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# Microplastics in food and drink: perceptions of the risks, challenges, and solutions among individuals in the ‘farm-to-fork’ food chain

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## ABSTRACT

Public concerns about the potential effects of plastic pollution on human health are high, especially following evidence of microplastics (MPs) in food and drink. However, scientific evidence on human health effects is unclear, and knowledge gaps remain with respect to sources, pathways, and toxicity. But alongside ‘the public’ and ‘experts’ are various groups in the ‘farm-to-fork’ food chain whose voices are less heard, despite their unique insights into different issues. These ‘involved groups’ or ‘stakeholders’ include people in the harvesting/production, processing/packaging, distribution/hospitality, and regulation sectors. To harness their viewpoints, we conducted 32 semi-structured interviews with members of relevant groups along the food chain. Interviews were recorded, transcribed, and coded using Thematic Qualitative Analysis. Although knowledge levels and beliefs about sources and pathways were diverse, interviewees echoed the wider public’s concerns about human health risks alongside low certainty about underlying processes. Feelings of powerlessness and frustration, and the unavoidability of (micro-)plastics were emphasized. The need for increased awareness and solution know-how was stressed, and systemic changes on the regulatory level were called for (e.g. bans, binding and economic regulations). Relevant conditions for policy acceptance were identified (e.g. feasibility, effectiveness, evidence of risk). Findings highlight the fact that system change requires all actors in a system to understand the issues and be willing to play their part in solutions. The feelings of powerlessness and disenchantment expressed by many involved in the current system suggest greater work is needed to systematically include these groups in solution-finding and decision-making initiatives.

## ARTICLE HISTORY

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## Introduction

The widespread production, use, and associated pollution of plastics has increased concerns about potential harmful effects on ecosystems, wildlife, and human health. The latter concern is particularly related to microplastics (MPs), defined as plastic particles in the size range between 0.1 or 1  $\mu\text{m}$  and 5 mm (SAPEA 2019). Depending on their source and formation, MPs can be grouped into primary and secondary MPs. Primary MPs are purposefully manufactured for the use in certain products (e.g. microbeads in cosmetics, pellets for industrial production, etc.), while secondary MPs are created through abrasion and break-down of larger plastics (GESAMP 2015). Initial research in this area mostly focused on the marine environment (e.g. Thompson et al. 2004), but recent research confirmed their widespread presence in other environmental compartments, including the atmosphere, soils, ice fields, and freshwater systems (Thompson et al. 2024). Not surprisingly, MPs have also been found in drinking water (see Danopoulos, Twiddy, and Rotchell 2020), and various food and drink products, including seafood, salt, fruits, meat, milk, vegetables, and beer (EFSA 2016; Kedzierski et al. 2020; Oliveri Conti et al. 2020; Toussaint et al. 2019).

Potential pathways of MPs into the human food chain are as diverse as their potential sources. For instance, MPs can enter agricultural production sites through wind, irrigation with recycled wastewater, or biosolids from wastewater treatment plants, which may contain MPs from sources like, e.g. tyre wear, abrasion of plastic products, clothing, etc. Plastics are also intentionally used in agriculture, for applications, such as mulch films, irrigation, or support ties (Hofmann et al. 2023). All these materials have the potential to fragment and be taken up by plants into their edible parts, or to be ingested directly by biota, such as fish or cattle (Garrido Gamarro and Costanzo 2022). Moreover, particles might be released into food products during packaging and production (Sánchez et al. 2022; Zangmeister et al. 2022), due to storage conditions, washing of plastic containers (Hee, Weston, and Suratman 2022), or food preparation processes (Sánchez et al. 2022).

However, there are evidence gaps surrounding the sources and quantities of MPs in food and drink, and potential adverse effects for human health (Thornton Hampton et al. 2022). A recent review by Liu and You (2023) suggests that MPs may affect tissues and organs in the digestive, nervous, respiratory, reproductive, and cardiovascular systems. Another cause for concern is the leaching of additives from plastics (UNEP 2023a), particularly for food contact materials (Muncke et al. 2023). However, there are still many unknowns, and critics claim that most research does not accurately reflect the conditions humans are actually exposed to (Mills et al. 2023). Thus, there remains insufficient scientific data to reliably assess the human health risks of MP exposure (SAPEA 2019; WHO 2022), posing considerable challenges to communication (Catarino et al. 2021; Leslie and Depledge 2020; Wardman et al. 2021). Koelmans et al. (2022) recently argued that it is not a question of if, but rather of when the risks of MPs become apparent. This evokes associations with other environmental issues, where early warnings were not adequately acted upon (e.g. asbestos), which led the European Environment Agency (EEA 2001) more than two decades ago to warn about 'paralysis by analysis' when there are reasonable grounds for concern, in line with the precautionary principle.

Cognisant of the limits of traditional risk analysis frameworks, the report therefore recommended to 'take full account of assumptions and values of different social groups' (EEA 2001, 169) to help increase the range of perspectives and evidence examined. Consistent with this, Hartmann, Hübner, and Siegrist (2018) argued that policy makers should consider both scientific risk assessments, but also public concerns in developing effective and acceptable regulation. The most recent WHO report on human health effects of MPs also suggested leveraging the 'constructive momentum built by widespread public awareness and an overwhelming consensus among stakeholders that plastics do not belong in the environment for efforts towards a more sustainable plastics economy' (WHO 2022, 95).

## ***Perceptions of plastics and microplastics***

Despite the considerable scientific uncertainty about the impact of MPs on human health, public concerns about plastic pollution in general and MPs in particular are already high (Davison et al. 2021; Dilkes-Hoffman et al. 2019; Hartley et al. 2018; Menzel, Brom, and Heidbreder 2021). Plastic pollution was the leading public health concern among several threats to the marine environment in a 14-European country survey (Davison et al. 2021) and also topped the list of broader environmental concerns including climate change and biodiversity loss among the Australian public (e.g. Dilkes-Hoffman et al. 2019). There is also a growing body of literature on public perception towards MPs specifically. While some studies revealed a lack of public awareness and knowledge (Anderson et al. 2016; Deng et al. 2020; Felipe-Rodriguez, Böhm, and Doran 2022; Henderson and Green 2020), two recent German studies found high awareness (Kramm et al. 2022; Raab and Bogner 2021), and most studies consistently found MPs to be considered as ‘something bad’ (Felipe-Rodriguez, Böhm, and Doran 2022), and/or a risk to the environment and human health (Kramm et al. 2022; Raab and Bogner 2021; Wu et al. 2023).

Two qualitative studies hint at a potential increase in awareness. Henderson and Green (2020) conducted focus groups in the UK in 2016/17 and found that most people did not know about possible human consumption of MPs through food and drink. However, data from in-depth qualitative interviews among German and Italian citizens in 2021 found that the food chain was perceived as one of the main pathways of MPs into the human body, especially in Italy (Janzik et al. 2024). Quantitative data supports this trend in awareness. The percentage of Germans knowing about MPs in food increased from 63% in 2016 (BfR 2016) to 93% in 2023, and it became the most pressing health concern for consumers, ahead of issues, such as antibiotic resistance, glyphosate, and e-cigarettes (BfR 2023). However, King et al. (2023) recently explored Irish farmers’ attitudes towards agricultural plastics and found that most farmers were concerned, although predominantly about aquatic environments compared to terrestrial environments and human health.

## ***Microplastic pollution: from problem to solutions***

While it is important to focus on MP occurrence and effects (the problem), the evidence is already strong enough to apply the precautionary principle (cf. Thompson et al. 2024), and it is crucial to find ways to decrease MP release into the environment and the human food chain (the solutions). Microplastic pollution can arise through the entire life cycle of a product, from production through use and to disposal. Considering the benefits of plastics, especially in the food sector (i.e. consumer safety; Andrady and Neal 2009), it is unlikely that plastic use will stop completely. However, a reduction of (micro-)plastics should be achieved through improvements at all stages of the life cycle. In a sample of MP experts, Grünzner et al. (2023) found that consumer education, deposit return schemes, bans on single-use plastics, simplified design, and circular economy principles were rated as most feasible and effective. The United Nation’s Intergovernmental Negotiating Committee (INC) proposes an international legally binding instrument on plastic pollution, including measures, such as the ban or reduction of certain products, improved waste management, improved product design, promotion of alternatives, economic regulations, and awareness raising and education (UNEP 2023b). In view of the complexity of the issue, implementing effective changes on all levels will require the contribution of multiple actors, including governments, industries, and individual consumers. In the ‘farm-to-fork’ food chain specifically, there are various ‘stakeholders’<sup>1</sup> or ‘involved groups’ with particular insights into different issues. For example, in an Italian study, younger, more highly educated farmers with smaller farms showed greater intentions to join plastic recycling programs (Galati et al. 2020). The effectiveness of a legally binding treaty will ultimately depend on understanding these groups’ perceptions of the problem as well as potential solutions (Tiller, Booth, and Cowan 2022).

