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Price above all else: an analysis of expert opinion on the priority actions to scale up production and consumption of plant-based meat in Brazil

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Introduction: Plant-based meats (PBM) are an emerging set of food technologies that could reduce the environmental impacts of food systems by mitigating consumer demand for animal products. However, scaling up the production and consumption of plant-based meats requires overcoming multiple technological, regulatory, political, and market barriers. An evidence-based prioritization of needs and actions may help actors (e.g., investors, funders, policymakers) who wish to help scale PBM achieve desired outcomes with limited resources.

Research question: What actions could most effectively help to scale up the production and/or consumption of plant-based meat in Brazil?

Methods: We selected Brazil as a case study of a country with a significant animal agriculture sector and a burgeoning PBM sector. We constructed a panel of nine experts and employed the Delphi technique during two rounds of an online survey to iteratively assess the degree of consensus and disagreement around the relative priority of 14 possible actions (identified from relevant literature) that could help to scale up the production and/or consumption of PBM in Brazil. We used the Importance, Neglect, and Tractability framework.

Results: The panelists collectively concluded that the top priority action for scaling up both the production and the consumption of plant-based meat in Brazil was to reduce the price of products for consumers. For most priority actions, there was greater consensus among panelists in the second round of the survey.

Discussion: Our findings contribute to an improved understanding of (a) which actions may be of highest priority for investors, funders, and policymakers, (b) synergies and differences between priority actions to scale up the production versus consumption of PBM in Brazil, (c) the relative merits of focusing on scaling up PBM production versus consumption, and (d) the strengths and limitations of assessing expert opinion on alternative protein futures using the Delphi technique.

KEYWORDS

alternative protein, consensus, cost, Delphi, effective altruism, policy, technology

1 Introduction

Animal agriculture has a significant environmental footprint, including on the climate and on land use. Livestock production is associated with a large proportion of the greenhouse gas emissions attributed to the global food system (Gerber et al., 2013; Xu et al., 2021), which in turn contributes about a third of total global greenhouse gas emissions (Crippa et al., 2021). Additionally, livestock production is a leading driver of deforestation (Steinfeld et al., 2006; Pereira et al., 2020), and land dedicated to grazing and animal feed production encompasses an estimated 50–78% of the world's agricultural land (Foley et al., 2011; Ritchie and Roser, 2019). Meat consumption is also associated with elevated risk of various human diseases (Papier et al., 2021) and with animal welfare concerns (Norcross, 2004; Heidemann et al., 2020).

Global shifts away from diets heavy in animal products toward more plant-based diets could help to reduce the environmental, human health, and animal welfare impacts of food systems. Many researchers, practitioners, and donors, including those concerned about climate change, land-use, and biodiversity loss, have advocated for broad scale shifts toward more plant-based diets that are less dependent on resource-intensive animal agriculture practices (Searchinger et al., 2019; Willett et al., 2019; WWF, 2020). Multiple interventions (e.g., policies, programs, technologies, behavioral nudges) have been developed and implemented to promote such shifts. Examples include national dietary guidelines that influence meat and dairy consumption (Behrens et al., 2017); greater availability of plant-based meals in college cafeterias to promote increases in vegetarian meal purchases (Garnett et al., 2019); self-monitoring text message campaigns using daily reminders on the health and environmental impact of meat consumption (Carfora et al., 2019; Wolstenholme et al., 2020); increasing the visibility and availability of plant-based products in supermarkets (Trewern et al., 2022); and production of plant-based substitutes for animal products (Apostolidis and McLeay, 2016).

Alternative proteins are an emerging set of food production technologies that could contribute to shifts away from animal agriculture by mitigating consumer demand for animal products. Alternative proteins include plant-based, cultivated, and fermented protein products that can be used as key ingredients in food products with sensory and nutritional profiles that closely mimic products traditionally derived from animals (Aiking, 2011; Tziva et al., 2020). These products comprise a new generation of products designed specifically to appeal to meat-eaters without the need to elicit major dietary changes (Tziva et al., 2020). If the production of alternative proteins scales up to account for a meaningful proportion of the total protein sector, these technologies could reduce the negative impacts of protein production on the environment (Tuomisto and Teixeira de Mattos, 2011; Goldstein et al., 2017; Poore and Nemecek, 2018; Springmann et al., 2018; Marinova and Bogueva, 2019), public health (Graça et al., 2019), and animal welfare (Santo et al., 2020). There is considerable uncertainty around the direction and magnitude of these potential environmental and health impacts of alternative proteins (e.g., Lynch and Pierrehumbert, 2019; Mariotti, 2023; Tay et al., 2023). Nonetheless, many stakeholders are sufficiently optimistic about the possible benefits of alternative proteins that they are heavily invested in scaling up the production and consumption of these food products (GFI, 2023a,b).

Plant-based meat (PBM) products are a class of alternative protein products derived from plant ingredients (Kyriakopoulou et al., 2019). PBM products generally have lower natural resource demands and environmental impacts as compared to animal-based meat products, including in terms of greenhouse gas emissions and land use (Smetana et al., 2023). PBM products can incorporate various plant proteins, including commoditized ingredients such as soy and pea protein as well as novel plant proteins with less well-developed supply chains (Kyriakopoulou et al., 2019; Ahmad et al., 2022). Functional ingredients (e.g., lipids, carbohydrates, flavors) from other plant sources are often added to improve the structural and nutritional characteristics of PBM products (Kyriakopoulou et al., 2019). PBM production processes typically involve protein isolation and functionalization, formulation, and various forms of extrusion and texturization (Rubio et al., 2020). Recent innovations in PBM product development include pretreatment procedures to improve functional properties and efforts to create products with enhanced nutritional compositions (Tachie et al., 2023). Global revenue for the PBM and plant-based seafood sector in 2022 was US $6.1 billion (GFI, 2023a).

