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Willingness among food consumers to recycle human urine as crop fertiliser: Evidence from a multinational survey

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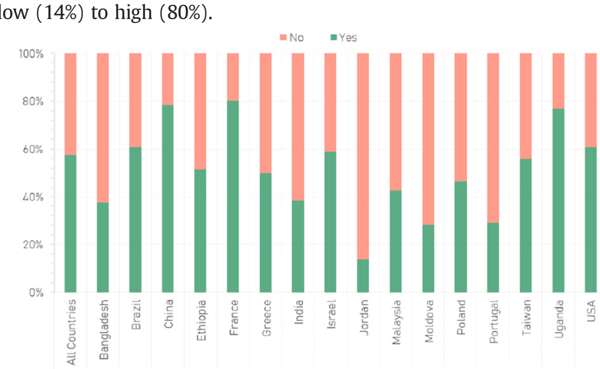
HIGHLIGHTS

- 3763 people surveyed to understand willingness to eat human urine-fertilised food
- Cross-cultural & country-level factors explanatory of respondent attitudes identified.
- Respondents had positive intention overall but were unwilling to pay price premiums.
- Social norms and cognitive awareness of urine's benefits & risks featured strongly
- Building consumer trust via context-specific messaging can improve acceptance of urine recycling.

GRAPHICAL ABSTRACT

Willingness to eat human urine fertilised food across the surveyed countries. Overall, 59% of respondents said they were willing to eat food grown using human urine as fertiliser, but in specific countries, stated willingness ranged from very low (14%) to high (80%).



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ABSTRACT

Source-separating sanitation systems offer the possibility of recycling nutrients present in wastewater as crop fertilisers. Thereby, they can reduce agriculture's impacts on global sources, sinks, and cycles for nitrogen and phosphorous, as well as their associated environmental costs. However, it has been broadly assumed that people would be reluctant to perform the new sanitation behaviours that are necessary for implementing such systems in practice. Yet, few studies have tried to systematically gather evidence in support of this assumption. To address this gap, we surveyed 3763 people at 20 universities in 16 countries using a standardised questionnaire. We identified and systematically assessed cross-cultural and country-level explanatory factors that were strongly associated with people's willingness to consume food grown using human urine as fertiliser. Overall, 68% of the respondents favoured recycling human urine, 59% stated a willingness to eat urine-fertilised food, and only 11% believed that urine posed health risks that could not be mitigated by treatment. Most people did not expect to pay less for urine-fertilised food, but only 15% were willing to pay a price premium. Consumer perceptions were found to differ greatly by country and the strongest predictive factors for acceptance overall were cognitive factors (perceptions of risks and benefits) and social norms. Increasing awareness and building trust among consumers about the effectiveness of new sanitation systems via cognitive and normative messaging can help increase acceptance. Based on our findings, we believe that in many countries, acceptance by food consumers will not be the major social barrier to closing the loop on human urine. That a potential market exists for urine-fertilised food, however, needs to be communicated to other stakeholders in the sanitation service chain.

1. Introduction

The global food system is the single largest contributor to the anthropogenic transgression of several planetary boundaries (Gladek et al., 2017). Among these boundaries, the boundary on biogeochemical flows of nitrogen (N) and phosphorus (P) is of particular concern, as the rate of human interference in these nutrient cycles has greatly exceeded its planetary-level safe space (Steffen et al., 2015), and there is a high risk of functional collapse (Rockström et al., 2009). Agriculture is the primary driver of global N and P cycles (Campbell et al., 2017), as crop productivity is dependent on plant-essential macronutrients being applied to soils. Historically, however, agricultural activities have promoted the depletion of non-renewable resources, such as the reserves of phosphate rock that are used to manufacture P fertilisers (Van Vuuren et al., 2010). The riverine runoff of fertilisers applied to agricultural fields also has severe negative impacts on public and environmental health through contribution to eutrophication (Diaz and Rosenberg, 2008), climate change (Kampschreur et al., 2009), loss of biodiversity (Campbell et al., 2017), and acidification of soils and waters (Guo et al., 2010). These aspects threaten the long-term sustainability of global food production (Béné et al., 2019), especially considering that the world population is still increasing (UN, 2019), as is per capita food consumption (EC, 2019).

There are several ways to reduce agriculture's transgression of the planetary-level safe space for N and P (Cordell et al., 2009; Elser and Bennett, 2011; Morone et al., 2018). Yet, many experts (Springmann et al., 2018; Steffen et al., 2015) believe that we can only operate within this safe space by implementing systemic solutions and by establishing new paradigms that reshape our entire food system. One such paradigm being deliberated is in the field of wastewater management (Guest et al., 2009; Larsen et al., 2009), where research into source-separating sanitation systems has led to the development (Harder et al., 2019; Larsen et al., 2013) and implementation (Skambraks et al., 2017) of technologies that safely recycle human excreta as crop fertiliser.

One promising fraction of domestic wastewater for reuse is human urine (Mihelcic et al., 2011; Winker et al., 2009), as it contains the majority of the plant-essential nutrients in human excreta and, when collected from healthy people, is typically free of pathogens (Karak and Bhattacharyya, 2011; Vinnerås et al., 2006). Human urine has historically been separated from faeces in some parts of the world (Esrey et al., 1998; Han and Kim, 2014). In modern sanitation systems, using a urine-diverting toilet allows for such separate collection (Tilley et al., 2014). Although there is evidence that urine is effective as a fertiliser (Heinonen-Tanski and van Wijk-Sijbesma, 2005; Jönsson et al., 2004; Viskari et al., 2018), there are many barriers to its widespread use in conventional food production systems. There is a technological barrier, as most urine-recycling technologies have shortcomings (e.g., in recovering all nutrients), low technical maturity, operation and maintenance issues, and are not yet commercially available (Harder et al., 2019; Naughton et al., 2018; Zhou et al., 2018). Switching to a source-separating sanitation system can also require installing urine-diverting toilets and additional pipes and/or ventilation, and there can be costs related to transporting excreta or excreta-based fertiliser to farmland, which represent economic barriers. In addition, there are institutional barriers, as national laws and regulations offer only vague or ambiguous guidance on the use of human excreta in agriculture (Johansson and Kvarnström, 2005; WHO, 2006). In previous studies, Lienert and Larsen (2009) found that certainty about the regulatory status was an important consideration for urine adoption by Swiss and German farmers. Moreover, it has been widely assumed that there are strong social barriers to recycling urine that will be challenging to overcome since there are norms surrounding the management of human excreta that are deeply grounded in traditions and culture and may be associated with taboos (Drangert, 2004; Jewitt, 2011; Rosenquist, 2005; Simha et al., 2017). However, few studies have specifically addressed this topic.