## **The current study**

In previous research, perceptions of different groups were considered, including experts, the public, government representatives, and environmental NGOs (e.g. Grünzner et al. 2023; Janzik et al. 2024; Thiele and Hudson 2021; Zilinskaite, Futter, and Collentine 2022). The focus was typically on risk perception more than solutions, and there is little research to date on perceptions of MPs in food and drink specifically.

In the present research, we took a holistic approach by not only including 'the public' or 'experts', but also additional groups involved in the human food system at various stages, whose voices are heard less despite their particular expertise and insights. Specifically, we included representatives of the areas of harvesting/production, processing/packaging, distribution/hospitality, consumption, and regulation, and conducted in-depth qualitative interviews including the use of visual material to support the conversations.

To help structure the concepts discussed in the interviews, we drew on the 'Climate Change Risk Perception Model+', adapted to the MP context (CCRPM+; van der Linden 2015; van Eck, Mulder, and van der Linden 2020). While cognitive factors (e.g. knowledge, perceived scientific consensus, etc.) can play a role in explaining risk perception and/or policy support, evidence is mixed (Garcia-Vazquez and Garcia-Ael 2021; Kramm et al. 2022; Thiele and Hudson 2021), and the CCRPM+ integrates a much wider range of relevant factors including emotions.

Thus, we aimed to gain insight into different involved groups' knowledge and perceptions of MPs in food and drink, and views on potential solutions. These could provide valuable input into designing group-specific risk communications and policy measures, which include and engage those directly involved in the supply chain and affected by regulatory measures. Austria is used as a case study here due to the importance of the agriculture and hospitality sectors, and efforts towards sustainable production and distribution (BMAW 2022; BML 2023).

## **Methods**

### ***Selection and recruitment of participants***

Participants were selected using a purposive sampling method and diverse recruitment approaches (e.g. mailing lists, direct contact). Participants were required to be at least 18 years old, have heard of MPs before, be fluent in German or English, and reside in Austria. Depending on the target group, different additional inclusion criteria were applied. For group A (production/harvesting), participants needed to work in the food production/agriculture/harvesting sector. For group B (processing/packaging), participants were required to work in a managing/decision-making position in a company manufacturing food/drink products. For group C (distribution/hospitality), participants needed to own or manage a business distributing food (e.g. restaurant/hotel). For group D (consumption), the target group was the general public. For group E (regulation), participants had to have worked in a position that prepares decision-making in an area related to the research topic for at least 1 year, e.g. working for the Austrian ministry.

Sampling followed the principle of 'theoretical saturation', meaning data collection stopped when no new additional information was found to develop aspects of a conceptual category (Glaser and Strauss 1967). Following the recommendations of Francis et al. (2010), we estimated an initial analysis sample of  $n=5$  interviews per group and  $n=10$  in the general public group and a stopping criterion (i.e. how many more interviews were conducted without new ideas emerging) of 2.

### ***Participant characteristics***

In total, 32 interviews were conducted, with  $n=6$  in group A (including dairy, grain, vegetable, arable, and livestock farming, including both conventional and organic farming),  $n=5$  in group

B (including meat, fruit, mineral water and dairy industry),  $n=5$  in group C (including hotels, restaurants and a food stall),  $n=10$  in group D (including diverse socio-demographic profiles), and  $n=6$  in group E (including persons responsible for environment, health, food safety, and agricultural issues), see [Table 1](#).

The full sample consisted of 18 females (56%) and 14 males (44%) and the average age was 42.2 years ( $SD=15.2$ ; range: 19–84). There was a wide range of educational backgrounds: 47% of the sample had a lower or medium degree of formal education, 53% had a high level of formal education. Ten participants were based in Vienna, while the rest was spread across the remaining eight Austria's federal states.

## Procedure

The study was preregistered on Open Science Framework (<https://doi.org/10.17605/OSF.IO/SEZFG>). Ethical approval was granted by the Ethics Committee of the University of Vienna (00881) on November, 9th 2022. Interviews were conducted between December 2022 and April 2023. Participants provided informed consent and completed the interview with the principal investigator or a second trained interviewer. Interviews were recorded and completed in-person or online via Zoom. The average duration of interviews was 42 min, ranging from 27 to 62 min. Interviewees received a 10€-voucher from an Austrian online market place. Participants were debriefed about the study purpose afterwards. The recorded interviews were transcribed and pseudonymized, and the original recordings were deleted after processing.

## Interview materials

Using a semi-structured approach, interviews were conducted along an interview guide based on relevant themes from the literature and the CCRPM+ model, beginning with broad questions

**Table 1.** Participants' sociodemographic characteristics.

(A) Harvesting/production ( $n=6$ )				(B) Processing/packaging ( $n=5$ )			
ID	Gender	Age	Education	ID	Gender	Age	Education
A01	Male	43	Higher secondary school	B01	Male	27	University degree
A02	Female	33	Apprenticeship	B02	Female	43	University degree
A03	Female	43	University degree	B03	Female	26	University degree
A04	Male	24	Apprenticeship	B04	Female	42	University degree
A05	Female	19	Higher secondary school	B05	Male	38	University degree
A06	Female	34	University degree				
(C) Distribution/hospitality ( $n=5$ )				(D) Consumption ( $n=10$ )			
ID	Gender	Age	Education	ID	Gender	Age	Education
C01	Male	28	University degree	D01	Female	29	Apprenticeship
C02	Male	55	Secondary school	D02	Female	30	University degree
C03	Female	24	University degree	D03	Female	56	Higher secondary school
C04	Female	60	Secondary school	D04	Female	55	Apprenticeship
C05	Male	36	Higher secondary school	D05	Male	84	Apprenticeship
(E) Regulation ( $n=6$ )				D06	Male	55	Secondary school
ID	Gender	Age	Education	D07	Male	29	Apprenticeship
E01	Female	56	University degree	D08	Female	55	University degree
E02	Female	60	University degree	D09	Male	52	Compulsory school
E03	Male	48	University degree	D10	Male	22	Higher secondary school
E04	Female	54	University degree				
E05	Male	61	University degree				
E06	Female	30	University degree				

and becoming more specific. The English translation of the full interview guide can be found in [Appendix A in the Supplementary Materials](#). For the regulation group, the guide was slightly modified due to differences in baseline knowledge and scope for decision-making. To aid diversity of thinking and interview flow, participants were also presented with a set of photos of different beverages and food items (i.e. water, other drinks, fruits, vegetables, dairy products, grains and pulses, meat, fish; see [Figure S1 in the Supplementary Materials](#)), and asked to indicate in which items they thought MPs were most and least likely to be found. Socio-demographic data was collected.

### **Data analysis**

Thematic Qualitative Analysis as described in Kuckartz (2014) was applied. Thematic categories were created deductively (inspired by the existing literature and the CCRPM+; van Eck, Mulder, and van der Linden 2020) as well as inductively (based on the data). Data was analysed in a multi-stage process of categorizing and coding. In the first phase, the data was coded roughly along the main thematic categories that had been formulated before starting data collection, mainly based on the interview guide. Then, the categories were further refined and sub-categories were created inductively, based on the collected interview data. In a second round of coding, the whole data was coded again, using the new, more elaborate coding scheme. The final coding system consisted of 19 main codes and 96 sub-codes. Simultaneous coding was possible, i.e. multiple codes could be applied to one text passage, and the mean number of coded statements per interview was 77. One researcher coded the transcripts to achieve consistency. To ensure reliability, a second coder independently coded 10% of the transcripts (O'Connor and Joffe 2020). An average coefficient kappa (Brennan and Prediger 1981) of 0.80 across all applied codes showed a 'substantial' inter-rater agreement (Landis and Koch 1977). All disagreements were discussed until consensus was reached. For processing and analysing data, MAXQDA software (Version 22.7.0) was used.

