

Consumers' Acceptance of Emerging Technologies for Reducing Phytates and Raffinose Family Oligosaccharides (RFOs) In Whole Legume Products: A Study of Chickpeas, Lentils, And Beans

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by

Chikaodiri David Uche

Master's Thesis in Food Systems

Faculty of Engineering (LTH), Lund University

Lund, Sweden

Supervisor:

Håkan Jönsson

Associate Professor, Division of Food and Pharma, Lund University

Examiner:

Claudia Lazarte

Associate Senior Lecturer, Division of Food and Pharma, Lund University

Department of Process and Life Science Engineering

Division of Food and Pharma

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Department of Process and Life Science Engineering
Faculty of Engineering LTH, Lund University
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Examiner: Claudia Lazar

POPULAR SCIENCE SUMMARY

As the number of people who are choosing to eat healthier and more sustainable diets is increasing, legumes like beans, lentils, and chickpeas are becoming more desired and important. They are rich in nutrients, affordable, and much better for the planet than meat. Despite their benefits, these legumes are still underused, mainly because they cause bloating, flatulence and have low mineral absorption. These challenges are caused by phytates and Raffinose family oligosaccharides (RFOs), which are both antinutrients.

To address these issues, food scientists are using emerging technologies to make legumes healthier and easier to digest by reducing the antinutrients. Technologies like high-pressure processing (HPP), Modern fermentation, ultrasound, Vacuum impregnation, and Pulse Electric Field (PEF) have shown potential in enhancing legume quality without compromising taste or nutrition.

This research focused on how consumers perceive these food processing methods and how open they are to accepting such innovations. By combining surveys and focus group discussions, this research examined people's awareness, attitudes, and expectations. The results showed that there is a very low awareness of antinutrients, and these emerging technologies used to mitigate them among highly educated people. Even though awareness was low, there was high acceptance of these technologies and willingness to try these enhanced legumes when the benefits were clearly explained to them.

Familiarity was important for the participants, as it shaped their acceptance. More participants trusted the technologies they were familiar with, for example, modern fermentation had the highest acceptance due to the knowledge of traditional fermentation methods. HPP, which is already used in juice production, ranked second, thus supporting the idea that recognition of familiar methods builds trust.

Participants expressed the need for clear, transparent, and simple labelling. Suggested captions included terms like "easier to digest" or "gentler on the stomach". Trust in food authorities also mattered, as many said they would feel more confident if institutions such as Livsmedelsverket (the Swedish Food Agency) endorsed the products. Also, participants linked better legumes with environmental benefits, expressing that if these products could encourage people to eat less meat, they would be motivated to try them.

Taste and cooking convenience were also important factors, with many participants suggesting that if these enhanced legumes had superior taste or cooked faster than the conventional legumes, they would be more likely to buy them too. All of these show that when new technologies are communicated effectively and also align with consumers' values and expectations, people would be willing to have them on their dinner tables. Consumers are not resistant to innovation; they want to make sure that these innovations are safe and healthy for them.

This research offers valuable insights to policymakers, researchers, and food manufacturers on how to ensure that food innovations are accepted by the public. With effective communication methods, transparency and benefit explanations, consumers are willing to make these legumes part of their regular eating routine while supporting both personal health and a more sustainable food system.

Abbreviations Of Words

HPP: High Pressure processing

PEF: Pulsed Electric field

VI: Vacuum impregnation

ANOVA: Analysis of Variance

g: gram

GHG: Greenhouse gas

LAB: *Lactic acid bacteria*

FDA: Food and Drug Agency

QR: Quick Response

Abstract

The global shift in the food system towards more sustainable diets has made legumes such as chickpeas, lentils and beans increasingly important due to their nutritional and environmental benefits. But despite these benefits that they offer, their consumption remains relatively low. A key reason for this, is the digestive discomfort they cause such as bloating and flatulence alongside reduced mineral absorption when consumed. These challenges are caused by antinutritional compounds in these legumes which are phytates and raffinose oligosaccharides (RFOs). Phytates interfere with mineral uptake while RFOs cause digestive discomfort.

Traditional methods such as soaking and germination have for years been to mitigate these issues. However, newer technologies which include High-Pressure Processing (HPP), Ultrasound, Pulsed Electric Field (PEF), Vacuum Impregnation, and modern fermentation techniques have presented more efficient alternatives that maintain and even improve the nutritional and sensory qualities of these legumes, while also being better for industrial applications.

In this study, how consumers perceive and accept these technologies were investigated using a mixed method approach that combined online survey (n=123) with focus group discussions. The findings from the study reveal a widespread lack of awareness about both anti-nutrients and emerging processing methods, even among highly educated individuals. Though when the benefits of these technologies were clearly explained, acceptance increased with 35.8% saying they will “definitely” try legumes processed by these technologies, and 48.3% saying they would “probably” try it. Among these technologies, modern fermentation and HPP were the most familiar and well received. Beans was also the most consumed legume among participants.

The main drivers for consumers’ adoption of these technologies included health benefits, food safety, environmental impact, improved taste, and also familiarity with technologies that are more known. Trust in scientific validation, simple and transparent labelling, and a premium price of not more than 30% also emerged as critical factors.

For emerging food technologies to succeed, it is important that consumers see how the innovation aligns with their needs and values. Other findings in this study also highlight the importance of bridging the gap between technological advancement and public understanding through targeted education, policy support and consumer focused communications.

This thesis contributes to the limited research on consumer engagement with emerging technologies. It also offers insights to researchers, food manufactures, public health advocates and policy makers with the aim to boost legume consumption and support innovations in the sustainable food sector.

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KEY WORDS

Antinutrients

Emerging technologies

Phytates

RFOs

Legumes

Consumer acceptance

1 Chapter 1

Introduction

1.1 Background and Importance of Legumes

Legumes have over the years been critical components of sustainable diets due to their high protein content (20- 40%), essential nutrients and low glycaemic index. They are also rich in fibre, improves serum lipid profiles and helps to improve cardiovascular health (Mudryj et al, 2014, Erbersdobler et al, 2017). Around the world, legumes serve as staple diets for billions, and especially in developing regions where animal protein may be scarce or unaffordable. For vegetarians and vegans, legumes serve as the primary protein source (Maphosa & Jideani, 2017). Not only are legumes nutritious for human consumption (Messina, 1999), but they also play a significant role in sustainable agriculture through nitrogen fixation, which can go a long way to reduce dependence on synthetic fertilizers and effectively reduce greenhouse gas (GHG) emission by becoming alternatives to animal meat proteins (Scheuermann et al.,2024; Watson et al.,2017).

There has also been a growing need for sustainable plant-based protein sources as with regards to the huge environmental challenges posed by animal sources (Willett et al.,2019) These calls for the transformation to healthy diets from a sustainable food system have made legumes valid options. That they can reduce environmental footprint while also maintaining human health makes them important crops. (Springmann et al., 2018).

Though these legumes are highly nutritious and important crops, their consumption has been low in high income countries including Sweden partly due to antinutritional factors like phytates and raffinose family oligosaccharides (RFOs) (Scheuermann et al.,2024). These compounds serve protective roles for plants but can have negative effects on humans. Phytates inhibit mineral absorption in humans and RFOs contribute greatly to stomach discomfort and flatulence that arises when they are consumed. These antinutrients components have created a significant barrier for the consumption of legumes (Marcos-Méndez et al., 2021; Elango et al., 2022)

For this study, beans, lentils and chickpeas have been selected because they are well consumed across diverse cultures, more familiar and also among the legumes with high phytates and RFOs contents, making them the best fit for the evaluation of consumers' acceptance of anti-nutrient reduction technologies (Hughes et al., 2022).

1.2 Problem Statement

With growing demand for plant-based food, there is a critical need for efficient, scalable, and nutrient-preserving technologies that address the limitations of legumes without altering their integrity or reducing their sensory quality. Even though the consumption of legumes is still low in Europe and Sweden, there is a drastic shift going on, as people are more open to trying plant-based food. Grimberg & Råberg (2024) reported that trends in food consumption within the EU and in Sweden show strong growth, up to 28%, for plant-based alternatives to meat.

Though legumes are nutrient dense foods, the issue of antinutrients still creates scepticisms among consumers despite global initiatives promoting the plant-based diets. The use of

emerging technologies like high pressure cooking, pulsed electric field, Ultrasound for the reduction of these antinutrients have demonstrated a higher antinutrient reduction when compared to conventional and traditional methods like soaking. (Martínez-Velasco et al., 2018; Das et al,2022). However, consumer acceptance of these technologies remains poorly understood, particularly regarding the trade-off between nutritional enhancement and the perceptions of “processed” foods.

This disconnect can be clearly seen in Scandinavian markets. Despite Sweden’s leadership role in sustainable food innovation, the consumption of legumes remains low. Rööf et al., (2020) reported a 12 g/day consumption of legumes in Sweden. Though this represents a slightly higher European consumption average which is 9.6 g/day, it is way less than the global consumption which is 21.1 g/day (European Union,2024). Preliminary studies suggest that Swedish consumers prioritize naturalness in food processing, creating potential resistance to novel technologies unless clearly communicated (Sörqvist et al., 2021). This tension between scientific advancement and consumer psychology forms the core challenges to be addressed in this research within Sweden, Europe and on a global scale.

1.3 Overall Objectives and Research Questions

To effectively understand how consumers feel about emerging processing technologies aimed at improving legume quality, it is essential to define clear research objectives and questions. Given the important role consumers play in the success of innovations, this study aims to investigate their perceptions, concerns, and willingness to adopt legume products processed with these methods. The research objectives and questions below provide a focused framework for examining these issues and identifying strategies to bridge the gap between food technology and public understanding.

Objectives:

- To assess consumer awareness and concerns regarding phytates and RFOs in legumes.
- To evaluate consumer perception and acceptance of emerging technologies for reducing these anti-nutrients.
- To identify barriers and drivers that influence consumer willingness to adopt these improved legume products.
- To provide recommendations for effectively marketing and communicating these innovations to consumers

Research Questions:

- What is the level of consumer awareness and concern about phytates and RFOs in legumes?
- How do consumers perceive traditional vs. modern processing methods for reducing these anti-nutrients?
- What factors influence consumer trust and acceptance of emerging food technologies in legume processing?

2 Chapter 2

Literature Review

For this research work, scholarly papers, peer reviewed articles and academic books were sourced from LUBsearch (Lund University's Library search engine), and Google Scholar. These academic tools ensured that only relevant and credible academic materials were used for this study. The table below shows some of the key phrases used for this study.

