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Acceptance of human excreta derived fertilizers in Swedish grocery stores

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ABSTRACT

Safe recycling of nutrients found in human excreta back to agriculture is an important component of a circular economy that can protect waterways and stabilize food prices. Although many technological advances for the recovery of these nutrients exist, large-scale implementation is lacking. A commonly cited barrier is a lack of acceptance of fertilizers from human excreta and for food products grown with such fertilizers. The food retail sector, as an intermediary between producers and consumers, is an important actor with power to influence opinions and purchasing practices. In this study, we surveyed 127 food retailers (stores) and reviewed publicly available retailer sustainability policies to assess acceptance of the use of recycled fertilizers. We gauged acceptance of three products relevant for the Swedish market – struvite, phosphorus from ash, and dehydrated urine. Most respondents felt that all three recovery techniques were unlikely to be harmful either to themselves or to the environment. It was more acceptable to use products further away from human consumption. In general, struvite and phosphorus from ash were perceived more positively. Acceptance of wastewater-derived fertilizers was largely dependent on perceived risks, especially the fate of pharmaceutical residues. While retailers in Sweden are not negative to reuse, they seem unlikely to provide strong support for nutrient recirculation from human excreta unless it becomes a greater concern for the public.

Introduction

Human activity has a great impact on the biogeochemical cycles of our planet, regionally and globally [21,47]. We increase local nutrient supply, in particular nitrogen, phosphorus, and potassium, with synthetic fertilizers and disrupt nutrient cycles by transporting food and fertilizers across the globe [46,3,23]. Our global mismanagement of nutrient cycles has already led us to exceed boundaries for what is likely to destabilize the ecosystems of the earth, our life support system [67,48]. An important step towards creating a sustainable society is learning to effectively (i.e. (efficiency, circularity, equity, and resiliency) manage our nutrient streams. The production of synthetic nitrogen fertilizer, via the Haber- Bosch method is energy demanding and leads to large greenhouse gas emissions [40]. Losses of nitrogen and phosphorus, via runoff and erosion from crop and animal agricultural lands or via insufficient treatment of wastewaters in cities, contributes to eutrophication and algal blooms in fresh waters and coastal ecosystems [17,50]. At the same time, removal of nutrients from wastewater also demands energy and chemical use. Human feces and urine are nutrient rich and can, similarly to manure from animals, make an excellent natural fertilizer [70]. Capturing and reusing nutrients from wastewater and excreta can potentially replace 20–100 % of current chemical fertilizer use depending on the country [60], decrease carbon dioxide emissions from wastewater treatment plants (Jönsson 2019), and ameliorate problems of eutrophication [34].

There are many technologies available to recover nutrients from the wastewater systems and research in this field is rapidly increasing [24]. The most common practice in many parts of the world is reuse of sewage sludge. However, the presence of pollutants such as heavy metals, pharmaceuticals, and other chemicals from society in sludge has led to resistance from industries and consumers to the use of sewage sludge in agriculture [32]. Alternative recycling methods, which minimize pollutants in the final product, include techniques for stripping nutrients from combined and source separated waste flows. For example, through the precipitation of phosphate minerals in the form of struvite or through incineration of sludge and chemical extraction of phosphorus from the ash [55,24]. The majority of heavy metals and chemicals in wastewater come from greywater and industrial fractions, while the majority of nutrients are found in urine and feces [30]. Source separation can capture most of the nutrients in a significantly smaller volume

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that is easier to treat to a safe product. For example, source separation of urine and subsequent alkaline dehydration of it results in a dry, nutrient-rich powder that is free from pathogens [56].

Despite technology advances in nutrient recovery from wastewater, the practice remains poorly implemented. Acceptance for using nutrients recovered from human excreta, or how public and private actors perceive public acceptance, has been identified as one of the largest challenges to overcome before increased progress can be made [73]; Ekman and Wallsten, 2021; [25]. The issue of acceptance is impacted by a general unwillingness to handle human excrement, as it smells bad and is potentially dangerous [72]. This has also led to an adverse reaction to including it in a policy or strategies that might incentivize circular nutrient systems [15]. Understanding what influences acceptance is thus an important, and growing, research area.

It is worth noting that a majority of existing studies looking at acceptance find that at least 50 % of the respondents are open to the idea of recycling. Yet, the acceptance of fertilizers derived from human excreta is also shown to be dependent on risk–benefit considerations for both farmers and consumers [36,58,65]. Among survey or interview responses in these studies, the most commonly identified risks are the spreading of disease by pathogens and potentially harmful effects of medicinal residues, such as pharmaceuticals, hormones, and antibiotics [36,38]. Other important factors affecting acceptance are feelings of disgust, shame, concerns about legal accountability and, in some studies, personal environmental views [33,61,58].

There are many human action theories, and no one theory addresses all factors that influence behavior or outcomes [19]. Acceptance is influenced by factors that operate internally to an actor, as well as the system they are positioned in. The disconnect between knowledge and strong feelings (e.g., yuck factor or fear) may mean that individual psychological factors, not simply information, may be a driver or hindrance for acceptance. Segrè Cohen et al. [58] put forth that it is thus important to ask questions about value orientations, affect and disgust, judgements about risks and benefits, and perceived naturalness to better understand consumer acceptance of emerging nutrient recovery technologies. The same group however, also acknowledges that the method of information delivery can influence acceptance [57]. Accounting for the above factors, the work of Segrè Cohen et al. [58] falls within the *Independent* metatheory, and more aligned with the *Independent Self* subcategory of human action in which personal attitudes are assumed to cause behavior [19].