## **Results**

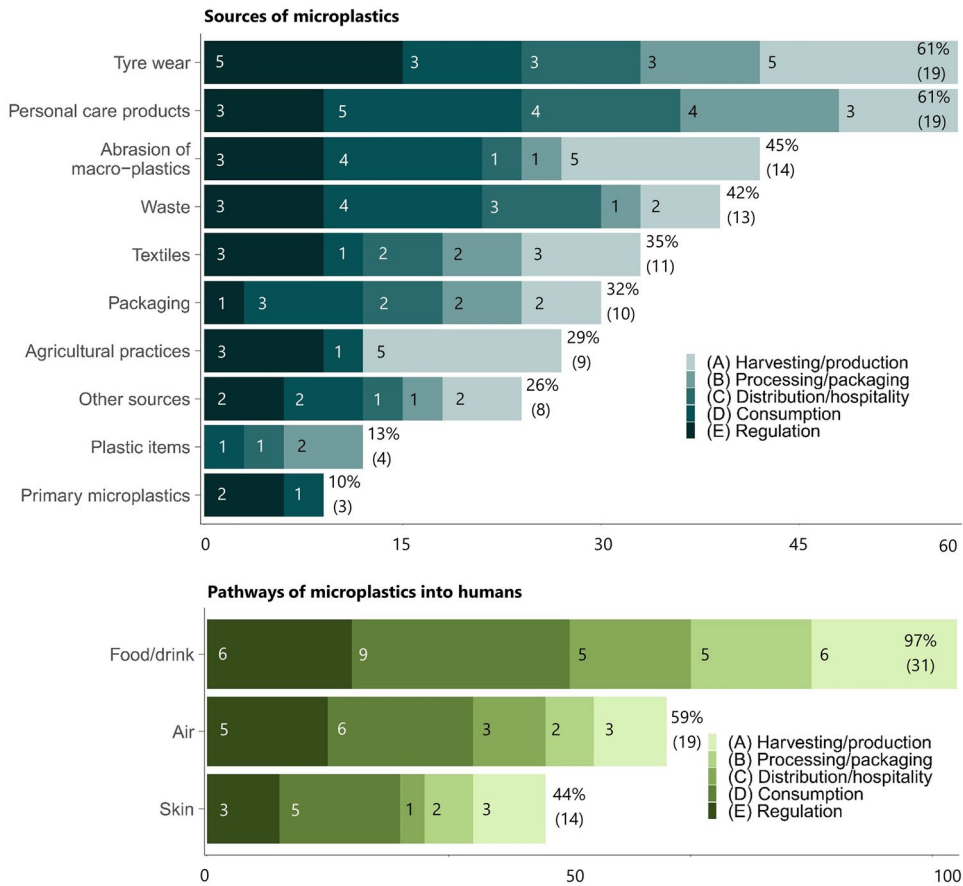
### **Knowledge about sources of MPs, presence, and pathways in food/drink**

#### **Sources of MPs**

At the start of the interviews, participants were asked to elaborate on their first associations with the term 'microplastics'. Almost half of the interviewees ( $n=14$ ) mentioned the marine habitat, for example 'when I think of microplastics, I think of marine pollution, fish in plastic traps, [...]' (B05). However, when further asked about MPs sources, in many cases, knowledge was far more nuanced. In particular, 61% ( $n=19$ ) of the interviewees mentioned tyre wear as a source, as well as MPs from personal care products (e.g. peelings, shower gel, detergents). The process of MPs resulting from the abrasion of macro-plastics (excluding tyre abrasion) was mentioned by fourteen participants. Other sources mentioned were waste, textiles, packaging materials, agricultural practices, plastic items in general (not further specified and without referring to the process of abrasion), primary MPs, and other sources (e.g. paint, construction, sports fields, shoe soles). Interestingly, agricultural practices were almost exclusively mentioned by the harvesting and regulation groups. A frequency distribution of all mentioned sources can be found in [Figure 1](#).

#### **Pathways into humans**

When talking about how MPs can get into the human biological system, almost all participants ( $n=31$ ) mentioned eating and drinking as a pathway. Take-up through inhalation was mentioned by 19 interviewees, and 14 thought that MPs can enter the human body via skin (see [Figure 1](#)).



**Figure 1.** Frequency distribution to illustrate the main types of MP sources and pathways into human body mentioned by participant group. Note. Percentages refer to the full sample (N = 32) and frequencies of mentions are not adjusted by group size. Note that the consumption group was twice the size of most other groups.

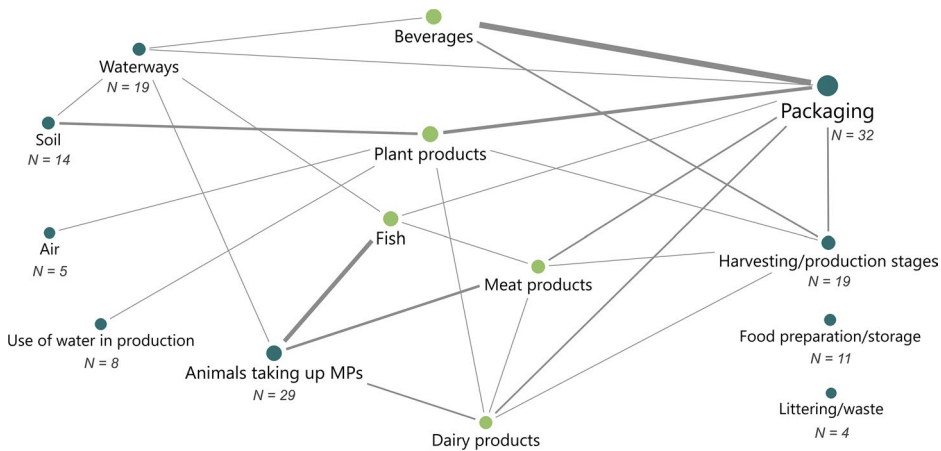
**Presence and pathways into food/drink**

The more specific parts of the interviews provided insights into people’s knowledge and perceptions of the presence and pathways of MPs in food and drink. Figure 2 visualises the frequencies of mentions of all identified ‘presence’ and ‘pathways’ codes as well as the relations between them (i.e. how often things were mentioned together in one sentence). In general, some interviewees assumed that ‘theoretically, it [microplastics] can be anywhere’ (D04). For the harvesting and processing groups, there was another common theme emerging, namely the trust in their own products. For instance, one farmer expected no MPs in meat ‘because we have a cattle fattening unit at home ourselves’ (A01), and one person from the processing group reported that ‘in our company, the entry is minimal’ (B02).

With regards to perceived pathways into food, it became apparent that interviewees across all groups thought of plastic packaging as one main issue, e.g. ‘it doesn’t matter whether it’s the lentils, or broccoli, or sliced sausage, probably there is simply more contamination possible because the packaging is made from plastics’ (B04). Explanations for this link included abrasion when opening plastic bottles, when cutting food in plastics, and higher release with longer time and higher temperatures.

Another perceived pathway across all groups was via animal take-up of MPs, with fish (both marine and local/fresh water) being seen as the most prone to take-up. Notably, the majority of interviewees also made the connection to other animals and expected MPs to be taken up





**Figure 2.** Code map of presence and pathways of MPs in different food/drink categories. *Note.*  $N = 32$ . The figure visualises the frequencies of mentions of all identified ‘presence’ (light) and ‘pathways’ (dark) codes (size of dot) as well as the relations between them in terms of how often two codes were assigned together on one text sequence (size of line). This map is limited to codes that co-occur at least 3 times.  $N$ s represent number of interviewees mentioning the pathway. For the presence categories, no  $N$ s are reported since most participants reflected on all categories due to the picture task.

by, e.g. cows, pigs, and chickens. The perceived processes included take-up through food, drinking facilities, and some assumed higher concentrations in meat compared to plant products due to MPs accumulating in animals over time. Some participants also further elaborated on the presence of dairy products due to animals taking up MPs, although most participants linked dairy products specifically to packaging. An interesting link from humans to animals was made by one farmer, ‘I mean, if it’s in breast milk, why shouldn’t it be in any other, in all other dairy products?’ (A06).

For plant products, people’s ideas of MP presence were quite diverse. Some did not expect MPs in plant products at all or referred to packaging as the only potential pathway. Others expressed elaborate ideas of pathways, including take-up through plant nutrient uptake in soil, watering of plants using contaminated water, and particles in the air adhering to the surface of certain vegetables and fruits. Interestingly, air as a potential pathway was predominantly mentioned in the consumption group. However, most respondents assumed MPs could be washed off from plant products.

A cross-product-category concept was contamination during harvesting/production stages, including through harvesting equipment, filling equipment, shredders, etc., for instance for beverages like wine or coffee, grains and pulses, and processed products like sausages. This was very prevalent in the harvesting group, while only mentioned by around half of interviewees in the other groups. Another pathway mentioned by more than half of participants, and particularly prevalent in the processing group, was contamination through waterways. This included oceans, rivers, lakes, groundwater, wastewater systems, and washdowns from streets, but also region-specific processes like glaciers, i.e. ‘glacier ski areas, for example, which are covered with plastic sheeting in winter, I can also imagine that this is somehow deposited and that this is also water flowing down again’ (D02). More than a third of the sample also referred to food preparation and storage as a potential pathway, including plastic cutting boards, food boxes, sponges, and spice grinders. Interestingly, this was not mentioned in the distribution and consumption groups.

