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Consumer acceptance of mycelium as protein source

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ABSTRACT

The mycelium of mushroom-forming fungi represents an underappreciated protein source that can be cultivated on agricultural rest-streams and industrially prepared substrates. Consumer food options include unprocessed fresh mycelium or products derived from purified mycelium protein. Both the use of rest streams and the association of fresh mycelia with moulds can create a tension between potentially disgusting and naturalness cues. The current paper investigates this tension in a 3 (substrate: manure, wood, glucose) by 3 (level of processing: unprocessed mycelium cake, purified mycelium protein powder, burger from mycelium protein) experimental survey (N = 449). Results show that substrate source has limited impact on disgust but a slightly greater influence on perceived naturalness. Level of processing has a significant effect on both disgust and naturalness. As expected, social value and attitude based on benefit-risk trade-off inform acceptance. While effects of disgust and naturalness on benefit-risk attitude and social value balance each other, a direct effect of disgust on acceptance remains, underscoring the pivotal role of disgust in shaping consumer acceptance. This suggests for mycelium producers there is freedom of choice of substrate as it has limited effect on consumer acceptance.

1. Introduction

Proteins are macronutrients of crucial importance for building and maintaining the body and its functions. With growing global population and increasing welfare, it is estimated that the demand for high quality proteins that provide a good balance of all essential amino-acids will double between 2000 and 2050 (FAO, 2006). The currently dominant sources of high-quality protein are animal based: meats, dairy and eggs. Production animals already provide a major burden on the environment, and accommodating the growing demand for proteins with animal protein will only aggravate these already serious environmental problems. Therefore, a wide range of alternative protein sources is being considered for human consumption. These include, amongst others, legumes, cultured meat, insects, algae and duckweed.

Among the potential protein sources, mushroom forming fungi have received limited attention. Fresh mushrooms contain a lot of water and hence their protein concentration is modest. The fruiting bodies of the fungi (i.e., the mushrooms) only represent a small part of the entire fungal organism making them fairly inefficient to produce. In addition, conventional protein assessment methods appear unreliable to determine protein and amino-acid contents of mushrooms making it hard to estimate their nutritional value (Derbyshire, 2020; Scholtmeijer et al., 2023). On the positive side, mushrooms are a traditional food in many cultures and are known to provide a good balance of essential amino acids (Ayimbila & Keawsompong, 2023). Mushroom forming fungi can be grown industrially in unlighted conditions (Kumar et al., 2022) and they are among the very few organisms that can convert lowly valued woody (lignocellulose rich) rest-streams such as straw, wood chips and sawdust into high quality proteins. Use of proteins from not only the mushrooms but also the mycelium of these fungi could make them a relevant sustainable protein source (Scholtmeijer et al., 2023).

Sustainability benefits of fungi derives in part from the used substrate. Common button mushrooms are grown on (pasteurised) manure mixed with straw, oyster mushrooms can be grown in used coffee grinds, shiitake and several other mushrooms are grown on wood. Although these substrates are sustainable, the sustainability benefits remain limited as the mycelium is not consumed. Food products made from mycelium and mycoproteins depend on food grade substrates, which reduces their potential sustainability benefits. The broadly marketed Quorn® mycoprotein is grown in a glucose-based substrate, tempeh is grown in soybeans, and white or blue moulds flavouring cheeses like Camembert or Roquefort grow on the cheeses. Some innovative mycelium products that use non-food grade substrates are being developed like MyBacon, a product created by slicing mycelium from aerial mycelium growth on wood chips into thin strips.

To optimise sustainability benefits, mycelium grown on such rest

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streams could be more broadly considered. The challenge is that mycelium grown in woody rest streams may need to be separated from the remainders of the substrate. This can be done by extracting and purifying the protein that is then used as ingredient for protein shakes or further processed into a ready-to-eat products, such as a fungi-based meat analogues. Such processing may reduce sustainability benefits. Alternatively, some partially degraded substrate remains in the product. In this case, the use of non-food grade substrates requires food safety assessment about the safety of the remaining substrate in the final consumer products (Scholtmeijer et al., 2023).

Besides technical challenges, consumer acceptance plays a key role in the success of novel proteins (see e.g. Bekker et al., 2021; de Beukelaar et al., 2019; Fischer et al., 2023; Onwezen et al., 2021; Van der Stricht et al., 2024) and will also be relevant to acceptance of mycelium. Disgust (e.g. Peksever et al., 2024; Sogari et al., 2023) perceived naturalness (e.g. Chia et al., 2024; Etter et al., 2024), their influence on risk benefit perception (e.g. Gonzalez Coffin et al., 2024; Pakseresht et al., 2023; Wang et al., 2024) and the impact of social influences (e.g. Engel et al., 2024; Valesi et al., 2024) are commonly investigated determinants of acceptance of new protein sources. However, to date research on mycelium remains scarce with some notable exceptions like consumer testing of mycelium cake harvested from stale bread which showed cautiously positive consumer opinions, particularly because of environmental benefits (Hellwig et al., 2020).

This paper aims to provide insight into consumer acceptance of potential mycelium products by investigating effects of processing levels and used substrates on acceptance.

2. Theoretical background and hypotheses

Consumer acceptance of new products can be conceptualised either as the actual uptake of the product (cf. Rogers, 2003) or as the general propensity, or willingness to accept a product in the future (cf. Fischer & Reinders, 2022). Given that mycelium products from woody rest streams are not yet in the market, in this paper acceptance is conceptualised as the willingness to accept. Such acceptance is an indicator of the utilitarian and emotional value consumers see in a product (Sweeney & Soutar, 2001), and depends on personal evaluations of the product considered (e.g. Bredahl, 2001; Poínhos et al., 2014; Ren et al., 2023). In the case of new products, the trade-off that people make is between perceived benefits and risks (Ronteltap et al., 2011; Ronteltap et al., 2007; Siegrist, 2000). Such a benefit risk trade-off can be summarised as an attitude like score that informs acceptance (e.g. Berezowska et al., 2015; Schenk et al., 2008).

Next to benefit risk trade-off, acceptance of new products also depends on the social value perceived in using such products (Dueñas-Ocampo et al., 2023; Matsuoka et al., 2023; Onwezen et al., 2022b; Sweeney & Soutar, 2001). Social value is based on the perception how peers will respond to a consumer who adopts the product. If positive peer responses are expected, the positive social value will lead to favourable a personally relevant norm (Lee et al., 2023) which supports acceptance (Schwartz, 1977). This leads to hypotheses:

Hypothesis 1 A more positive benefit risk trade-off leads to higher acceptance
Hypothesis 2: Higher social value leads to higher acceptance

The benefit risk trade-off is likely informed by initial responses after seeing the product. For food, visual cues can evoke a disgust response (Ammann et al., 2018a) which has a strong negative influence on acceptance (Egolf et al., 2019). The risks as feelings (Loewenstein et al., 2001) hypothesis shows that risk perception is in part based on emotions. Additionally, the affect heuristic (Finucane et al., 2000) suggests that in the presence of a negative emotion risk perceptions increase and benefit perceptions simultaneously reduce. Hence in the presence of negative emotions such as disgust, the benefit risk trade-off shifts to a more negative balance. Next to the effect of disgust on the benefit risk trade-off, disgust is also likely to convey a negative social value, as the adoption of disgusting practices is shown to evoke inferences of contagion that spread to social situations (Nemeroff & Rozin, 1992). Hence reduced social value is experienced for adopting foods that are considered disgusting. The effect of the negative emotion disgust (e.g. Russell & Lemay, 2000) on acceptance can be partially, or fully mediated through the benefit-risk trade-off and social values:

Hypothesis 3 A higher level of disgust leads to reduced acceptance
Hypothesis 4: The effect of a higher level of disgust on acceptance is mediated through a more negative benefit-risk trade-off
Hypothesis 5 Higher levels of disgust reduces perceived social value

Consumers may dislike the use of substrates that are considered inedible or even disgusting such as manure. In addition, mycelia themselves may be considered disgusting (Egolf et al., 2019). Waste streams converted into consumer products are frequently considered with disgust (Meng & Leary, 2021). Among waste streams manure and faeces stand out. It is clear these need to be kept away from food, as there is a strong link between excrements as a disease, which is one of the evolutionary precursors of a disgust response (Griskevicius & Kenrick, 2013). Even if the materials are processed in a way that disgust cues are no longer recognisable, consumers may still make the inference that the product is contaminated, through previous association (Rozin et al., 1985; Rozin & Nemeroff, 1990). Even biogas created from manure was considered with some levels of disgust (Herbes et al., 2018; Powell, 2021). In the case of mycelium, disgust can be associated with the substrate. A disgust response cannot be expected for materials like wood, that are just non-food but not disgusting per-se (Rozin & Fallon, 1980), nor from glucose syrup which is a food grade substance. Next to disgust caused by substrates, visually recognisable mycelium may lead to disgust based on the association with moulds (Ammann et al., 2018a). Nevertheless, removing visual or other disgust cues such may reduce disgust response in a similar way as for the production of insect protein for human consumption (e.g. Dagevos, 2021). Hence we argue that disgust is less likely for processed mycelium ingredients or products produced with mycelium where mycelium is no longer visually recognisable. This leads to:

Hypothesis 6 The use of a waste stream (such as manure) as substrate leads to higher levels of disgust compared to other non-food materials or processed food grade substrate
Hypothesis 7: Unprocessed mycelium leads to higher levels of disgust compared to mycelium processed to unrecognisable ingredients (protein powder) or a ready to eat product based on such ingredients

While disgust evoked by visual cues of unprocessed mycelium has a negative impact on acceptance, the use of unprocessed mycelium grown on natural substrates is also likely to be perceived as natural and healthier by consumers (e.g. Siegrist & Hartmann, 2020), which suggests that naturalness caused by low level of processing leads to a positive shift in the benefit-risk trade-off. Manure and wood being unprocessed waste streams are perceived as more natural than highly processed industrial products like glucose syrup (Hässig et al., 2023). Similarly the level of processing of the mycelium products themselves is likely to influence naturalness perception (Saulais et al., 2023). The level of processing of foods following the NOVA classification (Monteiro et al., 2010) aligns with perceived naturalness (Hässig et al., 2023) with more extreme levels of processing leading to lower perceptions of naturalness (Ares et al., 2016), at least as long as the processing procedure itself is not considered traditional and authentic itself (Etale & Siegrist, 2021). As the proposed new mycelia products are generally not traditional or authentic, the level of processing is hypothesised to be indicative of perceived naturalness.

Hypothesis 8 Higher levels of perceived naturalness lead to more positive benefit-risk trade-off

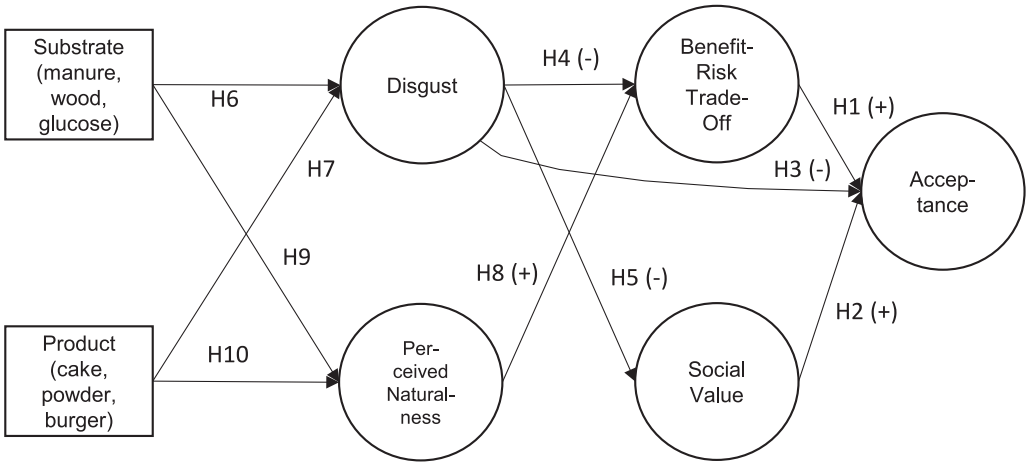

Fig. 1. Theoretical framework.

Hypothesis 9: The use of unprocessed waste streams or non-food materials as substrate are perceived as more natural compared to the use of a processed food grade substrate.

Hypothesis 10 Unprocessed mycelium products are perceived as more natural than either a processed ingredient (purified protein powder) or an ultra-processed consumer product (burger based on mycelium protein).

Together, these hypotheses predict that low levels of processing of mycelium and its substrates can have both positive naturalness effects as well as negative disgust effects (see Fig. 1).

3. Method

3.1. Design and sample

The 449 respondents (51 % female, mean age 44.7 year (SD=15.6)) were recruited through Prolific.[1] Participants were from the UK and at least 18 years of age. The experiment had a 3 (level of processing: non-processed, processed, ultra-processed) x 3 (substrate: edible food mass, non-food organic materials, organic residual stream) between subject design. The data of the experiment was collected through an online questionnaire in Qualtrics. The survey followed the ethical principles of social science research (see ethics statement at end of this paper) and was preregistered at https://osf.io/e3gxa/.[2] Data and materials can be retrieved from https://doi.org/10.5281/zenodo.10628634.

3.2. Manipulations

Level of processing was manipulated at three levels inspired by the NOVA classification system (Monteiro et al., 2019): 1) unprocessed processed, 2) processed ingredient, 3) ultra-processed product. Unprocessed was operationalised as a natural mycelium mould cake. Processed culinary ingredients and food products were a mycelium-based protein powder from dried ground mycelium. Ultra-processed food was a mycelium-based burger.

Substrate source was manipulated by three types of fungi growth substrate: 1) non-food waste, 2) non-food materials, and 3) food grade substrate. Non-food waste was operationalised as composted horse manure mixed with straw, which is the common substrate for button mushrooms. Non-food materials were hardwood logs, which are used to grow various kinds of fungi such as shiitake mushrooms. Food grade substrate was a glucose-based syrup like those used during the production of Quorn®. A scenario (Text box 1) was developed in which specific phrases and images represented the different experimental conditions. See Table 1 for the images and captions depicting each substrate or product. The scenario and images were checked by an expert in fungi cultivation.