Previous acceptance studies have focused on the attitudes of farmers and consumers. While many farmers were neutral or positively inclined towards nutrient recycling, they often pointed out the reluctance of food industries to purchase food fertilized with sewage sludge (e.g., [4]). Without a guaranteed buyer for their produce, farmers may be unwilling to use innovative fertilizers. Thus, the food industry, including processors, certification bodies, and retailers, has often been pointed out as a bottleneck to circular nutrient systems [4,41]. In addition, the food retail sector has been identified as having the power and opportunity to influence the attitudes and habits of their customers [20]. Large retailers affect food choices both in what they buy from suppliers and how they manage what they sell to customers, thus influencing consumer preferences and acceptance of different foods [13]. However, the food retail sector's view on fertilizer derived from human excreta has been poorly explored. This study thus seeks to investigate the acceptance of fertilizer products derived from wastewater among actors from the food retail sector.

The aim of this study was to assess the acceptability of human excreta derived fertilizers, as a way to gauge the readiness of Swedish food retailers to promote nutrient recycling as part of a sustainable food system. We used a survey that includes two axes of comparison: fertilizer product (use of dehydrated urine, struvite, and phosphorus from ash) and type of agricultural application (food, animal feed and nonedible plants). The survey was distributed to Swedish grocery stores and filled out by purchasing department staff.

Case information

This study was contextualized based on the Swedish food retail sector and using examples of human excreta derived fertilizers that are relevant to the Swedish context.

Swedish food retail landscape

Three major companies (ICA Sweden AB, Coop Sweden AB, and Axfood AB) dominate the food retail landscape in Sweden. Together these companies accounted for about 90 % of the Swedish market in 2019 [16]. ICA Sweden AB is the leading food retailer with around 1 300 stores and approximately 52 % of the market [1]. ICA stores are operated on a franchise basis with each store owner managing their own store so that they can adapt to local customer needs. Axfood AB is the second largest retailer with 18 % of the market. They are a family of distinctive store concepts, including chains Willys, Hemköp, Tempo, and Handlar'n. Coop Sweden AB is a cooperative chain that is owned by their 3.7 million members. They operate approximately 800 stores in Sweden, representing 18 % of the market. The remaining market share is split between Bergendahls Food AB and Lidl Sverige KB with just over 5 % of the market each. All Swedish retailers have developed their own food brands, often where they control the entire supply chain from farmers, proceeding to distribution. They thus have the potential to influence on-farm practice, including the use of nutrients.

All three of the major retailers have company strategies aimed at increasing sustainability in their operations. ICA Sweden AB has a sustainable development strategy that works to contribute to local communities, minimize environmental impacts (primarily related to climate), improve public health, contribute to a more inclusive society, and ensure quality and social responsibility [28]. Nutrient management is mentioned in policy documents in relationship to challenges within modern agriculture systems, e.g. use of pesticides, low biological diversity, and nutrients losses [27]. Axfood AB has a vision of providing affordable, good, and sustainable food. Relevant for this study, the Axfood strategy mentions problems with nutrient cycling and eutrophication caused by nutrient losses in the system, as well as the energy demand required to produce synthetic fertilizers [2]. Their sustainability program states that they will work towards a sustainable use of chemicals and a smart use of resources. Sustainability and social responsibility are key platforms in the company strategy of Coop Sweden AB. Coop has introduced a sustainability declaration for their products, with ten different measures, including eutrophication, pesticide use, climate relevant emission, water use and soil fertility [12]. Nutrient recycling is not explicitly a focus in any of these policies, but is related to several issues of concern, namely eutrophication, synthetic fertilizer use, and soil fertility.

Human derived fertilizers

This study focused on the acceptability of three human derived fertilizers. These fertilizers were chosen based on their level of development and relevance for Swedish conditions. Due to resistance to the use of sewage sludge [66], this study has thus chosen to focus on human derived fertilizers that extract nutrients from wastewater in cleaner forms than sewage sludge (Fig. 1). Precipitation and extraction of struvite from wastewater and recovery of phosphorus from sewage ash are the nutrient recovery techniques with the highest levels of technical readiness [24]. These two techniques were chosen because they target nutrient recovery at different stages of the wastewater treatment process, namely from liquid fraction and from the sludge. They are also currently piloted in Sweden. Finally, a third fertilizer product was considered that aims to withdraw nutrients before they even enter the wastewater treatment plant, namely dehydrated urine [64].

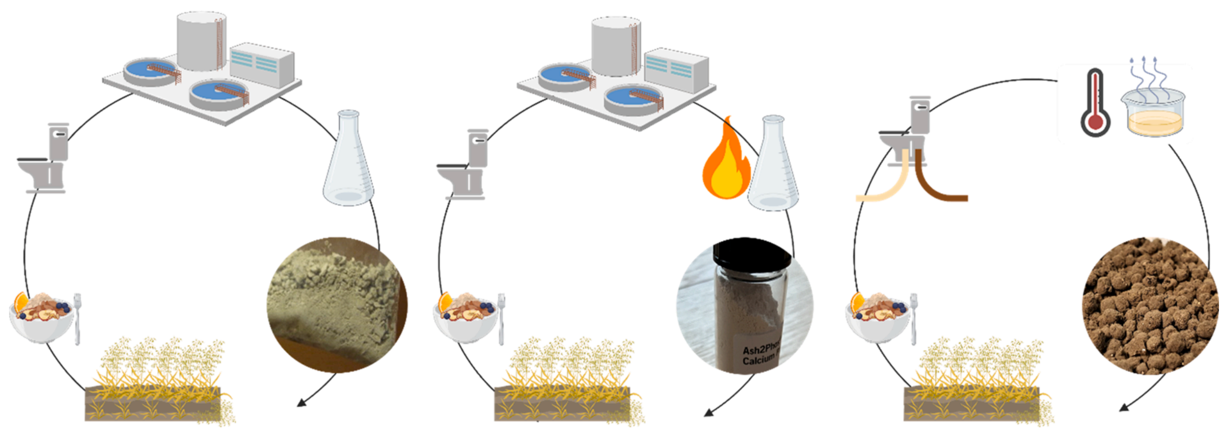

Fig. 1. Schematic system overview for the production of the three human derived fertilizers used in the survey. Created with BioRender.com and pictures from the authors.