Soil as a pathway was mentioned by around half of the respondents, and most prevalent in the regulation group, while, interestingly, not in the harvesting group. Another common perceived pathway in the regulation group was through littering/waste.

Generally, it seemed that, across groups, few interviewees felt confident in their knowledge about presence and pathways. In fact, since participants were encouraged to reflect on a range of food/drink items as part of the picture task, the expressed ideas were in many cases *ad hoc* speculations.

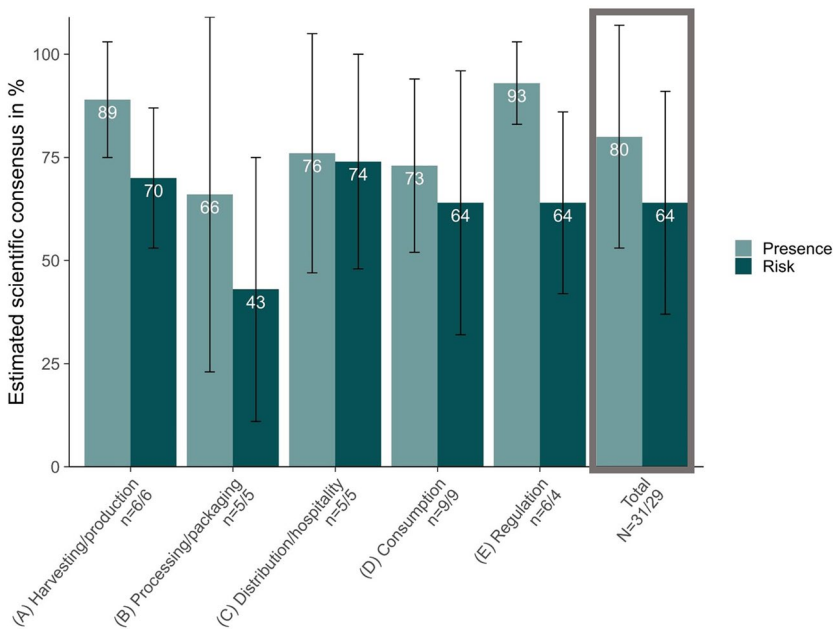
### ***Knowledge about consequences of MPs and perceived scientific knowledge***

Participants were then asked about the perceived consequences of MPs. This question was posed openly first, and subsequently broken down to consequences for human health specifically. Around 60% ( $n=19$ ) mentioned harmful consequences for animals, and around 50% ( $n=17$ ) referred to MPs as a threat to the natural environment. Regarding human health, 65% ( $n=21$ ) suspected that MPs can definitely or probably have negative consequences, with the majority spontaneously mentioning the human health aspect in response to the open question about consequences in general. A relevant theme characterizing interviewees' risk perception, across groups but particularly in the consumption and distribution groups, was a certainty about risks, but an uncertainty about more specific reasons for this assumption. For example, one farmer said, 'actually, I just think it's unhealthy, but I [...] don't know now exactly why it's unhealthy' (A05), while one hotel owner explained, 'that one has a negative impression or would rather classify it as dangerous based on one's feeling but is unable to explain this in more detail.' (C01). A few specific themes emerging were concerns about cancer ( $n=7$ ), hormone-activity ( $n=7$ ), and harmful additives ( $n=5$ ). While a large proportion of participants was certain about potential risks, others pointed out the uncertainty around the negative effects of MPs. This was particularly prevalent in the regulation group and accompanied by people's perceptions of scientific knowledge. Namely, all of the interviewees involved in the regulation referred to scientific knowledge gaps, for example, extensive knowledge about occurrence but lack of knowledge about consequences. This view was also shared by many interviewees in the other groups. Some, especially in the processing group, assumed that science currently knows very little about the subject, while others, especially in the consumption group, suspected extensive knowledge, sometimes paired with some kind of distrust in science communication or policy making, e.g. 'I believe [science knows] very, very much, only it is not all made so public' (D03).

Interviewees were also asked to provide an estimation of the scientific consensus, i.e. of all the scientists working on MPs, how many agree in percentages that (1) MPs can occur in food and drink ( $M=80\%$ ), and (2) that MPs in food and drink can pose a risk to humans ( $M=64\%$ ). The mean percentages for each group can be found in [Figure 3](#).

### ***Emotions and concerns about MPs***

When asked about their feelings when thinking about MPs in food/drink, interviewees expressed a diverse set of emotions. Most frequently mentioned across groups, and particularly in the harvesting and regulation groups, was a feeling of powerlessness/resignation, illustrated by e.g. 'I think, just like the whole climate crisis issue or the whole environmental issues, a bit of hopelessness, or a form of giving up' (C03) or 'Feelings? Well, partly it's a feeling of powerlessness when you can't prevent certain things.' (A01). Almost a third of participants, particularly in the harvesting and consumption groups, also expressed some form of anger or frustration when thinking about the issue. This was expressed through statements like, 'at the same time, it makes me a bit angry, because we do know about it and somehow do not manage to do anything about it' (A03). The anger was often directed towards politics, industry, and/or individuals who engage in littering or bad waste separation. While some interviewees, particularly in the consumption group, expressed worry and/or



**Figure 3.** Estimated percentage of scientists agreeing on (1) presence of MPs in food/drink (light) and (2) potential health risk for humans (dark). Note. Smaller sample sizes due to missings in some cases. Error bars show standard deviations (SD).

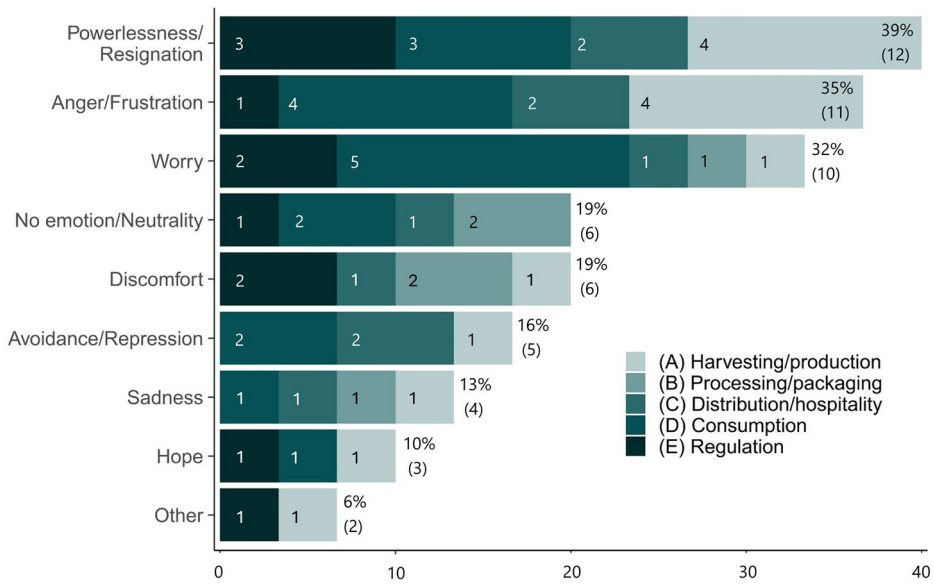
fear, e.g. ‘actually, I’m a bit worried, a bit scared, because it’s something so small and intangible’ (B01), others reported feeling some discomfort but emphasised that they were not worried or anxious, e.g. ‘discomfort but no panic’ (E01). Another sub-group shared emotional neutrality regarding the issue, either highlighting their rational way of thinking or admitting of never having thought about it before. Other emotions mentioned were avoidance/repression, sadness, and hope. A frequency distribution of all mentioned emotions can be found in [Figure 4](#).

When sharing their thoughts on specific concerns about the issue of MPs in food/drink, 15 interviewees explicitly expressed concern due to perceived uncertainty about the risks, for example, one farmer said, ‘it scares me a bit because you don’t know what all this is going to do to us’ (A04), and one producer very similarly reported that ‘too little is known about it [health effects], so it’s still a bit scary’ (B03).

Sixteen participants elaborated on their concerns about broader issues, including food in general (e.g. PFAS, other contaminants), the natural environment and pollution, or the future in general (e.g. wars, pandemics, inflation). For instance, ‘what worries me is the overall issue, not directly microplastics, but the overall issue of what often happens to food’ (D01), or ‘I don’t know how liveable our planet will still be in 100 years. [...] These are things that worry me, regardless of what happens to human health’ (A07).

However, about a third of interviewees ( $n=10$ ), predominantly from the regulation and processing groups, indicated that they had no or little concern about MPs in food/drink, illustrated by, for example, ‘there are so many substances in our food, so it doesn’t worry me specifically’ (E04) or ‘we have other issues to worry about at the moment’ (B05).

