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Public Perceptions of Faecal Sludge Biochar and Biosolids Use in Agriculture

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Abstract: Full-scale pyrolysis of faecal sludge is a credible technology for the safe removal of pathogens and the concurrent creation of biochar, which has been shown to enhance crop productivity. Faecal sludge biochar has the potential to improve acidic, low nutrient soils and crop yield in developing nations more at risk of climate change and food insecurity. Little research has been conducted into public acceptance of faecal sludge biochar as a soil enhancer in agriculture. In this study of the public in Swansea, Wales, an online survey examines their awareness of, and comfort levels of eating food grown using biosolids, wood biochar and faecal sludge biochar. Our findings show that males were almost twice as likely than females to have a positive perception of biosolids (OR 1.91, p value 0.004) and faecal sludge biochar (OR 2.02, p value 0.03). Those in the oldest age group (65+) were almost five times more likely to have a positive view of faecal sludge biochar than the youngest age group (OR 4.88, p value 0.001). Deployment of faecal sludge biochar must overcome a "disgust effect" related to its human faecal origins. This factor must be centrally taken into account when implementing management and policy decisions regarding the land application of biosolids and faecal sludge biochar.

Keywords: biochar; faecal sludge; land application; public perception; biosolids; Wales

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1. Introduction

Resource recovery and safe disposal of biological wastes is a major global environmental challenge, but one expressed differently in different parts of the world. Broadly speaking, in developing countries a lack of access to sewered water systems means that 4.5 billion people lack safely managed sanitation, relying on onsite sanitation facilities such as dry toilets, pit latrines or even open defecation, which is increasing in sub-Saharan Africa and Oceania [1]. Untreated sludge from pit latrines is disposed of directly into the local environment, reused untreated on farmland, or disposed of within the household compound [2]. This poor management of faecal sludge has led to negative public and environmental health outcomes from eutrophication of surface water bodies, and contamination of groundwater and soils [3], as well as poor social and economic development [4,5]. Consequently, faecal sludge management has emerged as a long-term and more sustainable approach to deal with the faecal sludge generated from onsite sanitation facilities without the need for expensive water and energy intensive sewer systems [6].

In developed nations, in contrast, sewage is carried through a waterborne system to a treatment plant, where it is processed via biochemical methods such as anaerobic fermentation or thermochemical methods such as the addition of alkaline materials. The insoluble solid residue remaining after treatment is termed biosolids, or sewage sludge (Box 1). As with faecal sludge, safe disposal of biosolids is an environmental challenge, the main disposal methods being soil application, dumping at sea, landfilling and incineration [7]. Land application of biosolids aligns with the ethos of a circular economy, since nutrients and, in particular, phosphorus from human waste are essential for continued global food security [8]. In 2009, there were around 20 million tonnes of municipal, commercial and industrial organic wastes disposed in the UK alone [9].

Staying with the challenge faced largely by developed nations to date, there are public health risks linked to biosolids, such as their pathogen and heavy metal content, even though it takes repeated applications to attain soil limit values. In the UK, maximum permissible concentrations of PTEs (Potentially toxic elements) in sewage sludge are provided by Defra [10]. In Europe, recent legislation (EU Directive 2018/851/EC) has resulted in a ban on landfilling and limited land application of sewage sludge, with the transition to a circular economy becoming a priority [11]. Indeed, faecal sludge biochar and biosolids are waste products that have supposedly been repurposed into resources as part of such a circular economy and the drive towards such an economy has recently gained momentum worldwide by nutrient and energy recovery [12,13]. Biological wastes are now seen as a valuable source of phosphorus, a finite resource and an irreplaceable plant limiting nutrient [14]. Almost 100% of fertilizer phosphorus is lost along the food chain, from farms to field to fork [15], and it is estimated that economically extractable mineral phosphorus will be scarce or even run out in approximately 50–100 years [14,16]. Peak phosphorus may even occur as soon as 2030, so it is crucial we begin to recover phosphorus from waste for future global food security [15].

Recent research has focused on the drying and pyrolysis of faecal and sewage sludge to produce biochar, a nutrient-rich soil conditioner that can improve agricultural yields [17]. It is produced from the carbon-rich, charcoal-like product of the thermochemical process pyrolysis, which occurs at temperatures of 350–1000 °C in the absence of oxygen [18]. A major benefit of this process of dealing with faecal and sewage sludge is its elimination of harmful pathogens [19]. Biochar differs from charcoal as its main use is as a soil amendment and it does not readily burn [20]. Its use to improve soil fertility and increase crop yield was inspired by Terra Preta, a dark, fertile soil of anthropogenic origin found in the Amazon basin, containing much higher nutrient levels and organic carbon than surrounding soils [21].

In spite of its clear potential, to date very few research studies have been conducted directly on the public acceptance of biochar as a soil enhancer in agriculture and specifically that of faecal sludge derived biochar. Studies that do exist tend to focus on perceptions from farmers rather than the general public [22,23]. Indeed, much of the public have not even heard of biochar, let alone biochar produced from human biological waste. For example, a 2017 study found that only 27% of Polish farmers surveyed were familiar with the term “biochar” [23]. Focusing on farmers, recent research has been conducted on their acceptance of sewage sludge hydrochar, a material similar to biochar but produced via lower temperatures and higher pressures. It was found that age and education, as well as economic considerations, were important factors affecting their attitudes towards use of sewage hydrochar [24]. Elsewhere, a scoping review [25] investigating willingness to pay (WTP) for human excreta-derived material, found that gender, education and experience were the most common factors that influenced farmers, with age, household size and income the next most important. In a study of farmers in Tanzania, climate change mitigation proved to be a motivating factor in biochar adoption, with male farmers having a greater chance of engaging in biochar technology than female farmers [26]. Finally, willingness to pay (WTP) for the application of biochar in agriculture as a crowdfunded climate mitigation project has been explored in Norway. This revealed that almost none of the participants knew about biochar. Unsurprisingly, then, participants were willing to pay far more for a crowd-funded solar panel project than for a biochar project. The results of biochar addition would appear mainly in the soil and so would be “invisible” to the public. This was seen as generating feelings of bewilderment and disengagement rather than enthusiasm for the technology [27].

Box 1. Definitions of sewage sludge, biosolids, faecal sludge and faecal sludge biochar.

Definitions
Sewage sludge: sludge generated during primary and secondary treatment of wastewater via sewer systems.
Biosolids: sewage sludge that has been treated at centralized treatment plant and meets land application standards (NRC, 2002). Treatment is usually comprised of biochemical processes such as anaerobic fermentation or a thermochemical process such as addition of alkaline materials.
Faecal sludge: sludge that has not been transported through a waterborne sewer system and originates from septic tanks, dry toilets and pit latrines.
FS (faecal sludge) biochar: a carbon-rich material produced from pyrolysis of dried faecal sludge which effectively destroys all its harmful pathogens.

The term "biosolids" has been adopted for treated sewage sludge more generally, as social science survey evidence suggested that it elicited a more positive perception than the word "sludge" [28,29]. Unlike for biochar, there have been numerous studies looking at its public perception [30–34]. This is in part because biosolid land application relies on public acceptance of key issues around its health, safety and environmental impacts. For example, public risk perception of biosolids in western Canada has been shown to be significantly affected by the gender and level of education of respondents, women generally identifying significantly higher health and safety risks of biosolids use [35]. In Sweden, stakeholders, whether or not involved in sewage sludge management, highlighted the disgust or unappealing image that is associated with sewage [36]. Similarly, farmers in Bangladesh who refused to eat food crops fertilized with faecal sludge compost gave a feeling of disgust as one of their main reasons [37]. Certainly, a common thread that runs through perceptions and attitudes towards the application of sewage sludge is its disgust effect.