Text box 1. The used scenario. Phrases and images for the different experimental conditions underlined

There is a new food product coming into the market, which is made from mycelium. Mycelium is the name for the roots of fungi and consists of bundles of white or cream coloured mould strings. These mould strings can take nutrients from their environment and make them into high quality protein. As a result, mycelium is rich in protein and can be considered as an alternative for animal- and plant-based protein. Mycelium protein will be available on the market as [a mycelium mould cake similar to tempeh/mycelium protein powder which can be used in smoothies or for baking/a mycelium burger] and will look similar to the picture below.

[Image and caption level of processing – cake/powder/burger]

Mycelium can be grown on either solid or liquid surfaces. The mycelium used for the new product is grown on [horse manure mixed with straw/hardwood logs/a glucose solution with added vitamins and minerals], which provides important nutrients and looks similar to the picture below.

[Image and caption of substrate – manure/wood/glucose]

3.3. Measures

Acceptance of the novel mycelium product, was measured by the item "would you consider consuming this product" (1 = would never consider consuming this product, 7 = would definitely consider consuming this product) from Baker et al. (2016) combined with the 3 items "This is a product that I would enjoy consuming", "This is a product that would make me want to consume it", "consuming this product would make me feel good" from the shortened perceived value (PERVAL) scale from Sweeney and Soutar (2001), forming a reliable acceptance construct (Cronbach α = 0.94). Social value was measured with the 3-item PERVAL social value subscale "consuming this product would help me feel acceptable", "Consuming this product would improve the way I am perceived", "consuming this product would make a good impression on other people" (Cronbach α = 0.93) (Sweeney &

[1] https://www.prolific.com/.

[2] Compared to preregistration minor adjustments were made to simplify the model: risks and benefits were merged into a single construct, and the effect of disgust on this combined construct was estimated, the moderation of environmental concern was dropped from the model.

Table 1
Images and captions used for the different levels of processing and substrates.

Substrates		
		
Composted horse manure mixed with straw	Hardwood logs as growth substrate	Substrate of glucose with added vitamins and minerals
Level of processing		
		
Mycelium mould cake	Mycelium protein powder	Mycelium burger

Soutar, 2001). Both PERVAL subscales were measured on a 7-point Likert scales (1 = totally disagree, 7 = totally agree).

Disgust was measured by 4 items "The thought to eating this food makes me nauseous", "I dislike the idea of having this food in my stomach", "I dislike the idea of this food because of what it is or where it comes from", "The thought of eating this food is disgusting to me" adapted from Martins and Pliner (2006) on a 7-point scale (1 = Not at all, 7 = Extremely) (Cronbach α = 0.97). Benefit-Risk trade-off was based on Yazdanpanah et al. (2015) and consisted of health environmental benefit and risk perception items "Consuming this product will provide health benefits"): "producing this product will benefit the sustainability of the environment", "consuming this product will result in health risks", and "Producing this product will increase the risk of environmental sustainability losses" on a 7-point scale (1 = not at all, 7 = a great deal), (Cronbach α = 0.70). Perceived naturalness was measured with the single item from Murley and Chambers (2019) "How natural do you perceive this product to be?" (1 = not at all natural, 7 = extremely natural).

Next to gender ('male', 'female', 'non-binary/other', and 'prefer not to say'), age in years, highest completed education was asked for in 7 levels corresponding to ISCED level 1 to 3 and 6 to 8 (ISCED, 2011).[3] Familiarity with mycelium as food (Martins & Pliner, 2006) and environmental concern (Steg et al., 2011) were included as potential control variables (both measured on a 7 point scale from 1 = very little to 7 = very much).

3.4. Pilot testing and procedure

Materials were pretested in a cognitive walkthrough with four participants where participants were asked to speak out load whatever came to mind when going through the materials and questions, leading to some minor revisions of the experiment. The experiment was then pilot tested with 11 online participants, where participants first completed the experiment and then were asked if the formulation of the scenario and questions was in a common language and easy to understand. The pilot study resulted in no further revisions.

Prolific participants entered the Qualtrics query through their account and were presented with a brief introduction, were assured that their response was anonymous, and that the data collected cannot be linked to them. Furthermore, they were informed that their participation was voluntary, and that the questionnaire could be stopped at any time. After which they agreed to informed consent. They were then randomly assigned to one of the nine conditions and were shown the corresponding informational text and pictures about a novel mycelium product. The participants were asked to read the text and analyse the pictures carefully, and were subsequently asked questions about the acceptance, social value, risk benefit trade-off, disgust, and perceived naturalness. Finally, the participants were asked demographic questions after which they were thanked for their participation. The questionnaire took approximately seven minutes to complete, and participants were paid 1£ to complete it.

3.5. Analysis plan

Data were analysed with IBM SPSS 28 (Cronbach α, item means, exploratory factor analysis (EFA)) and in R-Lavaan (v0.6–16 Rosseel, 2012) for the confirmatory factor analysis (CFA) and structural equation model (SEM). Commonly recommended indicators for good fit of CFA and SEM (Hu & Bentler, 1999; Schermelleh-Engel & Moosbrugger, 2003) with CFI and TLI>.90, RMSEA ideally below 0.05, fair below 0.08 and not above 0.10, SRMS below. 10, and $\chi^2 < 5$ per df were adopted.

In the confirmatory factor analysis for multi-item constructs an arbitrary item was assigned factor loading of 1 to allow error variance in all items. Give that this loading was not estimated, significance levels do not apply. A mix of positive and negative items as is the case for the benefit and risk trade off, can create a potential response bias (Greenberger et al., 2003). To compensate for this, the error terms of risk perception items were allowed to correlate as were those of the benefit items (cf. Van Giesen et al., 2018). Even though the error term correlation of benefit items was not significant it was retained for consistency.

[3] Choices for educational levels (ISCED classification not included to participants) Primary school reception class/nursery school (ISCED 0), Primary school (ISCED 1), GCSE (ISCED 2), A Levels (ISCED 3), Bachelor's degree (ISCED 6), Master's degree (ISCED 7), Doctorate (ISCED 8).

Given that structural models distinguish between latent variable variation and measurement error, for the single item construct naturalness 40 % of the variance was manually assigned to the error term (cf. Fischer & Frewer, 2008), simulating extracted variance of 60 %. After applying the initial model, modification indices suggested significant error correlation between the 3rd and 4th disgust item, which was consequently allowed. A reasonable fit for the subsequent measurement model was established (χ^2 = 375.62, df = 92; χ^2/df = 4.00; CFI=.96, TLI=.95. RMSEA=.08, SRMR=.06). Modification indices suggested no additional theoretically sensible modifications.

For the full structural model, the three level independent variables substrate and processing were dummy coded. The levels with most potential sustainability benefit (manure, (non-processed) cake) were set as baseline, allowing pairwise comparisons to that baseline. Creating a dummy set with a different baseline (reparametrizing) followed by rerunning the structural model, allowed for all pairwise comparisons. Indirect mediation effects were assessed by calculating the product of the path coefficients (Rosseel, no date).

4. Results

Means (SD) and factor loadings derived from exploratory factor analysis of individual items, measured on a 7-point scale, and background variables are provided in Table 2. Fig. 2 shows construct means of the latent construct based on the SEM factor loadings. Across all conditions the means for acceptance (3.21), social value (2.74), benefit-risk trade off (4.44), disgust (3.75) and naturalness (4.92), suggest that participants recognised benefits and naturalness, yet did no see much social value and were somewhat reluctant to accept mycelium products. Randomisation checks showed no differences between the 9 conditions for demographic and background variables (Table 2).