Struvite

Struvite ($MgNH_4PO_4 \cdot 6H_2O$) is a crystal of magnesium, ammonium and phosphate which forms under alkaline conditions [51]. Spontaneous struvite formation occurs in wastewater treatment plants and can form crusts that block pipes and valves [43]. Controlled precipitation of struvite can reduce maintenance problems at the plant and produce a fertilizer. To ensure crystallization and removal of struvite in a controlled manner, a source of magnesium, e.g. magnesium chloride, is normally added [51]. Precipitated crystals are collected, washed, and dried into a crystalline fertilizer product. The finished product contains low levels of medical residues [14], only trace heavy metals and no pathogens [42]. Pathogens are inactivated following proper drying of the struvite [5]. Recovery of nutrients may vary depending on how the process is operated. According to Rahman et al. [51], approximately 90 % of phosphorus can be recovered by struvite precipitation and Cho et al. [10] found that approximately 30 % of nitrogen may be extracted from the wastewater stream (noting that the majority of the phosphorus in a treatment plant will end up in the solid/sludge fraction, not the wastewater fraction). Different studies however vary between 50 and 80 % for phosphorus recovery [59]. Münch & Barr [43] report a nitrogen recovery rate of 6 %. In the survey, we used conservative recovery rates of 55 % phosphorus and 30 % nitrogen (see S.1.2).

Phosphorus from ash

This fertilizer is a calcium phosphate that is extracted from sewage sludge. First, the sewage sludge is dried and incinerated and the ash collected. The Ash2®Phos process patented by EasyMining [18] was chosen as a representative of various methods for extracting phosphorus from the ashes of incinerated sludge. Calcium phosphate is leached from the sludge ash with hydrochloric acid and lime [11]. Heat produced during incineration may be used for drying the sludge [68]. Heavy metals are removed in the process and pathogens and medicinal residues degraded during incineration [11]. Approximately 90–95 % of the phosphorus entering a wastewater treatment plant can be captured using this technique, though no other nutrients are recovered [71]. Nitrogen is lost to the atmosphere during incineration of the sludge [22].

Dehydrated urine

The majority of nutrients in domestic wastewater originate in urine, e.g. 80 % of nitrogen, 55 % of phosphorus, and 60 % of potassium [30]. Separate collection of urine before it is mixed with the rest of the wastewater is therefore an efficient way to collect nutrients, as well as reduce nutrient loading on treatment plants [53]. Dehydrated urine is produced by mixing source-separated urine with ash or lime to increase the pH, thus inhibiting hydrolysis of urea and loss of nitrogen to the atmosphere [52]. The urine is then dried at elevated temperatures. Thus, the process requires energy input. Urine does not normally contain pathogens, but it may be contaminated by feces during collection [26]. Levels of heavy metals in urine are also low [31]. Studies have shown that urine dehydration safely inactivates pathogens [56]. Of arguably larger concern is that pharmaceutical residues are found in urine, posing a potential ecological risk [37]. While dehydration may degrade these residues, there is uncertainty in the degree of degradation and further studies are needed [63]. Dehydratation of urine has been shown to capture up to 100 % of the phosphorus present in urine [64]. In the survey, we stated that dehydrated urine could capture 75 % [56] of the nitrogen and 55 % of the phosphorus from wastewater.

Methods

Development of the survey

The survey was modeled on a similar survey conducted in the United States to assess the consumer acceptance of fertilizers derived from urine [58]. First, demographic data, including gender, age, and education level and attitude information, specifically whether environmental issues were personally important to them, were collected. The centerpiece of the survey was a series of short primers about each of the three different human derived fertilizers. Respondents were shown a schematic (Fig. 1) of the production process for each fertilizer and a short text describing it, including the main advantages and disadvantages (see supplemental information SI.1). All three fertilizers were presented to each respondent; however, the order in which they were presented was randomized in order to avoid bias [54]. This was done using a randomizing question (question 5) in the survey. Following the short primer on the fertilizer, respondents were asked seven questions regarding whether the product was perceived as potentially harmful for human health or for the environment, if the product could benefit the environment, and in which types of agriculture the fertilizer product would be acceptable to use in (Table 1). Responses were recorded on a seven-point Likert scale, with the endpoints labeled as strongly disagree and strongly agree, respectively. The use of the Likert scale as an interval rather than ordinal points is supported by other studies [8]. The midpoints were not labeled due to limitations in the survey software (Google Forms), and to facilitate viewing for people opting to take the survey on a mobile device. The seven questions were repeated for each human-

Table 1
Overview of survey question types, including the order in which questions were asked. The middle section regarding the different fertilizers was repeated with identical questions for each fertilizer. The 7-point Likert scale was from (1 Strongly disagree – 7 Strongly agree). The order in which the fertilizers were presented was randomized with the help of a multiple-choice question, number 5, in which the respondent was urged to pick the topmost answer among alternatives that were randomly ordered.