Whilst there are potentially many advantages to the reuse of human waste in agriculture, it is essential that socio-economic constraints such as negative perceptions and attitudes from the general public are addressed. Improving public understanding and knowledge of FS biochar and biosolids, and highlighting their benefits, will be crucial for future mass production of biochar and its subsequent public acceptance. Reflecting this, the aim of the project from which the present paper originates was to explore public attitudes towards faecal sludge biochar, wood biochar and biosolids land application with particular reference to differences in gender, age, residential area and issue awareness. A key objective was to collect information on public perceptions of exposure and risks towards consuming crops grown using faecal sludge biochar. Results from the project should help to shape management and policy decisions concerning reuse of biosolids as part of a sustainable resource strategy within a more circular economy.

2. Materials and Methods

2.1. Survey

Data for this study were collected through an online survey of 349 members of the public residing in Swansea, Wales. Data collection took place between October and November 2020 via sharing in online community Facebook groups in Swansea.

An online survey rather than face to face interviews was conducted due to difficulties faced during the COVID-19 pandemic. It used Google Forms, a cloud-based data management tool for designing and developing web-based questionnaires. Online surveys provide time saving and cost saving benefits, less paper wastage, no interviewer bias, and allow the respondents to complete the survey in their own time [27]. However, they may present problems such as limiting access, low response rates and challenges in assuring anonymity [38,39]. Another disadvantage is that, unlike face-to-face interviews, it is not possible to clarify questions or statements and some participants may not fully understand the questions [40]. Mailout surveys have previously also presented challenges in obtaining adequate response rates from the younger population, who may not use the mail system readily [39,41]. However, the survey presented in this article recorded a low percentage of younger respondents despite being online. Overall, it was the best technique we could use at the time.

The standardized questionnaire—consisted of 12 questions including information about the respondent (gender, location, age) and their consumption of organic food and efforts to reduce their carbon footprint. Participants received details of the study purpose and confidentiality information. Informed written consent was obtained before starting the survey. Survey questions and details of informed consent are available at: https://data.mendeley.com/datasets/xnzwzmhbfs4/ accessed 15 October 2022.

A definition of biochar was presented at the beginning of the survey (Box 2) and respondent's attitudes towards consuming food grown in wood biochar, faecal sludge biochar and biosolids were assessed using a 5-point verbal scale similar to the Likert scale. Each question or statement was followed by a choice from five ranked responses: very uncomfortable; uncomfortable; neutral; slightly comfortable; very comfortable. This type of scale was instantly understandable and decreased the risk of respondent confusion compared to the Likert scale [42]. Two follow-up statements seeking more information on attitudes to FS biochar were also added to ascertain if a change in attitude could be elicited by providing more information on the safety of FS biochar and its carbon storage properties.

Box 2. Definition of biochar as given in the questionnaire.

> Biochar is a charcoal-type substance produced by heating organic waste such as wood, crop waste, cow manure and sewage sludge. The main use of biochar is as a fertilizer.

Fewer than one percent of participants reported their gender as something other than male or female. These responses were removed, and gender treated as a binary variable.

Fewer than 3% reported their organic food consumption as something other than the categories provided in the survey. Responses included: "I do not knowingly seek organic food, but my wife may purchase it and include items in our meals" and "Rarely odd occasions". These responses were grouped as "Other" and removed.

2.2. Statistical Analysis

Pearson's chi-square statistic was used to determine any statistically significant differences between expected and observed frequencies for key factors (age, gender, residential area, organic food consumption).

Ordinal regression analysis was also used to identify which demographic variables were most influential on the perception and attitude towards biochar and biosolids. Logistic regression was used to determine awareness of biosolids as a function of the independent variables (age, gender, residential area, organic food consumption) as the dependent variable is binomial (yes/no question). Models using every combination of independent variables were analysed and AIC scores for each of the models were compared to ascertain the most parsimonious model. For both regressions, the odds ratios (OR) for each pairwise comparison were determined from the most parsimonious models and 95% confidence intervals reported (95% CI). A Wilcoxon signed rank sum test was also used to establish if the public perceptions of faecal sludge biochar were altered after receiving a follow-up statement providing more information on the safety of FS biochar.

For all, a probability level below 0.05 was considered statistically significant. Analyses were conducted in R version 3.6.3.

3. Results

3.1. Profile of Questionnaire Respondents

Gender: 71% identified as female, 28% as male. This bias was not ideal but at least 97 men were involved in the study.

Age: skewed slightly to the age 35–44 group (Figure 1), with few in the 25–44 group. Other age groups were fairly evenly distributed. Overall, a good range of ages was covered.

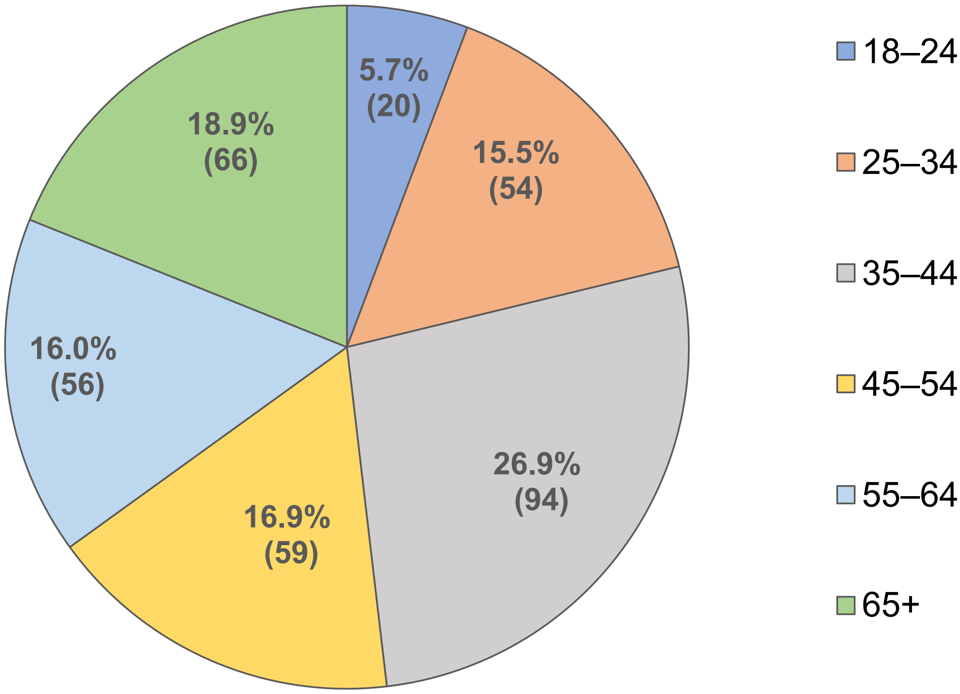

Figure 1. Age groups of respondents.

Location: the largest group lived in an urban area (Figure 2), but suburban and rural locations were still well covered.