Some interviewees also mentioned the role of media and expressed criticism of the social discourse. Particularly, several members of the processing and regulation group shared the view that the media creates ‘horror stories’ around MPs which contributes to a partly unjustified worry in citizens.



**Figure 4.** Frequency distribution to illustrate emotions mentioned when thinking about MPs in food/drink. *Note.* Percentages refer to the full sample ( $N = 32$ ) and frequencies of mentions are not adjusted by group size. Note that the consumption group was twice the size of most other groups.

**Thoughts about potential measures to avoid/reduce MPs**

We note that although the questions always referred to MPs in food and drink, respondents often spoke of ‘plastics’ in general, which is relevant in the solution context and taken up further in the Discussion section.

**Perceived control and personal impact**

The majority of interviewees across groups consistently reported feeling a lack of personal control related to avoiding MPs and/or mentioned a general unavoidability of plastics in society and its ubiquity in our lives. One regulator said that ‘avoiding it entirely is an illusion’ (E01), while a hotel owner could ‘not imagine a microplastic-free life, unless you put yourself under a ... no, not a plastic dome, but a glass dome’ (C01).

Participants were further asked about their individual roles as farmers, producers, distributors, consumers, or regulators, with regard to their perceived contribution to tackling the issue. Results are summarised in Figure 5.

**Responsibility**

When talking about who interviewees saw as responsible for dealing with MPs in food and drink, different entities were mentioned. The greatest responsibility was seen at the legislation level. Twenty-two participants saw authorities, politics, and/or governments at least partly responsible. This was followed by individuals, consumers or ‘everyone’ ( $n=20$ ), and industry ( $n=18$ ). Some also mentioned agriculture, science, and NGOs (see Figure 6).

**Perceived barriers**

From the participants’ answers, we identified ten perceived barriers in solving the issue of MPs in food and drink: (1) a lack of problem awareness/relevance, (2) the benefits of plastics, (3)






HARVESTING/ PRODUCTION	PROCESSING/ PACKAGING	DISTRIBUTION/ HOSPITALITY	CONSUMPTION	REGULATION
				
<ul style="list-style-type: none"> <li>- Circular economy (e.g., biological fertilizer)</li> <li>- Reducing use</li> <li>- Increasing recycling rates (e.g., mulching foils)</li> <li>- Using alternatives (e.g., wooden brooms, degradable foils)</li> </ul>	<ul style="list-style-type: none"> <li>- Improving packaging (e.g., recyclability, reducing material use, alternative materials)</li> <li>- Quality management in production</li> <li>- Cooperation with science</li> <li>- High requirements for suppliers</li> </ul>	<ul style="list-style-type: none"> <li>- "Same measures as individuals"</li> <li>- Reducing use (e.g., food packaging, hotel cosmetics, no daily room cleaning)</li> <li>- Contacting producers</li> <li>- Voluntary environmental certifications</li> </ul>	<ul style="list-style-type: none"> <li>- Informing (e.g., mother-meetings)</li> <li>- Recycling</li> <li>- Waste clean-ups</li> <li>- Avoiding plastics (e.g., packaging, plastic containers, conventional cosmetics, microfibers in clothing)</li> <li>- Talking to others</li> <li>- Conscious consumption</li> </ul>	<ul style="list-style-type: none"> <li>- Raising awareness</li> <li>- Action plans</li> <li>- Budget for research and monitoring</li> <li>- Cooperations with science and industry</li> <li>- Building networks with other authorities and countries</li> <li>- Policy advice</li> </ul>

Figure 5. Different groups' perception about their efforts in tackling the issue.

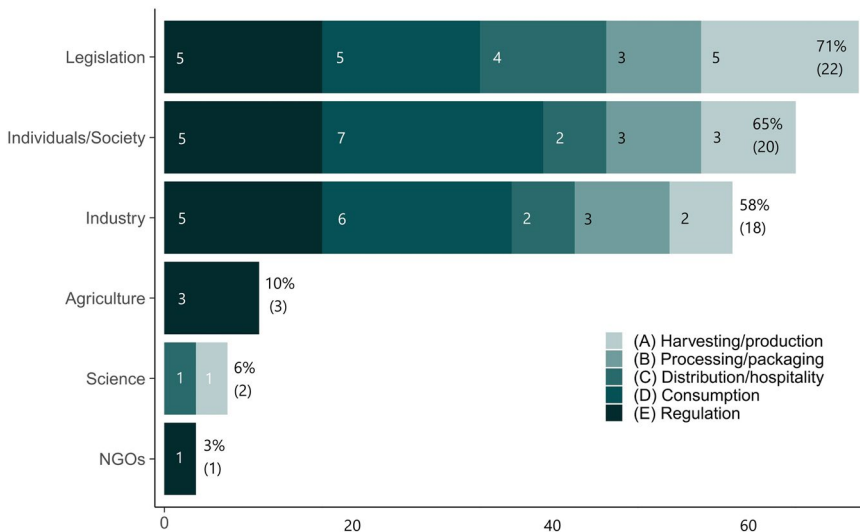


Figure 6. Frequency distribution to illustrate perceived responsibilities in dealing with MPs/plastics. Note. Percentages refer to the full sample (N = 32) and frequencies of mentions are not adjusted by group size. Note that the consumption group was twice the size of most other groups.

convenience, (4) limited/poorly accessible information, (5) the unavailability of alternatives, (6) the economic system, (7) the feeling of being trapped in a system, (8) the low cost of plastics, (9) the legal situation, and (10) limits of policy making. Detailed descriptions and examples can be found in Table 2, ordered by frequency of mentions.

While a lot of perceived barriers were distributed quite evenly across groups, some group-specific findings emerged. For instance, the legal situation (e.g. hygiene standards) was predominantly mentioned in the distribution group, and limits of policy making were prevalent

Table 2. Description and selection of quotes on perceived barriers ranked by the number of respondents who mentioned it.

Topic	N	Quotes
<b>Lack of problem awareness/ relevance</b>	25	<i>'To be honest, you don't think about it that much yourself. [...]. My impression is that very few people are upset about microplastics, because it is not visible. That is the problem.'</i> (D05) <i>'People simply don't care.'</i> (C02)
<b>Benefits of plastics</b> (e.g. hygiene, aesthetics, lightweight, resistance, longer shelf life of food)	18	<i>'I can vacuum pack food, then it will keep longer. If I don't vacuum it, I have to throw it away sooner.'</i> (C02) <i>'I'm drinking out of a plastic cup right now because the children can't break it.'</i> (D01)
<b>Convenience</b>	17	<i>'It's difficult to change the consumers' mind when it comes to their own comfort and convenience.'</i> (E02) <i>'And if it's easier to wrap something in plastic than to repackaging it [...], then that's what we'll do. So, I don't have any idealism there, because I see that every day. And even with employees who give a very sustainable impression in their lifestyle, as soon as it comes to convenience, sustainability often takes a back seat very, very quickly.'</i> (C02)
<b>Limited/ poorly accessible information</b>	16	<i>'There's a lot you don't know. There is no microplastic index on the tomatoes I buy.'</i> (C03) <i>'In agriculture, it is not so clear how this can be implemented, because we don't know exactly what we have to do, or how we are affected by it. I would like to have a table where I can see that an apple in my neighbourhood contains so and so much microplastics on average, and then I know, okay, well, if I live there, I can do that.'</i> (A06) <i>'So, [at school] you hear about the sea and the fish, but that's somewhere else, so to speak, we can't do anything about it anyway, because it affects other countries. But I don't have the feeling that it's a big issue at school.'</i> (A05)
<b>Unavailability of alternatives</b>	14	<i>'There is no company that packages French fries differently.'</i> (C04) <i>'That is the main reason because there is nothing comparable yet. There are alternatives, but as I said, they simply don't have the same properties. This isn't liked by the costumers, [...] for example, these plastic bottles made of some kind of maize thing and they smell a bit different.'</i> (B03) <i>'Because if the soil processing equipment has plastic, you can't do it any other way, because you can't buy it any other way.'</i> (A05)
<b>Economic system</b> (e.g. high investments, expensive alternatives, benefits from exporting waste)	10	<i>'Safety research is always last, or often last, because the companies are more interested in bringing their product to market relatively quickly in order to have a competitive advantage.'</i> (E02) <i>'And then there is also the question that this is certainly extremely expensive, financially, one has to say honestly, if I don't know concretely that this really has massive effects on health, the question also arises for me, is it affordable that I then take concrete action to avoid microplastic.'</i> (A06)
<b>Trapped in system</b> (e.g. supply chain, production system, capitalistic markets)	10	<i>'We even wrote to the manufacturers once. [...] They tell us that it is not possible for them because of hygiene, because of shelf life, because of product adulteration and I don't know what else. That's where it really starts. And we have no possibility at all.'</i> (C04) <i>'I think it's the whole supply chain. I'm just the end of the whole chain and the whole thing, unfortunately, doesn't work on environmental friendliness and compatibility, but it all works on efficiency, always just cost efficiency.'</i> (C03) <i>'It is difficult because you are trapped in certain production systems and cannot break out of them overnight.'</i> (A01)
<b>Low cost of plastics</b>	9	<i>'Glass, for example, is more okay than plastic, but glass is more expensive than plastic. Plastic could be used less often and glass could also be used, but it costs more, so the companies use plastic rather than glass.'</i> (D09) <i>'So, it's simple, I have three ways to fill our product. One is the metal can, the tin can, but even that is coated, or cardboard coatings. I have glass and I have plastic, and by far, by far the cheapest is the plastic.'</i> (B04)
<b>Legal situation</b> (e.g. hygiene standards)	7	<i>'So, in the health system, I think it's really difficult in some cases [to avoid plastics], because the hygiene requirements are sometimes so crazy.'</i> (D08) <i>'In a commercial enterprise, for example, [...] we have to use plastic cutting boards because wooden cutting boards are not allowed. We have to use plastic cooking spoons.'</i> (C01)
<b>Limits of policy making</b> (e.g. lack of resources, limited scientific knowledge, responsible legal areas, communication with public)	6	<i>'The difficulties are that we can't always do much in terms of regulation, because we have to comply with EU law and can't just stand up and say we're going to make a national law.'</i> (E06) <i>'We can't legislate yet because we don't know enough, and if there is no legislation, there is no research and therefore we don't know anything.'</i> (E03) <i>'Because one simply doesn't have enough resources, both in terms of time and finances, now speaking as an authority.'</i> (E01)