Several diverse groups of stakeholders make up the sanitation value chain (Poortvliet et al., 2018; Skambraks et al., 2017), all of which must be in favour of recycling urine if the vision to establish a new sanitation system based on urine diversion is to be realised. Past studies have shown that there is willingness among different stakeholder groups to use urine-diverting toilets (Ishii and Boyer, 2016; Lamichhane and Babcock Jr., 2013; Lienert and Larsen, 2009; Poortvliet et al., 2018; Wood et al., 2017) and urine/urine-based fertilisers (Andersson, 2015; Cofie et al., 2010; Lienert and Larsen, 2009; Segre Cohen et al., 2020; Simha et al., 2017). On the other hand, some studies have suggested that cultural preferences prohibit certain communities from using urine-diverting latrines (Nawab et al., 2006) and that health risk perceptions prevent end users from applying urine to crops or consuming food fertilised with it (Khalid, 2018; Mariwah and Drangert, 2011; Mugivhisa and Olowoyo, 2015). However, apart from a meta-analysis of European end-users by Lienert and Larsen (2009) and a survey conducted in Iraq, Turkey, and Egypt by Taher et al. (2018), few studies have elicited the attitudes of food consumers towards using human urine on crops destined for human consumption, especially at a regional or global scale. We therefore undertook the current study with the primary objective of evaluating the behavioural intentions of food consumers across the world to recycle human urine, particularly as fertiliser for food crops. Ultimately, our study contributes to achieving multiple

Sustainable Development Goals that include specific targets related to improving water quality by increasing safe reuse of wastewater, making more efficient use of natural resources, and reducing waste generation through recycling and reuse.

2. Methodology

In this study, we surveyed respondents at university communities. Today, universities increasingly offer space for innovations, as well as testing grounds for implementation of new environmental technologies and practices (Evans and Karvonen, 2014). For instance, university-supported living laboratories have allowed investigation of new sanitation technologies under real-life conditions. Examples include the living lab at the Chalmers University of Technology campus in Sweden, administered in partnership with Johanneberg Science Park and the housing company HSB; the Gates Foundation-supported engineering test bed at the University of KwaZulu-Natal in South Africa; and the Water Hub @ NEST at the EMPA/EAWAG campus in Switzerland. For this reason, we targeted consumers at universities in our survey.

2.1. Study design, participants, and data collection

We surveyed 3763 respondents at 20 different universities across 16 countries using a standardised questionnaire (Barton et al., 2020). We selected the universities based on ease of access through our professional networks and on the practical considerations of collecting large amounts of data. We designed the survey instrument in English but when needed, translated and administered it in the local language(s). The respondents were approached via an email containing a link to the survey and recruited by a combination of convenience sampling and systematic sampling (Fricker, 2008). We used an online Google Form to administer the survey in all of the countries except China, where respondents answered via an online crowdsourcing platform (Wenjuanxing). The invitation was initially sent to university email lists or, in the case of the University of South Florida, to a systematic sample consisting of every fourth full-time domestic student. At all universities, we kept the survey open for 30 days; during this period, we also sent weekly reminders to the participants on days 7, 14, 21, and 28.

Since our surveys collected responses anonymously and did not ask for sensitive personal data, ethics approval was not necessary except in the case of the University of South Florida, where its Institutional Review Board determined that the research met criteria for exemption from the federal regulations as outlined by Office for Human Research Protections regulation 45 CFR 46.101(b). The surveys were performed between September 2017 and May 2018. In total, 3763 responses were registered in the following countries: Bangladesh ($n = 155$; 2 universities), Brazil ($n = 523$), China ($n = 716$; 2 universities), Ethiopia ($n = 324$), France ($n = 260$), Greece ($n = 150$), India ($n = 60$), Israel ($n = 229$; 2 universities), Jordan ($n = 258$), Malaysia ($n = 96$), Moldova ($n = 85$), Poland ($n = 88$), Portugal ($n = 93$), Taiwan ($n = 163$; 2 universities), Uganda ($n = 126$), and the United States ($n = 437$). The raw and cleaned data, along with the instruments and a codebook explaining the variables have been deposited with Mendeley Data (Simha et al., 2020) and are freely accessible. An accompanying *Data in Brief* article (Barton et al., 2020) further describes the survey design and administration methodology and provides an overview of the entire data set.

The survey instrument was designed using the framework of Ajzen's (1991, 2002) theory of planned behaviour, literature (Dunlap et al., 2000; Ishii and Boyer, 2016; Lienert and Larsen, 2009; Simha et al., 2017), and by adapting questions from a previously validated questionnaire on consumer urine recycling intentions (Simha et al., 2018). In total, the instrument comprised 25 items and sought information about participants' demographic characteristics, their perceptions of urine recycling and particularly of using urine as a crop fertiliser, and their environmental outlooks. All questions were closed ended, with several ($n = 9$) having binary response choices (yes/no or female/male). However, for questions on urine recycling perceptions, the participants had the opportunity to provide open-ended comments for additional clarification.

The demographic information we solicited included age, gender, settlement type, academic discipline, and role in the university. We assessed general environmental and anthropocentric attitudes using the 15-question revised New Ecological Paradigm (NEP) scale (Dunlap et al., 2000). Through the opinion questions, we sought to elicit the respondents' opinions on three components of behavioural intention—attitudes, subjective norm, and perceived behavioural control. First, attitude was represented by their judgements of risks and benefits associated with the use of urine as crop fertiliser. We asked the respondents whether they thought human urine could be used as fertiliser and whether they were willing to consume food grown with human urine as fertiliser. We also asked whether they believed untreated urine posed any health risks and, if so, whether they thought those risks could be mitigated by treatment. Furthermore, they were asked to state what substances they thought urine normally contained (seven options; multiple selections possible). Second, we elicited perceptions of subjective norms, which can be divided into injunctive and descriptive norms, which have both been previously demonstrated to affect pro-environmental behaviours (Huber et al., 2020). In our survey, the injunctive social norm was represented by respondents' perception of their colleagues' willingness to consume urine-fertilised food, and the descriptive social norm by their acceptance of food grown with cow manure/urine as fertiliser. Third, perceived behavioural control was represented by their willingness to pay for urine-fertilised food. Last, we elicited participants' overall urine recycling intention by asking which among seven options they believed to be acceptable ways to deal with human urine. All questions were presented in a set order except for the NEP statements, which were randomised in blocks of five.