The other parts of this chapter offer more insight for this study. It describes what each component of the research is and then explains why this study is relevant. It follows a sequential pattern, starting with the antinutrients being studied; (phytates and RFOs), then brief explanations of traditional methods and emerging technologies for the reduction of these antinutrients, consumer acceptance and concludes with the knowledge gap

Table 2.1 *key phrases and sources of reference used for this study.*

Key search words	Database	Number of hits	Number of selected articles
antinutrients reduction with emerging technologies	Google scholar	17300	21
	Lubsearch (1990- 2025)		
Anti-nutritional factors in legumes	Google scholar	37700	28
	Lubsearch (1990- 2025)	455	
Consumer acceptance of emerging food technologies	Google scholar	911 000	14
	Lubsearch (1990- 2025)	471	

Traditional legume processing	Google scholar	137000	6
	Lubsearch (1990- 2025)	502	
Consumer perception & trust in food technologies	Google scholar	818000	22
	Lubsearch (1990- 2025)	775	

2.1 Anti-Nutritional Factors in Legumes: Phytates and RFOs

Phytate which otherwise is called phytic acid is a significant antinutrient factor in legumes such as beans, chickpeas and lentils. Phytate is the main form of phosphorus storage in legumes. It binds with other essential minerals like iron, zinc and calcium to form insoluble complexes that hinder their absorption in humans as humans do not produce the enzyme phytase (Das et al, 2022). Their phytic acid content in 100g dry weight range from 1.40–2.57 g/100 g in beans, 0.61–1.19 g/100 g in lentils, and around 1.12 g/100 g in chickpeas (Sinkovič et al.,2022). Due the mineral binding property of phytates, it can lead to deficiencies, such as anaemia, especially in children, pregnant and lactating women and also in populations which depend heavily on legumes as their main source of food are also vulnerable to this deficiency (Petry et al, 2010; Khattab and Arntfield, 2009)

Raffinose family oligosaccharides (RFOs), including raffinose, stachyose, and verbascose are indigestible carbohydrates which are present in legumes. In chickpeas, the average content of raffinose family oligosaccharides (RFOs) across different varieties ranges from 1.4 to 2.8 g/100 g for raffinose, 0.9 to 5.3 g/100 g for stachyose, and 0.12 to 0.15 g/100 g for verbascose (Elango et al., 2022). Tahir (2011) wrote in his doctoral report that the total content of (RFOs) in dry weight of 100g of lentils rare: raffinose (0.2–1.5 g/100 g), stachyose (1.1–3.1 g/100 g), and verbascose (ND–1.4 g/100 g) with various across species. The raffinose family oligosaccharide (RFO) content in common beans varies widely, with raffinose ranging from <0.05 to 2.5 g/100 g, stachyose from 0.2 to 4.2 g/100 g, and verbascose from 0.06 to 4.0 g/100 g on a dry weight basis (Kannan et al.,2018). Humans lack the enzyme α -galactosidase, which is responsible for hydrolysing these carbohydrates, thus, they are fermented in the colon. This fermentation is the major cause of stomach discomfort and flatulence people experience after they consume legumes About 5g per day consumption of RFOs is enough to cause flatulence and bloating (Amorim et al.,2020; Elango et al., 2022).

2.2 Traditional Methods for Reducing Anti-Nutrients

Traditional methods which include soaking, dehulling, milling, sprouting, germination, and thermal processes like boiling and roasting have long been used in reducing antinutrients in

legumes. (Ibrahim et al., 2002, Marcos-Méndez et al. 2021). Among these methods, soaking is the most common. Phytates and RFOs are soluble in water and will therefore leach into the soaking water after being kept for a while. Samtiya et al., (2020) reported that phytate level was observed to have decreased by 36% after soaking the legume water for 24 hours. Also, the combination of germination and soaking activate endogenous enzymes like phytase, which hydrolyses phytic acid and thus, enhance mineral bioavailability (Gupta et al., 2015). Fermentation introduces beneficial microorganisms that degrade anti-nutrients and improve the sensory attributes of legumes, while thermal treatments denature heat-labile anti-nutritional factors and enhances the nutritional quality of legumes ((Frias et al., 2010; Khattab & Arntfield, 2009).

2.3 Advantages of Emerging Technologies over Traditional Methods

Though traditional methods are effective to an extent in the removal of antinutrients from legumes, some of them have disadvantages. Many traditional processes require long processing times and involve multiple steps and may result in nutrient loss or undesirable changes in texture and flavour. Samtiya et al., (2020), Kumar et al., (2022) reported that milling and dehulling causes mineral loss in legumes. (Gupta et al., 2015) soaking for a long time also causes nutrient loss in chickpeas. They are best fitted for household application. (Ibrahim et al., 2002; Marcos-Méndez et al., 2021; Khattab & Arntfield, 2009; Sharma, 2021)). In contrast, the emerging technologies selected for this study; high-pressure processing (HPP), ultrasound, pulsed electric field (PEF), and vacuum impregnation (VI) offer greater precision, reduced processing times, and higher nutrient retention without compromising the sensory quality of legumes (Ohanenye et al., 2022; Nasab et al., 2024). These methods are also very valuable for industrial-scale applications, as they can be automated and optimized for efficiency and sustainability. Another advantage of emerging technologies is that they operate under milder thermal conditions, minimizing heat-sensitive nutrient degradation and preserving the integrity of plant-based proteins (Faizal et al., 2023; Redondo-Cuenca et al., 2022). Emerging technologies do not only offer better nutritional and sensory benefits, but also provide an industrial scalable solution aligned with sustainable food system demands.

Emerging technologies offer more efficient alternatives. For instance, high-pressure processing (HPP) has been shown to reduce antinutritional factors and improve protein digestibility in legumes without significantly affecting their nutritional quality (Linsberger-Martin et al., 2013). Pulsed electric field (PEF) treatment has been reported to decrease antinutritional factors and enhance protein digestibility in plant-based foods (Kheto et al., 2024). Moreover, vacuum impregnation techniques have been utilized to fortify legumes with essential minerals and reduce antinutritional compounds, thereby enhancing their nutritional profile (Arnal et al., 2025). These emerging technologies not only offer more effective reduction of antinutritional factors but also align with industrial scalability and consumer demand for minimally processed, nutrient-rich foods.

2.4 Modern and Emerging Processing Technologies

With consumer interests currently shifting to legumes, as source of protein-rich material, as well as other macronutrients, such as dietary fibre, starch, and fatty acids it is important to increase the protein bioavailability and digestibility of all macro and micronutrients in legumes. The importance of efficiency in antinutrients reduction and increasing the nutritional profiles of legumes have led to advancements in food processing. These emerging techniques aim to preserve the sensory quality of legumes while also greatly improving their nutritional profiles

by increasing the digestibility of legume proteins. They also offer several benefits, including rapid processing times, flexibility, and high performance at low temperatures, making them very sustainable. (Nasab et al., 2024)

2.4.1 High Pressure Processing (HPP)

HPP is a non-thermal technology which subjects food to pressures between 100 and 600 MPa, which disrupts cellular structures and inactivates undesirable enzymes and microorganisms without significant heat application (Upraity, 2024). This process increases the solubility of antinutrients like phytic acid and RFOs, leading to their degradation and improving mineral availability. Its effectiveness depends on factors like the pressure intensity, treatment time, and moisture content. Chickpeas and beans, with denser matrices could benefit from longer or higher-pressure treatment unlike lentils with a less dense matrices (Alsalman & Ramaswamy, 2020; Redondo-Cuenca et al., 2012). In beans, HPP reduced RFOs by 48% and Phytic acid at 11% (Linsberger-Martin et al., 2013). In chickpeas, it reduced RFOs by 68% and phytic acid by 56.9 % (Han & Baik, 2006; Nasab et al., 2022) and in lentils 56% for RFOs. The application of HPP technology also promotes a reduction in the hardness of legumes, hence, contributes to reducing their cooking time. (Redondo-Cuenca et al., 2022).

2.4.2 Pulsed Electric Field (PEF)

PEF is a sustainable processing technology which does not compromise the quality or safety of the food processed. It is a technology that involves the use of short bursts of electric field (usually 10-50kV/cm) to food placed between its electrodes at low temperature for a short period of time. The time is usually in nanoseconds or microseconds depending on the food it's applied on. The electric field leads to the electroporation of the food's cell membranes. Electroporation increases cellular permeability enabling the faster mass transfer during soaking or rehydration. As a result of this, RFOs and phytates which are soluble anti nutrients can be more effectively leached out into the soaking solution or removed during subsequent processing steps like cooking. (Kheto et al., 2024; Arshad et al., 2020). PEF can be reversible or irreversible.

In chickpeas, Andreou et al. (2021) observed that applying electric fields at 2.5 to 3.3 kV/cm with energy inputs up to 12.0 kJ/kg led to substantial extraction of RFOs during soaking, with reductions of approximately 47.7% for raffinose, 76.1% for stachyose, and 86.6% for verbascose after 300 minutes of rehydration. Nasab et al. (2024) reported that PEF processing resulted in a 15–20% reduction in phytic acid content in chickpeas

For beans, although Devkota et al. (2022) did not provide specific quantitative RFO and Phytate reductions, their study demonstrated that PEF-assisted hydration significantly improved water uptake and seed coat softening. These physical changes are known to support the removal of water-soluble oligosaccharides such as RFOs and phytates, suggesting that beans also benefit from PEF treatment in this regard. The parameters for an effective PEF treatment include the electric field strength used, the pulse duration and the electrical conductivity of the legume being treated (Taha et al., 2022)

2.4.3 Ultrasound Processing

Ultrasound processing works by creating cavitations that produce stable and unstable bubbles in food materials soaked in a liquid. On the implosion of these cavitation bubbles, energy gets accumulated in hot spots that generate extreme conditions causing turbulence and shear energy waves in the cavitation zone. (Miano et al., 2016) The rapid formation and, growth and collapse of these bubbles disrupt plant cell structures, improving the release and leaching of soluble

compounds, including anti-nutritional factors such as RFOs and phytic acid (Das et al., 2022; Sharma et al., 2022). The study conducted by Han, & Baik (2006), revealed that ultrasonic soaking (47 MHz) uncooked soaked lentils for 1.5 h decreased by 55.9–58.7%. In chickpea, RFOs content of chickpeas was effectively reduced 64.7% after soaking with ultrasound for 3 hr. In soybeans 45.8% was removed by soaking with ultrasound for 3 hr. Efficiency of Ultrasound depends on the frequency, intensity, and temperature at which the process occurs. Sarkhel & Roy (2022) reported in their studies that the phytic acid levels in green lentils, red lentils, and faba beans were reduced by 8%, 16%, and 15.30%, respectively, with an ultrasound amplitude of 70% (200–250 W for 2.5 hr). Nasab et al. (2024) also reported 18.2% and 30.7% reduction of phytic acid by the amplitude of 25% and 40%, respectively. The results from these papers suggest is a better method for RFOs reduction in legumes when compared to phytates, and it's more proficient for Lentils

2.4.4 Vacuum Impregnation (VI)

VI is a non-thermal processing technique that involves immersing food materials in a solution under reduced pressure, allowing the solution to penetrate the porous structure of the food matrix. Upon restoring atmospheric pressure, the impregnating solution fills the voids left by the evacuated gases, enhancing mass transfer processes such as hydration and solute diffusion. It is a food fortification technique which has been used to infuse beneficial minerals into foods. This method allows for the infusion of food grade enzymes, and essential minerals (K., M., & Y. B. 2017).