After including all hypothesised effects, modification indices suggested additional direct effects of source of substrate on benefit risk trade-off and from naturalness on social value, as well as correlation between disgust and naturalness and benefit-risk trade-off and social value. After inclusion of these relations, the structural model had a good fit (χ^2 = 456.02, df = 147, $p < 0.001$; χ^2/df = 1.55; CFI=.96, TLI=.94. RMSEA=.07, SRMR=.05) (Fig. 4).[4]

Based on all pairwise comparisons of coefficients from the structural model,[5] it was confirmed that manure as substrate did indeed result in higher disgust than wood but not compared to glucose, providing partial confirmation of H6. Both manure and wood were perceived as more natural than the glucose solution providing evidence for H9. Burgers were considered significantly less natural than unprocessed cake, with processed powder between those extremes providing partial evidence for H10. Unprocessed cake resulted in the strongest disgust score, followed by the burger and protein powder being perceived as least disgusting was found as well providing evidence for H7 (see Fig. 3). For both disgust and naturalness total effects of the 9 different conditions (df = 8), were modest with 7 % explained variance for either construct. The direct effects of dummies on the other latent variables were also modest, for acceptance R^2 = 0.04, for benefit-risk trade-off R^2 = 0.04, and for social value R^2 = 0.03.

As hypothesised disgust social value (H5) and had a negative effect on benefit-risk trade-off (H4), and while the indirect of effect of disgust mediated through benefit-risk trade-off was substantial (z = -4.28, $p < 0.001$), the effect was only partially mediated as shown by a remaining direct effect of disgust on acceptance (H3). Perceived naturalness showed a predicted positive effect on benefit-risk trade-off (H8), as well as a non-hypothesised effect on social value. Risk benefit trade-off (H1) and social value (H2) contributed to acceptance as hypothesised. A non-hypothesised remaining positive effect of the contrast between manure and glucose on benefit risk trade-off was found, suggesting glucose is considered more positively than explained through the mediation through disgust and naturalness. Additional negative correlations between naturalness and disgust and positive correlation between social value and benefit risk trade-off were also observed (see Fig. 4 and Table 3). Most indirect paths were significant (Table 4), except for the indirect path of substrate source through disgust, which provides confirmation for most hypothesised mediation effects.

5. General discussion

As expected and in line with extant literature (e.g. Schenk et al., 2008; Schwartz, 1977) both benefit-risk trade-off (H1) and social value (H2) contributed to overall acceptance of mycelium as food.

Disgust had an important impact on acceptance in three ways. Disgust had a negative effect on the benefit-risk trade-off (H4), which is in line with the affect heuristic (e.g. Slovic et al., 2004) or the specific disgust version thereof (Siegrist & Hartmann, 2020). Following the social contagion hypothesis (Rozin & Nemeroff, 1990), disgust had a negative effect on perceived social value of consuming mycelium products (H5). Even after accounting for benefit-risk trade-off and social value, a remaining negative effect of disgust on acceptance was found (H3). The finding that emotions are not fully mediated through benefit-risk trade-offs is in line with previous findings (e.g. Siegrist et al., 2007).

Perceived naturalness had the hypothesised positive impact on the benefit-risk trade-off (H8), which follows that attitude towards natural products is generally positive (e.g Vermeir & Verbeke, 2006) and perceived naturalness is a heuristic for positive evaluation (Siegrist & Hartmann, 2020). In addition, naturalness also had a positive impact on social value. This can be caused when consumers infer that using natural products meet with peer approval, which inference could be reflected in social norms and social value. An alternative explanation could be a halo effect where the positive interpretation of naturalness of a product spreads to other positive evaluations such as healthiness (Schuldt & Schwarz, 2010), or in this case to positive social value.

As predicted and in line with the NOVA classification, unprocessed mycelium (cake) was considered the most natural product and the highly processed burger least natural with the processed protein ingredient somewhere in between (H10). The products made from mycelium largely showed the predicted differences in disgust where the recognisable mycelium cake was considered most disgusting and the protein powder least (H7), although processed mycelium burger was considered more disgusting than the protein powder. This may be due to the perception that burger is even less natural compared to the protein powder, although it may also be caused by the visual stimuli used which depict a “cleaner” powder compared to the burger. The disgust response towards unprocessed mycelium in particular is in line with disgust responses to images of mouldy products (Ammann et al., 2018a; Hartmann & Siegrist, 2018), which suggest at least in part the visuals may have influenced perceptions.

Manure and wood were perceived as a more natural substrate compared to the glucose substrate (H9). The effect of substrate on disgust was, however, less clear, with manure being only slightly more disgusting than the other substrates (H6), leading to marginal indirect effects. Glucose based substrate showed a remaining positive effect on benefit-risk trade-off not mediated through disgust or perceived naturalness. This may be due to the specific association of glucose with sweetness which humans tend to like in products (Beauchamp, 2016). To substantiate this explanation, further research whether consumer

[4] Even though not all individual dummies were significant they were maintained as essential part of the manipulated factor which did significantly contribute. The interactions of the manipulated variables were also entered as dummies to check whether (non-hypothesised) interaction effects occurred, none of the dummies contributed to the model (all absolute z-values between 0.16 and 1.63). For simplicity the interaction terms are omitted from further reporting.

[5] Reparametrized where relevant to test the contrasts not directly estimated in the reported dummies.

Table 2
Descriptives table with item means (SD), scale reliability per construct and randomisation checks for background variables.