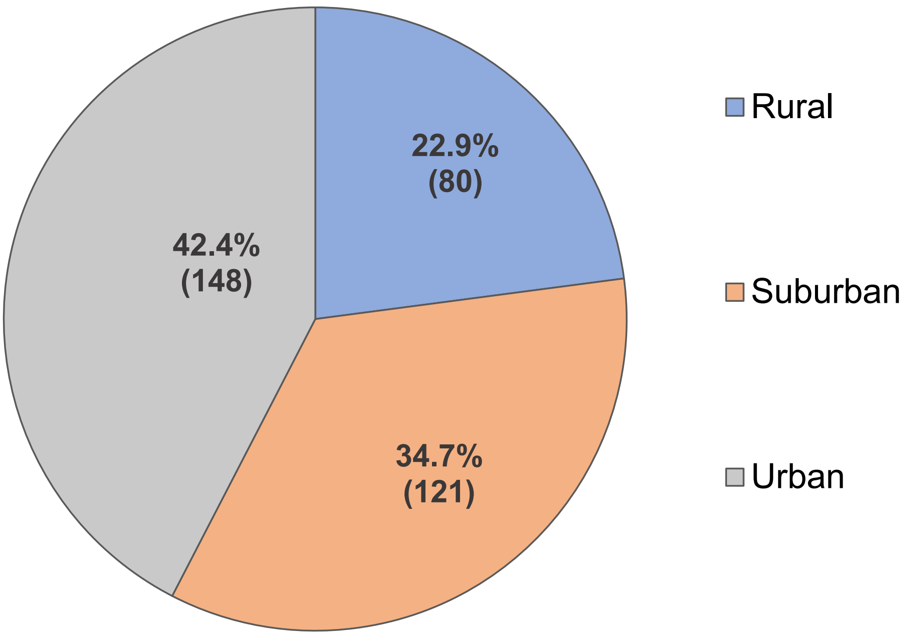

Figure 2. Residential location of respondents.

Organic food consumption: this was high amongst respondents, with 61.6% of respondents consuming organic food at least once a week (Figure 3).

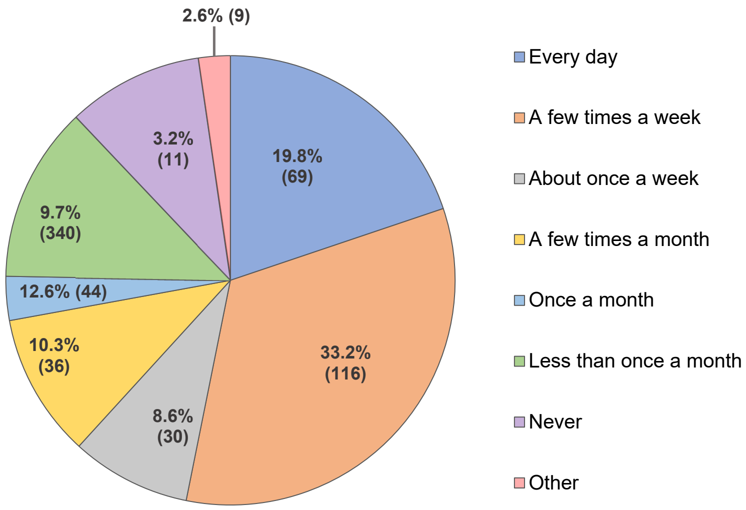

Figure 3. Frequency of organic fruit and vegetable consumption.

Carbon footprint: an overwhelming majority of participants (86.0%) stated that they "make an effort" to reduce their carbon footprint. Just 3.7% made no effort, whilst 10.3% "maybe" did.

3.2. Awareness of Biosolids

Overall, in terms of general awareness of using biosolids (treated sewage sludge) in agriculture, only 43.3% of respondents claimed to be aware of this practice. Thus, even for a sample of people seemingly "on the case" with consuming organics and reducing carbon, the survey results immediately reinforce the already-noted lack of popular awareness of biosolids. To acquire a greater sense of where this awareness is strongest and weakest, it will now be analysed by the key variables of gender, age, residential location, and whether or not organics are bought.

Gender (Table 1). A chi-square p value of 7.1×10^{-5} (dof 1) was significant at 95%: male respondents were markedly more aware of biosolid use than females. Using logistic regression, the most parsimonious logit model with the lowest AIC score (435.1) included the variables gender, age and location. This confirmed a statistically significant ($p < 0.05$) effect of increasing awareness of biosolids use based on gender, with males 41 times as likely to be aware of biosolids compared to females (OR 41.38, p value 0.0002) (Table 2).

Table 1. Awareness of biosolid use cross-tabulated with gender, age, location and frequency of organic food consumption.

		Aware of Biosolids?	
		Yes	**No**
Gender	Male	60.8% (59)	39.2% (38)
	Female	36.5% (91)	63.5 (158)
Age group (years)	18–24	20.0% (4)	80.0% (16)
	25–34	25.9% (14)	74.1% (40)
	35–44	35.1% (33)	64.9% (61)
	45–54	49.2% (29)	50.8% (30)
	55–64	51.8% (29)	48.2% (27)
	65+	63.6% (42)	36.4% (24)
Location	Rural	51.3% (41)	48.8% (39)
	Suburban	46.3% (56)	53.7% (65)
	Urban	36.5% (54)	63.5% (94)
Frequency of organic food consumption	Every day	53.62% (37)	46.4% (32)
	At least once a week	41.1% (60)	58.9% (86)
	At least once a month	38.3% (18)	61.7% (29)
	Less than once a month	36.4%(16)	63.6% (28)
	Never	52.9% (18)	47.1% (16)

Table 2. Binary logistic regression for awareness of biosolid application using logit model. Only statistically significant effects are shown (OR = Odds ratio, 95% CI = 95% confidence interval).

Comparison Category	Reference Category	z Value	Pr(>∣z∣)	Odds Ratio	95% CI
Male	Female	3.714	0.0002	41.38	13.67–285.73
Rural	Urban	2.129	0.0333	13.32	5.55–67.81
65+	18–24	2.403	0.0163	481.43	19.25–4.2 $\times$ 10^{-8}
45–54	25–34	2.54	0.0111	55.27	10.73–2.9 $\times$ 10^{-3}
55–64		2.786	0.0053	88.02	13.93–7.7 $\times 10^{-3}$
65+		3.523	0.0004	344.69	30.93–1.1 $\times$ 10^{-5}
45–54	35–44	2.086	0.0370	17.58	6.04–157.93
55–64		2.374	0.0176	25.37	7.63–311.71
65+		3.264	0.0011	73.50	15.53–1807.78

Age (Table 1). A chi-square p value of 5.2 $\times$ 10^{-5} (dof 5) was significant at 95%: there was a significant difference in awareness of biosolid use by age group, with a general trend of such awareness increasing with age. Ordinal regression also showed a significant effect of age on awareness of biosolids ($p < 0.05$). Those in the 65+ age group were almost 500 times more likely to be aware of biosolids use in agriculture than the youngest age group (OR 481.4, p value 0.0163). Generally, respondents aged over 45 were significantly more aware of biosolids, with those especially in the 55–64 age group more likely to have heard of biosolids than those in both the 25–34 and 35–44 age groups (OR 88.02, p value 0.0053 and OR 25.36, p value 0.0176, respectively) (Table 2).