Scaling up the production and consumption of alternative proteins, including PBM, requires overcoming multiple technological, policy, and market barriers (Stephens et al., 2018; Post et al., 2020). Such challenges include safety and regulatory hurdles (Hadi and Brightwell, 2021), consumer acceptance (Elzerman et al., 2011; Hoek et al., 2013; Bryant and Barnett, 2018; Graça et al., 2019; Malek et al., 2019; Siegrist and Hartmann, 2020; Onwezen et al., 2021), economic competitiveness with the animal-based meat industry (Ismail et al., 2020), and overcoming political influences that favor the incumbent animal-based meat industry (Vallone and Lambin, 2023). A range of factors affect consumer willingness and intent to purchase PBM, including demographics (Bryant et al., 2019), access to environmental and nutritional information (Chen et al., 2023), social norms and rituals (Jahn et al., 2021), and dietary preferences (Nezlek et al., 2023). Many of these factors vary by geography. As such, context-specific investment, innovation, policies, and research are likely needed to inform effective actions to overcome these barriers if alternative proteins are to achieve a meaningful scale and viable market traction.

An evidence-based prioritization of needs and actions may help any actor who wishes to scale up alternative proteins (e.g., investors, funders, policymakers) to achieve desired outcomes with limited resources. Funding, time, and labor are all finite, and resources to support the scaling up of alternative proteins are limited. Prioritizing resource allocation to actions that are likely to have the highest potential impact could help to maximize return on resources. Such an approach could also help reduce overall spending by forming a proactive rather than reactive resource investment agenda (Scherer et al., 2020). An efficient allocation of resources and effort could be aided by a systematic assessment of which actions would most effectively contribute to the goal of scaling up PBM production or consumption. While a growing literature (in part cited above) has characterized many of the barriers to scaling up alternative proteins, including PBM, we know of no research that attempts to quantitatively identify which potential actions to overcome these barriers are of greatest priority.

Questions about how to efficiently scale up the production and consumption of plant-based meat are of high relevance to stakeholders in Brazil, for multiple reasons. First, Brazil has a large animal agriculture sector that has both extensive environmental impacts and

nationally significant economic importance (Vale et al., 2019). Second, as global and domestic demand for protein increases, Brazil is predicted to remain one of the largest exporters and consumers of meat products (USDA, 2021). Third, Brazil has a burgeoning alternative protein sector, including a rapidly growing PBM sector (GFI Brazil, 2022). Brazil's plant-based foods sector (including PBM and seafood) reached approximately US $170 million in 2022, growing 42% from 2021 (GFI Brazil, 2023). At least 107 companies produce plant-based foods in Brazil and export to more than 30 countries (GFI Brazil, 2023). Approximately 14% of the total Brazilian population self-describe as vegetarian (SVP, 2022), and nearly 30% of Brazilian consumers have an interest in reducing their consumption of animal products (GFI Brazil, 2018). The stated intent of Brazilian consumers to eat PBM is influenced in part by how healthy, safe, and beneficial to the environment they perceived those products to be (Nezlek et al., 2023). PBM is now available in many Brazilian supermarket chains, although products tend to be more expensive and less widely accessible than animal-based meat (Reis et al., 2023). International non-profit groups have advocated for research to further develop the PBM sector in Brazil in consideration of the country's abundance of native plant species (Gallon, 2021). In combination, these factors make Brazil a globally significant actor in the past, present, and future of animal and plant protein production and consumption, and make it an important case study country to understand the opportunities and challenges associated with scaling alternative protein production and consumption. As such, in this paper we ask the research question: What are the actions that would most effectively help to scale up the production and/or consumption of plant-based meat in Brazil?

2 Methods

2.1 Case study: plant-based meat in Brazil

Our study focuses on plant-based meat rather than any other category of alternative protein products (e.g., plant-based dairy, cultivated proteins; fermented proteins) for several related reasons. We chose to analyze the potential of PBM as an alternative protein product that has relatively high market traction, and which is the focus of considerable investment and research in Brazil. We chose to focus on a single type and form of alternative protein product, because challenges and priorities likely vary dramatically between different *types* (e.g., plant-based dairy vs. plant-based meat) and *forms* (e.g., plant-based vs. cultivated) of alternative protein products. Therefore, each alternative protein type and form may face unique technological, policy, and market opportunities and barriers to scaling production and consumption.

2.2 Framework

We used the Importance, Neglect, and Tractability (INT) framework developed by the Effective Altruism (EA) movement (Todd, 2013). This framework was developed to prioritize causes and to compare alternative actions in terms of their potential impact. It can be applied to assess the value of allocating marginal resources to solving a problem or engaging in a particular action based on the importance, neglect, and tractability of that problem or that action (Todd, 2013; Dickens, 2016). In this context, an action is defined as: *important* if it would produce significant benefits, *neglected* if it is not currently being pursued or addressed; and *tractable* if it is likely to be successful.

2.3 Potential priority actions

We constructed an initial set of potential actions that could help to scale up the production and/or consumption of PBM. This list of actions was derived and synthesized from an amalgamation of barriers, challenges, and priorities identified in recent research papers and reports. We identified relevant peer-reviewed and gray literature using keyword searches (Supplementary Note S1) and a snowball approach. Some publications were particularly useful: for example, we drew on the future research opportunities identified by He et al. (2020) and the key actionable insights highlighted in The Good Food Institute's 2020 State of Plant-based Industry Report (GFI, 2020). We then reviewed the list and consolidated and clarified the candidate actions into a final list of 14 possible actions that may be considered priorities in helping to scale up the production and/or consumption of plant-based meat in Brazil (Table 1).