Results from the studies of Arnal et al., (2023), showed that the use of vacuum impregnation during soaking reduced the broad beans' soaking time by 77%. In further studies, Arnal et al., (2025) showed that the application of vacuum impregnation during soaking increased the hydration rate of broad beans and with incorporation of the enzymes bromelain or papain enzymes, phytic acid levels were best decreased after 1 hour. The enzymes also facilitated protein hydrolysis, with maximization of hydrolysis after 4 hours of soaking proving the result of VI in the enhancement and fortification of legumes.

Phytase and α -galactosidase are the enzymes responsible for the hydrolysis of phytates and RFOs respective, with the success recorded by Arnal et al., (2025), Prospectively, this method can be used to infuse these enzymes into the legumes to facilitate the reduction of anti-nutritional factors and enhancing nutritional value.

2.4.5 Modern Fermentation

Fermentation has been one of the oldest ways of process foods and legumes. The traditional fermentation process occurs naturally, without any human control leading to the possibility of cross contamination during the process, which could alter the desired result. Advances in microbiology and processing technology has made it possible to have more precise and controlled fermentation or Microbial biotransformation (Sawant et al.,2025; Senanayake et al., 2023). This type of fermentation involves controlling the process of and starting from the type and dosage of the starter culture and other environmental factors like pH and nutrient level. Solid state fermentation (SSF) by LAB strains of chickpea sourdough reduced the concentration of RFOs. More specifically, raffinose and stachyose contents were reduced by 88.3–92.3%, and 97.7–99.1% respectively (Xing et al., 2020). Curiel et al.,2015 also noted a 17% reduction of phytic acid in chickpeas sourdough fermented by *Pediococcus pentosaceus* and *Pediococcus acidilactici*. The stachyose and raffinose concentrations were reduced by 88.3–99.1% while verbascose amounts became undetectable. The reduction of RFOs and phytic acid during fermentation is primarily attributed to the enzymatic activities of

fermenting microorganisms. LAB strains produce α -galactosidase, which hydrolyzes RFOs into digestible sugars, and phytase, which degrades phytic acid. (Chiacchio et al., 2025; Sawant et al., 2025)

2.5 Consumer Perception of Food Technologies

For a food innovation to be successful, the consumers who it is made for have to accept to buy or use it. After all the technological and research put into food development and enhancement, it is important that the resulting product is adopted by the final consumers. Consumers' perception for adoption has a lot of factors at play affecting it. It could be emotional, cultural or social factors and in some cases religious. For novel technologies, previous research has shown that the main factors for acceptance are safety, health benefits, transparency, cost, familiarity and taste (Frewer et al., 2011; Siegrist & Hartmann, 2020).

Román et al., 2018 in his study revealed how naturalness is crucial for the majority of consumers as they mostly associate technological intervention in food processing with increased risk and loss of naturalness, even when scientific evidence could support the safety and nutritional importance of these products. The study then advised how neglecting naturalness in the food industry could be costly. The difficulty about the best way to present technologies to consumers is also a concern as even “clean label” means different things to different consumers (Asioli et al., 2017). While HPP, PEF can preserve more nutrients, reduce antinutrients and effectively reduce cooking time, they may still be rejected as being unfamiliar or industrial.

Some people have traits of food neophobia, which is the reluctance to try new or unfamiliar foods or processes. This could be a psychological barrier that can also hinder acceptance if these emerging technologies are not properly communicated or understood (Pliner & Hobden, 1992). Some people who lack the knowledge of food technologies may rely on the intuitive judgements and if familiarity with a process leads to higher acceptance (Cardello, 2003).

Legumes already face barriers in acceptance due to gastrointestinal discomfort and introducing more unfamiliar processing methods may further complicate their acceptance. It is therefore important to frame these technologies in a way that meets consumers' values and expectation

2.6 Communication, Trust, and Naturalness in Food Innovation

It is important to understand that trust is one of the strongest drivers for product acceptance. Trust in consumers can be built through transparency, clear communication and a perception that food innovations are developed in the interest of public health and wellbeing (Sánchez-Siles et al., 2020; Frewer et al., 2011). When consumers trust a food technology and believe it is beneficial, they will accept it even if they don't fully understand the technology behind it (Verbeke, 2005).

Though effective communications must be factual, they should also use innovative terms in a way that resonates emotionally and culturally using familiar methods as examples. Emerging technologies like HPP, PEF, and ultrasound can benefit from this approach by highlighting how they preserve nutrients, reduce cooking time and improve digestibility without compromising sensory quality. These advantages can be communicated using well known concerns such as stomach discomfort as it could aid acceptance (Siegrist & Bearth, 2021; Granato et al., 2020; Meijer et al., 2021; Lam et al., 2020)

2.7 Gaps in Literature and Research Relevance

While there has been so many studies and reviews exploring the technical aspects of reducing antinutritional factors in legumes, there has been just a few of this research focuses on the consumers' perceptions and acceptance of these processing methods. Since the success of food technologies does not rely on innovation alone but bridging the perception gap, understanding consumers' feelings about these technologies is crucial for its successful adoption and commercialization. This study will investigate consumer responses to various emerging technologies applied to reduce antinutrients in legumes. This research builds on the work of (Chatur et al., 2022) on the potential of utilizing processing technologies to increase the acceptance of plant-based legumes with desirable textures. (Frewer et al, 2011; Affrifah et al.,2023)'s works on consumers' acceptance of technologies will also be built upon.

3 Chapter 3

Methodology

3.1 Research Design

For this study, a mixed method design was used, integrating both quantitative and qualitative approaches to explore consumers perceptions, behaviours, acceptance and attitudes toward emerging technologies used to reduce anti-nutrients in legumes. The quantitative part was the use of an online survey while the qualitative part was the use of a guided focus group. This approach allowed for both the statistical generalization and deeper narrative insight in line with recommendations for consumer behaviour studies in food science (Creswell & Plano, 2011; Teddlie & Tashakkori, 2009).

Target Population and Sampling Strategy

This study recruited individuals who live both within Sweden and internationally and possess varying degrees of familiarity with legumes and food processing technologies. The reason is to make sure that the individuals engaged can provide meaningful insights into consumer perceptions of emerging technologies applied in legume processing.

The survey participants were recruited through university networks, food groups, and local communities involved in sustainability such as the Green Party Seniors in Lund. Invites were sent from social media like WhatsApp and Facebook. This network was for a diverse demographic so as to ensure a sample that reflects different consumer backgrounds.

For the focus group discussion, participants were selected from the same survey pool to ensure continuity and context familiarity (Krueger & Casey, 2015; Stratton, 2023). Invites were sent to those physically in Sweden. Since all focus group members had completed the survey prior to participation, it allowed them to engage more confidently and knowledgeably with the discussion topics.

3.2 Data Collection

Online Survey

An online structured questionnaire was designed and administered using Google Forms. It included both closed-ended questions with Likert scales, multiple-choice and a one open-ended question which will help to capture deeper reflections. The survey assessed:

Awareness of anti-nutrients (phytates and RFOs)

Familiarity with technologies like HPP, PEF, ultrasound, VI, and fermentation

Willingness to buy and pay more for processed legumes

Perceived naturalness, trust, and safety of the methods

This method was chosen for its accessibility, efficiency, and ease of data export and analysis (Vasantharaju & Harinarayana, 2016; Evans & Mathur, 2018).

The survey questions and the focus group questions can be found in the appendix.

3.3 Focus Group Discussion

The focus group methodology as described by (Nyumba et al., 2018; Kitzinger, J. 1994) was used. To ensure accuracy of opinions, the participants were selected from those who had already answered the survey question. A mix of homogeneity and non-homogeneity was employed to achieve complementary interactions and a bit of argumentative interaction. Two focus groups, which represent a mini focus group style (Kamberelis & Dimitriadis., 2020.) were conducted with five and four participants in each. There was also an assistant to support the moderator (Nyumba et al., 2018). The sessions were held at Kemicentrum's Christian Wilhelm Blomstrand class in Lund University after access had been granted by the librarian. All participants were resident in Sweden. The focus group was made of mixed homogeneity and other differencing factors such as age, origin and eating patterns. The first group had five participants. The members include a senior vegetarian from Sweden and a young European university student. The other three participants included two food science students from Asia and the other was a middle-aged Asian who has lived in Sweden and Europe for a long time. The second group had two flexitarians from the Seniors of Lund Green Party, two students from food science LTH who are also from Middle East and Asia. My assistant was a working-class Swedish flexitarian. The session was audio recorded with consent and transcribed manually for further analysis (Rabiee, 2004).

3.4 Ethical Considerations

The research followed ethical involvement in each step of the research as described by (Hasan, et al., 2021; Cacciattolo, 2015).). All participants in both the survey and focus groups were informed of the study's purpose, their rights, and data confidentiality. Participation was voluntary and anonymous. Informed consent was secured digital agreement at the start of the survey and verbally before the focus group.

3.5 Data Cleaning and Preparation

Since Google form was used to collect the Survey data, it was exported to Excel and SPSS. Incomplete, duplicate, or inconsistent responses were removed before each hypothesis was tested. Likert scale responses were numerically coded (e.g., 1 = strongly disagree, 5 = strongly agree). Open-text responses were reviewed for relevance. This preparation ensured clean, reliable data for statistical analysis (Van den Broeck et al., 2005).

3.6 Data Analysis Methods

Quantitative Analysis

The quantitative analysis was conducted via Microsoft Excel. The analysis is divided into two sections. The first section deals with the presentation of data collected from the online survey by descriptive statistics supported visual aids like bar charts and pie graphs for drawing conclusions and second section was creating hypotheses and drawing conclusions after statistical analysis.

To examine the relationship between consumer knowledge, attitudes, and behaviours toward legumes processed with emerging food technologies, quantitative data were collected using a structured survey. This survey included Likert-scale and ranking-type questions which were subjected to statistical analysis. The primary aim was to assess whether consumer awareness of emerging technologies significantly influenced their willingness to purchase legume products processed with such methods.

Data Transformation

Survey responses based on Likert scales e.g. (“strongly agree to strongly disagree”) and other ordinal measures in the survey were coded into nominal values to enable statistical testing. The Likert scale was assigned value from 1-5, with 1 representing the lowest level and 5 the highest agreement. Similar other categorical ranking data were ranked. This was to be able to convert the qualitative responses into a compatible parametric and non-parametric tests.