2.2. Data analysis

2.2.1. Coding and cut-offs

Our survey instrument consisted mostly of categorical questions. For questions with multiple option responses, we converted the responses to a continuous numerical score and then grouped the resulting scores into bins for categorical analysis. To facilitate analysis, we also combined certain questions, e.g., combining answers to the question of whether untreated human urine poses a health risk and the question of whether, if so, that risk can be treated, into a single three-category variable (no perceived risk, risk can be treated, and risk cannot be treated).

The urine recycling perception score was based on a multiple-choice question (Q19) in the survey instrument, which offered seven options: three recycling options (coded as “2”), three disposal options (coded as “1”), and the option of sending urine to a wastewater treatment plant (coded as “1.5”). We then took the mean of all coded options that each respondent selected to determine the perception score. For statistical analyses, we treated perception scores of ≤ 1.5 as negative and scores of >1.5 as positive or pro-urine recycling.

Environmental outlooks were evaluated using the revised NEP scale (Dunlap et al., 2000), which we separated into two sub-scales consisting of either the pro-dominant social paradigm (pro-DSP, considered by Dunlap to be an “anthropocentric” outlook) items or the pro-ecological items (pro-ECO). On each scale, responses were scored from 1 (strongly disagree) to 5 (strongly agree). For analysis, respondents' mean scores on the two sub-scales were binned and coded as anti-endorsement (scores of ≤ 3) or pro-endorsement (scores of >3) following the cut-off used by previous studies for the overall NEP scale (Van Petegem and Blieck, 2006).

Throughout this paper, we classified the percentages of acceptance/willingness in each sample population into the following five categories: very low (0 to 20%), low (21 to 40%), moderate (41 to 60%), high (61 to 80%), and very high (81 to 100%).

2.2.2. Statistical analysis

We conducted exploratory univariable binomial logistic regression to identify explanatory variables that correlated with our dependent variable, people's willingness to consume urine-fertilised food. Subsequently, we performed univariable logistic regression to assess the influence of the interaction of the variable 'country' with all the other variables. Finally, we constructed multivariable logistic regression models for each country that included all variables for which there were sufficient data. For all of the logistic regressions, we also calculated McFadden's pseudo-R^2 (R^2_{McFadden}) as a measure of goodness of fit to compare the proportions of the variance explained by the regression variables. For all pairs of variables, we used chi-square analysis followed by the Cramér's V post-test to assess the strength of association between the explanatory variables and the outcome variable. Following Mangiafico (2016), we interpreted the strengths of association based on Cramér's V as small (<0.3), medium (0.3 to <0.5) or large (≥0.5). All statistical analyses were performed using RStudio version 1.2.5042 and R version 4.0.0 (RStudio Team, 2016) and the packages *let*, *stats*, *car*, *agricolae*, and *psych*. The R scripts used for these analyses can be found in the supplementary material.

3. Results and discussion

3.1. Consumer perceptions of urine recycling

Our multinational survey revealed that overall, more university community members accepted recycling options for human urine than accepted disposal options, with the exception of sending it to a wastewater treatment plant (WWTP), which was considered acceptable by 68% of respondents. In general, more respondents found using urine as a crop fertiliser (57%) to be acceptable versus use of it to water gardens/lawns (41%) or generate electricity (38%). Few accepted the disposal options of diluting urine in surface water (15%), landfilling (14%), or incinerating it (10%) (Fig. 1). Respondents were not asked to rank the options in order of acceptability, however, only to indicate if each given option was acceptable.

3.2. Consumer perceptions of human urine as fertiliser

Overall, 59% of respondents ($n = 2167$) said they would be willing to eat food grown with human urine, indicating a moderate level of willingness. However, stated willingness differed greatly between countries (Fig. 2), ranging from very low (14%) to high (80%).

The belief that human urine could be used as a crop fertiliser was generally moderate to high (62% of respondents overall; range 16 to 89%) (Fig. 3). Most respondents believed that human urine either poses no health risk to them as food consumers (35%) or that it did pose a risk but that urine could be treated to pose no health risk (54%) (Fig. 4). Only 11% of all respondents believed that the use of human urine as fertiliser posed a health risk that could not be mitigated by treatment. When we accounted for interaction with country, perception of risks posed by human urine and whether they could be treated had a positive association of medium strength (Cramér's $V = 0.39$; see Table 1) with the willingness to eat food grown with human urine.

Despite a moderate overall level of willingness to eat food grown with human urine and generally very low risk perceptions, only a minority of respondents (15%) were willing to pay a price premium, i.e., more than what they usually pay for food today. Most respondents (63%) were only willing to pay the same amount, while the remainder (22%) wanted to pay less than they currently pay for food; proportions differed between countries (Fig. 5).

