall and storage polysaccharides by altering the integrity of tissue structure as well as disrupting protein-carbohydrate interactions. Transformation of plant substrates during fermentation promotes short chain polysaccharides which are easier to detect.

If the fermentation microbes produce fructosyltransferase, some sucrose in the carrot could have been converted into fructooligosaccharides (FOS). FOS are short chain soluble fibres, hence the increase in the fibre content. FOS can be synthetized from sucrose by the action of enzymes like fructosyltransferase or beta-fructofuranosidase. Synthesis of FOS within the matrix comprise enzymatic conversion of sucrose present in food matrix into FOS (Guerra et al, 2023). Carrots contain natural sucrose, therefore a spontaneous conversion into FOS by microbial enzymes produced during fermentation is biochemically achievable. To confirm this hypothesis, further biochemical or microbiological analysis is

required. The fermentation was spontaneous, meaning that no starter culture was added. This can contribute to a variation in the results depending on which strains grow during the process. Since the specific LAB strains were unknown in this analysis, it cannot be concluded that the fermented carrots with Ärtonnaise contains the strains that produce fructosyltransferase.

This could be of significant interest for further research, as sucrose may potentially be converted instead of utilised.

In the calculations it is assumed that all the DF content originates from the carrots. The DF content is derived not only from the carrots but also from the onions. Carrots contain a higher DF content compared to onions, 2.3 g/100g compared to 1.9 g/100g (Pearson et al, 2013). As the fermented carrots with Ärtonnaise contain a significantly higher number of carrots compared to onions, it is reasonable to assume that the carrots are the primary contributors to the DF content. It should also be noted that a minor proportion of the DF content can be attributed to the onion.

When comparing the results with the values regarding nutritional claims and regulatory requirements it can be observed that the fermented carrots with Ärtonnaise do not meet the criteria to claim as a source of fibre. The requirement for making a claim regarding a source of fibre is 3 g/100g. The value for fermented carrots with Ärtonnaise (2.7 g/100g) falls just below the requirement.

7.1.3 Limitations of the Study and Reflections for Future Research

To gain an a more comprehensive understanding of how beta-carotene and DF are influenced by the fermentation process, further studies are required. For future research on the fermented carrots with Ärtonnaise, it would be valuable to analyse and compare the nutrient content of fermented carrots, without the addition of Ärtonnaise or other ingredients with that of raw carrots. In this case the Ärtonnaise has likely influenced the analytical results, thereby limiting the ability to draw definite conclusion about the specific effects of fermentation on the nutrient content of the carrots.

The exact lactobacilli present during the fermentation remains unidentified. For future studies, it would be of interest to analyse the specific lactobacilli active during the fermentation process as previous research indicates that different lactobacilli act differently on the preservation of beta-carotene. Since the characteristics of LAB are influenced by the quality of the vegetables, and carrots

are sensitive to biotic and abiotic stress, which can affect the nutritional content, this must also be considered when interpreting the results.

One limitation of this study is the absence of detailed documentation regarding the analytical methodologies employed by the laboratory. Another noteworthy aspect of this study is the method applied for detection of DF and beta-carotene. The use of different analytical methods can result in varying results leading to incorrect interpretations. Most of the previous studies used in this thesis used HPLC for detection of beta-carotene. There are several different kinds of HPLC, which can yield different results depending on the target compounds and the objectives of the analysis. Variations in raw material can also affect the results in different studies. Similar concerns apply to the detection of DF where the choice of analytical method is critical to the reliability of the result obtained.

The MU reported for the energy content is considerably higher than what is generally expected for this type of analysis. Usually, the MU for energy ranges between ±5-15 kJ/100g, depending on method and homogeneity of the product. Several factors may have influenced the results, reflecting potential issues related to calculation methodology, sample preparation and data reporting. Unfortunately, the analytical results from the analysis did not permit the determination of MU for beta-carotene and DF.

As only a single sample was analysed, it is difficult to draw definitive conclusions or validate the hypotheses regarding the effects of fermentation on beta-carotene and DF. The inclusion of additional samples would have strengthened the analytical robustness of the study. Further research is necessary to confirm the observed effects of fermentation on nutrient content.

7.2 LCA

The climate impact of the fermented carrots with Ärtonnaise, kg 1.4 CO_2e/kg, is a reasonable result. When comparing with similar products on the market, a product from Orkla Foods named *Boston Gurka* has a carbon footprint of 3.15 kg CO_2e/kg (CarbonCloud), and a plain vegan mayonnaise from Unilever has a carbon footprint of 2.17 kg CO_2e/kg (CarbonCloud). Both companies have applied the same LCA methodology as was used to determine the footprint value of the ingredients in the fermented carrots with Ärtonnaise and was sourced from CarbonCloud. This approach was advantageous to obtain a more reliable and comparable result. When comparing the LCA value for the fermented carrots with Ärtonnaise, it can be observed that the product from Axfoundation has a relatively low carbon footprint compared to similar products.

The LCA performed on the fermented carrots with Ärtonnaise involved assumptions regarding transportation distance and diesel usage. The energy input data was sourced from a previous study by the Swedish Environmental Institute (Moberg et al, 2019), which provided general values for energy use in carrot production. However, the energy sources can vary by region and cultivars. The transportation distances were estimated based on assumptions regarding where cultivation potentially could take place.