Hypothesis Testing

To test the hypothesis that tech awareness of emerging processing technologies influences willingness to purchase processed legumes, a one-way Analysis of Variance (ANOVA) was conducted in Microsoft Excel 365. In the test, tech awareness (as the independent variable with three levels based on awareness scores) was compared against their reported willingness to buy (as the dependent variable). This allowed for identifying statistically significant differences in willingness across different awareness groups.

All analyses were conducted using Microsoft Excel 365, and significance was evaluated at the 0.05 level.

3.7 Qualitative Analysis

Thematic model for analysing qualitative data from the focus group section was used for this analysis. Focus groups sessions were record with phones. The recorded sessions were then transcribed verbatim by typing. To analyse the data, thematic approach was used. This involved reading through the transcripts severally to properly used it. Key ideas, phrases and patterns were identified and grouped into theme that reflected participants thoughts during the session.

4 Chapter 4

Results

4.1 Survey

4.1.1 Key insights from the data gotten from the survey which was conducted on this study.

This section provides a compressive interpretation of the original responses which was obtained from the survey. This will explain all the categories in the survey showing us how people from diverse backgrounds reacted to the questions in the survey.

Legume consumption Frequency and motivation for consumption

Most of the respondents agree with eating legumes. Out of the 123 responses, 17 said they eat it daily, 36 eat it 2-3 times weekly, 28 eat it once a week, 30 eat it once in a month and 12 people do not eat it at. This shows that there is a good engagement with legumes.

When asked about their most consumed legumes, the majority went for beans. 83 were in favour of beans, 23 for chickpeas, and 14 for lentils, though 3 people chose others, this goes to show that beans dominate, and this could make them the focus for any innovation which would improve digestibility and nutrition as they are the most consumed.

respondents were asked about their motivation for eating legumes and were allowed to choose from an array of options on why they eat legumes. The popular reasons include diverse nutrition, health benefits, and taste. These had 75, 64 and 45 responses respectively. 20 said they eat it for environmental reasons and 16 live a vegan or vegetarian lifestyle. These reasons are the first drivers for consumption of legumes and can become the building blocks as to how this technology can be communicated and sold to consumers.

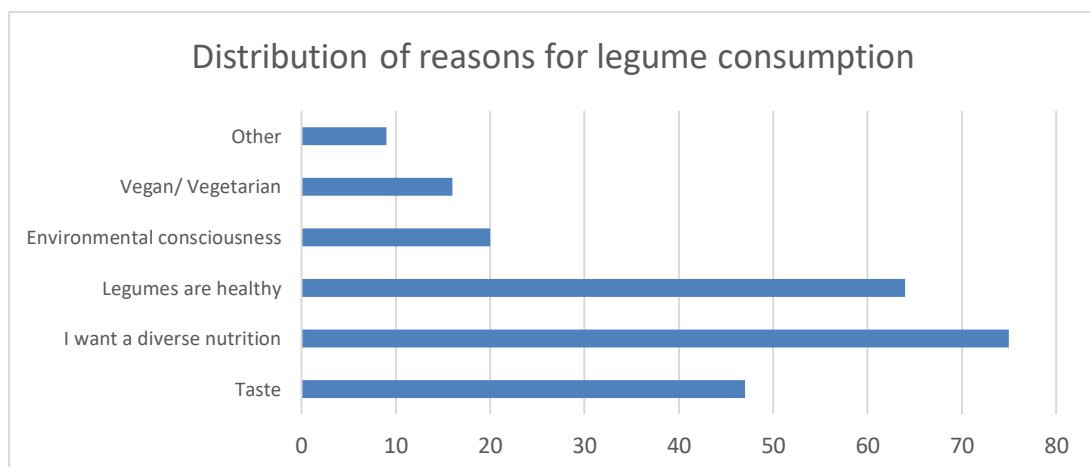


Fig1. shows motivation for consumption of legumes among survey participants

Digestive Discomfort and Awareness of Antinutrients (Phytates/RFOs)

Majority have experienced some discomfort. With 63 saying they have experienced digestive discomfort sometimes and 32 saying they experience it regularly shows that this is a concern that would be important to address. Only 28 said they have no discomfort. The data shows that about 77.2% of the total participants have experienced discomfort. 23.8% said they avoid eating legumes because of this discomfort, validating that RFOs is a reason for low legume consumption and showing the importance of reducing the RFOs. To reduce these antinutrients, 28.7% soaked or sprouted their legumes, 23.1% used digestive aids and 45.1% said they are not concerned about digestive discomfort.

When asked about RFOs and phytates, 74.6% did not know about phytates and RFOs before taking the survey.

Awareness of Emerging Processing Technologies

The same trend continues here. When asked if they were aware of food processing technologies like high-pressure processing (HPP), pulsed electric fields (PEF), etc, 91 people said no. Only 26% had some familiarity with the methods and the most known was HPP. 82.9% were either very familiar or somewhat familiar with traditional fermentation. When compared with other emerging technologies, 45.1% chose modern fermentation while 41% said they would go with any emerging technology, 9% chose other technologies over modern fermentation and 4.9% said they are not comfortable with any of the technologies. This makes modern fermentation the most accepted emerging technology and shows that there is also an acceptance of other technologies.

Willingness to try Tech-Processed Legumes

Despite limited awareness, many respondents were open to the idea of trying these enhanced legumes. Though the highest response was “Probably” from 48.3% of the respondents, signifying cautiousness. 35.8% of the respondents outrightly said they will definitely buy. These results are encouraging. This shows that though people may not understand the technologies they may be willing to try them. The caution possibly signifies that they have values that need to be met.

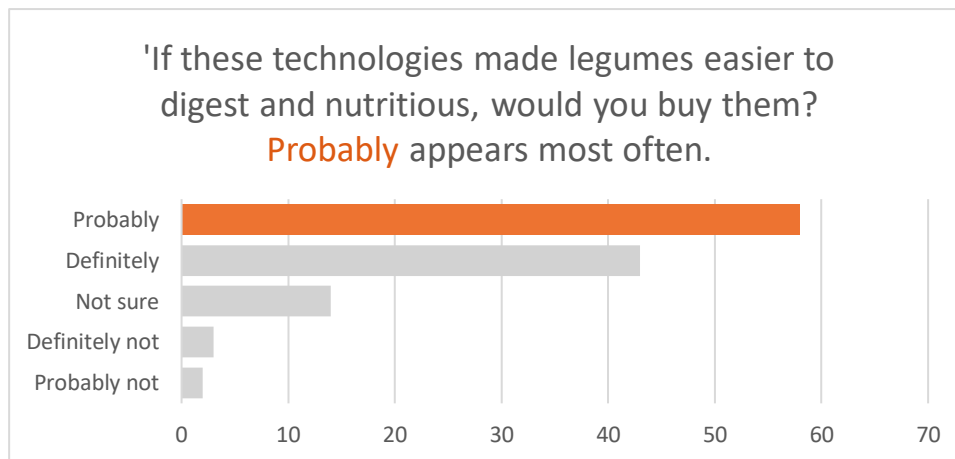


Fig 2. Consumers' willingness to buy tech processed legumes

When asked why they would buy, 76.9% mentioned safety and health benefits, followed by recommendation from health professionals. 38% and 30.6% choose environmental benefits and naturalness respectively.

Label Reaction

Almost half or the respondents said they would want more information before making a decision to buy if labels mentioned these techs used. Only 23% said they would buy them if they mentioned the technology.

Willingness to Pay

When it comes to paying a premium for these improved legumes, most people are cautiously optimistic. Sixty-two respondents said they might pay more, and 38 said they would. Only 19 flat-out rejected the idea. This suggests that while people may want to buy these legumes, price sensitivity exists.

Demographics

Respondents are globally diverse, mostly with higher education (Masters, Bachelors). 46.7% of the respondents live in Sweden, where this project is being conducted, 25.8% live in Europe and 27.5% live overseas. Though Africa has the responses in continent of birth at 47.1% of 121 respondents, Europe at 38.8%, Asia is 10.7%, North America 2.5% and South America 0.8%.

The audience is broad and could give us what other demographics think about these technologies making the insights widespread for further development in other regions.

4.2 Statistical Tests and Hypothesis Results

Some hypotheses from the survey were tested

To assess the relationship between consumer knowledge, behaviours, and attitudes toward legume products processed with emerging technologies, a few statistical tests were conducted. The study employed one-way Analysis of Variance (ANOVA) and Chi-square tests,

Tech Awareness vs. Willingness to buy (One-Way ANOVA)

H0: There is no relationship between tech awareness and willingness to buy tech

H1: There is a relationship between tech awareness and willingness to buy tech

A one-way ANOVA was used to analyze awareness of food processing technologies and its effect on participants' willingness to purchase legumes processed with these methods. The ANOVA results showed a significant difference ($p = 0.035$); therefore, the null hypothesis is rejected, and the alternative hypothesis is supported. This indicates a positive relationship between tech awareness and willingness to purchase, confirming the need for awareness of these emerging technologies, and it could be effective in making consumers buy these legumes.

Digestive discomfort vs frequency of legume consumption (Chi-square Test)

H0: digestive discomfort is not caused by the frequency of legume consumption

H1: digestive discomfort is caused by frequency of legume consumption

To analyse the effect frequency of legume consumption towards digestive discomfort, a Chi-squared test was conducted. P-value returned as 0.15, DoF = 8, thus we fail to reject the null hypothesis. There is no significant relationship found between legume consumption frequency and digestive discomfort. This implies that frequently eating legumes does not cause discomfort, confirming there is another cause for digestive discomfort which is RFOs.

Phytate & RFO Awareness vs. willingness to buy (Chi-square Test)

H0: There is no relationship between Phytate & RFO Awareness and willingness to buy tech

H1: There is a relationship between Phytate & RFO Awareness and willingness to buy tech

Chi-square Test analysis was used to test the relationship between awareness of Antinutrients and the willingness to try tech processed legumes, it came back with a DoF value of 1 and p-value = 0.02. Thus, we reject the null hypothesis. This shows that there is a significant relationship between the two variables as awareness creates more interest to buy tech processed legumes. This confirms the need for creating awareness about both the antinutrients and the technologies which are being used to mitigate it could make people try it, even though the awareness may not convince them to pay a higher price.