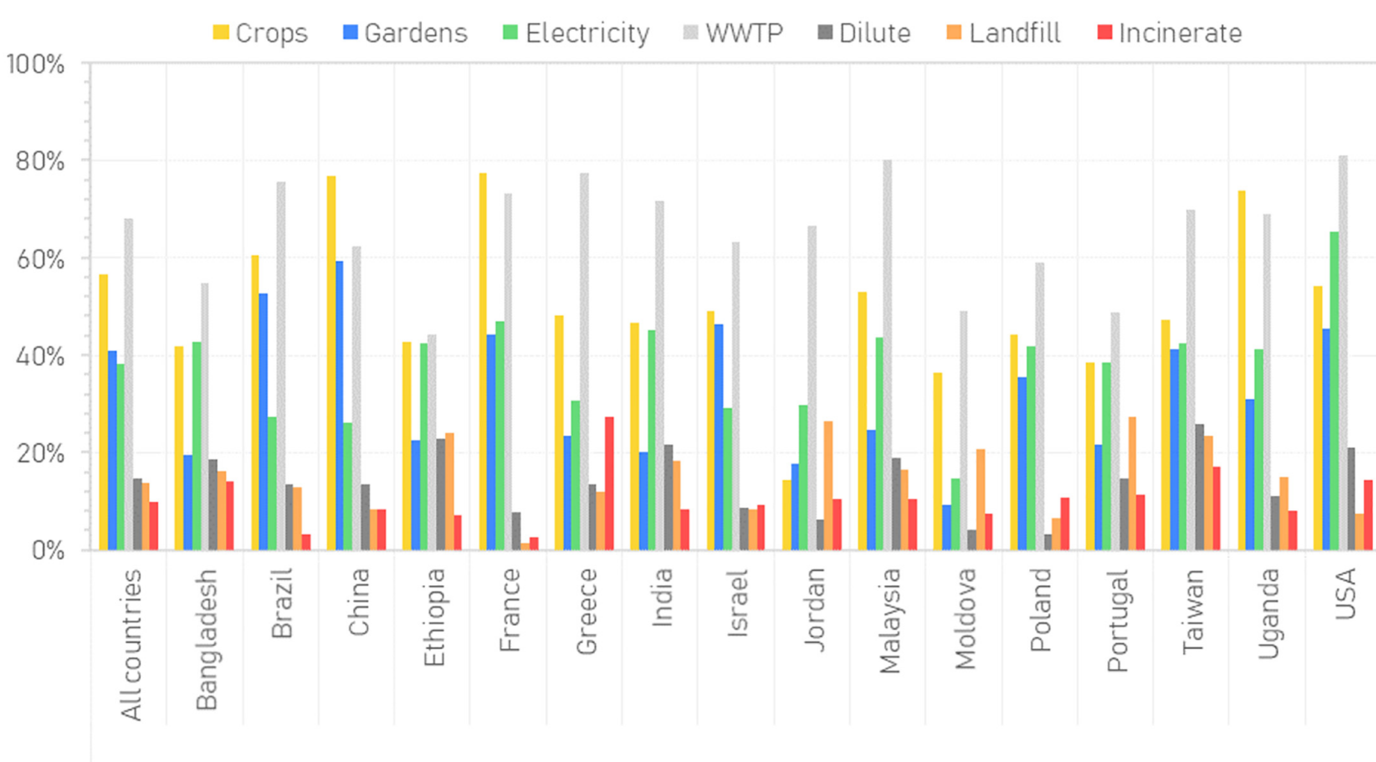

Fig. 1. Distribution (%) of university community member perceptions of how human urine should be handled. Respondents were presented with seven options for handling human urine, consisting of three recycling options (food crop fertiliser, lawn/garden watering, and electricity generation), three disposal options (dilute and dispose in surface water, landfill, and incinerate), and the option of sending it to a wastewater treatment plant (WWTP). Respondents were instructed to select all options they considered acceptable but were not asked to rank the options in order of preference. In all countries, more respondents considered the recycling options to be acceptable than the non-WWTP disposal options. However, the most widely accepted option was to send urine to a WWTP. Shown are the percentages of respondents in each country who found a given option acceptable.

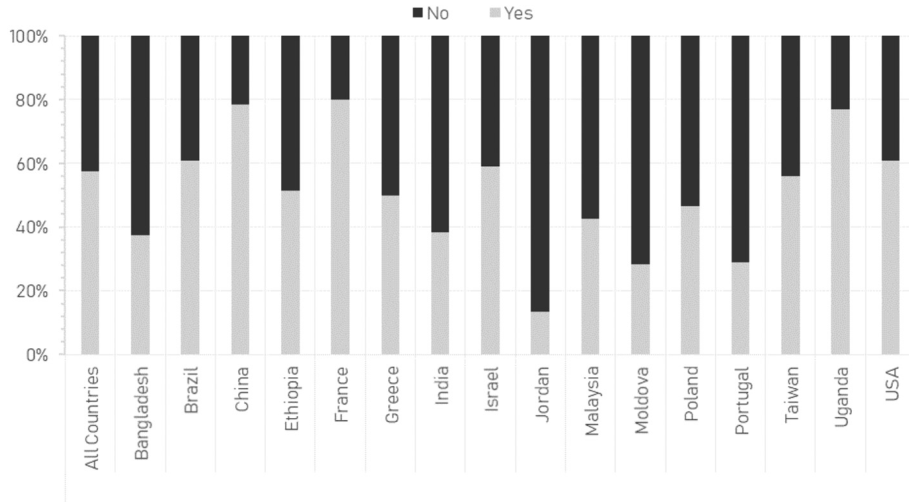

Fig. 2. Willingness to eat food grown using human urine as fertiliser. Overall, 59% of respondents said they were willing to eat food grown using human urine as fertiliser, but in specific countries, stated willingness ranged from very low (14%) to high (80%).

3.3. Explaining attitudes towards food grown with human urine

3.3.1. Culturally cross-cutting factors

Univariable binomial logistic regression showed that, while all variables except settlement type were significantly correlated ($p < 0.001$) with willingness to eat food grown with human urine (see Table S1 in the supplementary material for full results, including odds ratios), only four variables, namely country (Cramér's $V = 0.37$), perception of urine as fertiliser, the recycling perception score, and colleague's willingness to consume urine-fertilised food, had a medium or better strength of association. Multivariable model comparison (see Table S3 in the supplementary material) also indicated that social norms and risk/benefit perceptions explained the greatest variation in the data, and that the group of demographic variables was not strongly explanatory.

When we accounted for country by setting it as an interaction variable for all opinion factors, all of the tested interaction variables were significant at the level of $p < 0.001$ (Table 1). Perception of human urine as fertiliser showed the largest strength of association (Cramér's $V = 0.71$) with the willingness to consume food grown with human urine, and perception of colleagues' opinions (Cramér's $V = 0.55$). Willingness to eat food grown with cow excreta (Cramér's $V = 0.50$), and urine recycling perception (Cramér's $V = 0.51$) also showed large strengths of association. The remaining variables (risk perception and pro-ECO and pro-DSP outlooks) had medium strengths of association.