2.4 Expert panel

We used the Delphi technique to conduct iterative surveys to assess the informed opinions of a panel of experts. The Delphi technique is a method for gathering data from respondents within their domain of expertise and is designed to facilitate a convergence of opinion on a specific complex issue (Hsu and Sandford, 2007; Scherer et al., 2020). The Delphi technique provides panelists with the opportunity to reassess their initial survey responses after reviewing results from previous survey iterations (Figure 1; Hsu and Sandford, 2007). Advantages of the Delphi technique as a tool for expert consensus building include its capabilities to offer panelists anonymity, to reduce the effect of noise through a controlled feedback process, and to enable the use of statistical analysis in data interpretation (Hsu and Sandford, 2007). For example, when panelists provide quantitative data (e.g., scores, rankings), results from the Delphi method can be used to capture consensus by calculating the mean and standard deviation (Scherer et al., 2020). We solicited the panel members' perspectives on our primary research question: What are the actions that would most effectively help to scale up the production and/or consumption of plant-based meat in Brazil?

The principal inclusion criterion for an individual to qualify for the panel was self-declared expert knowledge, understanding, and/or experience relevant to our research question. We identified potential panelists through our own networks, and by asking for panelist suggestions from key individuals who worked in this area. We contacted a total of 21 individuals by email and/or via social media (e.g., LinkedIn). Thirteen individuals agreed to participate in the study, and all 13 responded to the round one of the Delphi panel survey. Four people did not respond to the round two and were thus lost from the study due to attrition. The final nine-person panel included four individuals whose primary affiliation was in the private sector (two working for PBM companies, two working as investors) and five individuals whose primary affiliation was a research institution (two at universities, three in public sector research agencies). All panel members had deep subject-area expertise on the topic of PBM in Brazil, either through applied research (including

TABLE 1 List of 14 potential priority actions to scale up the production and/or consumption of plant-based meat, identified through a review of the literature.

#	Priority action	Description
1	Protein sources	Identify new crops as viable sources of plant protein for PBM production.
2	Financial capital	Increase investment and funding for PBM production.
3	Start-up support	Improve access to technology accelerators, mentorship, and business support for PBM companies.
4	Sensory profile	Improve the sensory profile of PBM to more closely mimic their animal-based analogs.
5	New product types	Expand the diversity of PBM products available to consumers.
6	Manufacturing efficiency	Improve the efficiency of production facilities for PBM manufacturing.
7	Manufacturing facility capacity	Increase the number and/or capacity of manufacturing facilities for PBM production.
8	Level playing field	Alter the regulatory environment to create fair competition for alt-protein companies (e.g., create fair labeling laws, remove subsidies for animal products, introduce true-cost accounting for animal-based products).
9	Health, nutrition, and safety	Develop and adopt national food safety and quality standards for PBM products.
10	Price	Reduce the cost of PBM products for consumers.
11	Availability	Increase the availability of PBM products (e.g., by selling them in a wider range of retail outlets).
12	Visibility	Adopt strategies to leverage the consumer choice architecture environment (e.g., grocery store organization, menu order) to encourage purchasing of PBM products.
13	Marketing	Improve marketing strategies to promote consumption of PBM products.
14	Consumer acceptance	Reduce barriers to consumer acceptance of PBM (e.g., by influencing perceptions, attitudes, cultural norms).

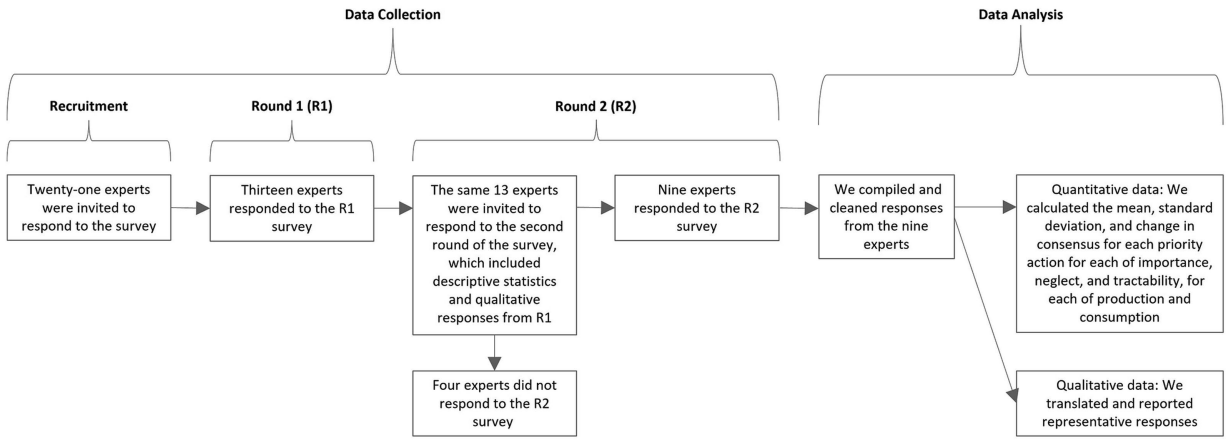

FIGURE 1
Schematic explanation of the methodology for this paper, including data analysis using the Delphi technique (involving recruitment and two rounds of an online survey) and data analysis of the quantitative and qualitative survey responses.

with multiple publications) and/or through active engagement in the development of PBM products.

In consideration of the time-intensive nature of the survey commitment (completion time for round one was estimated to be 20 min; round two additionally included the need to read the quantitative summaries and extensive qualitative responses of other panel members from round one), during the panelist recruitment process we included an invitation to be a co-author of the resulting paper as an incentive. This incentive was provided to aid recruitment and to reduce attrition between rounds, and to add additional expert insight to the framing and interpretation of the paper. We believe that any potential concerns about conflict of interest were mitigated by three actions: (a) we kept panelist identity confidential until after data collection was completed, (b) we allowed panelist co-author input into the Introduction and Discussion sections of the paper, but we restricted data analysis and the Results section of the paper to non-panelist authors, and (c) we offered no material incentives for survey completion. We observed precedence for including interviewees as co-authors in methodologically-similar papers (e.g., Kelly et al., 2019; Scherer et al., 2020).