3.3. Attitude towards Eating Food Grown in Biosolids

Overall. The majority of respondents were generally okay with eating food grown with treated sewage sludge (biosolids) (Figure 4), with 65.9% at least slightly comfortable with the practice. Only 18.9% were uncomfortable or very uncomfortable with it.

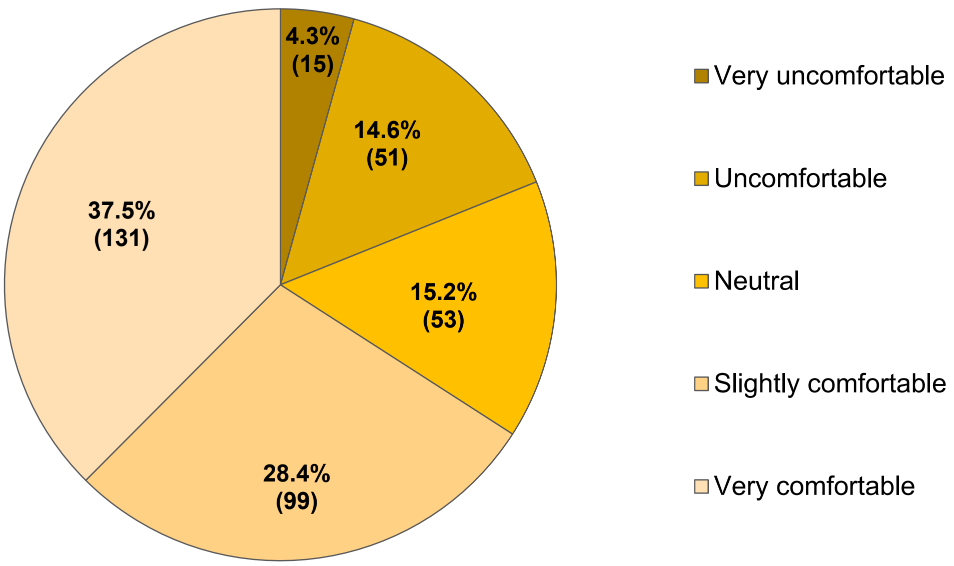

Figure 4. Attitude towards eating food grown in biosolids.

Gender (Table 3). A chi-square p value of 0.01 (dof 4) was significant at 95%: males were generally more comfortable with eating food grown in biosolids then females (32.1%).

Table 3. Attitude towards eating food grown in biosolids cross-tabulated with gender.

		Attitude towards Eating Food Grown in Biosolids				
		Very Uncomfortable	Uncomfortable	Neutral	Slightly Comfortable	Very Comfortable
Gender	Female	4.4% (11)	15.3% (38)	17.3% (43)	30.9% (77)	32.1% (80)
	Male	4.1% (4)	12.4% (12)	9.3% (9)	21.6% (21)	52.6% (51)

Using ordinal regression, the most parsimonious model with the lowest AIC score was one containing only gender as an independent variable. The model showed a statistically significant ($p < 0.05$) effect of increasing comfortableness with biosolids based on gender, with males almost twice as likely to have a positive perception of biosolids than females (OR 1.91, p value 0.004) (Table 4).

Table 4. Ordinal logistic regression for attitude and perception of biosolid application using logit model. Only statistically significant effects are shown (OR = Odds ratio, 95% CI = 95% confidence interval).

Comparison Category	Reference Category	t Value	*p* Value	OR	95% CI
Male	Female	2.846	0.004	1.912	1.23–3.02

Only gender showed any significant effect on attitude towards eating food grown in biosolids. Chi-squared values and ordinal regression tables for age, location and organic food consumption can be found in Appendix A.

3.4. Attitude towards Eating Food Grown in Wood Biochar

Overall. Most respondents were very comfortable (68.5%) with consuming fruit and vegetables grown using wood biochar (Figure 5), with none being very uncomfortable.

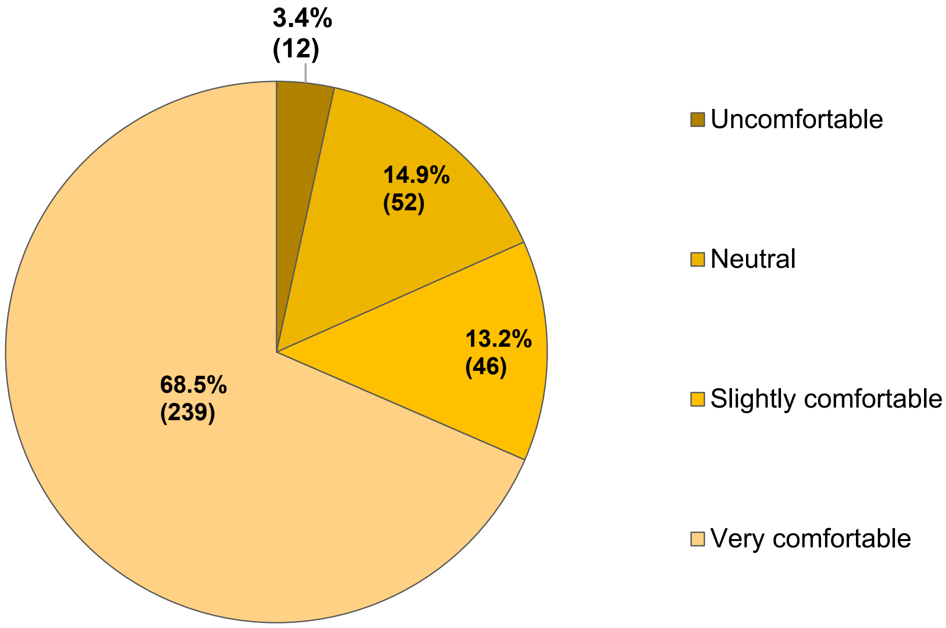

Figure 5. Attitude towards eating food grown in wood biochar.

Gender (Table 5). A chi-square p value of 0.016 (dof 3) was significant at 95%: men were more comfortable with food grown in wood biochar. However, using ordinal regression to examine perceptions and attitudes towards wood biochar, the most parsimonious model only contained the independent variable organic food consumption.

Table 5. Attitude towards eating food grown in wood biochar cross-tabulated with gender.

		Attitude towards Eating Food Grown in Wood Biochar			
		Neutral	**Slightly Comfortable**	**Uncomfortable**	**Very Comfortable**
Gender	Female	14.9% (37)	15.7% (39)	4.0% (10)	65.5% (163)
	Male	14.4% (14)	6.2% (6)	2.1% (2)	77.3% (75)

Organic food consumption (Table 6). It was not possible to condense the data into groups that met the assumptions of a chi-square test. From the data it is clear that respondents had an overwhelmingly positive attitude towards wood biochar. Attitudes towards eating food grown in wood biochar were not strongly associated with respondents' frequency of eating organic food but respondents who never consumed organic food had the lowest positive attitude towards wood biochar (67.6%) use compared to those who ate organic food every day (91.3%).

Table 6. Attitude towards eating food grown in wood biochar cross-tabulated with frequency of organic food consumption.