One factor that could explain risk perception, which was a medium-strength predictor of attitudes towards consuming food grown with human urine, is the belief that urine contains potentially harmful substances that may contaminate food crops or otherwise harm human health. While the composition of human urine can vary considerably, it normally contains nutrients (mostly urea, potassium ions and phosphates), salts, vitamins, and hormones (Rose et al., 2015). Urine from healthy people is normally sterile, but when it is collected in source-separating sanitation systems, urine is usually cross-contaminated with faeces (Schönning et al., 2002). However, the risk of environmental transmission of diseases when applying urine fertilisers can be managed via treatment (e.g. storage) (Senecal et al., 2018; Vinneras et al., 2008). Although heavy metals are present in urine, they are excreted in very low amounts (Jönsson et al., 1997). Residues of pharmaceuticals and their metabolites can be excreted via urine if they are being administered (Lienert et al., 2007). Most respondents in our study believed that urine typically contains salts (80%), pharmaceuticals (69%), pathogens (60%), and hormones (57%). Some believed that urine contains vitamins (37%), heavy metals (25%), and radioactive substances (11%). In open-ended responses, respondents also mentioned additional components they

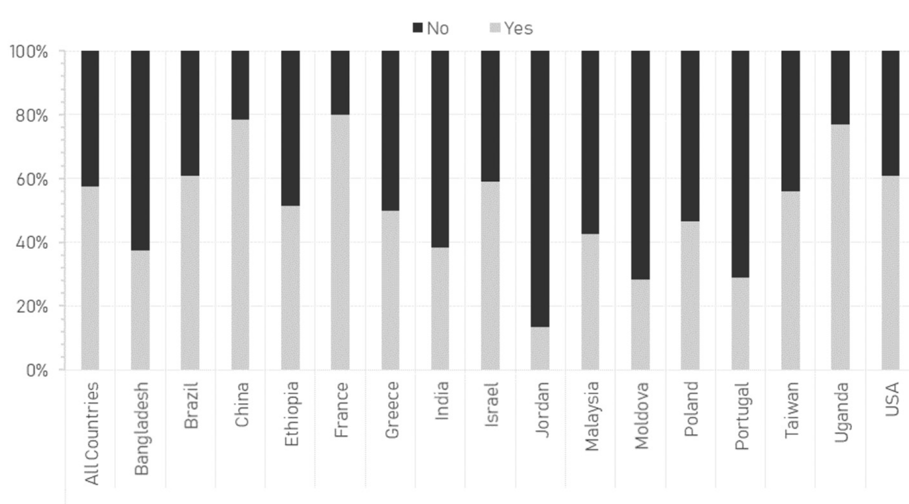

Fig. 3. Perceptions of human urine as a crop fertiliser. All respondents were asked if they believed human urine could be used as a crop fertiliser.

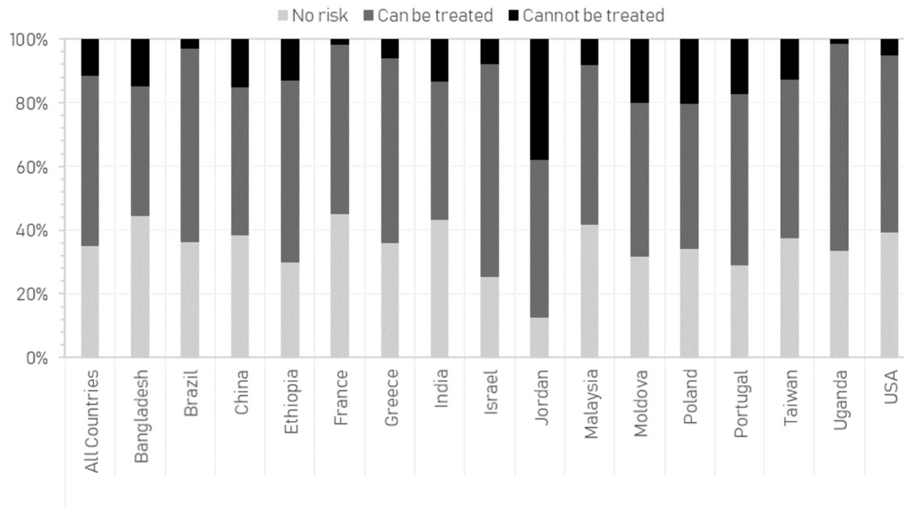

Fig. 4. Consumer risk perceptions of human urine as a crop fertiliser. Respondents were first asked if they believed untreated human urine used as fertiliser posed a human health risk. Those who answered "yes" were then asked if they believed urine could be treated to mitigate that risk.

believed to be present in urine, such as urea, minerals, potassium, phosphorus, creatinine, and traces of alcohol and recreational drugs.

Social norms, represented by perceptions of colleagues' opinions and by willingness to consume food grown with cow excreta, were both strong explanatory factors. Only 30% of the respondents who answered the question about whether their colleagues would eat food grown with human urine answered "yes" (55% answered "no," and 15% did not answer this question). For the use of cow excreta as fertiliser, on the other hand, we found very high levels of acceptance; overall, 94% of respondents (range 80 to 100%) believed cow urine or manure could be used as fertiliser, and 89% (range 74 to 100%) said they would be willing to eat food fertilised with cow excreta.

In addition to the generally positive attitudes towards urine recycling reported above, we found that on average, respondents in all countries expressed pro-ecological outlooks (mean pro-ECO score, 3.80 ± 0.65; range, 1 to 5; Cronbach's α, 0.75), which were positively associated with willingness to eat food grown with human urine. At the country level, mean outlooks measured by the pro-dominant social paradigm (DSP) subscale ranged from moderately opposed to moderately in favour of an anthropocentric outlook (mean pro-DSP score, 2.89 ± 0.68; range, 1 to 5; Cronbach's α, 0.65). Mean scores and measures of internal consistency for all countries are shown in Table S5 in the supplementary material. General environmental attitudes were also significantly correlated with willingness to eat food grown with human urine, albeit with a medium strength of association (Cramér's $V = 0.38$ and 0.39 for pro-ECO and pro-DSP scales, respectively, when controlled for country as an interacting variable); both pro-ECO and anti-DSP attitudes were correlated with greater acceptance of food grown with human urine, but the associations were weaker than those for social norms or perception of benefits.

Table 1
Results of univariable logistic regression and strengths of association for non-demographic explanatory variables, controlled for interaction with country.

Interaction variable (country × explanatory variable)[a]	$R^2_{McFadden}$	p	Cramér's V[b]
Perception of human urine as fertiliser	0.421	<0.001	0.71**
Colleagues' perceived willingness to eat human urine-fertilised food	0.247	<0.001	0.55**
Willingness to consume cow excreta-fertilised food	0.205	<0.001	0.5**
Urine recycling perception score	0.212	<0.001	0.51**
Perceived risk perception	0.117	<0.001	0.39*
Pro-DSP score	0.116	<0.001	0.39*
Pro-ECO score	0.117	<0.001	0.38*
Perception of cow excreta as fertiliser[c]	0.131	<0.001	N/A

Notes: [a]Univariable logistic regression was conducted with the interactions of opinion factors with country as the explanatory variables. [b]All tested variables were significant ($p < 0.001$), so in addition to McFadden's pseudo-R^2 to measure goodness of fit, we calculated Cramér's V based on chi-square analysis as a post-test for strength of association. Interpretation of strength of association based on Cramér's V for $k = 2$ (where k is the minimum number of categories in either rows or columns) is as follows: <0.3, small; 0.3 to <0.5, medium (*); ≥0.5, large (**) (Mangiafico, 2016). [c]When accounting for interaction with the country variable, Cramér's V could not be calculated for belief that cow excreta can be used as fertiliser due to some levels not containing enough data points. DSP, dominant social paradigm; ECO, ecological.