		Mould cake			Protein powder			Burger			Factor loadings (EFA)	Cronbach α
		Horse Manure	Wood logs	Glucose	Horse Manure	Wood logs	Glucose	Horse Manure	Wood logs	Glucose		
Construct	n Item	50	51	50	50	50	49	50	50	49		
Acceptance[1]	Consuming this product would make me feel good (A4)	3.62 (1.94)	3.56 (1.68)	3.82 (1.73)	3.78 (1.60)	4.12 (1.39)	4.37 (1.19)	3.33 (1.57)	4.22 (1.59)	3.76 (1.44)	0.90	0.94
	I would consider consuming this product (A1)	3.98 (2.25)	3.60 (1.93)	3.82 (2.02)	4.10 (1.87)	4.64 (1.56)	4.43 (1.73)	3.67 (1.99)	4.35 (1.90)	4.08 (1.89)	0.93	
	This product is one that I would enjoy (A2)	3.30 (1.74)	3.12 (1.42)	3.35 (1.61)	3.58 (1.44)	3.96 (1.37)	3.78 (1.23)	3.39 (1.69)	3.88 (1.39)	3.59 (1.43)	0.92	
	This product would make me want to consume it (A3)	3.16 (1.99)	2.88 (1.48)	2.92 (1.74)	3.46 (1.56)	4.04 (1.43)	3.63 (1.59)	3.00 (1.54)	3.65 (1.54)	3.37 (1.65)	0.94	
Social Value	Consuming this product would help me feel acceptable (S1)	3.24 (1.83)	3.00 (1.71)	3.27 (1.59)	3.32 (1.60)	3.40 (1.50)	3.16 (1.48)	2.80 (1.59)	3.08 (1.48)	2.82 (1.60)	0.91	0.93
	Consuming this product would improve the way I am perceived (S2)	2.80 (1.55)	2.74 (1.51)	3.04 (1.55)	2.90 (1.50)	3.22 (1.45)	2.94 (1.51)	2.49 (1.42)	2.86 (1.35)	2.57 (1.62)	0.95	
	Consuming this product would make a good impression on other people (S3)	3.18 (1.64)	2.98 (1.62)	3.10 (1.48)	3.12 (1.52)	3.76 (1.57)	3.35 (1.59)	2.88 (1.64)	3.14 (1.46)	2.82 (1.69)	0.94	
Benefit Risk trade-off	Consuming this product will provide health benefits (HB)	4.34 (1.56)	3.98 (1.29)	4.51 (1.37)	4.22 (1.38)	4.60 (1.16)	4.71 (1.46)	3.82 (1.68)	4.20 (1.26)	4.20 (1.35)	0.75	0.70
	Consuming this product will result in health risks (HR) (R)	2.90 (1.53)	2.76 (1.30)	2.57 (1.29)	3.12 (1.42)	2.64 (1.06)	2.63 (1.15)	3.12 (1.41)	2.82 (1.63)	2.59 (1.08)	−0.76	
	Producing this product will benefit the sustainability of the environment (EB)	5.22 (1.43)	5.26 (1.28)	5.29 (1.53)	4.96 (1.38)	5.18 (1.38)	5.33 (1.27)	4.94 (1.64)	5.29 (1.37)	5.08 (1.38)	0.81	
	Producing this product will increase the risk of environmental sustainability losses (ER) (R)	2.60 (1.31)	2.44 (1.07)	2.76 (1.23)	2.42 (1.18)	2.70 (1.37)	2.47 (1.14)	2.88 (1.44)	2.65 (1.28)	2.51 (1.14)	−0.58	
Disgust	I dislike the idea of having this food in my stomach (D2)	3.82 (2.19)	3.72 (2.27)	4.16 (2.07)	3.34 (2.04)	2.84 (1.80)	2.67 (1.88)	3.92 (2.03)	3.00 (1.95)	3.29 (2.12)	0.96	0.97
	I dislike the idea of this food because of what it is or where it comes from (D3)	3.94 (2.15)	3.52 (2.19)	3.78 (1.96)	3.30 (2.10)	2.80 (1.98)	2.69 (2.01)	4.08 (2.09)	3.08 (1.89)	3.14 (2.00)	0.95	
	The thought of eating this food is disgusting to me (D4)	3.78 (2.12)	3.60 (2.30)	3.76 (2.01)	3.08 (2.08)	2.52 (1.78)	2.39 (1.80)	3.71 (2.02)	2.76 (1.88)	3.02 (2.04)	0.97	
	The thought of eating this food makes me nauseous (D1)	3.66 (2.18)	3.82 (2.27)	4.16 (2.12)	3.08 (1.97)	2.60 (1.71)	2.41 (1.59)	3.71 (1.97)	2.98 (1.95)	3.22 (2.05)	0.95	
Perceived Naturalness	How natural do you perceive this product to be? (PN)	5.40 (1.49)	5.38 (1.54)	4.86 (1.68)	5.06 (1.41)	5.06 (1.42)	4.69 (1.53)	4.92 (1.66)	4.96 (1.63)	4.00 (1.76)	N.A.	
Randomisation check M(SD) and ANOVA for age (df(8, 436)), familiarity and environmental concern; count and $\chi 2$ for gender (df = 5) and education (df = 32)												
Age[2]	What is your age?	43.48 (14.25)	44.64 (16.65)	46.22 (15.31)	46.54 (14.80)	43.16 (15.34)	41.43 (17.14)	45.39 (17.11)	46.08 (15.46)	45.67 (14.73)	F=0.59, $p = 0.78$	
Gender[3]	Male	29	22	25	24	27	25	23	23	21	$\chi^2 = 9.53$, $p = 0.09$	

(continued on next page)

Table 2 (*continued*)

Construct	n Item	Mould cake Horse Manure	Mould cake Wood logs	Mould cake Glucose	Protein powder Horse Manure	Protein powder Wood logs	Protein powder Glucose	Burger Horse Manure	Burger Wood logs	Burger Glucose	Factor loadings (EFA)	Cronbach α
		50	51	50	50	50	49	50	50	49		
	Female	21	28	25	26	23	24	27	27	28		
Education level[4]	GCSE (ISCED 2)	9	6	8	10	8	2	9	12	7	$\chi^2 = 37.30$, $p = 0.24$	
	A levels (ISCED 3)	11	15	14	11	14	18	15	11	15		
	Bachelor's degree (ISCED 6)	15	25	21	16	19	21	13	16	22		
	Master's degree (ISCED 7)	12	3	6	10	7	7	13	7	4		
	Doctorate (ISCED 8)	3	2	1	3	1	1	0	4	1		
Familiarity		1.86 (1.59)	1.63 (1.30)	1.64 (1.01)	1.64 (1.16)	1.90 (1.34)	1.55 (1.08)	1.58 (1.07)	1.76 (1.47)	1.51 (1.39)	F=0.56, $p = 0.81$	
Environmental concern		5.47 (1.05)	5.74 (1.03)	5.90 (1.01)	5.74 (1.11)	5.76 (1.04)	5.80 (1.00)	5.71 (1.31)	5.92 (0.99)	5.74 (1.16)	F=0.74, $p = 0.66$	

[1] individual items included as these are part of the SEM. Code between brackets indicates item abbreviation used in Fig. 4; (R) indicates item recoded for calculating Cronbach α, original items used in SEM [2] 4 participants did not provide age hence N for age was 445. [3] 1 participant did not disclose gender and was omitted for randomisation check [4] 1 participant reported no formal education (ISCED 0) and was omitted for randomisation check.