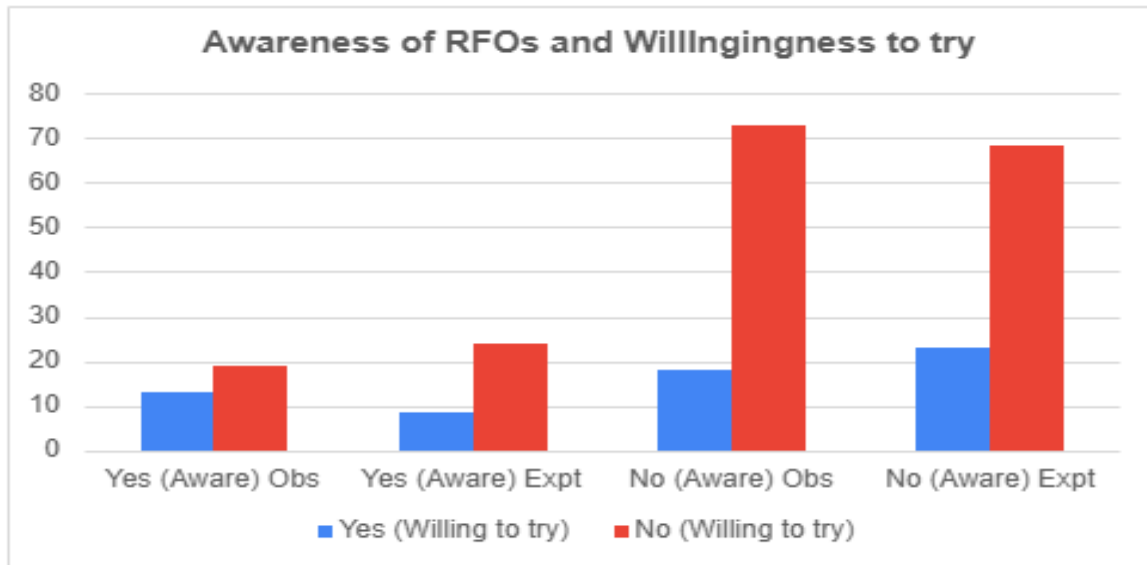


Fig 3. Awareness of antinutrients and the willingness to try/purchase tech-processed legumes.

Digestive discomfort vs willingness to try tech processed legumes (Chi-square Test)

H_0 : digestive discomfort does not affect the willingness to try tech processed legumes

H_1 : digestive discomfort affects the willingness to try tech processed legumes

To analyse if digestive discomfort affects the willingness to try tech processed legumes, a Chi-squared test was conducted. P-value returned as 0.23, thus we fail to reject the null hypothesis. There is no significant relationship found between digestive comfort and willingness to try tech processed legumes. This implies that though participants experienced digestive discomfort, it may not be the only reason for them to try tech processed legumes, other factors like taste, environmental impact, and or improved mineral absorption may motivate them to try these legumes. Proper targeted education could also be important to motivate them to try this technology.

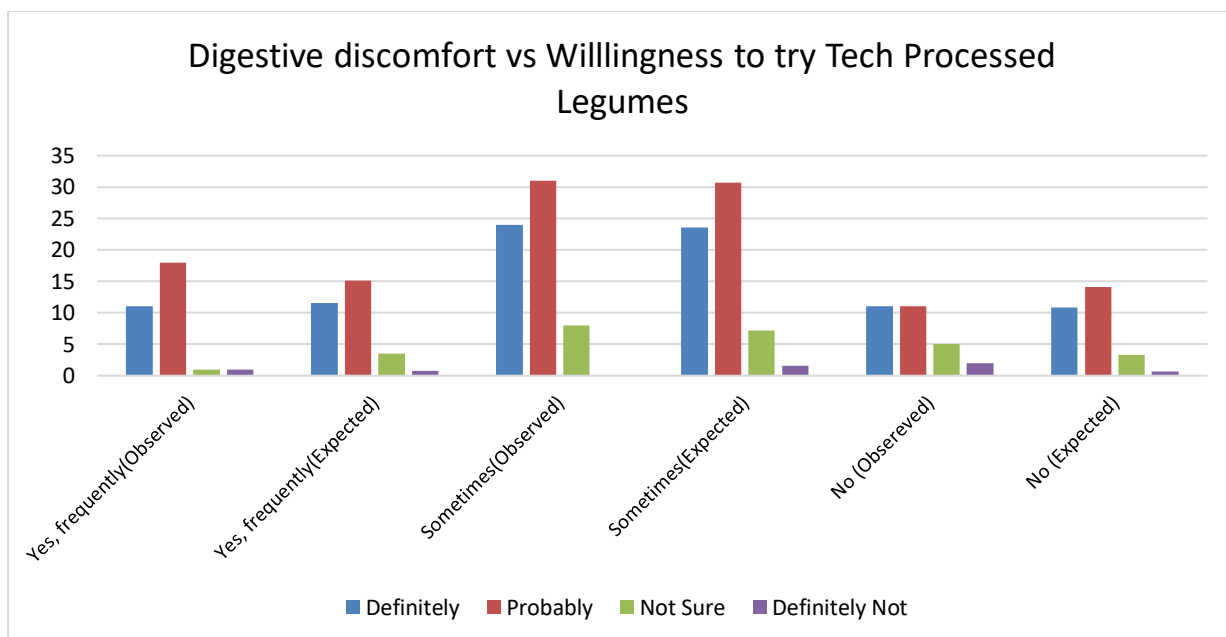


Fig 4. *Digestive discomfort vs willingness to try tech processed legumes*

4.3 Focus Group Discussion Summary: Key Themes and Responses

4.3.1 General perception of legumes and anti-nutrients:

The participants in both focus groups admitted widely to be eating legumes regularly. While some eat it as a cultural norm, especially those with Asian origin, others eat it because they find it healthy and for environmental purposes. For the flexitarian and vegetarian participants, they ate it as a lifestyle. The participants were also surprised that phytates chelate nutrients as they didn't have an earlier idea of that phenomena until they did the surveys and participated in the focus groups.

Across both focus groups, participants generally reported moderate to high consumption of legumes. Many consumed legumes two to three times a week, with some eating them daily particularly among vegetarians, flexitarians, or culturally influenced diets. Reasons included nutritional value, taste, dietary restrictions (e.g., vegetarianism), cultural traditions, affordability, and availability.

When asked about discomfort after eating legumes, all the participants in the second group admitted to having had discomfort, in group A one participant admitted to having discomfort from eating black and red beans but not much more from other legumes. Others said they soak their legumes as a means of avoiding stomach discomfort. While some attributed this to under-soaking or overconsumption, others noted it as a common and expected reaction. A few soaked their legumes as a means to reduce this discomfort. Overall, the issue of discomfort was widely acknowledged. This shows that the incidence of discomfort is relevant with legume consumption

When asked about how familiar they are with the phytates and RFOs, the participants explained that they had low initial awareness of these phenonium especially in relation to low mineral absorption. There was low initial awareness of phytates and RFOs, but participants were receptive to learning about them. After explanation, most understood their impact on nutrient

absorption and digestive discomfort. This understanding sparked interest in potential solutions, especially in technological interventions.

4.3.2 Familiarity and Trust in Processing Technologies

Many were familiar with fermentation as a processing technology. But when asked about pulsed electric fields (PEF), high-pressure processing (HPP), Ultrasound and vacuum impregnation (VI) were new to many amongst them, especially those without a food science background. Those with educational or professional backgrounds in food science were very familiar with them, open and confident in their safety. One participant in group A, who studies food science in LTH expressed scepticism, especially as methods sounded "unnatural." She said "No, I would be hesitant to try them even if I learn about all these technologies. What kind of byproducts are made, is it safe? Fermentation is old and safe and will choose to stick with that. But if there are scientific proofs and human tests then I can consider trying them". Whilst admitting the unnatural feeling about the methods, another student from Greece said she is familiar with them because she studies food science and if she was not studying in this field, she would have seen them as unnatural. Her words were "All sounds natural, and I don't see them as foreign maybe because I have known about them from my studies, and if I didn't know them from the studies, I would feel it wouldn't be natural". Thus, her knowledge about these processing technologies is the reason why she would try legumes processed with them. The Swedish seniors in both groups said they have more trust in the technologies if there is confirmation from the Swedish food agency Livsmedelsverket. About their safety for consumption. This shows that manufacturers must work with health authorities and policy makers to ensure that the safety of these methods are guaranteed as this could be a vital reason why consumers would be convinced enough to try legumes which have been processed with these technologies.

4.3.3 Willingness to Try Tech-Processed Legumes

Generally, there was openness to trying legumes processed with emerging technologies and particularly, if they helped reduce digestive discomfort and cooking time. Participants also emphasized the importance of safety, transparency, and consumer education as these are critical areas that would ensure that people are motivated to try these processed legumes. Several noted that while unfamiliar names might be turned off at first, they would be more open if the health and environmental benefits were clearly communicated. The participant from Indonesia in her reason for wanting to try them said "Yes, it will be important for me to try them as I have struggled with some of the beans already and so I would want something that can help with this problem. It would also be fascinating to have something that would lead to less soaking and cooking times and so it would be good for me." One of the senior flexitarians noted that she is not a technology enemy and would want to try it as long as safety is guaranteed and as it is also not dangerous for the environment. The student from the Middle East mentioned safety, price and convenience for her willingness to try, she said "yeah same for me, as long as it is not dangerous it doesn't change anything in the DNA of the legumes. And also, not that much increases the price. Because it's also an important factor for me, then why not. Yeah, I will use it. Sometimes you can't cook the legumes immediately when you want to. You have to soak them at home, especially when you don't buy the ready to eat ones. When you buy the package, you have to soak them. You can't say I want this food right now and make it. You have to prepare it, so if it's ready to eat you can cook it easily." The participant who said she doesn't trust the process still emphasised that she would not try these legumes, unless it has been proven to be healthy especially with scientific proofs and maybe after five years of being in the market, she may be willing to try them. One of the seniors who is a flexitarian said he

would not be willing to try products made with fermentation as the taste is always sour and he doesn't like it. Using his words, "I mean when it is sour I don't like it. When I grew up, if the food was sour, it wasn't good. There is something that happened to it. So that is from childhood". All these prove that there are different factors which would motivate consumers to try these legumes

4.3.4 Labelling Expectations and Consumer Communication

Label was a concern as participants wanted transparency but also stressed on the importance of simplicity. One participant who studies in LTH mentioned that too many labels could increase the cost of production. They finally suggested the use of clear, friendly language. Their suggestions included texts like "easier to cook", "More nutritious and eco-friendlier" rather than the use of technical terms which could confuse the buyers and make them change their minds. The student from Greece suggested the use of barcodes or QR codes for deeper explanations, allowing consumers to learn more if interested. The Swedish vegetarian from group A pointed out that people need more than names or labels, stating that information can also be spread through media outlets and even in newspapers. Others supported this idea and also added that the use of social media is also very important for this type of information to reach to most consumers. In group B, one of the seniors cited the Oatly as an example, saying the manufacturer of these legumes can draw inspiration on how to use very catchy headings and possible, little stories to advertise how important these products are, their ability to be more nutritious, reduce cooking time, and being eco-friendly. These were all salient points which made the manufacturers understand how efficient communication can aid them in making these products more acceptable to the populace of consumers.