3.3.2. Factors at the country level

While for each country the overall mean urine recycling perception score was favourable, there was considerable variation (see Table S4 in the supplementary material), with mean perceptions of urine recycling being less favourable in Jordan (score = 1.51) and Moldova (score = 1.57) than in France (1.81) or China (1.79). In three countries (China, France, and Uganda), more respondents preferred using human urine as a crop fertiliser than sending it to a WWTP (Fig. 1). The stated willingness to consume food grown with human urine as fertiliser ranged from very low (14% in Jordan) to high (80% in China). The perception that human urine could be used as fertiliser varied similarly, from very low (16% in Jordan) to very high (89% in China). Perception of risk, however, varied less; even in Jordan, the country in our survey with the most consistently negative attitudes towards urine recycling and human urine being used as fertiliser, the majority (62%) of respondents believed that urine is either safe or can be treated to present no risk. In some countries, respondents were more willing to pay for food grown with human urine. More than a quarter of respondents in China (28%) and Uganda (26%) were willing to pay a price premium, whereas <5% of respondents in Malaysia, Moldova, and Jordan were willing to do so. In Ethiopia, the majority of respondents willing to eat food grown with human urine (52%; 86/167) were only willing to do so if it was available at a lower price than that of conventionally grown food.

At the country level, to identify variables explanatory of the willingness to eat food grown with human urine, we developed univariable logistic regression models for each country, including demographic variables (where possible), as well as the substances perceived to be present in untreated urine (Fig. 6; see also Table S2 in the supplementary material for Cramér's V values). We found that, across the countries, none of the demographic factors (age, gender, and settlement type) was a major explanatory factor for people's willingness to consume urine-fertilised food. Moreover, the same groups of factors identified in the overall analysis (Table 1) remained important at the country level,

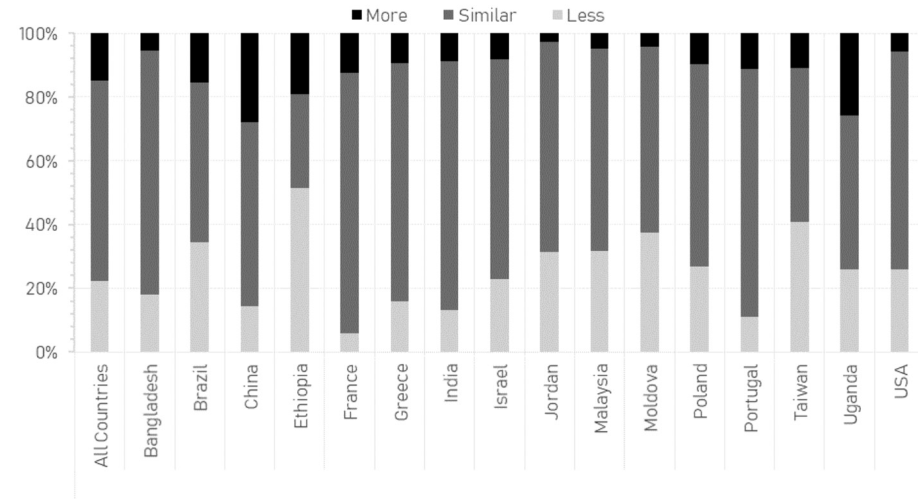

Fig. 5. Willingness to pay for food grown with human urine. Respondents who stated that they were willing to eat food grown with human urine ($n = 2167$; 59% of all respondents) were asked if they would be willing to pay more, less, or similar amounts to what they currently pay for food.

although the strengths of association of the factors differed between countries (Fig. 6). For example, in almost all countries, respondents perceived their colleagues as being less likely, often much less likely, than themselves to be willing to eat human urine-fertilised food. However, one case stands out: respondents from Ethiopia perceived their colleagues as slightly *more* likely than themselves to eat food grown with human urine (61% assumed colleagues would vs. 52% self-reported as willing). For Ethiopian respondents, perception of colleagues' opinions