only in the regulation group. With respect to perceived barriers, another relevant theme was a general disenchantment with or distrust in the system overall. This was, for instance, expressed as doubt about the dissemination of scientific knowledge, about the competence and motives of political decision-makers, or about the independence of research and politics from industry lobbying. A member of the regulation group themselves voiced their awareness of this, saying, 'I mean, you know, authorities are not always very popular with consumers' (E02). However, some also mentioned trust in scientists or Austrian authorities regulating drinking water or food/drink quality, e.g. 'I think, in Austria, the food we have is very well monitored anyway.' (A01).

### **Potential solutions and facilitators**

Interviewees were also encouraged to talk about potential solutions in dealing with MPs. Thirteen different themes emerged: (1) individual behaviour change, (2) raising knowledge/awareness, (3) bans, (4) binding regulations, (5) alternatives, (6) research and monitoring, (7) economic regulations, (8) removal/filtering, (9) reducing emissions, (10) recycling, (11) engagement/activism, (12) sanctions for littering, and (13) partnerships between groups. Detailed descriptions and examples are presented in Table 3 ordered by frequency of mentions.

Again, there were some group-specific findings, i.e. sanctions for littering were almost exclusively mentioned in the regulation group, and those involved in processing were the only group not to mention economic regulations.

Participants also reflected on positive trends and facilitating factors. Almost half of the interviewees, including all members of the regulation group, mentioned some kind of positive recent development, for instance, high research interest in the issue, more regulations, increasing supply and demand of non-packaged products, increasing public awareness, and a general trend towards sustainability.

**Table 3.** Description and selection of quotes on possible solutions ranked by the number of respondents who mentioned it.

Topic	N	Quotes
<b>Individual behaviour change</b> (e.g. avoiding plastics, using alternatives, avoiding littering, changing demand through consumption of non-plastic products)	27	<i>'For me, it is more important that the consumer, or humans, are careful not to spread plastics in the environment and thereby cause microplastics.'</i> (E02) <i>'You can do very simple things, like simply buying the noodles in paper packaging rather than the noodles in plastic packaging, or not buying mineral water bottles but using tap water.'</i> (D02) <i>'And I don't believe that the individual can wait for something to come from above, but that if you really want to change something, you have to start with yourself.'</i> (A06)
<b>Raising knowledge/ awareness</b> (e.g. media coverage, integration into the school curriculum, awareness campaigns)	19	<i>'So, my proposed solution would be to have sustainability lessons in schools. [...] If the parents can't do that, then it has to be done at school.'</i> (E06) <i>'Well, that it is a bit more present in regional information. [...] That people no longer simply read about it and say they read something at some point, but that we simply say that it is present, that it concerns us and that we should deal with it. But then it has to be more present somewhere, because micro is not present.'</i> (C04)
<b>Bans</b> (includes general ban and ban of certain products)	19	<i>'As we saw with the ban on plastic bags, it is of course possible to introduce a measure that bans certain products from one day to the next. That is the ultima ratio [last resort].'</i> (E05) <i>'Also, a ban of plastic in general is something I would like to see, but I know it's not realistic.'</i> (D10) <i>'I believe that, as with everything, politics plays a central role in prohibiting many things [...] that cannot be solved at the individual level. This means that we have to go much further in terms of sensible paternalism. We have also succeeded in banning plastic bags and straws, things that are really not necessary.'</i> (A03)

(Continued)

Table 3. Continued.

Topic	N	Quotes
<b>Binding regulations</b> (includes regulations targeting businesses as well as individuals; e.g. standardized packaging, mandatory labelling, limit values)	16	<i>'Even if humanity, the population, I have the feeling, has more and more the attitude, "I don't want to be forbidden anything and we are a free country", yes, but unfortunately people also need certain rules and political decisions.'</i> (C05) <i>'So, in production, the responsibility definitely lies with the manufacturers, as it does with us, but we cannot do this without framework conditions from politics, and here at least the European level. [...] But we need these regulations in order to be able to compete and in order to be able to be sure, for example, that the material we receive from our suppliers complies with the regulations.'</i> (B01)
<b>Alternatives</b> (includes biodegradable plastics, alternative materials, a wider range of unpackaged products, provision of alternatives to car travel)	15	<i>'The silage bales from the farmers [...], you could, for example, use degradable foils made of some kind of organic material that degrades in the environment after one or two years.'</i> (E03) <i>'So, I think you just have to completely change what's on offer in the shops so that it's just natural to buy other things.'</i> (D08) <i>'Perhaps also in production one can consider: Do I always have to use plastic for everything I produce, do I have to use plastic tools? Can I also replace that, perhaps with wood or stainless steel?'</i> (A06)
<b>Research and monitoring</b>	13	<i>'That we identify certain entry paths and then say what can be done to exclude these entry paths as far as possible in the future, or at least to minimise the entry.'</i> (E05) <i>'I think monitoring would be good, so that you can detect or observe changes [in MPs concentrations].'</i> (A01)
<b>Economic regulations</b> (includes monetary incentives, e.g. subsidies for alternatives; deposit systems or disincentives, e.g. plastic tax)	12	<i>'The best incentive system for consumers is the deposit system, because they will get their money back. We have to give our food, our packaging a good value.'</i> (E06) <i>'It would probably make sense, if there were subsidies for non-plastic products in all possible areas, now in terms of packaging or even materials.'</i> (D10) <i>'I would be very much in favour of taxing plastics. I would really think about whether there is a sensible way to make this material more expensive, so that it is simply used in a way that it is not a throwaway product, where it doesn't matter how much of it I use, but where I really have to think carefully about what happens to it, how it is actually recycled and it doesn't end up everywhere.'</i> (A03)
<b>Removal/ Filtering</b> (e.g. ocean clean-ups, drinking water filters, air filters)	10	<i>'I would also like to have structures that it [plastics] doesn't run into the sea, I don't know, rakes, every city needs its rake, and has to get its trash out again.'</i> (D08)
<b>Reducing emissions</b> (general reduction of the production and/or use of plastics without further specification)	9	<i>'It's just a bit difficult because I don't really know what measures can be taken, but in principle it's probably just about reducing plastics enormously.'</i> (A05)
<b>Recycling</b>	7	<i>'I would say that if you get a grip on the waste system and also on recycling and also on plastics etc., then you will also get a grip on microplastics.'</i> (B05)
<b>Engagement/ Activism</b> (includes talking to the immediate social environment as well as increasing the pressure on the legislator/ industry)	6	<i>'Of course, also engagement, socially, that people advocate for good regulations, i.e. increasing the pressure on the legislator.'</i> (E01) <i>'I think you can do something as an individual. I don't think I have much power, but I can also convince those around me.'</i> (D02)
<b>Sanctions for littering</b>	5	<i>'I think a certain amount of pressure with sanctions doesn't hurt either, in terms of littering.'</i> (E04)
<b>Partnerships between groups</b>	4	<i>'That we have various sectors, i.e. industry, scientists, authorities, also working on this together in order to somehow make progress.'</i> (E03)

### Willingness to accept policies aiming to avoid/reduce MPs

Interviewees were also asked to consider regulatory measures aiming to avoid or reduce MPs in food and drink. In most cases, no specific examples of potential measures were given to participants. Instead, they were free to reflect on what came to their mind. From the participants' answers, nine different characteristics of acceptable (or non-acceptable) policies were formulated: (1) feasibility, (2) perceived effectiveness, (3) a general openness to measures, (4) evidence of risk, (5) perceived fairness, (6) perceived benefit, (7) availability of alternatives, (8) transparency/participation, and (9) essentiality. Example quotes can be found in Table 4, ordered by frequency of mentions.