		Attitude towards Eating Food Grown in Wood Biochar		
		Negative	**Neutral**	**Positive**
Frequency of organic food consumption	Every day	0.0% (0)	8.7% (6)	91.3% (63)
	At least once a week	5.5% (8)	11.0% (16)	83.6% (122)
	At least once a month	2.1% (1)	21.3% (10)	76.6% (36)
	Less than once a month	2.3% (1)	15.9% (7)	81.8% 3(6)
	Never	5.9% (2)	26.5% (9)	67.6% (23)

Ordinal regression also showed that those who consumed organic food every day had a more positive perception compared to those who ate organic food less regularly. Every day consumers were over four times more likely to have a positive view on wood biochar (OR 4.54, p value 0.002) compared to those who stated that they never eat organic food (Table 7).

Table 7. Ordinal logistic regression for attitude and perception towards wood biochar using logit model. Only statistically significant effects are shown (OR = Odds ratio, 95% CI = 95% confidence interval).

Comparison Category	Reference Category	t Value	*p* Value	OR	95% CI
Everyday	At least once a week	2.46	0.014	2.58	1.25–5.75
	At least once a month	2.64	0.008	3.29	1.38–8.23
	Less than once a month	2.55	0.011	3.20	1.33–8.09
	Never	3.13	0.002	4.54	1.78–11.99

Only gender and organic food consumption showed any significant effect on attitude towards eating food grown in wood biochar. Chi-squared values and ordinal regression tables for age and location can be found in Appendix A.

3.5. Attitude towards Eating Food Grown in Faecal Sludge Biochar

Overall (Figure 6). There was greater reluctance to eat food grown in faecal sludge biochar, with over a quarter of respondents (25.8%) expressing clear discomfort, even if over a third (35.2%) were still very comfortable in doing so.

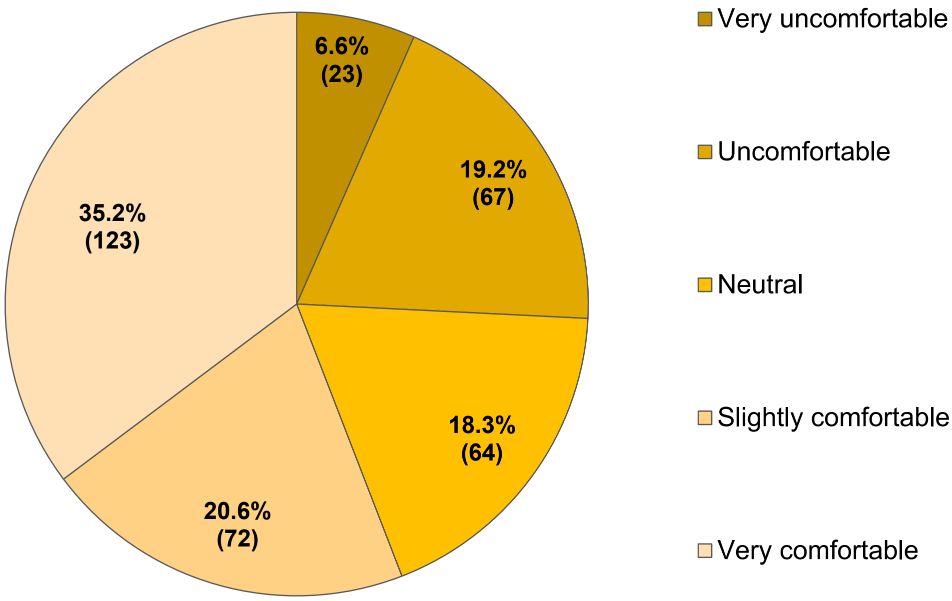

Figure 6. Attitude towards eating food grown in faecal sludge biochar.

Gender (Table 8). A chi-square p value of 0.00316 (dof 4) was significant at 95%: males were more comfortable overall in eating food grown in sludge biochar than females.

Table 8. Attitude towards eating food grown in faecal sludge biochar cross-tabulated with gender.

		Attitudes towards Eating Food Grown in Sludge Biochar				
		Very Uncomfortable	**Uncomfortable**	**Neutral**	**Slightly Comfortable**	**Very Comfortable**
Gender	Female	7.2% (18)	21.7% (54)	19.3% (48)	22.5% (56)	29.3% (73)
	Male	5.2% (5)	11.3% (11)	15.5% (15)	16.5% (16)	51.5% (50)

Age (Table 9). A chi-square p value of 0.0045 (dof 10) was significant at 95%: older respondents were broadly happier with eating food grown in sludge biochar.

Table 9. Attitude towards eating food grown in faecal sludge biochar cross-tabulated with age.

		Attitudes towards Eating Food Grown in Sludge Biochar		
		Negative	**Neutral**	**Positive**
Age group	18–24	65.0% (13)	10.0% (2)	25.0% (5)
	25–34	20.4% (11)	18.5% (10)	61.1% (33)
	35–44	28.7% (27)	17.0% (16)	54.3% (51)
	45–54	30.5% (18)	18.6% (11)	50.8% (30)
	55–64	23.2% (13)	16.1% (9)	60.7% (34)
	65+	12.1% (8)	24.2% (16)	63.6% (42)

Ordinal regression also shows a similar pattern, age having a significant effect on perception of FS biochar ($p < 0.05$). Those in the 65+ age group were almost five times more likely to have a positive view of faecal sludge biochar than the youngest age group (OR 4.88, p value 0.001) (Table 10). However, it should be noted that very few participants were in the 18–24 age group. There is a statistically significant ($p < 0.05$) effect of increasing comfortableness with FS biochar based on gender, with males twice as likely to have a positive perception of faecal sludge biochar than females (OR 2.02, p value 0.03) (Table 10).

Table 10. Ordinal logistic regression for attitude and perception towards faecal sludge biochar using logit model. Only statistically significant effects are shown (OR = Odds ratio, 95% CI = 95% confidence interval).

Independent Variable	Comparison Category	Reference Category	t Value	*p* Value	OR	95% CI
Gender	Male	Female	2.999	0.003	2.024	1.28–3.22
Age	65+	18–24	3.289	0.001	4.88	1.90–12.67
	25–34		2.919	0.004	4.09	1.59–10.64
	35–44		2.489	0.013	3.11	1.27–7.68
	45–54		2.062	0.039	2.67	1.05–6.87
	55–64		2.939	0.003	4.15	1.61–10.82

Only gender and age showed any significant effect on attitude towards eating food grown in faecal sludge biochar. Chi-square values and ordinal regression tables for location and organic food consumption can be found in Appendix A.

Wood versus sludge biochar (Table 11). A chi-square p value of 2.2×10^{-16} (dof 12) was significant at 95%: those with a positive attitude towards wood biochar also tended to be positive towards faecal sludge biochar, and vice-versa.

Table 11. Attitude towards eating food grown in faecal sludge biochar cross-tabulated with attitude towards eating food grown in wood biochar.

		Attitudes towards Eating Food Grown in Faecal Sludge Biochar		
		Negative	**Neutral**	**Positive**
Attitudes towards eating food grown in wood biochar	Negative	75.0% (9)	0.0% (0)	25.0% (3)
	Neutral	40.4% (21)	51.9% (27)	7.7% (4)
	Positive	21.1% (60)	13.0% (37)	66.0% (188)

After measuring the public's "comfortableness" with eating food grown in faecal sludge biochar, a follow-up statement and further question was provided:

"Biochar produced from faecal sludge is perfectly safe to handle, has no odour and no harmful bacteria. Reading this information how comfortable now would you be eating fruit and vegetables that had been grown in this biochar?"