Question		Answer type
Demographic & attitude questions		
1	Gender	Multiple choice
2	Age	Multiple choice
3	Education level	Multiple choice
4	Environmental questions are important to me personally	7-point Likert scale
5	Randomizing question	Multiple choice
Questions following on human derived fertilizer (repeated for each fertilizer)		
6	Use of [this] will be harmful for the environment	7-point Likert scale
7	Use of [this] will be harmful for my health	7-point Likert scale
8	Use of [this] will overall be positive for the environment	7-point Likert scale
9	It is acceptable to use [this] to grow inedible plants such as flowers, trees, and grass	7-point Likert scale
10	It is acceptable to use [this] to grow food only eaten by animals	7-point Likert scale
11	It is acceptable to use [this] to grow food for people to eat	7-point Likert scale
12	I would be willing to eat food grown with [this]	7-point Likert scale
Prioritization in purchasing		
13	Rank the following factors after how important they are to you when purchasing food (profitability, origin, environmental impact, food safety, other)	Ranking, 1–5

derived fertilizer.

Following the questions regarding the human derived fertilizers, a final question asked respondents to rank a set of factors based on how they influence purchasing choices. The factors included profitability, origin, environmental effect, food safety, and "other". A free text field was then provided to specify other priorities if needed. The complete survey can be found in the SI section S.1.1 in Swedish and S1.2 in English.

Survey distribution

The survey was originally sent via email to section managers at ICA, Axfood and Coop who were willing to forward it on to their staff. Section managers are those responsible for procurement of food for different types of food within each company (e.g., dairy, fruits and vegetables, non-perishables). Of the eight managers we could get contact information for, five responded, three of which forwarded the survey. The survey was sent out twice within two weeks. While this distribution method should have reached approximately 450 people, it resulted in only six responses. Attempts were also made to reach procurement sections at Lidl and Bergendahls, unfortunately unsuccessfully.

As the survey did not work at the centralized management level, it was slightly reformulated to target individual storeowners and managers across Sweden. The survey was distributed to all grocery stores for which individual email addresses could be found: 1 240 ICA stores, 188 Hemköp (Axfood), 171 Handlar'n (Axfood), 112 Tempo (Axfood) and 41 Bergendahls stores. This list excludes Willy's (Axfood), Coop and Lidl, since these stores do not have individual email addresses. A central request was made to these companies; however, they all declined to distribute the survey. In total, 1 752 stores were contacted. Of these, 64 emails failed to deliver, resulting in 1 688 receivers. This distribution yielded 136 responses (8 % response rate), of which 110 came from ICA stores.

Data analysis

Survey results were analyzed and visualized in R using RStudio (RStudio Team 2021). Likert data was handled with the Likert package [6] and tables were constructed with the reactable package [39]. The answers for the Likert scale questions were compared by testing the difference between mean responses among fertilizers with an analysis of variance (ANOVA) followed by a Tukey post-hoc test. Likert ratings were treated as interval data on a seven-degree scale between 1-Strongly disagree and 7- Strongly agree. The p-value associated with each test is a probability that the result is indeed from the same population; a p-value below 0.05 thus signifies that the probability of the difference among tested groups occurring through random sampling of a larger population is less than 5 percent. We used an ANOVA with Tukey post-hoc to adjust p-values to analyze differences in answers depending on individual respondents' environmental importance and for the order of sections answered given we were comparing more than two groups and because the groups were not equal in size.

Demographic data was analyzed using Welsh two sample t-tests and Chi square tests. The Welsh two sample *t*-test was used to examine how education and age related to acceptance of the three fertilizer products. The Chi square analysis looked for differences in education level between genders and correlation between responses of personal importance of environmental issues and ranking of importance of environmental effects for purchasing behavior. For example, respondents were grouped in low (1–5) or high (strong agreement, 6–7) regarding personal importance of environment. A Pearson's chi-squared test was then used to look for differences in responses between those two groups. In this study, we consider a p-value below 0.05 to indicate statistical significance across our tests.

Finally, we reviewed policy documents/websites from the retailers in order to contextualize the data (retailers' sustainability policies) - policy descriptions in section 2.1 are given to set the landscape for the reader.

Limitations

The distribution of the survey, and thus the number of respondents, as well as the diversity of companies represented, was dependent on the willingness of managers within the organizations to distribute it to their co-workers. Several section managers replied to us that they receive many surveys and were thus unwilling to distribute yet another survey to their team. In general, individual contact information was available to a larger degree for ICA stores, thus more individuals from ICA were contacted, leading to an overrepresentation in the results. This is due to their business model where each store is owned by individuals. Distribution of the survey was thus uneven and may bias results. In addition, even though we reached out to procurement officers in food retail, responses are hard to differentiate between individual preference and company policy. In order to compensate for this, we included a review of company policy document in our discussion of the results.

While the design of the survey allowed us to compare acceptability between products, the amount of information in the survey may have influenced response rates, e.g. participant attention decreased or new information changed opinions. Thus, the order in which the three human-derived fertilizers were presented in the survey affected the results. For example, dehydrated urine received a more positive rating for five out of seven questions if it was presented first rather than the second or third. For phosphorus from ash, four questions were rated more negatively if it was the first fertilizer presented. Responses to struvite were not statistically affected by the order for the presentation (see section S.1.3, Tables S1-S3). Using a between-subjects design (wherein each participant is only asked about one fertilizer alternative) may have mitigated those impacts. However, such a design would have come with its own challenges, namely requiring a larger sample size, and results would not have been comparable with the survey studies we based our work on.

The presentation of information about each technology option may have also influenced responses. Although we tried to keep the level of detail and presentation among the three options the same, we also needed to show differences. In the case of dehydrated urine, we opted to show a picture of a urine diverting toilet as this is a key part of the infrastructure required. However, in the two other technologies we used a toilet icon. This could have inadvertently created a stronger negative response to the dehydrated urine option. Similarly, we used the word urine (which has a clear link to human excreta) in only one option, which could have had a negative influence on acceptance.