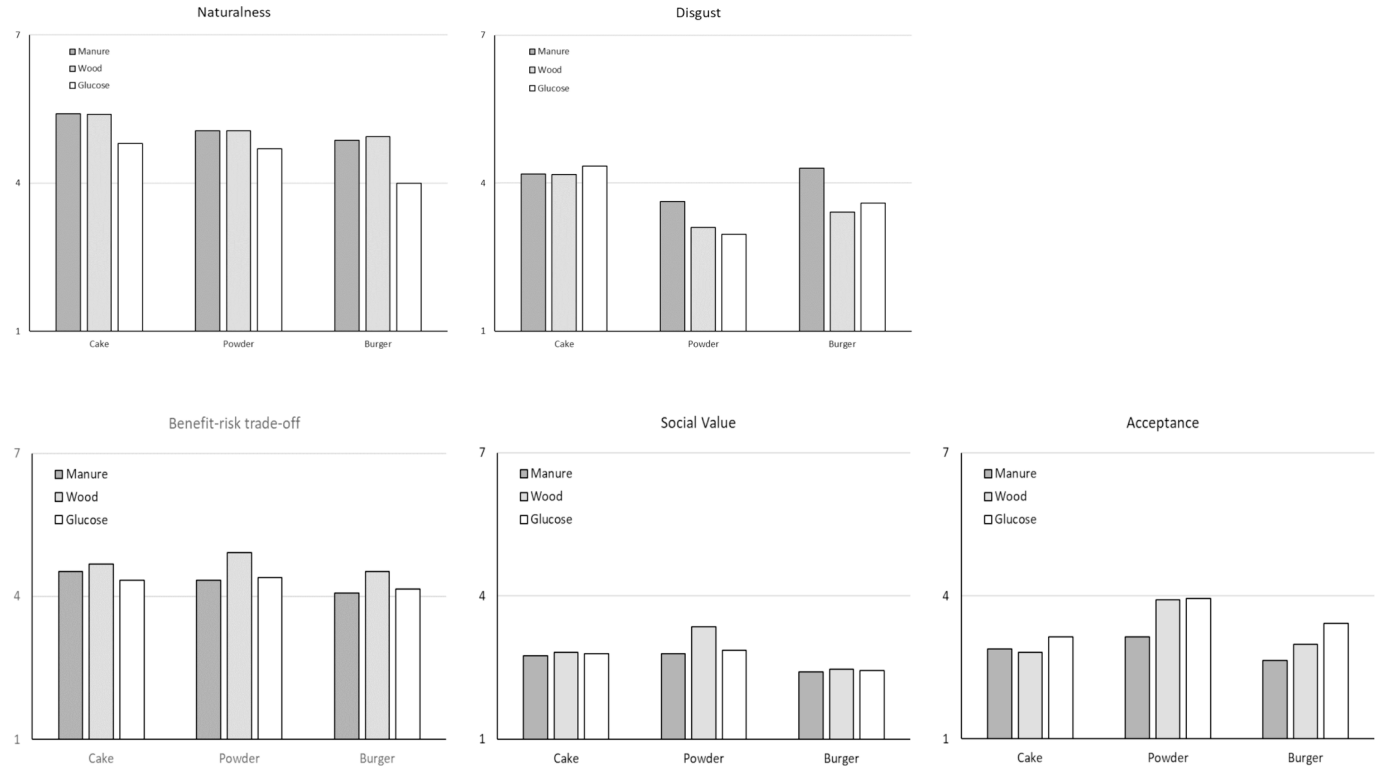

Fig. 2. Means of the latent constructs (based on intercepts and factor loadings of items from SEM).

recognise glucose as such is however required.

The coefficients of the negative impact of disgust and the positive impact of naturalness on benefit-risk trade-off were comparable. Given that naturalness positively contributes to the benefit-risk trade-off and social value, this suggests that less processing of both the mycelium and the substrate on which it is grown is positive (Hässig et al., 2023). Less processing of mycelium and substrate also increased disgust. Thus, it appears that naturalness in part compensates for disgust at least on benefit-risk trade-offs and towards perceived social value. This suggests potential ambivalence towards mycelium products and their substrates as the same product properties increase both disgust and perceived naturalness. Finding a balance between lowered naturalness perceptions and disgust after processing may unveil the most acceptable product lines.

5.1. *Theoretical implications*

The current paper has several theoretical implications. As expected,

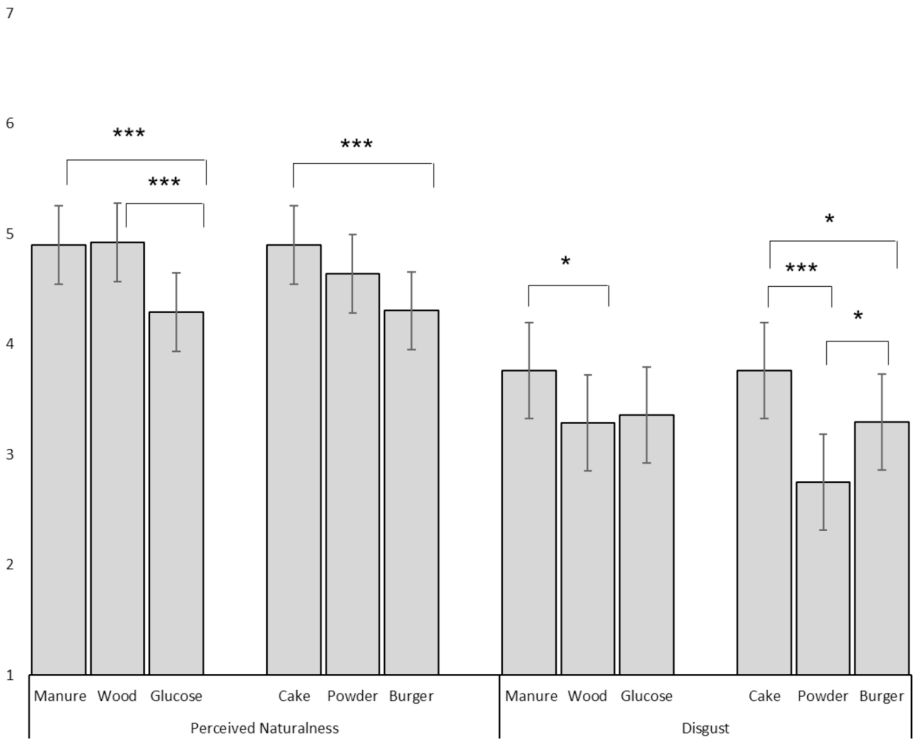

Fig. 3. Means (95 % CI estimated in SPSS) for perceived naturalness and disgust (based on intercept and factor loadings of items). Given non-significant interaction effects, only main effects shown. Significant differences between conditions derived from SEM dummy contrast significances (LSD). * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

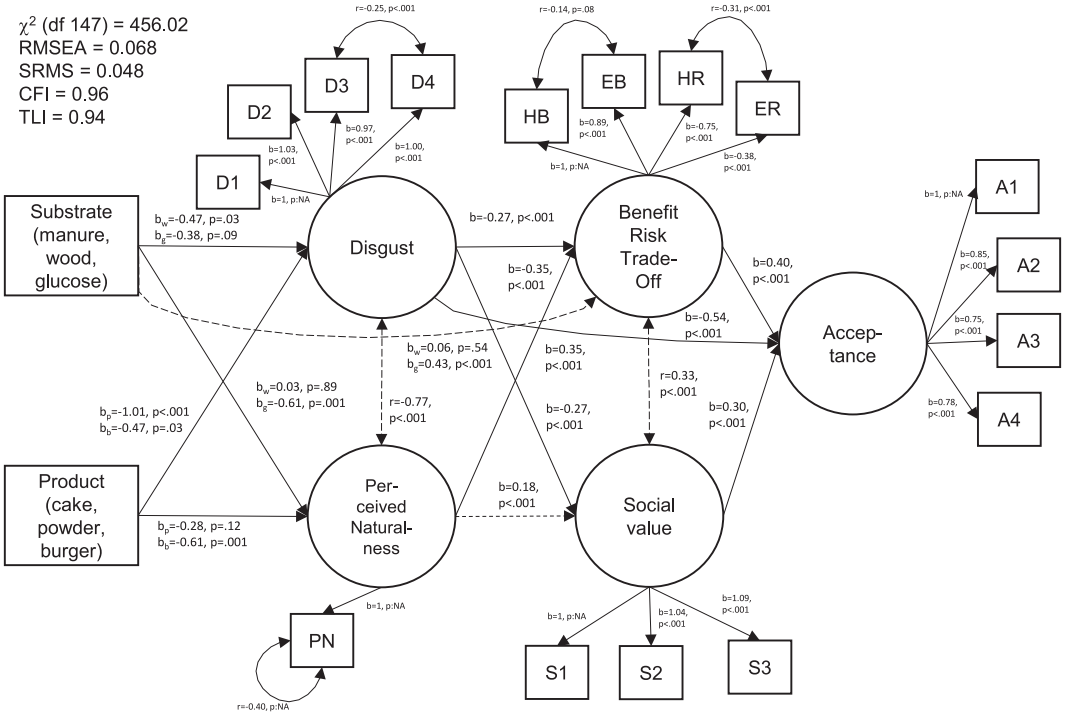

Fig. 4. Structural model. For the manipulations different scores compared to baselines manure for substrate, cake for product reported, subscript indicating the compared condition. Dashed arrows depict exploratory relations (non-hypothesised). p values for fixed first loadings not applicable, perceived naturalness has an imposed variance on the single item to simulate measurement variance. Item abbreviations as defined in Table 2.