A Wilcoxon signed-rank test was used to examine if providing more information about biochar causes a significant shift in public perceptions. This confirmed that attitudes towards faecal sludge biochar significantly changed when more information regarding the safety of faecal sludge biochar was provided ($p = 2.2 \times 10^{-16}$).

3.6. Wariness of Eating from Sludge Biochar and the "Disgust Factor"

Studies related to sanitation and sewage sludge management have often noted a "squeamishness" and even a "taboo" around the whole topic [43]. Moreover, certain cultures find the handling of human waste repulsive or ritually polluting (faecophobic) [44]. In some cultures, even the words associated with waste are very distasteful [45,46]. However, any encultured desire to physically and mentally distance oneself from our biological wastes can have a major negative impact on the economic value of recoverable waste [47] and is a major challenge for such practices.

To explore attitudes to FS sludge biochar further, the final question of the survey asked: "What are the reasons (if any) that you would be wary of eating fruit and vegetables that had been grown in faecal sludge biochar?" In response, many respondents (36%) stated they had no issue with such consumption but approximately a quarter (24.1%) identified a "disgust effect" for such biochar. Detail of this disgust effect was identified by reading through every response. Examples included statements such as "Difficult to combat or neutralize a lifetime's negative imprint", "I don't know enough about it and the name 'faecal sludge' makes me feel queasy!" and "Simply psychological-the thought is revolting".

A word cloud (Figure 7) was produced using the respondent's answers, with all statements where respondents indicated that there was no wariness at all in consuming products grown in FS biochar labelled "None". The minimum frequency of words expressing the disgust effect was set at three and filler words (about, all, more, just, need, like, any, enough, long, think, used, still, same, always, way, before, sure, see, currently, over, because, much, put, find, found, being) removed from the word count.

Figure 7. Word cloud showing reasons given by respondents expressing wariness in eating fruit and vegetables grown in faecal sludge biochar.

A second word cloud—minimum frequency two, again with filler words removed—was then created from just the clear "disgust factor" statements (Figure 8) to identify which words were most frequently used to express participants' discomfort with FS biochar. Notably, many of the statements regarding disgust focused on the very words "faecal sludge":

- I don't know enough about it and the name "faecal sludge" makes me feel queasy!
- I think it's mostly the wording. Faecal sludge sounds obviously disgusting and off putting and like no one would want to eat anything that had been in it.
- It's just the word faecal. Makes me think of dangerous bacteria
- It could do with some branding work. Maybe de-emphasis faecal?

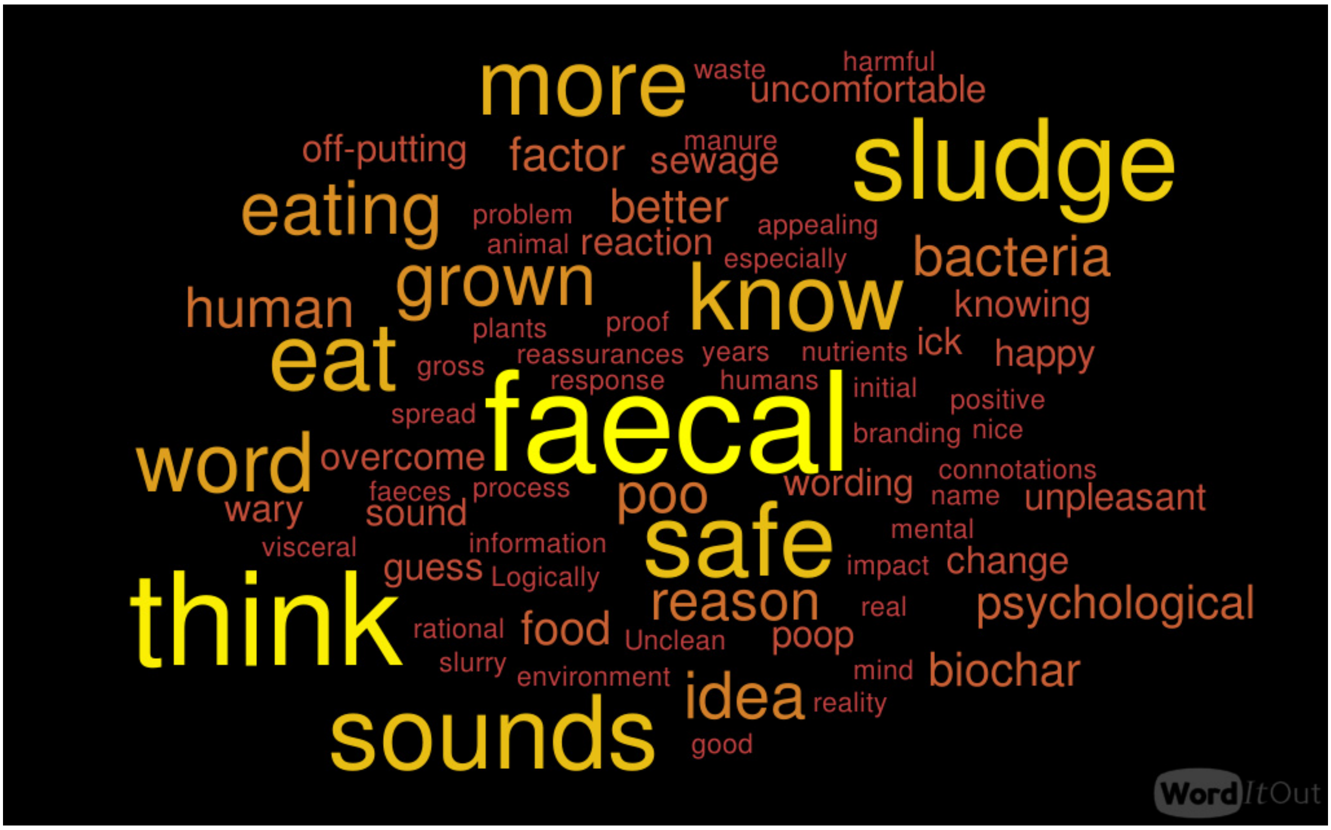

Figure 8. Word cloud showing words that related to the "disgust factor" of consuming food grown in FS biochar.

From this, it is clearly worth considering the latter "branding issue" if FS biochar is to be more readily accepted by the public.

Aside from the words "faecal sludge", many statements showed wider evidence of "squeamishness" or, as one participant called it, the "ick factor". Many also admitted that they knew their attitude was not "logical" or "rational":

- Just difficulty to shake the associations with "faecal sludge", even while trying to think about it rationally-a very visceral recoil away from associating "faecal" with food. I'd rather just not know!
- Just does not sound nice. Not really a rational answer
- It's probably profoundly illogical, but it just sounds unpleasant. Perhaps the disgust reaction is too ingrained-I think there's a linguistic aspect here, as "sludge" is such an unpleasant word. Nonetheless, I'm sure that with adequate reassurances and if it benefitted the environment (or at least wasn't as harmful as aggressive farming techniques using pesticides that deplete the bees, etc) it could be overcome!
- Logically I know it's safe but the thought of it has a bit of an ick factor

4. Discussion

From the outset, a degree of selectivity in the sample of respondents was noted. First, and most noteworthy, more women completed the survey than men (71% vs. 28%), a bias that has often been noted for questionnaire response [48–50]. Second, age of respondents was skewed towards the 35–44 age group (26.9%), with just 5.7% in the 18–24 age group. This lack of young adults is quite surprising as older individuals have often been found less likely to participate in questionnaires [49,51,52]. What seems to be the case here is that interest in the survey topic was critical in engaging (or not) individuals to take part. This is suggested, for example, by 86% of those surveyed saying they made an effort to reduce their carbon footprint. People participated in the survey because it is an issue they felt strongly about, again a not uncommon or surprising finding [53,54]. Cautiously, if women and older people are more interested in biosolids and biochar use, a challenge to be overcome if such use is to be increased and normalised is to engage men and younger adults more. This is in spite of a significantly higher percentage of male respondents stating awareness of biosolids, which may reflect again previously noted higher level male self-confidence regarding science processes in subjects as diverse as medicine [55] and computer science [56].