Results

Response rates

There were 127 respondents answered the entire survey, with a few neglecting to answer one or two questions, and 15 who received the survey did not consent to take the survey (so 142 responses in total). The majority of responses (80 %) were from ICA, followed by Axfood with 21 responses (17 %), and only one and three responses from Bergendahls and COOP respectively. No difference could be seen between answers for respondents from ICA and from other companies combined.

Importantly, some respondents conveyed that lack of knowledge on the subject made it difficult to answer the survey correctly. Although such feelings of lack of knowledge did not always result in a respondent refusing to answer questions, respondents did communicate this via the comments section of the survey (4/8 comments received were about insufficient knowledge) or via direct email contact (8/26 emails).

Comparison between fertilizer types

Overall, struvite and phosphorus from ash were perceived more positively (Fig. 2 and Table S4). Most respondents disagreed with the statements that the use of the three products would be harmful either for the environment or for themselves (top 2 questions in Fig. 2, Table S5 for mean and standard error for the answers). However, disagreement was stronger for phosphorus from ash and struvite than for dehydrated urine. More specifically, respondents thought struvite was less harmful to the environment than urine (Table S4, $p \leq 0.05$), and were consistent when the question was flipped (i.e., they thought that struvite had a better overall impact on the environment when compared to urine, $p \leq 0.01$). Struvite and ash were also perceived as less harmful to their own health than urine (Table S4, $p \leq 0.01$). In what order the sections were answered had an effect for dehydrated urine, where those that answered this section first were more positive than those that started with one of the other products (see section 2.5 Limitations).

Comparison of agricultural application

The use of products derived with all three techniques on inedible plants were considered largely acceptable (Fig. 2, Table S4). For use on food for animals, humans, or for the respondents themselves, dehydrated urine was considered less acceptable than struvite or phosphorus from ash, which ranked similarly (Table S4 $p \leq 0.0001$).

Indeed, respondents were more accepting of human derived fertilizers farther from human consumption (Table 2). Testing the acceptance of the different uses for each technique separately showed that the respondents were significantly more positive to use of struvite or dehydrated urine on inedible plants than for animal feed. Responses were more positive towards use on inedible plants than for human consumption, and more positive for use on animal feed than for human consumption for all fertilizers. There was no difference between the respondents' acceptance for use on crops for human consumption and their willingness to eat food grown with any given product.

Factors affecting purchasing decisions and individual acceptance of techniques

Food safety was ranked as the most important factor affecting food purchasing decisions (Fig. 3). Here, 63 % of respondents ranked food safety as their top concern, followed by environmental impact, origin, and profitability, respectively. In one case, a respondent rated the quality and the taste of food being the most important factor for purchasing food.

In the overall survey comment section, two respondents mentioned that their answers were related to potential problems with medicinal residues, with one of them specifically mentioning antibiotic resistance as a worry. One respondent expressed concern on the spreading of diseases and noted that it was important with clarity in the processes involved. One respondent expressed they felt no problem with using excrement as fertilizer if it uses less resources than industrial production. Respondents that rated environmental questions higher, as a six or

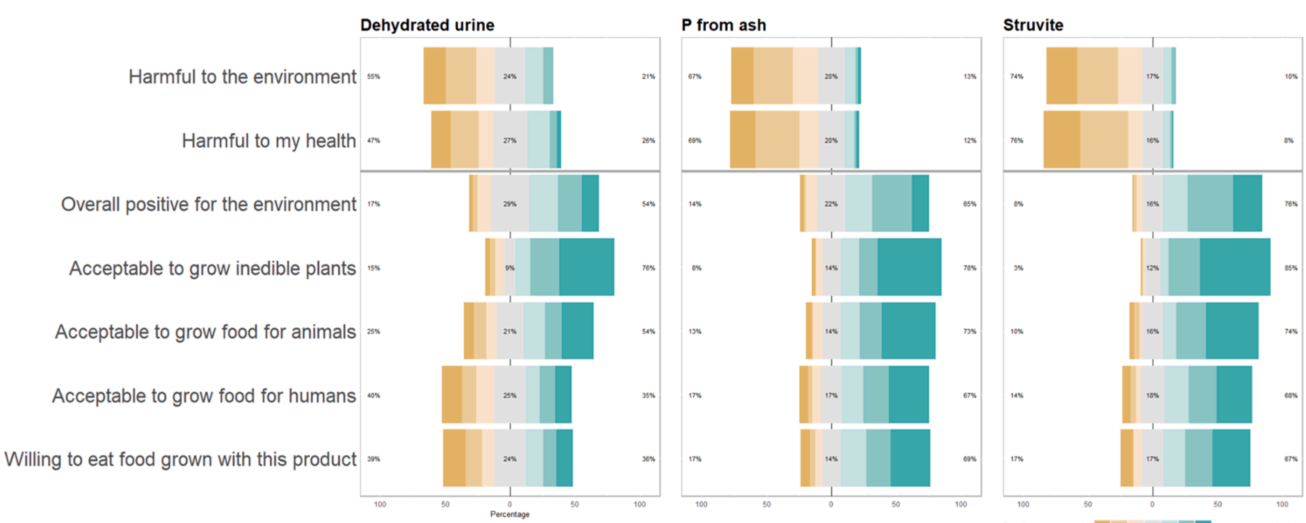

Fig. 2. Responses to the Likert scale questions concerning dehydrated urine (left panel), phosphorus from ash (middle panel), and struvite (right panel). The response scale is from 1: Do not agree at all, to 7: Agree completely. Note that the phrasing of the first two questions differ from the rest (above the thick gray line), here a 'negative response indicates that respondents are more favorable to the use of nutrients derived from each technique. The percentages are the proportion of respondents that answered negatively (left of each panel), neutrally (middle of each panel), and positively (right of each panel) to the specific question.