2.5 Online survey

We developed and disseminated an online survey using Qualtrics™ software (Supplementary Note S2). The survey first collected information on the panelists' professional experience. Panelists were then asked to use a sliding scale tool to assign values

of 0 to 100 to the importance, neglect, and tractability of each of the 14 potential actions in relation to their role in helping to scale up the production and consumption, separately, of PBM in Brazil. For both production and consumption ranking activities, we instructed panelists to give the priority action that they considered to be most impactful a score of 100, and to evaluate the other actions relative to their top ranked action. Panelists were allowed to rank multiple actions as 100 if they felt they were of equivalent impact.

We conducted two rounds of the survey. The first round (R1) was conducted between February 21 and March 21, 2022. After R1, key data were summarized and shared with the panelists via email as required pre-reading ahead of the second round (R2) of the survey. The data shared ahead of R2 were: (1) the mean and standard deviation of the values assigned to each of the 14 potential actions (summarized in six dot plots, one for each combination of production and consumption, crossed with importance, neglect, and tractability), and (2) the de-identified, full qualitative responses from each panelist in response to the R1 question "Please provide a justification for your ranking decisions above" for each ranking exercise. Sharing the summary of key data from R1 enabled the panelists to read other panelists' responses and to adjust their responses in the second round if they were persuaded by anything that the other panelists said. In this way, the Delphi technique allows a form of asynchronous dialogue between the panelists. R2 was conducted between April 4 and May 5, 2022.

The first round of the survey was made available to panelists in both English and Brazilian Portuguese. All panelists elected to use the Brazilian Portuguese version, and so we developed the second round of the survey only in that language (Supplementary Note S3). We used the DeepL Translator software for translation in both directions, and a native Brazilian Portuguese speaker (RLMS) verified and, where necessary, improved the translation for all text where precise translation was critical (e.g., the survey, and cited quotes).

2.6 Data cleaning

We compiled the data in Excel and any identifiable information was first removed from each round of the survey. Next, each response was validated to ensure that respondents completed all questions and followed the instructions provided. Any incomplete or duplicate responses were then removed from the analysis. For any respondents that failed to rank any action as 100 in a particular exercise, their responses were rescaled relative to the highest score provided (see Supplementary Data S1, S2).

2.7 Data analysis

Data analysis was conducted in R (version 4.2.1) (Supplementary Data S3). For both survey rounds, we calculated the mean and standard deviation for the importance, neglect, and tractability of each action for production and consumption (Supplementary Tables S1, S2). We assessed consensus for each priority item by using the standard deviation (i.e., smaller standard deviations indicated more agreement and vice versa) after each survey round. To examine how consensus changed between R1 and R2 survey rounds, we subtracted the R2 standard deviation from the R1 standard deviation. A positive value indicated greater consensus in the second round (i.e., the standard deviation in R2 was less than in R1) (Supplementary Table S3). We report all values as rounded to the nearest integer, and thus report any consensus value between −0.49 and 0.49 as a zero change in consensus. We then created a prioritization score by averaging the importance, neglect, and tractability scores for each action for both consumption and production (Supplementary Table S4). We determined the final priority scores using only R2 data, since this was the final survey round and participants had considered the responses of other participants in R1.

3 Results

Here, we report the most and least important, neglected, and tractable actions, using the quantitative results from R2 of data collection. These findings represent the combined final rankings of the nine panelists, following two rounds of the online survey and following an opportunity to read each other's perspectives before responding in R2. The qualitative data used to illustrate the quantitative results are drawn from both R1 and R2.

3.1 Production

3.1.1 Importance

The potential action identified as being most important for scaling up production of PBM in Brazil was *protein sources* (mean ± SD score = 92 ± 7), which was described as "Identify new crops as viable sources of plant protein for PBM production." Second most important was *price* (89 ± 23), which was described as "Reduce the cost of plant-based meat alternative products for consumers" (Figure 2).

In relation to *protein sources*, several panelists highlighted the need for domestically sourced, Brazilian crop inputs. For example:

> "It is essential to ensure the country's sovereignty and sustainability in the production of raw materials for plant-based products."

> "Brazil is still very dependent on imported raw materials, except soy. The priority is to establish domestic options for vegetable protein and derived ingredients."

In relation to *price*, panelists commented that production would not be able to increase until the price was reduced and demand increased. For example:

> "To increase production, it will be necessary to increase consumption, both in higher and lower income segments [of society]."

Finally, at least one panelist connected these two issues, highlighting the interrelatedness of different barriers and priorities:

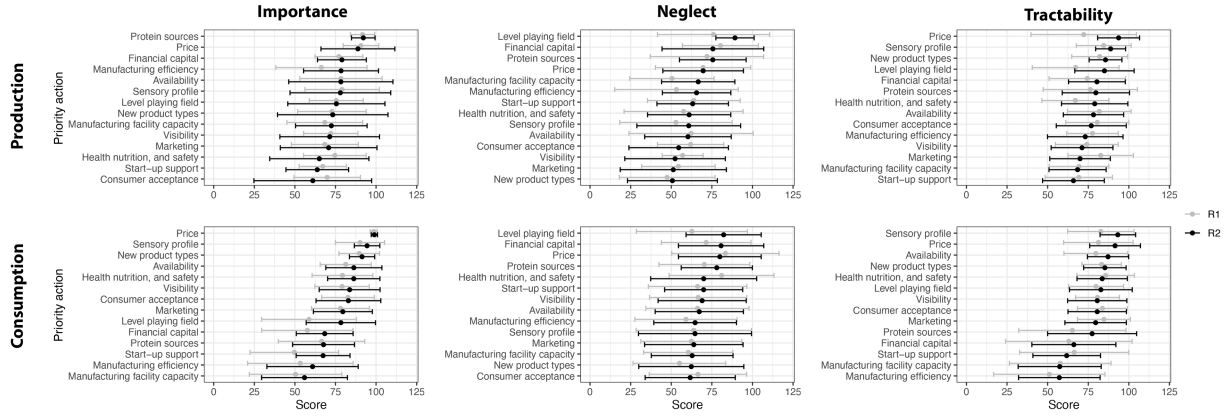

FIGURE 2
Comparisons between the importance, neglect, and tractability scores for each priority action to promote plant-based meat production and consumption in Brazil between Round 1 (R1, gray) and Round 2 (R2, black) from the Delphi analysis. Error bars represent the standard deviation, which we use as a proxy measurement of agreement among respondents.