Focusing on general attitudes to biosolid and biochar use, most participants showed a positive attitude towards biosolids use (65.9%), only 18.9% having a negative perception. However, negative perception towards FS biochar (25.8%) was higher, which may be related to unfamiliarity and lack of knowledge about this "new" product and also to its "disgust factor". The latter is supported by far lower negative attitudes towards the equally new and unfamiliar wood biochar (3.6%), which does not have a noted disgust factor to provoke reactive negativity, especially if little understood. In addition, only 20% of those positive towards wood biochar were negative about FS biochar, suggesting some overall embracing of biochar is emerging.

In terms of attitude by gender in detail, chi-squared testing confirmed a significant relationship between gender and awareness of and attitudes towards biosolids, FS biochar, and wood biochar, with men being more positive. Generally, results are in in line with findings elsewhere showing differences in risk perception between the genders [57]. Although engaging with the subject more via a higher response rate, those identifying as female are typically less willing to consider new ideas and technologies with perceived health risks [57,58]. Issues where those identifying as female have greater risk perceptions include climate change, chemical pollution and bacteria in food [59]. Recently, females perceived greater risk than males of COVID-19 [60]. Previous work has also shown that male farmers have a more positive attitude towards eating food fertilized with sewage sludge compared to female farmers [61] and have a more positive perception of wastewater for vegetable irrigation [62]. Most directly, a recent survey on biosolids' public risk perception found a higher risk perception from females than males [35]. In contrast, a scoping review examining perceptions of agricultural use of human waste and waste-derived products found gender an inconclusive predictor, due to contextual and methodological differences between studies [63]. Our ordinal analysis also showed there was not a statistically significant ($p < 0.05$) effect of the perception of wood biochar based on gender. Generally, however, our results support the theory that gender plays a significant role in the perception of health and safety risks for human waste-derived products. A key policy challenge is thus to make women more positive about biosolids and human waste derived biochar.

Turning next to perceptions of biosolids and biochar in relation to age, there was no significant difference in attitudes towards consuming food grown in wood biochar or biosolids but with use of FS biochar there was a significant effect. The overall feel was that older adults were more accepting of these new "technologies" than younger adults. Certainly, for FS biochar, the oldest age group (65+) had the greatest percentage "very comfortable" with it (47%) and the youngest age group (18–25) the lowest percentage (15%). Thus, not only is there a challenge to get more younger adults engaged with biochar but their greater discomfort with the technologies has also to be overcome.

Where respondents lived in terms of how urban/rural showed no significant relationship with attitudes towards consuming food grown in biochar or biosolids. Clearly, there is no "closer to food production" impact, with no specific attention needing to be given to urban, suburban or rural populations. Neither urban lack of biosolids/biochar application close to their homes nor rural residents' possibly negative perception of applications near where they reside came through. While research to date focuses mainly on urban perceptions and attitudes towards human waste [44], a US study investigated biosolid application perceptions of residents of a rural and a suburban/urban community [33]. It found that as distance between biosolid application and personal property increased—lessening the chance of personal contact—there was a noticeable reduction in opposition to biosolid application. This was also suggested in the present study by those living in urban areas having an overall more positive perception towards biosolids but as noted, it was not statistically significant. Ordinal regression showed, unsurprisingly, that respondents living in rural areas were more likely to be aware of the use of biosolids.

The survey collected data on the frequency in which participants consumed organic food to determine whether those who consumed food grown without pesticides would be more willing to consume food grown in biochar and biosolids, perhaps as part of a broader awareness or critical perspective on the general production of food today. Again, findings were far from conclusive. On the one hand, respondents who consumed organic food every day had a very positive attitude (93%) towards wood biochar, with no negative responses recorded, whilst individuals who never consumed organic food had the lowest positivity percentage (69%) and a higher percentage viewing biochar unfavourably (6.9%). Chi-square tests showed no overall statistically significant relationships between frequency of organic food consumption and attitude to biosolids, or FS biochar. However, ordinal regression analysis revealed the frequency of organic food consumption had a significant effect on attitude towards wood biochar. Wood biochar is the only product in the survey that has no relation to human waste and the only product where attitudes were not significantly affected by age or gender. This generally suggests that simple knowledge of biosolid and faecal sludge biochar usage and potential is a main initial step needed to allow these technologies to be more broadly embraced.

Finally, focusing specifically on FS biochar, Melo et al. (2019) found that feelings of disgust were one of the main reasons given by farmers in Brazil not to use sewage sludge biochar as a soil amendment [24]. Attitudes towards wood biochar (which is not associated with human waste) were not significantly affected by age, location or gender. The characteristics and nature of human waste-derived products in general and sewage sludge in particular produce powerful negative images in the public's mind and strong feelings of disgust [36,64–66]. The origin of this disgust effect associated with human waste is believed to originate from a disease avoidance mechanism that protects us against disease-causing pathogens [67].

Disgust certainly seems to lie at the heart of many of our findings. In our study, as noted, females showed a significantly more negative attitude towards human waste-derived products than males. This finding is corroborated by previous research that found females identified significantly greater health and safety risks associated with the use of biosolids [35]. This links in with the disgust effect, females generally being more disgust-sensitive with consistently higher levels of disgust than males [67–72].

Considering other variables' connection to disgust, age was also a factor effecting perceptions and attitudes towards FS biochar, with those in older age groups significantly more positive. This finding corroborates with the decline in disgust sensitivity with age reported in previous studies [73–76]. The reason for this decline with increasing age is not fully understood although it has been suggested that with age comes past experience of disgust experiences that over time make an individual less sensitive to disgust cues [67].

Turning to information, perceptions and attitudes towards faecal sludge biochar significantly changed when more information regarding the safety of faecal sludge biochar was provided. A previous study also demonstrated that providing more information on the potential benefits of sludge changed farmers' willingness to use it [77]. However caution must be used as offering further information on a subject does not necessarily always alter people's perception or behaviour [78].

Overcoming, in sum, the disgust effect—often deeply engrained via childhood health and safety lessons of faecal products as dirty, harmful or disease containing—may be the most challenging task to address if FS biochar is to take its place alongside wood biochar and biosolids generally in the near future. Disgust effect feelings, even if misdirected and sensationalized, are very real and must be taken into consideration, respected and addressed if the public are to get on board with land application of biosolids and FS biochar as a soil amendment [31].