Table 2
Comparing the acceptance of different uses of the three techniques by ANOVA. A positive value signifies that the first mentioned use of the fertilizer is rated more acceptable than the second. P-values (adjusted using the Tukey method across 4 estimates) below 0.05 are bolded. 95 % confidence interval is also presented.

Question	Tech	Mean of *diff.*	95 % CI low	95 % CI high	P-value
Inedible plants against animal feed (3)	*Dehyd. urine*	0.92	0.52	1.32	**0.000**
	Struvite	0.56	0.24	0.88	**0.000**
	P from ash	0.28	−0.03	0.58	0.098
Animal feed against crops for human consumption (3)	*Dehyd. urine*	0.71	0.31	1.11	**0.000**
	Struvite	0.43	0.12	0.75	**0.003**
	P from ash	0.36	0.05	0.67	**0.014**
Inedible plants against crops for human consumption (3)	*Dehyd. urine*	1.63	1.23	2.03	**0.000**
	Struvite	0.99	0.68	1.31	**0.000**
	P from ash	0.64	0.33	0.95	**0.000**
Crops for human consumption against personal willingness (3)	*Dehyd. urine*	0.10	−0.30	0.50	0.921
	Struvite	−0.03	−0.29	0.35	0.994
	P from ash	−0.01	−0.30	0.32	1.00

seven, (73/127 respondents) were more likely to rank environmental impact as important to their purchasing decisions ($p = 0.05$).

Respondents that rated environmental questions of higher personal importance saw greater benefit to using struvite and phosphorus from ash (Table S6). There were few significant differences between those who ranked the environment as important, and those who did not. This 'environmental' response group thought that ash was less likely to be harmful to the environment or their health than respondents who did not rank environmental questions as important to them ($p \leq 0.05$). Additionally, the 'environmental' group found dehydrated urine to be less acceptable for human consumption.

Demographics can also drive response patterns, although in our dataset we could not detect a strong influence on acceptance. Most of the respondents were men (69 %), between 40 and 60 years of age (61 %), and with compulsory school or gymnasium as their highest education (71 %, Figure S1). Female respondents were more highly educated and somewhat more positive to phosphorus from ash and struvite, but somewhat more negative to dehydrated urine than male respondents. Education was not a strong variable affecting acceptance, however it did influence the judgment of risk for the respondents (i.e. those with higher education saw less risks with using ash or struvite on their own health, section S2.2).

Discussion

The aim of this study was to assess the acceptability of human derived fertilizers among people in the food retail sector, as a way to gauge the readiness of Swedish food retailers to promote nutrient recycling as part of a sustainable food system. Overall, the opinion of the respondents was that the three techniques were unlikely to be harmful to either themselves or the environment and might even be positive for the environment. We found most positive responses with products that are more 'processed' and when the fertilizer is used further away from human food consumption. This is in line with studies with other types of respondents. A review article of attitudes towards urine reuse in Europe found high acceptance in the public (85 %) and moderate approval by farmers (50 %) [38]. A global survey of consumers found that 59 % of respondents would be willing to eat food grown with human urine [65]. Similar to this study, Segrè Cohen et al. [58] also found that consumers preferred use of urine-derived fertilizers on nonedible plants. This study found that dehydrated urine was rated worse than the other fertilizers and was not deemed acceptable to use for growing food for people. This relatively weaker acceptance may be due to the other products being more processed before application, or respondents may have been affected by the use of the word urine in the name. Segrè Cohen et al. [58] found that food disgust is a determining factor in the acceptance of human waste derived fertilizers. In our study, one respondent suggested naming the products without direct references to feces or urine. In general, people were positive about reuse of nutrients from wastewater fractions, although this varied between the different reuse products and type of reuse.

Influence of individual attitudes and characteristics

Demographics and environmental attitudes have previously been studied as predictors of acceptance. In this study, female respondents were somewhat more accepting of struvite and phosphorus from ash, but

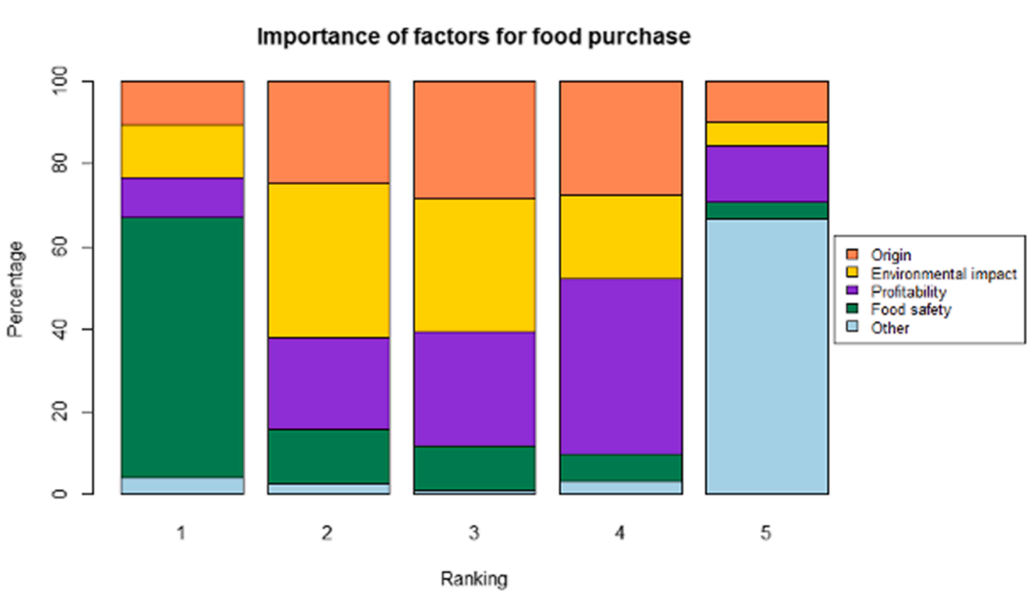

Fig. 3. Responses to the ranking question on the importance of factors for food purchasing. Ranking 1 represents the most important factor, while ranking 5 is the least important factor. The height of each color in each bar represents the percentage of respondents that ranked that factor (see legend to the right) in a given position. The "Other" factor was defined by the respondents themselves: responses were related to quality and taste, in one case relevance (ranking 1) and in one case "working conditions" at the producer (ranking 2). When "Other" was ranked last, respondents had not specified and thus can be considered a blank.