**Table 4.** Description and selection of quotes on conditions for policy acceptance ranked by the number of respondents who mentioned it.

Topic	N	Quotes
<b>Feasibility</b> (i.e. financial, practical, capacity-related)	15	<i>'Measures that go too far would be, I believe, to impose additional analytical requirements on us, or to really hand over responsibility to us completely.'</i> (B01)
<b>Perceived effectiveness</b> (i.e. impact, effectiveness, meaningfulness)	9	<i>'So, basically I think that what people like to follow, is something where a sense is seen, that what is being regulated there really has an effect or makes sense.'</i> (E01)
<b>General openness to measures</b>	8	<i>'I would even find it almost liberating if certain things were simply no longer allowed. Yes, that's why I would see that all these solutions would actually, even if it sometimes feels a bit affronting, but I think that overall, it's high time to think about something. That's why none of these measures would bother me.'</i> (A03)
<b>Evidence of risk</b> (i.e. proportionality, reasonableness)	7	<i>'As an authority or as a representative of the policy, you always have to distinguish between where to take the precautionary principle and where you wait until you know more. [...] And in principle, if you want to achieve a lot, it makes sense to start primarily where there is a large quantity and a high risk.'</i> (E01)
<b>Perceived fairness</b> (includes fairness towards other countries and groups, but also in the sense that the own group does not face disadvantages)	6	<i>'So, what we see, regardless of whether it is an animal welfare issue or a packaging issue, if the regulations are there and if they contribute to us having a safer or better solution, by all means [willingness to accept regulations]. But we are still, you have to remember, in an international competition, and therefore we have to make sure that everyone plays by these rules.'</i> (B01)
<b>Perceived benefit</b>	5	<i>'The person must be able to see an advantage why he or she should do it. [...] And the motivation why someone does something can be very different, from I want to save the world to I want to save money.'</i> (E01)
<b>Availability of alternatives</b>	5	<i>'So how should I put it, a complete ban of plastics without alternatives, that would not be something I would support, because the wheel must keep turning.'</i> (C01)
<b>Transparency/ Participation</b>	4	<i>'I think you have to be able to explain that you're doing this because it makes so and so much less waste, and so and so much less contamination, so I don't think people will go along with it if it's dictatorial and something is directed and no one understands why.'</i> (D08)
<b>Essentiality</b> (e.g. medical applications)	4	<i>'What would I not accept? Very far-fetched, but maybe things in the medical field where there are no other options. Something that is really vital and where you simply need the material for it. If you then ban that, that doesn't make sense to me.'</i> (A06)

## Discussion

The current study provided insight into different involved groups' knowledge and perceptions of MPs and plastic-reducing measures in the context of food and drink. We took a 'from farm-to-fork' approach including interviewees from harvesting, production, hospitality, consumption, and regulation in Austria. Below we unpack some of the key themes that emerged.

### *Microplastic associations and perceptions*

Despite Austria's landlocked nature, people's first association with the term 'microplastics' was often related to the marine environment, in line with previous results from Norway and Germany (Felipe-Rodriguez, Böhm, and Doran 2022; Kramm et al. 2022). Many shared quite refined ideas about potential sources, including tyre wear, personal care products, abrasion of macro-plastics, waste, textiles, packaging, and agricultural practices. Agricultural sources were only mentioned by interviewees working in harvesting or regulation, suggesting low awareness of agricultural plastics among groups not directly involved. The food chain was considered the main pathway of MPs into the human body (see also Janzik et al. 2024). When elaborating on pathways into the food chain, participants had quite sophisticated ideas that went beyond the familiar fish narrative and included other animals taking up MPs, waterways, soil, harvesting/production stages, food preparation/storage, use of water in production, air and littering/waste. Almost all participants across groups mentioned plastic packaging, reflecting the largest end-use market of plastics in Europe (PlasticsEurope 2021).

It is noteworthy here that although tyre abrasion was identified as the main source of MPs, interestingly, it was not as salient for participants in terms of human intake. Thus, despite a certain level of technical-scientific knowledge about sources and pathways, people's overall perception of pathways focused on partial aspects of the issue. This may, to some extent, reflect proximity aspects, whereby food packaging is more readily retrievable and salient in this context compared to more distal sources, like tyre abrasion.

### ***Perceived risks and concerns***

Perceived negative consequences of MPs for environmental and human health were present across all groups (see also, Felipe-Rodriguez, Böhm, and Doran 2022; Kramm et al. 2022; Raab and Bogner 2021; Wu et al. 2023). Consistent with Janzik et al. (2024), while people had relatively wide-ranging ideas about health effects, they could not explain underlying mechanisms. This was replicated in our sample across the food chain, with interviewees expressing certainty about health risks alongside an uncertainty about more specific reasons for this assumption. A large proportion of interviewees, especially consumers expressed concerns, particularly about the perceived uncertainty surrounding potential risks. Our data supports the assumption made by Janzik et al. (2024) that uncertainty was not connected to more caution in making inferences about risks, but rather led people to assuming more negative effects. Concern based on uncertainties about MPs effects was also found among more topic-experienced people in previous research (Grünzner et al. 2023; Thiele and Hudson 2021).

Expanding on the theme of uncertainty and concern, people often felt powerless and resigned. The majority of interviewees reported feeling a lack of individual control given the current ubiquity of plastics in society and potential associated health risks (also see Jansen et al. 2019 for perceived lack of control in the context of uncertain risks). Although consistent with Janzik et al.'s (2024) findings from Italian and German consumers, here we show that these feelings are shared by other actors in the supply chain even though they may have somewhat more control given their higher involvement in actual decisions.

Many participants also discussed broader health, environmental, or societal issues, including food safety, environmental pollution, the climate crisis, economic developments, or wars, rather than MPs in their food. Particularly in the regulation and processing groups, some explicitly reported not to be concerned about eating and drinking MPs, and named others, in their view, more pressing issues. These sense-making processes illustrate a larger debate in the literature around a potential dramatisation of certain risks, leading to a distraction from other important issues (Kramm, Völker, and Wagner 2018). Some interviewees involved in processing and regulation also criticised the media discourse around MPs as potentially being too one-sided or sensational (Völker, Kramm, and Wagner 2020; Welzenbach-Vogel et al. 2022). The representation of (micro-)plastics in the media has been studied by various scholars (Keller and Wyles 2021; Schönbauer and Müller 2021; Völker, Kramm, and Wagner 2020). For instance, Schönbauer and Müller (2021) identified three phases, where MPs are initially a potential but yet-to-be-determined risk, followed by a portrayal as toxic and harmful. The final phase is characterised by emerging controversies and discussion of scientific uncertainties, leading to an increasingly ambiguous media landscape, and potentially contributing to higher perceived risk due to perceived uncertainty and lack of scientific consensus (Janzik et al. 2024).

### ***Challenges and solutions***

Here it was notable that participants tended to talk about measures to reduce *macro-plastics*. 'Plastics' as an overarching concept and direct transfer from macro to micro was also found by Janzik et al. (2024). While this reflected participants' understanding of sources and pathways of MPs, it also highlighted their difficulties in disentangling the two. Respondents across groups

expressed low knowledge and high uncertainty about solutions. Lack of knowledge due to limited information and unavailability of alternatives were perceived as some of the main barriers in tackling the issue. Although a lack of awareness and relevance of the problem among the wider public was also frequently raised, in fact, public opinion polls show high awareness, for example in Germany (e.g. BfR 2023).

The benefits and convenience of plastics were also mentioned as barriers. Some participants raised the trade-offs between more plastics in the food chain, and better hygiene, greater protection from physical damage and contaminants, and extending shelf life which help address a key objective of reduced food waste, particularly for foods associated with high environmental impacts (e.g. meat; UNEP 2022). On the other hand, concerns about human health effects have been raised particularly related to chemicals leaching into food products from plastic packaging (Muncke et al. 2023), and calls for human health to be placed at the centre of policy debates have become louder (Deeney et al. 2022).