5. Conclusions

This paper has given some indication of the appreciation of and attitudes towards use of biosolids, wood biochar and FS biochar from a diverse cross-section of Swansea residents. It revealed a wide range of attitudes and feelings about these technologies, now recognized within the scientific community as having much potential within a future and sorely needed sustainable resource strategy within a more circular economy. Our findings reveal that interest in the survey topic was critical in engaging (or not) individuals to take part as it was noted 86% of those surveyed made an effort to reduce their carbon footprint. Males, those in older age groups and those living in rural areas were more aware of the use of biosolids in agriculture. Gender was the most significant factor in terms of attitude towards biosolids use with males more comfortable with the use of biosolids. Frequency of organic food consumption was an important factor in attitudes towards wood biochar, with everyday consumers over four times more likely to have a positive view on wood biochar (OR 4.54, p value 0.002) compared to those who never eat organic food. Gender and age were significant when examining perceptions of faecal sludge biochar with males and older respondents more likely to have a positive attitude towards FS biochar. Attitudes towards faecal sludge biochar significantly improved when more information regarding the safety of faecal sludge biochar was provided ($p = 2.2 \times 10^{-16}$). This finding in particular suggests that the immediate challenge for these technologies is to make more people—some groups especially, i.e., females and the younger age groups—more knowledgeable about these technologies, most especially for FS biochar. Engagement with a "disgust factor" that can further separate the technology from the general public is absolutely crucial for adoption of these technologies.

Finally, it is hoped that future work will soon build on and add to this study's insights so that faecal sludge biochar and biosolids use in agriculture can be more fully realised. Research needs to explore the role of education level, for example, which was not included in the demographic variables analysed in this paper.

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Appendix A

Age (Table A1). A positive label was assigned to slightly comfortable/very comfortable and negative to very uncomfortable/uncomfortable to tighten up the table and allow analysis. A chi-square p value of 0.12 (dof 10) was not significant at 95%: the age of respondents did not correlate with the comfortableness of eating food grown in biosolids.

Table A1. Attitude towards eating food grown in biosolids cross-tabulated with age.

		Attitude towards Eating Food Grown in Biosolids		
		Negative	**Neutral**	**Positive**
Age groups	18–24	15.0% (3)	20.0% (4)	65.0% (13)
	25–34	20.4% (11)	11.1% (6)	68.5% (37)
	35–44	20.2% (19)	14.9% (14)	64.9% (61)
	45–54	13.6% (8)	18.6% (11)	67.8% (40)
	55–64	33.9% (19)	10.7% (6)	55.4% (31)
	65+	9.1% (6)	18.2% (12)	72.7% (48)

Residential location (Table A2). A chi-square p value of 0.189 (dof 8) was not significant at 95%: where respondents lived was not strongly linked to comfort in eating food grown in biosolids.

Table A2. Attitude towards eating food grown in biosolids cross-tabulated with residential location.

		Attitude towards Eating Food Grown in Biosolids				
		Very Uncomfortable	**Uncomfortable**	**Neutral**	**Slightly Comfortable**	**Very Comfortable**
Location	Rural	7.5% (6)	17.5% (14)	12.5% (10)	17.5% (14)	45.0% (36)
	Suburban	4.1% (5)	11.6% (14)	18.2% (22)	30.6% (37)	35.5% (43)
	Urban	2.7% (4)	15.5% (23)	14.2% (21)	32.4% (48)	35.1% (52)

Organic food consumption (Table A3). A positive label was assigned to slightly comfortable/very comfortable and negative to very uncomfortable/uncomfortable to tighten up the table and allow analysis. A chi-square p value of 0.22 (dof 8) was not significant at 95%: comfort in eating food grown in biosolids was not strongly linked to whether or not a respondent consumed organic food.

Table A3. Attitude towards eating food grown in biosolids cross-tabulated with frequency of organic food consumption.

		Attitude towards Eating Food Grown in Biosolids		
		Negative	**Neutral**	**Positive**
Frequency of organic food consumption	Every day	17.4% (12)	14.5% (10)	68.1% (47)
	At least once a week	21.2% (31)	11.0% (16)	67.8% (99)
	At least once a month	19.1% (9)	14.9% (7)	66.0% (31)
	Less than once a month	20.5% (9)	13.6% (6)	65.9% (29)
	Never	11.8% (4)	32.4% (11)	55.9% (19)

Age (Table A4). A chi-square p value of 0.313 (dof 6) indicated no significant relationship between attitudes towards consuming food grown in wood biochar and the age of respondent. However, the age groups had to be combined to meet the assumptions of the chi-square test. It is clear from the data that the majority of respondents across all age groups had a positive attitude towards wood biochar (81.7%).

Table A4. Attitude towards eating food grown in wood biochar cross-tabulated with age.

		Attitude towards Eating Food Grown in Wood Biochar			
		Uncomfortable	**Neutral**	**Slightly Comfortable**	**Very Comfortable**
Age groups	18–34	5.4% (4)	13.5% (10)	10.8% (8)	70.3% (52)
	35–54	3.3% (5)	14.4% (22)	15.0% (23)	67.3% (103)
	over 55	2.5% (3)	16.4% (20)	12.3% (15)	68.9% (84)

Location (Table A5). A positive label was assigned to slightly comfortable/very comfortable and negative to very uncomfortable/uncomfortable to tighten up the table and allow analysis. A chi-square p value of 0.57 (dof 4) was not significant at 95%: attitude to eating food grown in wood biochar was not closely related to where respondents lived.

Table A5. Attitude towards eating food grown in wood biochar cross-tabulated with residential location.

		Attitude towards Eating Food Grown in Wood Biochar		
		Negative	**Neutral**	**Positive**
Location	Rural	2.5% (2)	13.8% (11)	83.8% (67)
	Suburban	3.3% (4)	19.0% (23)	77.7% (94)
	Urban	4.1% (6)	12.2% (18)	83.8% (124)

Location (Table A6). A chi-square p value of 0.8866 (dof 8) was not significant at 95%: where respondents resided did not have a strong relation to attitude towards consuming food grown in sludge biochar.

Table A6. Attitude towards eating food grown in faecal sludge biochar cross-tabulated with residential location.

		Attitudes towards Eating Food grown in SLUDGE Biochar				
		Very Uncomfortable	**Uncomfortable**	**Neutral**	**Slightly Comfortable**	**Very Comfortable**
Location	Rural	7.5% (6)	18.8% (15)	13.8% (11)	20.0% (16)	40.0% (32)
	Suburban	5.8% (7)	17.4% (21)	19.8% (24)	24.0% (29)	33.1% (40)
	Urban	6.8% (10)	20.9% (31)	19.6% (29)	18.2% (27)	34.5% (51)

Organic food consumption (Table A7). A chi-square p value of 0.1971 (dof 8) was not significant at 95%: attitudes towards consuming food grown in sludge biochar did not seem to be related to frequency of organic food consumption.

Table A7. Attitude towards eating food grown in faecal sludge biochar cross-tabulated with frequency of organic food consumption.

		Attitudes towards Eating Food Grown in Sludge Biochar		
		Negative	**Neutral**	**Positive**
Frequency of organic food consumption	Every day	17.4% (12)	17.4% (12)	65.2% (45)
	At least once a week	26.0% (38)	14.4% (21)	59.6% (87)
	At least once a month	31.9% (15)	14.9% (7)	53.2% (25)
	Less than once a month	27.3% (12)	25.0% (11)	47.7% (21)
	Never	29.4% (10)	29.4% (10)	41.2% (14)

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