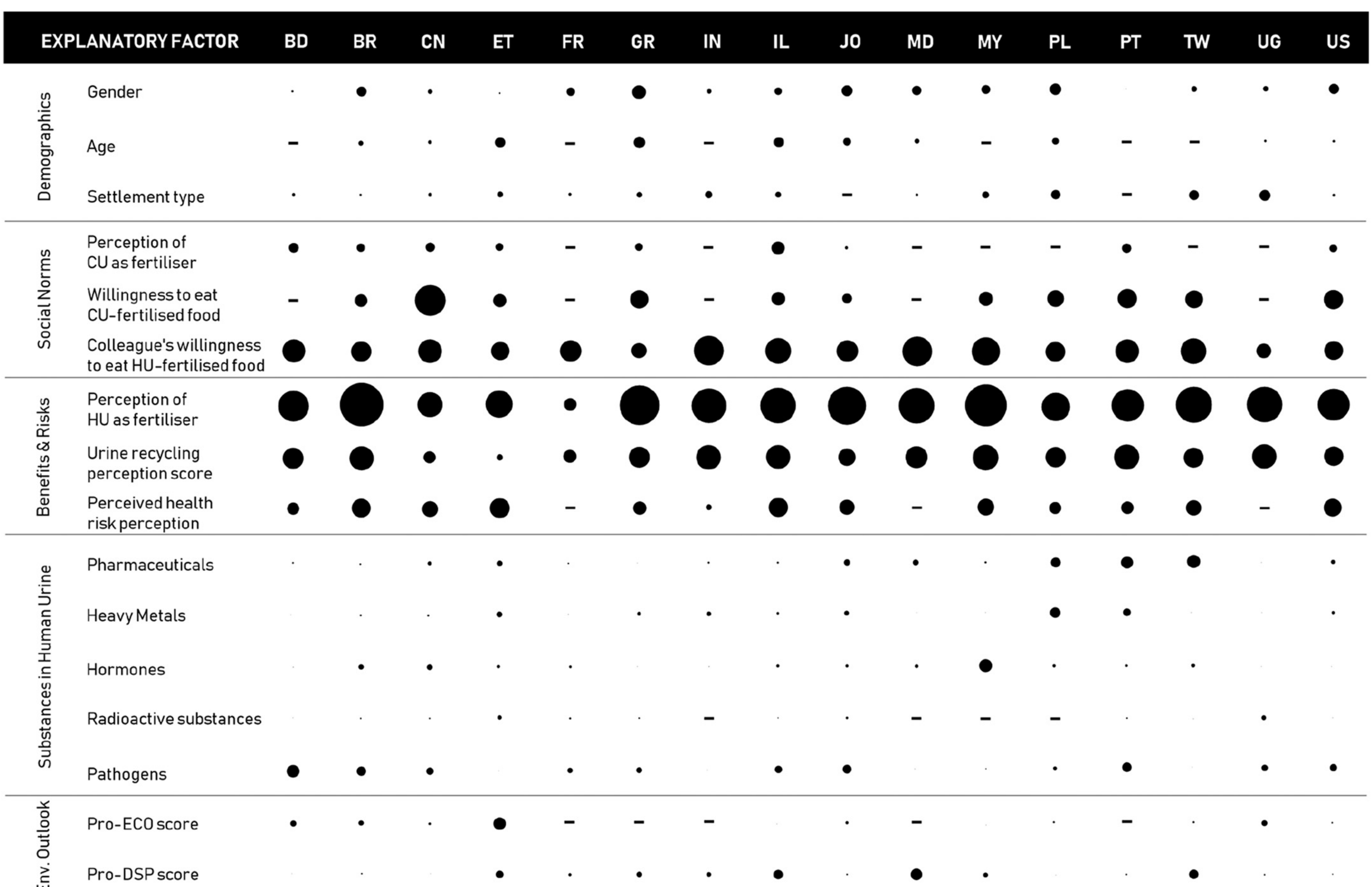

Fig. 6. Strengths of association for factors explaining attitude towards human urine as fertiliser in university community samples from 16 countries. Here, we show the strengths of association (Cramér's *V*, based on chi-square analysis) for each explanatory factor, arranged by country. Factors are grouped by demographics, social norms, benefit/risk perception, substances that respondents believed are normally excreted in urine, and environmental outlooks. Dots are proportional and indicate the strength of association; dashes indicate categories that could not be analysed due to insufficient data. For specific Cramér's *V* values, see Table S2 in the supplementary material. CU, cow urine/manure; HU, human urine; BD, Bangladesh; BR, Brazil; CN, China; ET, Ethiopia; FR, France; GR, Greece; IL, Israel; JO, Jordan; MY, Malaysia; MD, Moldova; PL, Poland; PT, Portugal; TW, Taiwan; UG, Uganda; US, United States.

was less strongly associated with willingness to consume food grown with human urine (Cramér's $V = 0.35$; medium) than it was in other countries such as India ($V = 0.57$; high) or China ($V = 0.45$; medium).

In most countries, including those with high support for using human urine as fertiliser, as well as those with very low support, perceived benefits—particularly the perception that urine can be used as a crop fertiliser, but also a positive perception of urine recycling in general—had the strongest strength of association among all variables. In France, however, the perceived opinions of colleagues were relatively more important than the perception that human urine can be a crop fertiliser in explaining willingness to consume food grown with human urine (Cramér's $V = 0.41$ vs. 0.24). In China, the willingness to eat food grown with cow excreta was relatively more important as an explanatory factor (Cramér's $V =$ 0.59 vs. 0.48). Although the perception of benefits was more strongly associated overall than the perception of low risks with willingness to eat food grown with human urine, our results suggest that different potential risks may be regarded as more important in different contexts (e.g., pathogens in Bangladesh, hormones in Moldova, and pharmaceutical residues in Taiwan).

4. Study implications

Among the respondents of our survey, the most widely accepted option to manage human urine was to send it to a WWTP. Both pro- and anti-urine-recycling respondents selected the WWTP as an acceptable disposal option for urine, indicating a widespread level of at least basic trust in the concept of wastewater treatment. Respondents likely make the assumption that the WWTP will safely treat the urine. However, in many of the countries we surveyed in this study, people have poor access to safely managed sanitation and low connectivity to wastewater treatment plants (WHO and UNICEF, 2019). According to Global Water Intelligence (2009), only about 7% of the world population is connected to advanced wastewater treatment plants that remove nutrients from the effluent, but only partially remove micropollutants, including pharmaceuticals (González et al., 2016). Moreover, the prospects of a considerable increase in global advanced treatment capacity are low (van Puijenbroek et al., 2015). On the other hand, research and pilot implementation projects have demonstrated that innovative sanitation systems based on urine source separation and decentralised treatment can be equally, if not more, effective at managing wastewater, especially in terms of life cycle environmental impacts (Harder et al., 2019; Kjerstadius et al., 2017; Lam et al., 2015; Larsen et al., 2013). However, if urine-diverting sanitation systems are to gain wider acceptance, they need to be connected to treatment systems that perform equally to or better than the currently widely accepted WWTPs. Subsequently, increasing awareness among end users about the effectiveness of new sanitation systems can help increase the acceptance of food grown with urine-based fertilisers.

Among the respondents in our study, there was also widespread belief that human urine can be used as crop fertiliser and that health risks from its use were low or could be mitigated. Both factors featured strongly in determining their willingness to consume food grow with urine (Fig. 2), which was moderate to high in 12 of the 16 countries we surveyed and was only very low in in one country (Jordan). A majority of respondents in all countries other than Ethiopia stated willingness to buy urine-fertilised food at prices comparable to what they currently pay. This suggests that there is a potential market for urine-fertilised food, meaning that food sales could partially contribute to cost recovery in the sanitation chain (Otoo and Drechsel, 2018). We also found that while most people did not expect to pay less for urine-fertilised food, only a small minority was willing to pay a price premium in most countries. However, in China and Uganda, where perceived favourability to urine as fertiliser was high, more than a quarter of respondents stated that they were willing to pay a price premium. Why willingness to pay differs across countries needs further exploration. Here, research should try and identify aspects that makes food grown using human urine more or less attractive than food grown conventionally.