both naturalness and disgust were shown to matter and were shown to have an opposite effect towards acceptance. In particular the introduction of unprocessed mycelium products and manure as substrate was considered natural, but also disgusting. Processed protein power and burgers, as well as industrial glucose substrates were seen as both less disgusting and less natural. This suggests that consumers do recognise

Table 3
Overview of latent constructs and their predictors.

Variable	Predicted by (coefficient of)	β	se	p	95 % CI LB	95 % CI UB
Acceptance ($R^2 = 0.84$[1])	Social value	0.30	0.05	**0<.001**	0.21	0.39
	Benefit Risk trade-off	0.40	0.08	**0<.001**	0.24	0.57
	Disgust	−0.54	0.04	**0<.001**	−0.61	−0.48
Benefit Risk Trade-off ($R^2 = 0.63$)	Disgust	−0.27	0.03	**0<.001**	−0.33	−0.22
	Perceived Naturalness	0.35	0.04	**0<.001**	0.27	0.42
	Dummy source (Manure-Wood)	0.06	0.11	0.54	−0.14	0.27
	Dummy source (Manure-Glucose)	0.43	0.11	**0<.001**	0.22	0.65
Social Value ($R^2 = 0.22$)	Disgust	−0.27	0.03	**0<.001**	−0.33	−0.20
	Perceived Naturalness	0.18	0.05	**0<.001**	0.09	0.27
Disgust ($R^2 = 0.07$)	Dummy source (Manure-Wood)	−0.47	0.22	**0.03**	−0.91	−0.04
	Dummy source (Manure-Glucose)	−0.38	0.22	0.09	−0.81	0.06
	Dummy process (cake-powder)	−1.01	0.22	**0<.001**	−1.45	−0.58
	Dummy process (cake-burger)	−0.47	0.22	**0.03**	−0.91	−0.04
Perceived Naturalness ($R^2 = 0.07$)	Dummy source (Manure-Wood)	0.03	0.18	0.89	−0.33	0.38
	Dummy source (Manure-Glucose)	−0.61	0.18	**0<.001**	−0.96	−0.25
	Dummy process (cake-powder)	−0.28	0.18	0.12	−0.63	0.08
	Dummy process (cake-burger)	−0.61	0.18	**0<.001**	−0.96	−0.26
Correlations		*r*	se	*p*	LB	UB
Disgust	Perceived Naturalness	−0.77	0.15	**0<.001**	−1.06	−0.48
Benefit Risk Trade-off	Social value	0.33	0.06	**0<.001**	0.21	0.45

[1] A substantial part of the explained variance of acceptance is due to the other latent variables. The direct effect of the manipulations on acceptance (while significant) only showed $R^2 = 0.03$ (which is in line with modest explained variances of the manipulations on disgust and perceived naturalness).

the relevance of processing to create safe foods by showing a reduced disgust response, and support arguments of food technologists that processing is crucial for food safety (Bonciu, 2018). Nevertheless, consumers also recognise processing as unnatural. This suggests that in developing mycelium products at least latent ambivalence (cf. Van Harreveld et al., 2015) may occur when consumers are first confronted

Table 4
Indirect paths indicated in the structural model.

	Estimate of indirect effect	se	z	p
Dummy source (Manure-Wood) → Disgust → Benefit-Risk → Acceptance [a]	0.048	0.026	1.818	0.07
Dummy source (Manure-Glucose) → Disgust → Benefit-Risk → Acceptance [a]	0.040	0.026	1.573	0.12
Dummy source (Manure-Wood) → Disgust → Acceptance [b]	0.242	0.121	1.992	**0.05**
Dummy source (Manure-Glucose) → Disgust → Acceptance [b]	0.205	0.122	1.677	0.09
Dummy source (Manure-Wood) → Disgust → Social value → Acceptance [c]	0.036	0.019	1.882	0.06
Dummy source (Manure-Glucose) → Disgust → Social value → Acceptance [c]	0.031	0.019	1.609	0.11
Dummy source (Manure-Wood) → Naturalness → Benefit-Risk → Acceptance [d]	0.002	0.024	0.095	0.93
Dummy source (Manure-Glucose) → Naturalness → Benefit-Risk → Acceptance [d]	−0.084	0.031	−2.723	**0.01**
Dummy source (Manure-Wood) → Naturalness → Social value → Acceptance [e]	0.001	0.010	0.095	0.93
Dummy source (Manure-Glucose) → Naturalness → Social value → Acceptance [e]	−0.034	0.014	−2.432	**0.02**
Dummy source (Manure-Wood) → Benefit-Risk → Acceptance [f]	0.016	0.041	0.392	0.70
Dummy source (Manure-Glucose) → Benefit-Risk → Acceptance [f]	0.160	0.052	3.050	**0<.01**
Dummy product (cake-powder) → Disgust → Benefit-Risk → Acceptance [h]	0.110	0.035	3.144	**0<.01**
Dummy product (cake-burger) → Disgust → Benefit-Risk → Acceptance [h]	0.050	0.026	1.870	0.06
Dummy product (cake-powder) → Disgust → Social value → Acceptance [i]	0.084	0.024	3.528	**0<.001**
Dummy product (cake-burger) → Disgust → Social value → Acceptance [i]	0.038	0.019	1.947	**0.05**
Dummy product (cake-powder) → Disgust → Acceptance [j]	0.560	0.125	4.467	**0<.001**
Dummy product (cake-burger) → Disgust → Acceptance [j]	0.252	0.122	2.068	**0.04**
Dummy product (cake-powder) → Naturalness → Benefit-Risk → Acceptance [k]	−0.038	0.026	−1.492	0.14
Dummy product (cake-burger) → Naturalness → Benefit-Risk → Acceptance [k]	−0.085	0.031	−2.777	**0.01**
Dummy product (cake-powder) → Naturalness → Social value → Acceptance [l]	−0.016	0.011	−1.437	0.15
Dummy product (cake-burger) → Naturalness → Social value → Acceptance [l]	−0.035	0.014	−2.461	**0.01**
Disgust → Benefit-Risk → Acceptance	−0.108	0.025	−4.279	**0<.001**
Disgust → Social value → Acceptance	−0.083	0.015	−5.395	**0<.001**
Naturalness → Benefit-Risk → Acceptance	0.135	0.030	4.479	**0<.001**
Naturalness → Social value → Acceptance	0.055	0.016	3.428	**0<.01**