4.3.5 Packaging Preferences and Product expectations

In packaging there were various opinions from the group. In group A, most of the students said they wanted the product to be sold as raw and that they can cook for themselves. The participant from Indonesia who is a working parent said that ready to eat would help, as she does not have time to cook most times and would prefer something that is ready to be eaten. The senior vegetarian also indicated that she would have loved it to be raw if she was younger, but that now that she is older., she prefers something that would be easy for her to cook, in other words, precooked but very safe. These were her words" I have always loved it to be raw, as I know there are so many things in the air and water, so I want to cook my stuff. But now that I am older, I prefer to have it precooked, but it is also important to make it easier to eat in a way that is safe." In the second group, the participants were mostly open to the raw forms of the legume's seeds. The participant from the Middle East gave a price factor in precooked legumes as it could affect the price, she also stated that having it raw makes it easier for one to cook and add their own recipe as they want. Discussion also continued in group B were they of the seniors mention that she would prefer to have the packaging with less plastic as it is very environmental and health friendly. This infers that though most consumers want the final processed legumes in raw forms, they would also be open to precooked legumes especially people with families and seniors. This gives an on which types to push to the market first and the type to push later to check their market feasibility.

4.3.6 Concerns About Safety and Long-Term Health Effects

Safety was a recurring theme. Participants were generally confident in European food regulations but expressed caution about unknown long-term effects. Some worried that technologies could unintentionally reduce beneficial compounds. However, most believed that with proper testing and regulation, the health benefits would outweigh risks.

4.3.7 Willingness to Pay More

Most participants were open to paying more and some accepted to pay slightly more for tech-processed legumes if they offered clear benefits like improved digestion, reduced cooking time, more mineral utilization and convenience. Though both groups were open to paying a bit more, but not too much. In group A, participant Indonesia said she wanted it to be the same price, while others considered the advantages it would have other than the regular ones in the market and then accepted, they would pay a bit more for the price. In the second group, the female Swedish flexitarian said she would be willing to pay up to 30% more in price for these legumes. The student in Iran reacted in response saying, "It depends how often you want to eat them. If it's daily, even a small price increase matters." The male senior flexitarian was on a more charitable side saying that if it is too expensive, that he would rather buy something cheaper and donate it to the people in need. He also made a very strong argument for Swedish policy makers saying, "Healthy food shouldn't be more expensive than unhealthy food. We need better taxes to fix that." In some countries like Slovakia, Cyprus and Spain healthy food like vegetables, fruits and even legumes are taxed less. (European Union, 2025)

This goes to show that though people are open to pay a bit higher price for these tech processed legumes, they would not want to pay much more than regular legumes. In the other way, the argument for making safe foods cheaper calls for critical thoughts and ideologically shifts for governments and how to tax health food producers.

4.3.8 Broader Societal and Environmental considerations.

When asked about what the long-term effects of these tech processed legumes could be, some participants admitted that it would be a healthier option, they connected their preferences to broader social and environmental goals. Several participants believed that making legumes easier to digest and cook could help people eat less meat, which benefits the environment. And if these discomforts are addressed, many more people would be willing to eat legumes as discomfort is a turn off for many who would have loved to eat it but experience these problems. The flexitarian stated, "If lentils are easier to cook and more nutritious, people won't say they need meat for nutrients anymore." Other concerns from the second group included tax breaks for sustainable foods and wider public education campaigns.

Participants in both focus groups were generally optimistic about new technologies but emphasized the importance of trust, food safety, and education. Though some were sceptical, it shows that everyone wanted clear benefits, minimal risks, and user-friendly information. This shows the importances of education, transparency and accessibility in new product development. Overall, these discussions reveal that these consumers were not anti-technology. They simply want to understand what they're eating, why it's better, and whether it's worth the cost. If those questions can be answered, they're ready to give innovation a chance.

4.4 Discussion

This research work was done to explore consumer perception, behaviour, reactions and acceptance of food processing technologies which are used to improve the digestibility and nutritional values of legumes, particularly through the reduction of phytates and RFOs. The results from the research help to answer our research questions and complements its objectives.

Low awareness of anti-nutrients and emerging technologies

Both the quantitative and qualitative data confirmed the issues of stomach discomfort among consumers of legumes irrespective of demography. Even though many have these discomfort, this research reveals a widespread lack of awareness regarding RFOs or phytates and the emerging technologies for mitigating them. This knowledge gap suggests that there is a critical disconnect between the scientific advancements in the food industry and public understanding. The statistical results have shown that this knowledge gap is detrimental to the acceptance of these enhanced legumes, proving that the higher the awareness, the higher the chances of accepting them. This shows that it is important for consumers to understand these innovations.

In similar research, Verbeke (2005) found that general consumer knowledge about innovative food technologies was low and in a US study with 1204 adult respondents, only 8% recognized the term “high pressure processing” (Hicks et al., 2019) while also noting that awareness levels did not vary notably across different education or income groups, reinforcing the widespread nature of the issue observed in this research.

These findings validate that increasing consumer awareness could play a pivotal role in increasing the acceptance of legume products processed with emerging technologies.

Influence of familiarity on Acceptance of Emerging technologies

Modern Fermentation had the highest acceptance among the other emerging technologies that were studied because more people admitted to knowing about the traditional fermentation, which is perceived as natural, safe, and culturally embedded hence the need to align with what is familiar. This highlights the importance of aligning novel processing techniques with established consumer experiences to build trust and facilitate acceptance. Banovic & Grunert (2023) observed that in Denmark, when prompting modern fermentation with its similarity to traditional fermentation, it positively influenced consumer perceptions and acceptance.

HPP emerged as the second most accepted technology, which can also be attributed to a relatively higher level of consumer exposure. HPP is increasingly used in commercial food products, particularly in juices and ready-to-eat meals which gives it a growing presence in retail environments especially in Western markets. Consumers who could have encountered HPP-labelled products or maybe through studies will be more open to its use in legumes, suggesting that moderate familiarity can positively influence perception (Nath et al., 2019; Hicks et al., 2019).

Though PEF, VI and ultrasound also received favourable acceptance but not as much as modern fermentation or HPP. These findings are also in alignment with previous research in which Siegrist and Hartmann (2020) reported that consumers were more accepting of food technologies they perceived as “natural” or familiar, as this reduces the incident of food technology neophobia.

These patterns show that familiarity enhances trust, demonstrating the importance of aligning new technologies with established consumer experience. Further confirmation was also seen in the hypothesis testing where awareness of the technology showed a significant relationship with the willingness to purchase the products.

Food safety and Health benefits concerns:

Food safety and health benefits emerged as one of the core drivers for acceptance both in the survey and focus group discussions. Both factors are very crucial as they form the foundation for public trust in innovative foods. Though consumers are willing to try these tech-enhanced legumes, they emphasised the need for assurances of food safety and proven health improvements. They need these legumes to have scientific validation and endorsements from health authorities. This trust on institutional credibility aligns the findings in the literature of Siegrist (2000), where he reported that perceived safety especially when supported by regulatory assurances is among the strongest predictors of public acceptance for novel food technologies. Nath et al., 2019 also mention the roles of regulatory agency like the US Food and Drug Administration, (FDA) in making sure that emerging technologies are safe. When these methods are certified by regulatory agencies, it builds the public trust that these processed legumes meet all the safety, nutritional and functionality standard that makes it safe for consumption.

Although some researchers like Frewer et al., (2011) had written that consumers were about sceptic in their trust for government when it came to technologies like HPP and PEF, in this research, the Swedish respondents in the focus groups indicated greater trust in the technology if Livsmedelsverket (the Swedish Food Agency) approves of it. This shows that Swedish consumer trusts their government's ability with food safety. Other participants also agreed with them and also mentioned that trusted health influencers, and other scientific proofs will be a strong reason for them to try out these legumes. This highlights how institutional backing, whether through government institutions or other authorities in health affairs can help build consumer confidence and trust for food technologies. Consumers want to make sure that what they eat is safe, and this vital in reducing food neophobia among consumers.

Another important driver for acceptance the perceived health benefit of these products, which had equal responses with food safety in the survey results. Though legumes are highly nutritious foods, many consumers are discouraged from consuming them regularly due to anti-nutritional factors like phytates and raffinose family oligosaccharides (RFOs), which can hinder nutrient absorption and cause digestive discomfort. These emerging processing technologies are specifically designed to reduce these compounds without compromising nutritional integrity.

Emerging technologies have led to improvement in digestibility and nutrient bioavailability of these legumes which the major reason for this study. Several participants mentioned that enhanced legumes would be more appealing if they could be consumed without the common side effects of bloating or stomach discomfort. This aligns with consumer trends favouring functional foods those believed to offer specific health benefits beyond basic nutrition (Verbeke, 2006). Consumers want healthier foods and are also most times willing to pay a premium for it. This shows how important nutritional benefits are to consumers (Alsubhi et al., 2023). Since these legumes are nutritional better than the conventional legumes, they can be marketed as not only safe but also gentler on digestion and richer in bioavailable nutrients, which could position it more favourably in the consumer's mind.

Food safety and health benefits have in this research shown to be the major drivers of acceptance of emerging food technologies. Clearly communicating these benefits through trusted channels and on product labels can help manufacturers significantly increase the adoption of tech-enhanced legumes, particularly among health-conscious and also environmentally aware consumers.

Sensory, Environmental and Cooking time factors

Taste was also mentioned as an important factor why consumers would consider trying legumes that are processed with new technologies. Participants in the focus groups stated that it would be more encouraging for them to try these legumes if they offer superior taste than the conventional ones. This was also reflected in the survey where participants mentioned taste was one of the major factors why people consume legumes. These shows that people do not only want to eat healthy foods, but they also want it to be tasty. It would therefore be important that these emerging technologies can make legumes tastier.

High Pressure Processing (HPP), for instance, has been shown to better preserve the natural flavour and colour of foods compared to traditional heat treatments. According to Oey et al. (2008), have reported that HPP helped food products hold onto their aroma and colour, avoiding the flat flavours that sometimes result from boiling or other high-heat methods. Studies from (Yuan et al. 2025; Somogyi et al., 2025) have also reported that Ultrasound softens legumes while resulting in a texture that is smoother and easier to eat. Modern fermentation also plays a major role as Sawant et al. (2025) found that it reduces the strong beany taste many people dislike, while creating a richer and more complex flavours with better taste for these legumes.