Other barriers people mentioned were the general feeling of being trapped in a system (e.g. the existing supply chain, production system, unavailability of alternatives), economic constraints (e.g. high necessary investments, no incentives for change), including the cheapness of plastics as a material, and the legal situation, e.g. plastics as a requirement for adhering to hygiene standards in distribution/hospitality. These factors are largely beyond the control of individuals as well as the individual sectors in which they operate and require changes and partnerships on all levels of the system, including the regulatory level.

Consequently, responsibility was ascribed to regulation (i.e. authorities, politics, governments), including among the regulation group themselves who also reported facing several additional obstacles, e.g. lack of financial or human resources, lack of scientific knowledge to justify action, the structure of responsibilities and legal areas as well as efficient communication with the public. Furthermore, interviewees attributed responsibility more to individuals or society than to industry and producers. Particularly those involved in regulation placed remarkably high importance on preventing littering, not least through sanctions. This could be a result of media and industry narratives focusing on consumers and their behaviour as an important lever in reducing MP pollution. For instance, Schönbauer and Müller (2021) reported an imbalance in the media discourse, as calls to action were primarily addressed to the public, creating the questionable idea that consumers have great influence while, in fact, significant sources lie beyond their control (e.g. focus on avoiding single-use plastic cups, while less attention is devoted to other major sources of MP pollution requiring systemic and large-scale changes, like e.g. tyre abrasion). In contrast, industry figures were rarely mentioned as responsible actors, which creates a situation where consumers are 'over-responsibilised' while policy and industry fail to implement measures. This imbalance can contribute to public distrust, particularly in combination with a risk narrative characterised by uncertainty and ambiguity (Schönbauer and Müller 2021). A prominent theme, particularly in the harvesting, distribution, and consumption groups, was a general disenchantment with or distrust in 'the system' (e.g. politics, regulation, industry, lobbying, science, etc.) and frustration about how this issue and other environmental/societal issues are handled.

MPs are a 'wicked' problem (Ballantyne and de Cros Péronard 2023, 268) for which no single or straightforward solution exists (Rist et al. 2018). In our study, interviewees suggested increased media coverage, specifically focused on solutions, an integration into the school curriculum, and public awareness campaigns (cf. Grünzner et al. 2023). In addition, there were calls for restrictions and binding regulations to encourage individual change. In particular, interviewees across groups suggested general bans, bans of certain products, regulations concerning standardised packaging and labelling as well as economic regulations, e.g. subsidies for using alternatives, deposit systems, or disincentives, like a plastic tax. The only group not to suggest economic regulations was the processing group in this study. However, the generally strong desire for top-down guidance is consistent with previous research on consumers (Cowan, Setsaas, and Nørstebø 2023; Janzik et al. 2024), but here found support across the supply chain.

As the effectiveness of legally binding measures ultimately depends on their acceptance by those affected, it is crucial to understand what conditions involved groups see as important and what expectations they have. The most important characteristics to make regulations acceptable reported by our interviewees were consistent with the classification discussed in previous microplastics-related research, namely their effectiveness and feasibility (e.g. Grünzner et al. 2023; Pahl, Richter, and Wyles 2020). Specifically, what most interviewees across groups considered important was the financial, practical, and capacity-related feasibility of a measure. For instance, interviewees from the harvesting and processing groups expressed concern about high investments when switching to alternative materials or processes. Furthermore, perceived effectiveness or impact was seen as important, and, linked to this, evidence of risk was seen as an important prerequisite for the implementation of measures. In other words, people want to know that what is being regulated makes sense, is proportionate, and has actual effects. These desired features pose challenges in the context of an issue not yet fully understood.

Other conditions for policy acceptance were perceived fairness, perceived benefit, availability of alternatives, considerations of essentiality (e.g. medical applications), and transparency/participation, highlighting a great number of factors beyond the severity and likelihood of the risk in question.

### **Implications**

In sum, our results offer insight into knowledge and perceptions of different involved groups' understanding of MPs in food and drink as well as their views on potential solutions, which can provide some guidance on risk communication and policy making around (micro-)plastics, a complex issue concerning both environment and health.

First, our findings highlight the fact that system change requires all actors in a system to understand the issues and be willing to play their part in solutions. While a significant amount of research concentrates on 'the public' or 'experts', the voices of other involved groups are often not given sufficient consideration. We argue that with an issue as complex as MPs in the food chain, the involvement of all actors is crucial for designing effective risk communication and management strategies. Emphasis should be placed on communicating group-specific feasible actions to help alleviate feelings of powerlessness (Janzik et al. 2024). This includes consideration of how to avoid unwanted concomitant risks or backfire effects. For example, public knowledge of degradation properties of 'bioplastics' has been found to be low (Filho et al. 2021), implying that knowledge about correct use and disposal among consumers, but also perhaps in agriculture, might be lacking as well. Thus, awareness and information campaigns need to account for potential 'user errors' as well, not least to do justice to people's demand for measure effectiveness.

Second, the current state of research should be communicated in terms of what is known as well as what is unknown. Scholars have observed an underreporting of science as a process rather than a linear success story and a lack of discussion of uncertainties of new knowledge (Felt and Fochler 2013; Schönbauer and Müller 2021). To address concerns around uncertainties, a focus should be on enabling citizens to learn about science as a process and normalising uncertainty in policy debates (Jansen, Claassen, and Boomsma 2024).

Our results further highlight the need for systemic changes and developments on the regulatory level. Although positive trends were being mentioned (e.g. increasing regulations, growing supply of alternatives), the majority of our interviewees across groups called for more binding and economic regulations and bans.

Crucially, an important factor influencing environmental policy support is trust in authorities (e.g. Fairbrother, Johansson Sevä, and Kulin 2019). A reoccurring theme across most of our groups was a disenchantment with or distrust in the system (i.e. politics, regulation, but also specifically industry, lobbying, science). To promote acceptance of systemic changes, the creation

of an environment of trust is key. This is particularly true in the face of uncertainties because under these conditions, lower trust in authorities is associated with higher perceived risks (Siegrist and Cvetkovich 2000). Thus, our findings indicate that there is a need for more systematic inclusion of these groups in solution-finding and decision-making initiatives, not least to strengthen their trust in the system.

### **Limitations**

As we have taken a qualitative approach, our results are not generalisable. Moreover, our sample was limited to individuals who had heard of MPs before and were willing to participate in the study. Following our initial qualitative exploration, future quantitative research should investigate people's perceptions on a population scale, testing the suggested theoretical framework. We also want to point out again that the quantitative data we present above is for illustration and should be replicated with larger samples. Also, our findings may not extend to other countries than Austria. As the plastics treaty is debated on a global scale, different cultural, socio-economic, and geographical contexts should be considered. Moreover, future research should take into account nanoplastics, particles even smaller than MPs, which have been shown to exhibit distinct behaviours (Gigault et al. 2021) and might also be perceived differently.

### **Conclusion**

Our study sheds light on different involved groups' perceptions of MPs in the human food chain as well as potential solutions from 'farm-to-fork'. The present results reveal multifaceted ideas about sources and pathways of MPs, and interviewees echoed the wider public's concerns about negative outcomes for human health alongside low certainty about underlying processes. Although multi-layered, people's feelings were largely characterized by powerlessness and frustration, and the unavoidability of (micro-)plastics was emphasized even among key actors in the food chain who have direct experience of various stages in the production, distribution, consumption, and regulatory processes. With regards to solutions, respondents, although aware of the lack of individual control, frequently mentioned individual behaviour changes. Participants further suggested building awareness and solution know-how, and they demanded systemic changes on the regulatory level. On the legislation level, several barriers regarding regulations were mentioned, including challenges in efficiently communicating with the public. From our findings, conditions can be defined that are likely associated with higher acceptance of policy measures (e.g. feasibility, perceived effectiveness, evidence of risk, perceived fairness, perceived benefits). Considering these should help in engaging the necessary range of involved groups and implementing recommended or binding measures in the face of a complex and not yet fully understood environmental and health risk, such as (micro-)plastics. Crucially, our findings highlight the importance of increased involvement of all actors in a system to foster a better understanding of the issue and greater willingness to play part in solutions.

### **Note**

1. We decided to avoid the term 'stakeholder' due to the debate surrounding its potentially colonial connotations (see Reed 2022).

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## Author contributions

LF: conceptualization, methodology, investigation, formal analysis, writing—original draft, writing—review and editing, visualization. LMS: investigation, writing—review, and editing. UF: funding acquisition, conceptualisation, supervision, writing—review, and editing. TH: funding acquisition, investigation, writing—review, and editing. MPW: writing—review and editing. SP: funding acquisition, conceptualisation, supervision, writing—review, and editing.

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