less so of dehydrated urine than male respondents. Conversely Segrè Cohen et al. [58] found, in the US, men were on average more accepting, while Simha et al. [62] found no correlation with gender in India.

Concerning pro-environmental attitudes, this study found few statistical differences between respondents who ranked environmental questions as more important for purchasing. Similarly, Simha et al. [62] found no correlation between environmental views and acceptance of fertilizers derived from urine, whereas Segrè Cohen et al. [58] found only a small effect. We conclude that gender and environmental attitudes do not appear to be a determining factor for acceptance.

In contrast, risk perceptions appear to have a strong influence on acceptance. The fate of pharmaceutical residues seems to be a deciding factor in the rating of the different techniques. Two comments on the survey also specifically mentioned that this was the deciding factor for them. Information in the survey about dehydrated urine specifically stated that it could potentially contain medicinal residue and this was one of the major differences between it and the other products on the information sheets. The worry about medicinal residues have also been identified as a major factor by other studies, both among farmers and consumers. In a survey of Swiss farmers in which 57 % considered urine-based fertilizer a good idea, micro pollutants were still a large concern for 30 % of the farmers [36]. Similarly, while 78 % of German farmers considered urine fertilizer a good idea, 61 % were worried about pharmaceutical residues [44]. In a review study, Lienert & Larsen [38] also found concerns about the presence of medicinal residue in urine based fertilizers in other studies. As concerns for medicinal residues are clearly established, it seems reasonable that this may explain why dehydrated urine rated poorly in this study.

Influence of subject-specific knowledge

Closely linked to risk perceptions in the unwillingness of the respondents to have an uninformed opinion. Food safety was ranked as the most important criteria for decisions in purchasing. Given this, one can infer that acceptance of struvite over dried urine implies that the respondents think it is safer. Lack of knowledge combined with concern about safety also seems to make respondents less willing to consider nutrient reuse techniques from wastewater or even answer the survey. Among the comments sent by the respondents of this survey and answers to the invitation to take it, 35 % expressed that they did not feel they knew enough to either answer it and/or that their answers were not sufficiently informed. It has been shown that knowledge of the benefits of nutrient recycling brings a greater acceptance of them [49,57,58]. Although we did not set up this study with a 'information deficit' model of behavioral change (see introduction for study motivation), the survey tool did increase information (see section 3.4). Knowledge campaigns targeting the food retail sector could potentially change the results of this survey.

Readiness of the retail sector

Our results do not show a clear and consistent picture of the readiness of Swedish food retailers to promote nutrient recycling as part of sustainable food systems. While a majority expressed the opinion was that reuse products were not harmful, there was more disagreement on acceptable areas of use. This is comparable to how nutrient recycling is used in policy documents of the food retailers. The policy documents clearly show an awareness of sustainability issues within the food system and the role that agriculture plays in nutrient management (see 2.1). However, policies do not specifically mention nutrient recycling, nor set targets for improving nutrient management. Possibly because it is unclear how food retailers should influence farmers and waste managers who are the primary actors managing nutrients. The closest that policies come is the need for smart use of resources and decreasing the energy demand of synthetic fertilizers [2]. However, it may be possible for human derived fertilizers to tap into some of these issues when developing quality certification and marketing. For example, documenting energy consumption per kilo of fertilizer produced or avoided eutrophying emissions from wastewater treatment could be selling points. However, as this study also shows, knowledge to make these indirect links between sustainability food goals and recycled fertilizers is currently low in the sector. Targeted communication plans would need to reach food retailers before they could play a role in promotion of recycled nutrients.

These results are supported by other studies that conclude that the role of retailers in driving environmental actions is not clear. There is a general agreement that food retailers have the ability to influence public opinion towards more sustainable consumer habits [20] and retailers are willing to market more sustainable alternatives. For example, ICA aims to support the development of more plant-based alternatives and increase the amount of produce produced sustainably and locally, in Sweden [27]. However, studies have also shown that retailers are also unwilling to remove unsustainable options, mainly because they fear losing market shares and customers [9]. Retailers have also been found to be largely pragmatic in their implementation of environmental sustainability actions, aiming for economic benefit or improving their brand [29,35,45]. In addition, there is a lack of pressure from consumers to change retailer action, since consumers see the responsibility for creating policy aimed at changing consumption patterns as the responsibility of the government [9]. Thus, food retailers will likely need to be guided by government policies and regulations to enable them to take more concrete sustainable initiatives [69].