Apart from taste, environmental concerns were also important for acceptance. Participants linked their willingness to try processed legumes with broader goals like eating less meat and helping the planet. Since legumes already have a low environmental footprint, using these energy efficient processing methods makes them an even greener choice. Belmiro et al. 2018; Rostamirad et al 2025) also found that ultrasound and pressure-based technologies help reduce energy use by cutting down cooking time making them a better option for eco-conscious consumers.

Cooking time was another significant factor in this study. Participants mentioned how the long cooking time of legumes discourages them from regular consumption. With most soaking for 12 hours even before stating to cooking. This shows a big concern and in line with research results from Affrifah et al., (2023) which reported that consumers avoid legumes due to their long cooking time. Technologies like ultrasound have been shown to significantly reduce cooking times. This makes legumes not just healthier, but also easier to fit into everyday routines. Similarly, HPP speed up preparation while improving how the legumes feel and taste, and this can be valuable for busy consumers who still want nutritious meals(Belmiro et al. 2018)

It is important to note that, if these technologies can improve the way legumes taste, reduce cooking times, and support sustainability, they can play a key role in helping people eat better and more often. For this to happen, consumers need to understand and trust how these technologies work and that starts with clear, science-backed communication.

Desire for Transparency and Simple Labelling

Both survey and focus group respondents were in favour of a clear, benefit-oriented labelling. (e.g., "Easier to Digest") was favoured over having too much technical terms which could deter them from buying. It is also important that a simple information about the processing be put on

labels as consumers would like to know why it is more beneficial than the normal legumes. previous research has also stated that the provision of information about tangible benefits is considered a key factor in consumer's acceptance. The use of consumer benefits such as nutrition, taste or even environmental gains is also more acceptable to consumers. (Sorenson & Henchion, 2011; Nath et al., 2019).

Other information tools like QR codes, social media and websites were seen as helpful secondary information sources with more detailed explanation for consumers to understand these technologies better.

Price and Willingness to Pay More

Though cautious, consumers are generally willing to pay more for enhanced legumes at a threshold of no more than 30%. This indicates that while consumers value the health and improved digestibility offered by these innovations, they are also very price sensitive and prefer the price to be the same or very slightly above the conventional legumes. This finding correlates Alsubhi et al. (2023), who reported 30.74% as the average consumers' willingness to pay premium for healthy foods. Though many people have argued for lesser price for healthier foods, research from Springmann et al. (2025) showed that reducing price of healthier foods leads to more consumption of these foods. These highlights the importance of maintaining cost competitiveness while marketing enhanced legumes. It is therefore important for policy makers and stakeholders in the food industry to find a common ground on prices which will be both helpful for all income classes of consumers.

Demographic trend

Despite a large section of the respondents being highly education, lack of awareness of emerging technology and antinutrients was widespread. This knowledge gap was consistent across all demography including geographical locations and educational levels. Interestingly, this lack of awareness existed despite the significant consumption of legumes among all demography, suggesting that consumption habits do not reflect the understanding of food science concepts or innovations.

This lack of awareness aligns with Hicks et al., 2019 result where even highly educated participants in his American survey had only 8% being aware of HPP. This further confirms that there is a disconnect between food industry advancements and consumer understanding. As statistical analysis in this study showed awareness of either antinutrients or emerging technologies positively impacts the acceptance of enhanced legumes, it is therefore very important to bridge this knowledge gap. To address this, targeted consumer education strategies must be developed with respect to demographic differences and regional contexts. Melios et al., (2025) in their study on demography variations in novel food acceptance, recommended customizing educational efforts to each population's cultural context, concerns, and informational needs to effectively boost acceptance. They advocated for broad-based educational initiatives such as integrating food technology into school curricula, government-led public awareness campaigns focused on food safety, and industry efforts to clearly explain how emerging processing methods work and the benefits they provide.

Other methods could be the use of non-governmental organisations (NGOs), adverts and even social media in educating consumers. Bridging this knowledge gap through an inclusive, well

targeted education could be the vital recipe for driving consumer acceptance of processed legumes.

5 Chapter 5

Future Application, Recommendation and Conclusion

5.1 Potential Applications of the Findings

5.1.1 For Manufacturers and Food Innovators

Product Development

Manufacturers should develop legume-based product that directly connects with consumer priorities such as digestive comfort, nutritional enhancement, food safety, environmental sustainability and taste. Familiarity with traditional practices increases acceptance and so, emerging technologies should be positioned as modern extensions rather than unfamiliar innovations. This type of position could reduce risk effects and increase consumer willingness to try them. This could gradually start with with modern fermentation and HPP consumers always prefer what they are familiar with.

Labelling Strategies

Label is a tool that can build trust. There should be transparency in the labelling of these legumes. Catch words like “Gentle on stomach”, could attract a curious buyer. Social media, websites and QR codes could also be used to explain the processes in detail.

Taste enhancement and functional optimization:

The importance of taste and cooking convenience, food scientists should work to enhancing taste profile and reduced preparation time. Enhanced legumes should have a better taste and cooking profile than the conventional legumes. Manufactures can also optimize this benefit as on the ways these legumes could be communicated for acceptance.

5.1.2 Implications for Public Health and Policy Makers

Consumer Education Campaigns

There is a clear need for a target consumer education program on antinutrients, legume digestibility and food technology. Public health agencies, NGOs, and even schools can collaborate to make emerging technologies unpopular and understood.

Governments Support through incentives

To promote healthier and more sustainable food choices, government can consider giving incentives such as tax reductions for these enhanced legumes. This could increase acceptance by reducing price sensitivity.

Price Regulation

With the sensitivity of price, it will be important for policymakers to regulate the price in a way that is beneficial to all income levels.

5.1.3 Reflection on Limitations

While this research provides valuable insights, several limitations must be acknowledged: Though the sample size of 123 was from diverse regions, it may not be statistically representative of global populations. There are also other antinutrients like saponins, tannins and processing technologies like microwaving. Dielectric heating that was not discussed in this research which would have been more insightful. Self-reporting bias could also happen from surveys and in the focus groups. Lastly, there are still many processed legumes in the market as it could be more accurate to get consumers ideas from what they could taste, feel or see.

5.2 Recommendations for Future Research

Given the limitations of these research, several avenues for further research are proposed:

Longitudinal studies to investigate how consumers' acceptance changes over time with increased exposure to tech-processed legumes.

Taste, digestive comfort effects, cooking time research of tech processed legumes should be explored to see how consumers react to them in practical scenarios.

Test the effectiveness of different labelling strategies in real markets which will compare scientific, simplified, and emotive styles in communicating food tech benefits.

5.3 Conclusion

This research was done to understand consumers' perception and acceptance of emerging technologies used in the reduction of RFOs and phytates in legumes.

Using a mixed method approach of both combining quantitative and qualitative focus groups discussions, this study explored how consumers, feel about these emerging technologies. The findings showed a lack of awareness of antinutrients and the technologies. When the benefits like health, safety, antinutrient reduction and environmental benefits, consumers demonstrated openness to try these legumes. Findings from the research show that as awareness and understanding of these technologies grew, consumers' trust also grew, enabling them to embrace these innovations.

Food safety, nutritional benefits, taste, environmental impact and familiarity with the technology were found as the major drivers for acceptance as these align with the needs and values of the respondents. Manufacturers, researchers, marketers and policy makers can leverage these drivers to encourage the acceptance of these technologies. Transparency, education and minimal labelling are also key for emerging technologies to succeed in the market. This is reflective for both the Swedish and global market.

These findings contribute to closing the knowledge gap between technological innovation and public understanding as it also emphasis the need for effect consumer education. By making technological developments in line with consumer expected values, emerging technologies have the potential to contribute immensely to encouraging legume consumption and more sustainable diets.

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7 Appendix

7.1 Survey questions

Consumer acceptance of technologies used for reducing stomach discomfort and low nutrient absorption caused by biomolecules in legumes

Survey Introduction & Purpose

Hello, and thank you for opening this survey!

I am Chikaodiri David Uche, a master's student of the EIT Food Systems at Lund University, Sweden. This survey is part of my thesis on how people feel about food technologies used to improve legumes like chickpeas, lentils, and soybeans.

These legumes contain natural compounds such as Phytates, which can block nutrient absorption, and Raffinose Family Oligosaccharides (RFOs), which can cause flatulence (farting) and bloating. Scientists are exploring safe, non-GMO methods to reduce these compounds and make legumes more nutritious and easier to digest.

This survey takes about 10–15 minutes, is completely anonymous, and is used for research purposes only. Your input will help shape healthier and more sustainable food options.

Thank you for your time!

Screening Questions

How frequently do you consume legumes? (Chickpeas, beans or lentils)

Daily

2-3 times a week

Once a week

2-3 times a month

Rarely or never

Which legume do you consume most?

Lentils

Chickpea

Beans

Other

Why do you eat legumes? (Select all that applies to you)

Vegan/ Vegetarian

I want a diverse nutrition

Legumes are healthy

Environmental consciousness

Taste

Other

Have you ever experienced digestive discomfort (e.g., bloating, gas) after consuming legumes?

Yes, frequently

Sometimes

No

Has this discomfort affected your choice of eating legumes?

Yes

No

Maybe

Were you aware before now that phytates can reduce nutrient absorption in legumes and RFOS can cause stomach discomfort and gas?

Yes

No

If you experience digestive discomfort, how do you usually address it? (Select all that apply)

I soak or sprout legumes before cooking

I consume digestive aids (e.g., probiotics, enzymes)

I avoid eating legumes

I am not concerned about digestive discomfort

Perception of Traditional and Other Processing Technologies

Researchers are exploring other technologies to reduce Phytates and RFOS. In this section, we shall look at these technologies with a short description of each. Kindly share your thoughts about what you think of them.

Are you aware of any of these food processing techniques: vacuum impregnation, high-pressure processing (HPP), ultrasound processing, and pulsed electric fields (PEF) ?

Yes, I am familiar with some of them

No

If yes, which one(s). Choose all that apply

High Pressure Processing

Vacuum Impregnation

Pulse Electric field

Ultrasound

High-Pressure Processing (HPP)

Uses high-frequency sound waves, which are non-toxic, to inactivate phytates and RFOs while maintaining taste and nutrition.

How willing are you to try legumes processed with this method?

Definitely willing

Somewhat willing

Neutral

Somewhat unwilling

Definitely unwilling

Vacuum Impregnation

Through pressure changes this process replaces air in legumes with food enzymes for better digestion. This is a healthy method for removing phytates and RFOs and in legumes.

How willing are you to try legumes processed with this method?

Definitely willing

Somewhat willing

Neutral

Somewhat unwilling

Definitely unwilling

Pulsed Electric Field (PEF)

Uses short electrical pulses to break down phytates and RFOs without producing harmful by-products while keeping the legumes fresh.

How willing are you to try legumes processed with this method?