Note: indirect paths sharing a superscript character indicate the combined effect of the dummies for a manipulated 3 level factor. Italics indicate non-significant indirect effects if the path is not significant for all dummies.

with such products. While ambivalence can help consumers to consider new alternatives in an open and comprehensive way (van der Weele & Driessen, 2019), ambivalence itself can also provide a negative feeling of uncertainty that may lead to a negative conclusion about the product and hence contribute to rejection of products (e.g. Pauer et al., 2022). Managing ambivalences so that latent ambivalence does not become a strongly negatively felt ambivalence will be an important task when further developing mycelium products. How ambivalence in the case of mycelium products is experienced and resolved may in part depend on personality traits like disgust propensity (Hartmann & Siegrist, 2018) a trait correlated with neophobia (Al-Shawaf et al., 2015; Ammann et al., 2018b). Other personality characteristics may emphasise the need for naturalness for example for those consumers for whom naturalness is a dominant food choice motive (e.g. Román et al., 2017; Steptoe et al., 1995). Figuring out the relevant personality characteristics of consumers and how these influence acceptance is therefore a venue for future research.

The emotion disgust is shown to influence benefit-risk trade-off and social value. One explanation is that benefit-risk trade-offs and perceived social values are generally considered to be rational and/or utilitarian evaluations of an object. This suggests that rational intermediate perception and evaluation stage towards acceptance (e.g. Finucane et al., 2000; Schenk et al., 2008; Siegrist et al., 2007) does not sufficiently capture the impact of emotions. Instead, it suggests that emotions are also an important proximal factor for acceptance of protein products (Loewenstein et al., 2001; Onwezen et al., 2022a). This asks for further study on how different psychological processes combine towards acceptance (cf. Chaiken, 1980; Kahneman, 2011), and emphasises the need to study the impact of emotions on food choice (Dalenberg et al., 2014).

5.2. Practical implications

For the introduction of mycelium products, the current research has a number of implications. The negative disgust effects of unprocessed mycelium cakes and the use of manure were in part compensated by the positive effect of these product cues on perceived naturalness. This suggests that for practical application, a balance between naturalness and disgust needs to be found that fits the specific product and consumer group. A similar discussion was raised for introducing insects as food, where disgust is a frequently found determinant of acceptance (e.g. Engel et al., 2024; Sogari et al., 2023). For insects, consensus is emerging that disgust and fear for whole, unprocessed insects is prohibitive for acceptance and that processing is the best way forward (Dagevos, 2021). These results are specific for insects and translation to mycelium should be investigated. The cautiously positive findings of Hellwig et al. (2020), and the familiarity of consumers with mycelia in cheeses and possibly tempeh suggest that unprocessed mycelium has a better marketing potential. Other new protein sources such as algae and legumes generally do not evoke disgust. This suggests that the balance of positive and negative determinants may at least in part depend on the specific protein source. Further research is recommended to confirm this.

The current research also suggests that substrates can be part of the narrative of a product, both leading to disgust but also to perceived naturalness. For the use of woody side streams from agriculture, the current research gives a promising starting point as consumers recognise the naturalness of these materials while wood does not cause a disgust response. Nevertheless, it seems that differences in substrates only have a modest impact on acceptance, which suggests substantial leeway for producers in the choice of substrate.

5.3. Limitations

Given the responses of consumers towards glucose depicted in an industrial flask and the mycelium cake giving a “mouldy” impression, it is likely that the specific images in this study have influenced the outcomes. While this may have contributed to some unexpected outcomes, for example the low disgust score for the clean looking protein powder versus the “wet” burgers, it may nevertheless have helped participants to visualise the concept of mycelium food, making the manipulation less hypothetical to a certain extent (cf. Erfanian et al., 2020). Nevertheless, it is likely that substrates will not be visualised in marketed products. This is already the case with the manure grown common button mushroom which is not communicated extensively. Hence future research is suggested on the impact of substrates. In addition, using processed mycelium may not feature prominently on the final products either. Once mycelium production in woody rest streams starts to be implemented and the first pilot products are created, future research is recommended using actual products and images to show the robustness of current findings. Similarly, the framing as mycelium, fungi, mould strings and the explicit statement the protein was high quality in the explanatory texts may have influenced consumer responses. Although these frames were identical for all experimental conditions insight into their impact their impact on mycelium introduction should be investigated.

In the current study the benefit-risk trade-off was operationalised as the balance between sustainability and health perceptions combined into a single construct. While the scope of the current study selected the underlying motives health and sustainability as important in this situation, consumers are likely to also consider risks and benefits related to other motives such as taste, convenience, and price (cf. Grunert, 2002; Steptoe et al., 1995; Verain et al., 2021). Future research is therefore recommended to explore which are the relevant consumer motives to judge mycelium and substrate sources. In addition it might be worthwhile to consider whether a simpler model that combines benefit-risk perceptions in a trade-off may be expanded to a model that considers risk and benefits perceptions as different constructs (as for example in Schenk et al., 2008) or even considers different risks and benefits (e.g. health, environmental) as distinct constructs.

While the manipulations did have an effect on both disgust, naturalness and a direct effect on acceptance, the effect sizes were modest at best (between small and medium following Cohen, 1988, 1992). This may suggest that the current measures did not fully capture the effects of differences in substrate and production process. One explanation is that additional constructs, such as expected taste, capture such effects. Another explanation may be the sensitivity of the measures for disgust and naturalness to capture largely unconscious perceptions in a self-report measure. It may also suggest that consumers do not make a clear distinction between, in particular, substrates as this psychologically is relatively far removed from their final product (as seen before for food production methods by e.g. Steenis & Fischer, 2016). That the common button mushroom is well known to be grown on manure without obvious signs of consumer disgust seems to support such a psychological distance hypothesis. To shed light on whether the found effects relate to perception of mushroom cultivation, for future research on mycelium it is recommended to include mushroom and their substrates into consumer research on mycelium food. That products and substrates may differ in terms of psychological distance to the end-product is however beyond the scope of the current study.

5.4. Conclusions

Consumer acceptance of mycelium depends on a benefit-risk trade-off, perceived social value and experienced disgust. Social value and benefit-risk trade-offs are in turn influenced by disgust and naturalness heuristics that partially counteract each other. Substrate and processing level inform perceived naturalness and disgust to a modest extent. Through this modest influence substrate and processing levels are nevertheless likely to influence the balance between naturalness and disgust. When developing mycelium products, getting the substrates and processing levels right to find the optimal balance of perceived naturalness and disgust should provide the optimal way forward.

Ethics statement

Data were collected following the ethical standard of the university. Participants were asked to digitally agree with an informed consent form in which they were told their online participation was voluntary, that collected data was anonymised and could not be traced to individual participants, that the study lasted 10 min that they would receive 1£ compensation upon completion, and that they could leave any time during the experiment whenever they wanted.

CRediT authorship contribution statement

Arnout R.H. Fischer: Writing – original draft, Supervision, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Owen Hilboesen:** Writing – review & editing, Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Arnout Fischer is member of the editorial board of Food Quality and Preference.

Data availability

Data and materials can be retrieved from https://doi.org/10.5281/zenodo.10628634.

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