Previous studies (Ishii and Boyer, 2016; Lienert and Larsen, 2009; Poortvliet et al., 2018; Segre Cohen et al., 2020; Simha et al., 2018) have shown that several factors can shape pro-urine recycling attitudes; these include age, education level, nationality, cultural practices, perceived risks and benefits, subjective mood, environmental outlook etc. Our analysis suggests that the strongest explanatory factors promoting such food consumption behaviour will vary in different socio-cultural settings, although cognitive factors (such as perceptions of benefits of urine recycling and, to a lesser degree, risks) and social norms were cross-cutting factors that feature strongly in shaping urine recycling intentions. This suggests that communicating and demonstrating the benefits of a resource-oriented sanitation system that recovers nutrients from human urine for reuse could lead to increased acceptance of food grown with urine-based fertilisers among food consumers. In order to reach a wide segment of the population, communication strategies will also need to adapt cognitive and normative messaging to target people who are at different levels of awareness, acceptance and intention to use (Rogers, 2003). The importance of cognitive awareness of benefits with alternative systems was previously highlighted in a study of the Dutch transition from cesspools to sewage, in which cognitive perception of disease preceded normative and regulative changes that enabled the emergence of sewer systems (Geels, 2006). This study also highlighted the importance of influencing both users and managers of the systems. Thus, more widespread knowledge of benefits of resource-oriented sanitation, such as water conservation, resource efficiency, risk reduction, and environmental protection may enable a cognitive shift towards valorisation of these systems.

The variation between countries found in this study also points to the need to match the spread of scientific knowledge with context-specific normative messaging. However, norm-based persuasive communication campaigns need to be designed with great care and linked to solid factual evidence (Cialdini et al., 2006). Communicators working to increase the adoption of urine recycling can find guidance in the focus theory of normative conduct (Cialdini et al., 1990). This theory posits that both pointing out that many others are engaging in a behaviour and motivating action by promising social sanctions (rewards and punishments) can effectively engender behavioural change (Cialdini et al., 2006; Griskevicius et al., 2008). However, such an approach might not be as effective in all cultural contexts, as demonstrated by the Ethiopian respondents in our study, who were less influenced by the perceptions of colleagues than respondents in other countries were. Perceptions regarding the specific risks from urine and the overall degree of risk also differed between countries. Therefore, communication messages about both cognitive facts and social norms need to be context specific.

In an earlier study (Simha et al., 2018), we suggested that context could also determine the relationship between people's environmental sensitivities and their urine recycling intentions. Results from the current study demonstrated that this connection is not straightforward. We found that the acceptance of food grown with human urine was relatively high even among respondents with anti-ecological outlooks (as measured by low scores on the pro-ecological NEP scale items), indicating that education and communication strategies need not focus solely on environmental messaging but on the full range of benefits from recycling urine. In addition, it should not be assumed that pro-ecological consumers will view urine recycling as being an inherently pro-ecological activity. However, we found that our choice of the revised NEP scale (Dunlap et al., 2000) to measure environmental outlooks made it difficult to interpret results. Although it is widely used as a unidimensional measure, the NEP scale can have context-dependent dimensionality (Amburgey and Thoman, 2011; Dunlap et al., 2000), as was evident from the poor levels of internal consistency in a few of our country samples despite overall acceptable consistency (Cronbach's $\alpha = 0.7 \pm 0.2$). Ajzen (1991) argues that to accurately predict behaviour, intentions and perceptions of behavioural control must be context specific and relate to the behaviour in question. Therefore, for future studies, we recommend inclusion of targeted questions about people's current pro-environmental behaviours related to recycling, resource use, food consumption, etc. (e.g., Whitmarsh and O'Neill (2010)) and perceptions of health risks and regulations that could be more directly relevant to understanding their urine recycling intentions. Such an approach would also have the advantage of being more readily comparable across countries than a philosophy-based environmental outlook scale like the NEP.

5. Conclusions

In this study, we found relatively high willingness among respondents in most of the surveyed countries to consume food grown with human urine. We also found that both cognitive factors (perceptions of risks and benefits) and social norms are strongly associated with consumer attitudes. Therefore, communication strategies focused on both of these factors have the potential to increase acceptance of the idea of recycling urine. Based on our findings, we believe that in many contexts, acceptance by food consumers will not be the key factor limiting the acceptance of products from new sanitation systems (e.g. urine-based fertilisers), as long as consumers are convinced that the products are safe. Acceptance of urine recycling systems may well be limited by internal actors in the sanitation sector (e.g. utilities, city planners and developers), who are reluctant to change for a variety of reasons. Future social research on urine recycling may thus benefit from focusing on other stakeholders in the sanitation chain, especially in contexts where consumer acceptance of the concepts is already high.

CRediT authorship contribution statement

Prithvi Simha: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Melissa A. Barton:** Data curation, Formal analysis, Investigation, Validation, Writing – original draft, Writing – review & editing. **Luis Fernando Perez-Mercado:** Formal analysis, Investigation, Software, Writing – review & editing. **Jennifer R. McConville:** Investigation, Writing – review & editing. **Cecilia Lalander:** Investigation, Writing – review & editing. **Maria Elisa Magri:** Investigation, Writing – review & editing. **Shanta Dutta:** Investigation, Writing – review & editing. **Humayun Kabir:** Investigation, Writing – review & editing. **Albert Selvakumar:** Investigation, Writing – review & editing. **Xiaoqin Zhou:** Investigation, Writing – review & editing. **Tristan Martin:** Investigation, Writing – review & editing. **Thanasis Kizos:** Investigation, Writing – review & editing. **Rupam Kataki:** Investigation, Writing – review & editing. **Yoram Gerchman:** Investigation, Writing – review & editing. **Ronit Herscu-Kluska:** Investigation, Writing – review & editing. **Dheaya Alrousan:** Investigation, Writing – review & editing. **Eng Giap Goh:** Investigation, Writing – review & editing. **Daniela Elenciuc:** Investigation, Writing – review & editing. **Aleksandra Głowacka:** Investigation, Writing – review & editing. **Laura Korculanin:** Investigation, Writing – review & editing. **Rongyu Veneta Tzeng:** Investigation, Writing – review & editing. **Saikat Sinha Ray:** Investigation, Writing – review & editing. **Charles Niwagaba:** Investigation, Writing – review & editing. **Christine Prouty:** Investigation, Writing – review & editing. **James R. Mihelcic:** Investigation, Writing – review & editing. **Björn Vinnerås:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Supervision, 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.

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Appendix A. Supplementary data

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