> "In my view, the price is a very important factor for the consumer to choose the vegetable product. To reduce the price of products, it is essential to have local ingredients available. Today we have the limitation of very few ingredients: soy protein and peas, and the pea protein is imported. This makes the production cost very high, due to the exchange rate."

The least important potential priority action for scaling up production was *consumer acceptance* (61 ± 36), which was described for participants as "Reduce barriers to consumer acceptance of PBM (e.g., by influencing perceptions, attitudes, cultural norms)." The second least important potential priority action was *start-up support* (64 ± 19), which was described for panelists as "Improve access to technology accelerators, mentorship, and business support for PBMA companies."

Regarding *consumer acceptance*, one panelist claimed that this should not be a major concern, and rather returned to the importance of lowering the price of products.

> "I really think that the concern with consumer acceptance is of little importance, I believe that the current bottleneck is the price".

3.1.2 Neglect

The potential action identified as being most neglected in the scaling up of production of PBM was *level playing field* (mean ± SD score = 89 ± 12), which was described to panelists in the survey as "Alter the regulatory environment to create fair competition for alternative protein companies (e.g., create fair labeling laws, remove subsidies for animal products, introduce true-cost accounting for animal-based products)." The second most neglected potential actions were *protein sources* (76 ± 21) and *financial capital* (76 ± 31), which was described to panelists as "Increase investment and funding for PBM production."

In relation to the idea of creating a *level playing field*, one panelist noted that insufficient progress has been made on that front:

> "We have failed to achieve a level playing field for competition and production."

In relation to protein sources, one panelist observed that there had been little effort to establish domestic sources of key crop ingredients for plant-based meat:

> "It is unbelievable that we have to import cereals like peas for the production of plant-based meats in a country like Brazil, which has enormous productive potential. It is complex because this neglect needs to be changed by several actors, not only the plant-based meat industry itself."

Regarding *financial capital*, one panelist commented on the lack of investment in the plant protein sector, particularly in comparison to the conventional meat sector:

> "The neglect of capital investments in the plant-based meat industry becomes clearer when compared to the extent of sustained support for conventional meat production in Brazil."

The least neglected potential priority actions were *marketing* (51 ± 33) and *new product types* (51 ± 28), which were defined as "Improve marketing strategies to promote consumption of PBM products" and "Expand the diversity of PBM products available to consumers" respectively. Second least neglected potential priority action was *visibility* (52 ± 31), which was defined as "Adopt strategies to leverage the consumer choice architecture environment (e.g., grocery store organization, menu order) to encourage purchasing of PBM products."

3.1.3 Tractability

The potential action identified as being most tractable in scaling up production of PBM in R2 was *price* (mean ± SD score = 94 ± 13). Second most tractable was *sensory profile* (89 ± 9), which was described as "Improve the sensory profile of PBM to more closely mimic their animal-based analogs."

In relation to the tractability of *price* reduction, one of the panelists commented that investments in the production chain and product formulation will have a significant impact on the price:

> "Investment in the entire supply chain, scaling up raw materials and producing nutritious products will bring price reduction, thus leading to a definitive impact on consumption".

Regarding the tractability of sensory profile, one panelist commented that:

> "Indeed, sensory profile and price […] tend to be the most treatable to overcome in order to boost the market".

The potential action identified as being the least tractable for scaling up production of PBM in R2 was *start-up support* (66 ± 19). The second least tractable was *manufacturing facility capacity* (68 ± 18), which was described as "Increase the number and/or capacity of manufacturing facilities for PBMA production."

3.1.4 Range of responses

The range between the lowest mean value for any action and highest mean value for any action was smallest for the question of tractability of actions to scale up production (a 28-point gap). In comparison, this range was a 31-point gap for importance and a 38-point gap for neglect. This suggests relative indifference among the panelists as to which actions were more tractable than others. This sentiment was captured by one panelist:

> "The feasibility of most of the [actions] seems high to me, as long as there are investments to pursue the necessary advances."

3.1.5 Priorities

When importance, neglect, and tractability rankings were averaged, *price* emerged as the top priority action in R2 for scaling up production of PBM in Brazil (Figure 3; Supplementary Table S4). The joint second priorities were *level playing field* and *protein sources*. The lowest priorities were *marketing*, *consumer acceptance*, and *start-up support*.

3.2 Consumption

3.2.1 Importance

The potential priority action identified as being most important to scaling up consumption of PBM in R2 was *price* (mean ± SD score = 99 ± 2) Second most important was *sensory profile* (94 ± 8) (Figure 2).

Price was referred to repeatedly by panelists. For example:

> "Price is still a major impediment to the popularization of the products."

> "The consumer will increase consumption when the price is affordable."

Sensory profile was secondary, but also considered important:

> "Consumers who have a habit of consuming conventional meat will be willing to switch foods if they meet the sensory needs and price parity."

> "Plant meats should have adequate nutritional composition, but ensure that sensory characteristics (taste, texture, color) are similar to animal products."

The potential priority action identified as being the least important for scaling up consumption was *manufacturing facility capacity* (56 ± 26). The second least important was identified as *manufacturing efficiency* (61 ± 28), which was described as "Improve the efficiency of production facilities for PBM manufacturing."

3.2.2 Neglect

The potential action identified as being most neglected in the scaling up of consumption of PBM in R2 was *level playing field* (mean ± SD score = 82 ± 23). Second most neglected was *financial capital* (81 ± 26).