According to the results of this study, the Swedish food retailer sector does not appear to be either a barrier nor a significant leverage point for supporting a transition to more circular nutrient systems. The retail sector is aware that it has a role to play in changing consumer habits and is willing to promote sustainable action. Yet, the results of this study suggest that there is a lack of knowledge within the retail sector about the possibilities for nutrient recycling. Targeted information campaigns to these actors could increase their willingness to expand their sustainability strategies to include nutrient recycling. Particularly, if the quality of recycled nutrients and food safety can be assured. However, without increased pressure from government policy or the demand from their customers it is unlikely that food retailers will take nutrient recycling initiatives on their own. An additional finding from this study was that food retailers are difficult to reach. The retail sector is already viewed as a leverage point by various industries and social movements. Thus, they are heavily targeted for surveys and people did not have time to respond. Getting the retail sector to see nutrient recycling as a priority among many other issues may be challenging.

Retailers as actors for system change

The study design we built on [58] fit within the *Independent Self* metatheory of human action [19], but our results highlight how it may be more complicated to use such a tool on individuals who act as both individual food or fertilizer consumers and middle-men (consumer for a retail chain). We (the authors) ascribe more closely to the *Interdependent* metatheory of change, where actions are theorized as being continually created via feedback loops in the system [19]. This is why we were so interested in examining the retail sector; actions in this space are both responding to signals about what is acceptable or desirable, but also setting standards and influencing what other actors may think is acceptable (e.g. farmers and shoppers they do business with). The survey tool however, was not designed to identify feedback loops and it was not possible to separate out individual opinions as a consumer vs. a specialist consumer for a store. By looking at explicit retailer goals on nutrients, we aimed to better contextualize individual responses within the larger organizational action space.

Our theoretical conception of drivers for retailer 'consumption' is perhaps more in line with the grounding used in Burgman and Wallsten [7] where the authors examined how policy discussions/opinions about recycling of phosphorus in sewage sludge in Sweden have changed over time and differ among actors. They used a chemo-social relation lens that acknowledges both how physical flows of materials and different actor objectives and positions influence each other. They found that the discourse on sludge reuse has moved towards extraction (or more highly processed) fertilizer products in documents and interviews with diverse actors (although not the retail sector). Our survey was not set out to look at feedback or system level interactions, but our results show a similar preference in the retail sector for the use of human derived fertilizers further away from human consumption and more acceptance for products which were perceived as 'more processed'.

Future research directions

This study raises a number of questions regarding both specifics of survey design and the larger scale of who needs to accept human derived fertilizers. The design of this survey provided respondents with detailed information about different human derived fertilizers in order to compare their acceptability. However, limitations with this method may have been an information overload that impacted results or simply the length of the survey reduced the number of responses (see 3.4). Recommendations for future survey design would be to make shorter surveys, e.g. by doing between-subjects surveys in which each respondent only sees one product. This type of survey could also test the impact of imagery by showing different respondents different images or calling products by different names, e.g. not using the word urine in the name. Shorter surveys may also have better response rates, which would be particularly important to gain a better understanding of the acceptability of both product types and communication strategies simultaneously. There is work to be done in designing acceptance surveys to get more representative responses by filtering the type and amount of information provided. However, the challenge still remains on how to get more responses from individuals who are already taxed with multiple surveys and priorities.

One reason to have longer surveys with information is that the survey itself can be a tool for sharing knowledge. However, we (researchers and interested parties) must also ask ourselves: who needs to know about the technical processes and resulting fertilizer qualities? Most consumers never have access to all the details behind the products that they consume. Yet, in the case of human derived fertilizers, food producers are legitimately worried about the possible negative media reaction if it were to be known that their products were fertilized with excreta (see introduction for references on how consumer acceptance is a barrier to change). As we transition to a more circular economy we anticipate more such questions: In circular systems, where does the burden of evidence lie? Do managers of circular resources (e.g. waste managers and farmers) need to adapt technology to what is currently acceptable by retailers or consumers or should there be a third party for certifying and informing of circular products?

In summary, our survey and cursory review of food retailer goals gave us insights into an actor type that has not been heavily engaged in the recycled fertilizer conversation. Building on an existing survey framework was a robust first step, but the results highlight that it may be necessary to engage this part of the food chain with different methods, given that the questions raised in this study link to larger system level questions, as opposed to only questions about individual acceptance.

Conclusions

Purchasers in the Swedish retail sector are not strongly opposed to using fertilizers derived from human excreta. Most respondents felt that all three recovery techniques were unlikely to be harmful to either themselves or the environment. The use of more processed nutrient extractions were more generally acceptable. However, acceptance of wastewater-derived fertilizers was largely dependent on perceived risks, especially the fate of pharmaceutical residues. While retailers in Sweden are not negative to reuse, they seem unlikely to provide strong support for nutrient recirculation from human excreta unless it becomes a greater concern for the public.

Multi-lateral action across concerned stakeholders will be necessary to support a fully circular nutrient use in food systems. As the challenges of increased water scarcity and floods related to climate change, along with disrupted nitrogen and phosphorus cycles, come to the forefront of urban and rural life, alternative wastewater and sanitation systems that recognize the interconnection of food security and water quality will be needed. One way forward could be to work not only with food retailers to increase knowledge (and decisions) regarding the benefits of human derived fertilizers but also to invite them into larger co-production exercises with national governments, urban planners, farmers, and customers. Although nutrients are increasingly on the agenda, all parts of the food chain must engage in order to enable nutrient recycling from safe and effective sanitation systems.

CRediT authorship contribution statement

Jennifer R. McConville: Conceptualization, Methodology, Supervision, Writing – original draft. **Geneviève S. Metson:** Conceptualization, Methodology, Supervision, Writing – original draft. **Hugo Persson:** Methodology, Investigation, Formal analysis, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary material

The suppplementary material contains additional information on methods and results, including the survey tools, an analysis of how the order in which the technologies were presented affected the survey results, complete results regarding attitudes towards the different fertilizer types and correlations between demographic variables. Supplementary data to this article can be found online at https://doi.org/10.1016/j.cacint.2022.100096

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