Definitely willing

Somewhat willing

Neutral

Somewhat unwilling

Definitely unwilling

Ultrasound Processing

Ultrasound treatment uses high-frequency sound waves to disrupt cellular structures, aiding in the reduction of phytates and RFOs.

How willing are you to try legumes processed with this method?

Definitely willing

Somewhat willing

Neutral

Somewhat unwilling

Definitely unwilling

A traditional, but modernized technology that can be used for this same purpose in legumes is fermentation. How familiar are you with fermentation as a food processing method?

Very familiar

Somewhat familiar

Not familiar at all

Modern fermentation allows for controlled microbial activity, improved safety, and predictable nutritional enhancement in legumes. Which of the following do you feel more comfortable with as a processing method for these legumes?

Modern Fermentation

Other technologies (like ultrasound, PEF, etc.)

No preference

I'm not comfortable with either

Which of the following factors would influence your acceptance of food products made with emerging technologies? (Select all that apply)

Food safety

Health benefits

Naturalness of the process

Environmental impact

Scientific backing

Brand or manufacturer trust

They are not GMOs

Willingness to Try and Purchase

If these technologies made legumes easier to digest and nutritious, would you buy them?

Definitely

Probably

Not sure

Probably not

Definitely not

If a food label mentioned that legumes were processed with any of these technologies to reduce anti-nutrients, how would you react?

I would be more likely to buy it

I would need more information before deciding

I would be sceptical

I would avoid it

Other

What type of information would encourage you to try these processed legumes? (Select all that apply)

Scientific studies proving safety and benefits

Recommendations from health professionals

Labels emphasizing naturalness and minimal processing

Information about sustainability and environmental benefits

Would you be willing to pay a higher price for legumes processed with emerging methods if they had improved digestibility and health benefits?

Yes

No

Maybe

Demography

For the quality of this research, basic information about respondents' background is important. This data is only used for the analysis of the survey and will not be stored.

Country of Residence

Choose

Continent of birth

Choose

What is your highest level of education

Highschool

Bachelors

Masters

Doctorate

Other

Do you have any additional comments or concerns about consuming legumes processed with modern technologies?

Your answer

Back

Submit

7.2 Figures from online survey.

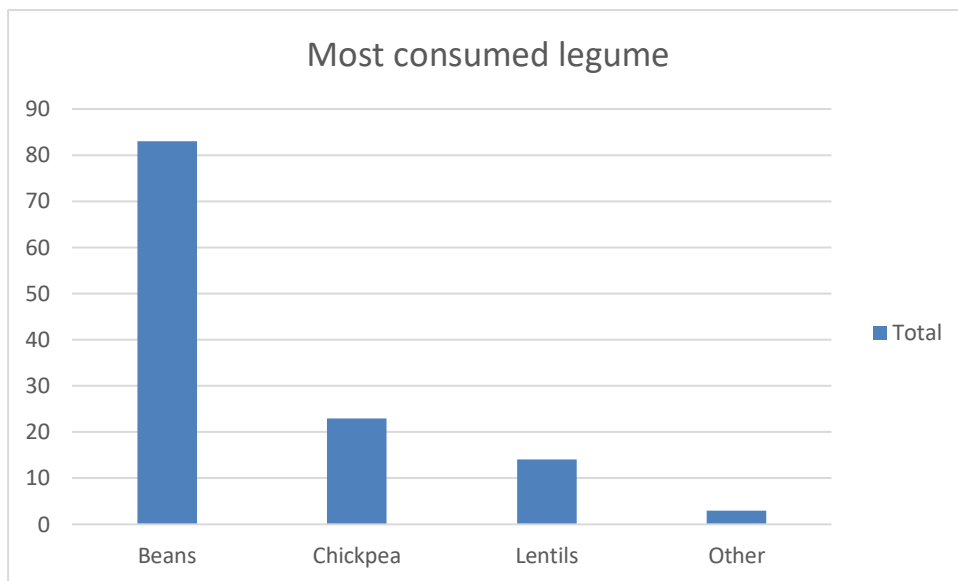


fig.7.1. *Legume consumption preferences among participants*

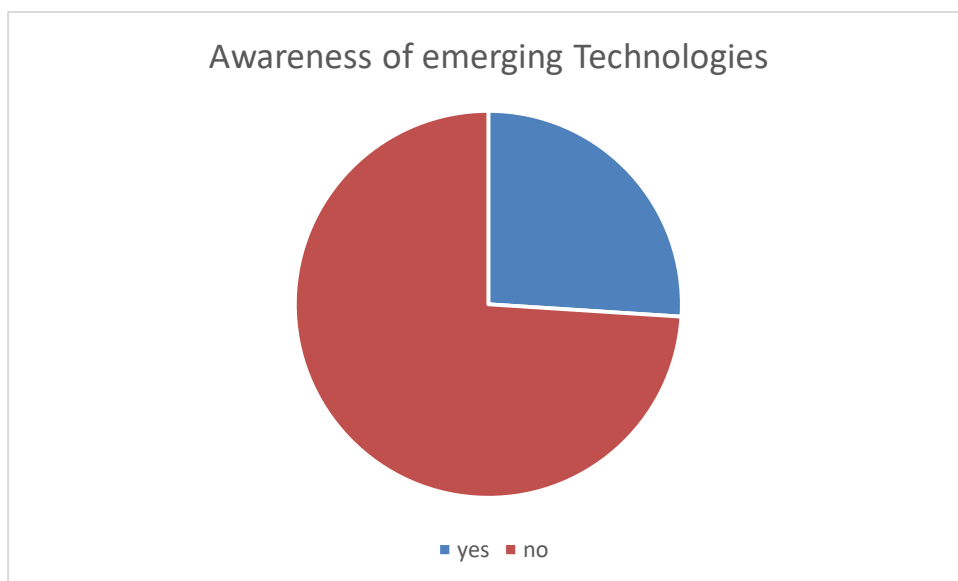


Fig 7.2. *Awareness of emerging technology*

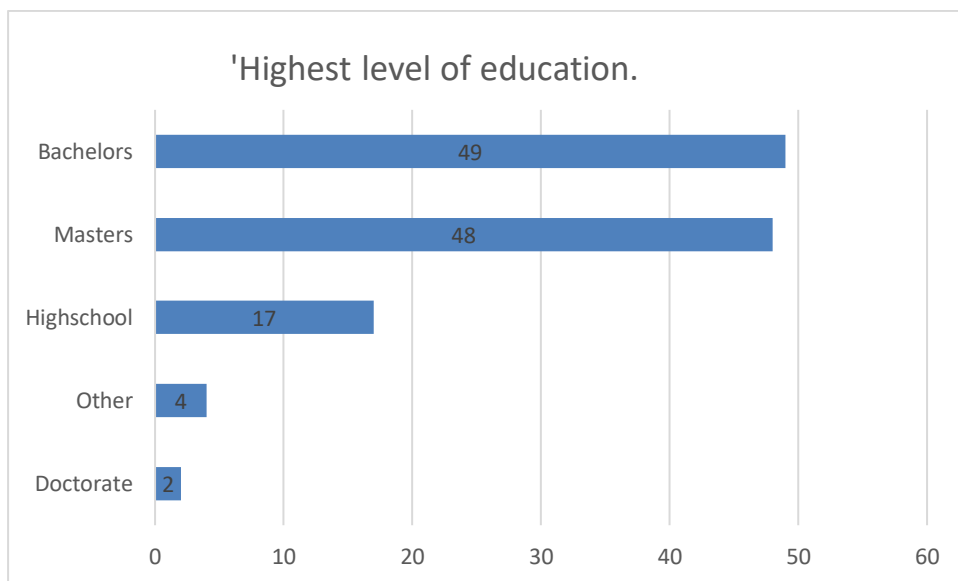


Fig 7.3 Educational Levels among respondents

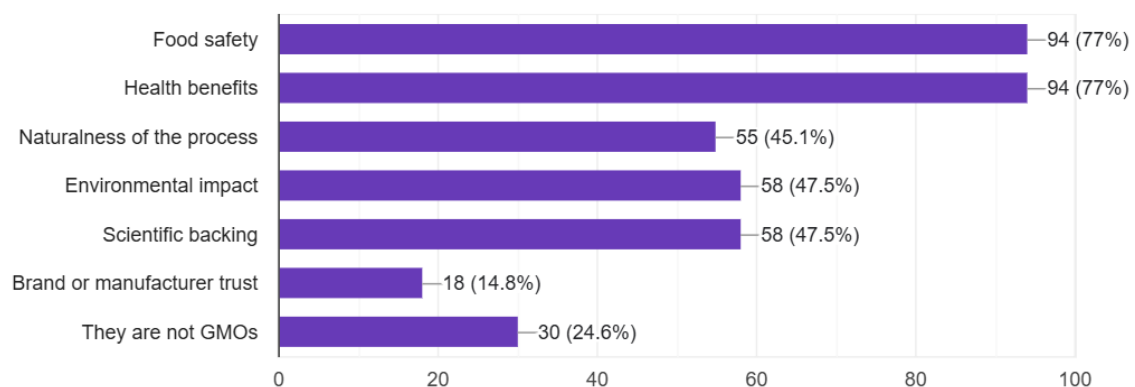


Fig 7.4 Drivers for consumers' acceptance of tech processed legumes

7.3 Focus Group Questions.

Section 1: General Perception of Legumes and anti-nutrients

1. Can you describe how often you eat legumes like chickpeas, lentils, or beans?
2. Do you know that anti-nutrients can affect nutrient absorption or cause gas?
Have you experienced this kind of discomfort?
3. If these compounds could be reduced through processing, would that make

you more likely to eat legumes more often?

Section 2: Introducing Processing Technologies4. What are your first impressions of hearing about technologies like:

1. Pulsed Electric Field (PEF)
2. High-Pressure Processing (HPP)
3. Ultrasound Processing
4. Vacuum Impregnation (VI)
5. Fermentation

4. What are your first impressions of hearing about technologies like:

1. Pulsed Electric Field (PEF)
2. High-Pressure Processing (HPP)
3. Ultrasound Processing
4. Vacuum Impregnation (VI)
5. Fermentation

5. Do these sound like safe and natural ways to process food? Any differences between the methods?

6. Would you be willing to try legumes processed with any of these methods? Why or why not?

7. What would make you feel confident about trying legumes processed with one of these methods? Do you think there could be any future effects in the long run due to these technologies?

Section 5: Product Expectations and Labels

8. Would you prefer legumes that are sold ready-to-eat (e.g., in a can) or raw but improved (e.g., cook faster, easier to digest)?

9. Would you want to see information on the package about the technology/ies used to trust the product, if yes, what type of information?

Section 6: Final Thoughts

10. Is there anything else you'd like to share about legumes, processing technologies, your preferences or anything else that would influence your buying decision?