Regarding creating a *level playing field* to increase the consumption of plant-based products, a panelist commented that the allocation of investments and subsidies in the conventional (animal) protein sector is a constraint on the growth of consumption of the alternative protein sector:

> "Several other sectors are kept at a low rate of development because of this [constraint]."

In relation to the neglect of *financial capital* to increase the consumption of plant-based products, one panelist commented that:

> "[The country needs] to invest in better access."

The potential priority actions identified as being least neglected for scaling up consumption of PBM in R2 were *new product types* (62 ± 32) and *consumer acceptance* (62 ± 28). The second least neglected was *manufacturing facility capacity* (63 ± 25).

Regarding *new product types* and *consumer acceptance* as less neglected actions, two panelists commented that:

> "I believe that marketing and consumer issues are reasonably established and not so neglected"

> "The low score for consumer acceptance is because I believe it is already greater than product availability"

3.2.3 Tractability

Sensory profile was the potential action identified as being most tractable in scaling up consumption of PBM (mean ± SD score = 93 ± 11). Second most tractable was *price* (92 ± 16).

Regarding s*ensory profile*, one of the panelists commented that it needs to improve quickly, as it affects consumer acceptance:

FIGURE 3
Priority scores (+) for each priority action to promote plant-based meat production and consumption in Brazil, calculated by averaging Round 2 (R2) importance (•), neglect (▲), and tractability (■) scores from the Delphi analysis.

> "Initiatives in R&D, both public and private, will contribute more rapidly to the improvement of the nutritional and sensory quality of plant-based products, enhancing their acceptance by consumers."

Panelists offered ideas about how prices could be reduced, and why they thought that doing so was feasible. For example:

> "[Prices] can be significantly reduced with the increase of new raw materials"

> "Raw materials at scale, with nutritious products, will bring price reduction and therefore the impact on consumption will be definite"

The least tractable potential priority actions for scaling up consumption were identified by panelists as *manufacturing efficiency* (57 ± 26) and *manufacturing facility capacity* (57 ± 25), followed by *start-up support* (62 ± 21).

3.2.4 Range of rankings

The range between the lowest and highest mean values was smallest for the question of neglect of actions to scale up consumption (a 20-point gap), compared to importance (43-point gap) or and tractability (35-point gap). This suggests relative indifference among the panelists as to which actions were more neglected than others.

3.2.5 Priorities

For scaling up the consumption of PBM in Brazil, *price* was ranked as the top priority when importance, neglect, and tractability rankings were combined (Figure 3; Supplementary Table S4). The second and third priorities were *sensory profile* and *level playing field*. The lowest priorities were for *start-up support*, *manufacturing efficiency* and *manufacturing facility capacity*.

3.3 Changes in consensus: production

3.3.1 Importance

Between the two rounds of data collection, there was less participant consensus concerning the relative importance of most actions for increasing PBM production in Brazil (Figure 3; Supplementary Table S4). Ten out of the 14 total actions had less expert consensus in their second round rating as compared to first round ranking. *Consumer acceptance* (−16), *visibility* (−14), *level playing field* (−13), and *new product types* (−13) were the actions with the greatest decrease in consensus. *Manufacturing efficiency* (+5) and *manufacturing facility capacity* (+1) were the only actions with a greater expert consensus in the second round of data collection. There was no change in consensus for *financial capital* and *protein sources*.

3.3.2 Neglect

Ten out of the 14 total actions had greater consensus in production neglect rankings in R2 as compared to their R1 ranking (Figure 3; Supplementary Table S4). *Level playing field* had the largest increase in consensus (+23). *Manufacturing efficiency* (+17) and *protein sources* (+14) had the second and third greatest increases in consensus, respectively. *Visibility* (−18), *consumer acceptance* (−10), *marketing* (−10), and *financial capital* (−8) were the four actions that had less consensus in their production neglect rankings in R2 as compared to R1.

3.3.3 Tractability

Ten of the 14 total actions had greater consensus in production tractability rankings in their R2 ranking as compared to their R1 ranking, indicating that more consensus was reached for most actions. *Price* (+20) was the action that had the greatest increase in consensus, followed by *level playing field* (+8), *protein sources* (+8), and *sensory profile* (+8). *Manufacturing efficiency* (−7), and *consumer acceptance* (−2) and had less consensus in R2 compared to R1. *Health, nutrition, and safety*, described as "Develop and adopt national food safety and quality standards for PBMA products." and *visibility* had no change in consensus.

3.4 Changes in consensus: consumption

3.4.1 Importance

Between the two rounds of data collection, nine out of the 14 actions for increasing the consumption of PBM products in Brazil had greater consensus in their R2 ranking as compared to their R1 ranking. *Financial capital* (+11), *start-up support* (+11), *protein sources* (+8), and *level playing field* (+8) were the actions with the greatest increase in consensus regarding their importance for increased PBM product consumption. *Consumer acceptance* (−4), *availability* (−2), and *visibility* (−2) were the only actions with less consensus in the second round of data collection. *Marketing* and *price* had no change in consensus.

3.4.2 Neglect

Twelve out of the 14 total actions had greater consensus in their neglect rankings for increasing the consumption of PBM products in Brazil in their R2 ranking as compared to their R1 ranking. *Level playing field* had the most significant increase in consensus (+11), followed by *price* (+8), *protein sources* (+6), *start-up support* (+6), and *manufacturing efficiency* (+6). Only one action, *new product types* (−4) had less consensus in their consumption neglect rankings in R2 as compared to R1. *Health, nutrition, and safety* had no change in consensus.

3.4.3 Tractability

Greater consensus was reached for nine of 14 actions in R2 regarding their tractability for increasing PBM consumption in Brazil. *Start-up support* (+13) and *financial capital* (+13) were ranked as the most tractable actions for increasing consumption of PBM products, followed by *sensory profile* (+9) and *manufacturing efficiency* (+9). Five of the 14 total actions had less consensus in consumption tractability rankings in their second round rating as compared to first round ranking: *visibility* (−5), *consumer acceptance* (−3), *marketing* (−3), *level playing field* (−2), and *new product types* (−1).