It is important to note that the LCA values obtained from RISE, CarbonCloud and the Swedish Environmental Institute are based on methodologies that are similar but not entirely identical. Each organization has included and excluded different parameters in their carbon footprint calculations. LCA includes a wide range of environmental aspects that can be evaluated. In this thesis, the scope has been limited to the carbon dioxide footprint.

The carbon footprint values from RISE and CarbonCloud have been calculated using different system boundaries and other parameters when calculating for the kg CO_2e/kg compared to the methodology used for the carrots. This aspect is important to consider when interpreting the results, as the carbon footprint value calculated for carrots may not be directly comparable to those of other ingredients in the fermented carrots with Ärtonnaise. Nevertheless, these values have been used in estimating the carbon footprint of the fermented carrots with Ärtonnaise. If the product had consisted solely of fermented carrots, without the Ärtonnaise, it would have been possible to obtain a more precise carbon footprint value.

These uncertainties and assumptions illustrate the potential sensitivity of the results. If transportation were the major contributor to the fermented carrots with Ärtonnaise carbon footprint, even minor changes in transportation choices could have a large impact on the total CO_2e relative to changes in other stages of the lifecycle. It is unknown whether the transportation has been climate compensated, that could influence the results. This analysis illustrates the need for more precise data on some of the input data as well as access to information regarding waste within the public sector.

Looking ahead, it would be of great interest to conduct a new LCA once the product is introduced to the market. At that stage, data on food waste in the public sector and packaging of the fermented carrots with Ärtonnaise could be incorporated in the evaluation.

8. Conclusion

This thesis has investigated the effects of fermentation on beta-carotene and fibre content in a product consisting of fermented, grated carrots blended with a vegan mayonnaise made with peas. Nutritional analysis confirmed an increase in detectable beta-carotene and fibre, aligning with the initial hypothesis and supporting previous research indicating that fermentation can enhance the bioavailability of various nutrients. The LCA provided a reasonable estimate of the carbon dioxide footprint associated with the fermented carrots with Ärtonnaise. However, this estimate should be interpreted with caution due to differences in methodology, including several assumptions and differences in the treatment of raw materials.

While the findings support many of the thesis initial hypotheses, various factors such as the quality of the carrots, the specific lactobacilli strains involved and the analytical methods employed, contributed to the observed results. Therefore, further research is required to evaluate and confirm the mechanisms by which fermentation affects nutrient content. In conclusion, this study contributes valuable insights into the nutritional and environmental aspects of fermented vegetable-based products and highlights the potential benefits of fermentation as a food processing technique.

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Popular Science Summary

This master thesis was conducted in collaboration with Axfoundation as part of their initiative *Blood and Turnip*. The aim of the study was to explore how lactic acid fermentation affects the nutritional content of a newly developed product consisting of fermented, grated carrots with a pea-based mayonnaise. The focus was on two key nutrients, beta-carotene (a precursor to vitamin A) and dietary fibre, and to see whether fermentation could increase the detected nutrient content. The samples were analysed by an external laboratory. Further, a life cycle assessment was carried out to estimate the climate impact of the fermented carrots with Ärtonnaise.

The results indicated increases in detected beta-carotene and fibre following fermentation. This supports previous research suggesting that fermentation can make certain nutrients more available to the human body. The climate analysis indicated that the product had a lower carbon footprint compared to similar alternatives on the market. However, the result depends on factors like raw material, quality of vegetables and production methods.

In conclusion, the study suggest that fermentation may improve the nutritional value of carrot-based foods. However, further research is required to comprehensively understand the impact of fermentation on nutrient bioavailability and to validate these findings under varying conditions.

Appendix 1

Table 7. Recipe of the fermented carrots with Ärtonnaise.

Carrots	1000 g
Onion	200 g
Mustard seeds	80 g
Water	100 g
Salt	30 g
Sugar	100 g
Ärtonnaise	1500 g

Appendix 2

Table 8. Kg CO_2e/kg for each ingredient.

Carrot	0.23 kg CO_2e/kg
Onion	0.24 kg CO_2e/kg
Mustard seeds	5.39 kg CO_2e/kg
Salt	0.22 kg CO_2e/kg
Sugar	1.45 kg CO_2e/kg
Ärtonnaise	2.07 kg CO_2e/kg

Appendix 3

Table 9. Corrected recipe to receive 1 kg of the fermented carrots with Ärtonnaise.

Carrot	1000 / 3020 * 1000 = 331 g
Onion	200 / 3020 * 1000 = 66 g
Mustard seeds	80 / 3020 * 1000 = 26.5 g
Salt	30 / 3020 * 1000 = 9.9 g
Sugar	100 / 3020 * 1000 = 33 g
Water	100 / 3020 * 1000 = 33 g
Ärtonnaise	1500 / 3020 * 1000 = 498 g

Appendix 4

Table 10. Calculations with recipe corresponding to functional unit and kg CO_2e/kg.

Carrot	0.33 kg * 0.23 kg CO_2e/kg = 0.08
Onion	0.066 kg * 0.24 kg CO_2e/kg = 0.02
Sugar	0.033 kg * 1.45 kg CO_2e/kg = 0.05
Mustard seeds	0.03 kg * 5.39 kg CO_2e/kg = 0.16
Salt	0.01 kg * 0.22 kg CO_2e/kg = 0.002
Ärtonnaise	0.5 kg * 2.07 kg CO_2e/kg = 1.04

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