3.5 Production vs. consumption

Panelists held a range of views on the relationship between production and consumption, and the relative merits and importance of focusing resource allocation to one or the other or both. Some panelists believed that production should be the focus since a greater scale is needed to drive down prices. For example:

> "As a priority, increased production can reduce the final price to the consumer, which is one of the biggest bottlenecks. Greater product availability also depends on increased production. In general, I understand that the biggest constraints are in production."

Others believed that consumption should be the focus, since without a strong market demand there was no possibility of scaling up production. For example:

> "I believe that to increase production … you first have to have products that meet the needs of a greater number of consumers. Before sensory and visibility aspects comes the need for competitive prices. Only then will there be a greater demand, requiring production increases."

Yet others felt that the two processes were deeply interconnected, and that it was not especially meaningful or possible to consider them separately. For example:

> "It's like asking 'which came first, the egg or the chicken.' The actions of production and consumption grow in parallel."

4 Discussion

4.1 Summary of results

Our nine panelists collectively concluded that the highest priority action for scaling up the production and consumption of plant-based meat (PBM) in Brazil was to reduce the cost of products for consumers. They identified the need to create a *level playing field,* described as to "alter the regulatory environment to create fair competition for alternative protein companies (e.g., create fair labeling laws, remove subsidies for animal products, introduce true-cost accounting for animal-based products)," as the second-priority action for production and the third-priority action for consumption. To increase PBM production, they collectively ranked *protein sources* as the third-highest priority action. For increasing PBM consumption, they collectively ranked *sensory profile* as the second-highest priority action.

Different actions emerged as the most important (i.e., *protein sources*), neglected (i.e., *level playing field*), and tractable (i.e., *price*) with respect to production. Similarly, with respect to consumption, *price* was the action identified as being most important, *level playing field* was the action identified as being most neglected, and *sensory profile* was the action identified as being most tractable.

Out of any of the total 84 values (14 actions, for each combination of importance, neglect, and tractability in relation to both production and consumption), the highest degree of consensus among panelists was that price was the most important action to scale up consumption. This action (i.e., decreasing the cost of PBM) received the highest mean value ranking (99) and the lowest variance (SD = 2) out of any of the total 84 values.

4.2 The future of plant-based meat in Brazil

Many actors in the public, private, and nonprofit domains are focused on developing the PBM industry in Brazil (Lazarin, 2022). The country has significant capacity and expertise in business, agriculture, technology, and supply chains. Some stakeholders have pointed to the high biodiversity of some of Brazil's biomes (e.g., Amazonia, Cerrado) as possible sources of novel raw materials for the production of PBM (GFI Brazil, 2021). Collectively, this nexus of skills and capital could help Brazil become a global forerunner in alternative protein production and consumption.

Price emerged as a clear focal priority for stakeholders interested in scaling up PBM production and consumption in Brazil. To the extent that priorities can be well-identified by our methodology and

the Importance, Tractability, and Neglect framework, reducing the cost of PBM products for consumers should perhaps therefore be a central focus of resource allocation. *Price* was ranked as the top priority action for scaling up PBM production and consumption, the most tractable production action, and the most important action for scaling PBM consumption in Brazil. This finding aligns with previous research that has found that Brazilian consumers are price-sensitive with respect to meat consumption (Hötzel and Vandresen, 2022) and that PBM tends to be significantly more expensive than animal meat in Brazilian supermarkets. On average, PBM products are 96% more expensive than animal products in Brazil (Reis et al., 2023) primarily due to costs associated with post-processing, production scale, and supply chains (Szenderák et al., 2022). PBM products are also less widely available than animal-based products, and less promoted through price reduction and multi-buy offers by retailers (Reis et al., 2023). Furthermore, Brazilian consumers tend to perceive PBM products as being much more expensive than animal products (GFI Brazil, 2018; Neto et al., 2020).

Prioritizing the reduction of PBM product prices may be especially important in Brazil and other low-and middle-income countries. Brazil is a middle-income country, with an average per-capita income of US$ 8,917 and with roughly 12% of the population living below the poverty line (World Bank, 2023). The average Brazilian consumer is likely to contend with a considerably more constrained food expenditure budget when juxtaposed with their counterparts in high-income nations, such as the United States and the Netherlands, where PBM products have gained substantial traction. These considerations may partially explain why the experts who participated in our panel considered reducing product prices critical to making PBM more widely accessible to Brazilian consumers. Furthermore, reducing product prices to encourage increased consumption was regarded by experts as a necessary precondition to scaling both the production and consumption of PBM products in Brazil. Increased PBM demand could stimulate increased sales volumes and the expansion of product offerings, which could facilitate further price reductions through economies of scale.

A focus on reducing product prices could help to create a clear objective for stakeholders interested in promoting the expansion of Brazil's PBM sector. For example, there could be opportunities for stakeholders to address some of the underlying causes leading to higher PBM prices present across different stages of the production supply chain (e.g., currently, a significant proportion of raw materials are imported; sourcing these ingredients domestically at scale may help reduce costs). Major meat processing companies in Brazil (e.g., JBS, BRF) may be best positioned to achieve rapid price reductions in consideration of their access to large-scale production plants, existing distribution systems, and relationships with retailers (Morais-da-Silva et al., 2022a; Reis et al., 2023). Smaller PBM companies and startups, in turn, may face greater difficulties in competing with meat processing companies' analogous products and entering into new distribution and retail channels. In addition, realizing significant reductions in PBM product costs within the short term may be challenging due to the typically higher manufacturing costs associated with PBM products in comparison to animal-based meat products (Morais-da-Silva et al., 2022a).

Reducing the price of PBM may increase consumer accessibility to these products. However, there is limited evidence to suggest that consumers would choose plant-based meat products over animal-based meat products, even if the two were comparable in terms of price, taste, and convenience (Peacock, 2023). Therefore, reducing product prices may not alone produce dramatic changes in production and consumption of PBM. Further, it is unclear whether price reductions would increase consumer willingness to actually *substitute* PBM alternatives for animal-based meats or whether price reductions would necessarily lead to substantive economic, environmental, or animal welfare gains. For example, PBM purchasing has not been found to deter meat demand among meat purchasing households (Neuhofer and Lusk, 2022). Another study found that decreasing the market cost of PBM meat by 10% could lead to a decrease in US cattle production of just 0.15% (Lusk et al., 2022). Relatedly, a study in Brazil found only very modest increases in fruit and vegetable consumption as a result of higher income, lower prices of fruit and vegetables, and/or higher prices of other foods (Claro et al., 2007). As a final example, data suggests that US consumers may purchase PBM primarily as a substitute for chicken, turkey, and fish rather than for more emissions-intensive beef (Zhao et al., 2023).

Creating a *level playing field* was identified as the most neglected action for scaling both production and consumption of PBM in Brazil. These findings support previous research identifying the need for adequate food policies to help guide a transition toward PBM products (Bryant and van der Weele, 2021; Newton and Blaustein-Rejto, 2021; Mancini and Antonioli, 2022; Morais-da-Silva et al., 2022a). In the EU and US, while some governmental initiatives have begun to support the alternative protein sector, powerful vested interests can maintain funding and regulatory environments that favor animal agriculture (Vallone and Lambin, 2023). Bringing more attention to the action of creating a level playing field could require engagement from policymakers to identify and reform policies that may be contributing to an unlevel playing field for PBM products. Policymakers could address any such policies that foster inequities between the PBM and animal agriculture sectors. To maximize Brazil's potential socio-economic benefits from the growth of the PBM sector, policymakers could develop national and/or regional plans customized to the natural resources and human capital in specific geographic regions (Morais-da-Silva et al., 2022a). It is currently unclear whether policymakers in Brazil are motivated to create a level playing field for PBM products, and stakeholders from the country's animal agriculture sector may be resistant to policy change. Non-profit organizations or advocacy groups in Brazil could help to scale up production and/or consumption of PBM by lobbying for policy change and communicating to consumers the potential benefits that PBM products could offer. Of course, interpretations of a level playing field may vary among various actors, and the potential exists that some PBM advocacy groups could overcorrect and excessively favor alternative proteins in their pursuit of rectification.

Identifying new protein sources emerged as the most important action for scaling up PBM production. This action has previously been identified as a high-impact opportunity for Brazilian agricultural producers in light of the abundance and diversity of native and introduced plant species (e.g., lupin beans, faba beans, and rapeseed oil) in PBM production (Kyriakopoulou et al., 2019; Morais-da-Silva et al., 2022a). Some work has been initiated to tackle this action. For example, there has been investment into research to identify indigenous sources of Brazilian plant protein from the Amazon and

Cerrado biomes (Gallon, 2021). In addition, it may be necessary for Brazilian agricultural producers to adapt their practices in compliance with GMO-free standards and develop new processing plants to render new protein sources suitable for incorporation into PBM products (Morais-da-Silva et al., 2022a).

Finally, improving the *sensory profile* of PBM products to more closely mimic their animal-based analogs was identified as the most tractable action to scaling PBM consumption in Brazil. Although the sensory profiles of PBM products have become increasingly similar to animal meat products, the taste and texture of PBM remains a potential barrier to acceptance by Brazilian consumers (Morais-da-Silva et al., 2022a). Health, safety, and nutrition are key attributes that affect consumers' willingness to purchase plant-based products in Brazil (Gómez-Luciano et al., 2019). Improving the sensory profile of PBM to increase consumer acceptance may involve reducing undesirable flavors sometimes associated with plant ingredients, such as a beany flavor, bitterness, or astringency (Wang et al., 2022). Other opportunities to improve the sensory profile of PBM products include using genetically engineering microbes to produce fat with melting points comparable to the melting point of animal fat, or using fungi-based products to improve the structural and fibrous quality of products (Tachie et al., 2023). Finally, PBM could be blended with animal meat or with other alternative proteins to create better-tasting products (Grasso et al., 2022).

Collectively, these findings suggest that stakeholders could most usefully direct resources to reduce PBM product costs, improve the sensory experience of PBM products, and champion the creation of a regulatory environment that creates fair competition for alternative protein companies. The actions panelists ranked as the highest priority align with previous research on opportunities to increase PBM production and consumption in Brazil (Morais-da-Silva et al., 2022a,b; Reis et al., 2023).

4.3 Scaling up production and consumption

Among the 14 potential actions examined in the study, some exhibited a stronger emphasis on the production side of the supply chain, such as improvements in manufacturing efficiency and manufacturing facility capacity. In contrast, others were oriented toward the consumption side of the supply chain, such as marketing and consumer acceptance. We initially expected that very different actions would be prioritized, depending on whether a stakeholder was responding, within our survey, to questions about how to promote PBM *production* or *consumption*. For example, *in principle* Brazil could become a globally significant export producer of plant-based meat. With a strong export market, it may be less of a priority to promote demand among consumers in Brazil. Conversely, *in principle* Brazilians could consume large quantities of PBM, with demand met through imports from the US and elsewhere. In such a scenario, Brazil's PBM production could remain relatively limited. *In practice*, it appeared from our data that many Brazilian stakeholders involved in the PBM sector are invested in increasing both production and consumption within Brazil, simultaneously.

We expected that production-focused actions would emerge as the priorities for scaling production, and that consumption-focused actions would emerge as the priorities for scaling consumption. However, our results demonstrated that panelists perceived demand-side challenges as being impediments to the growth of both production and consumption within the plant-based meat sector in Brazil. For example, among the actions for scaling PBM production, *protein sources* was identified as the most important action, *level playing field* was identified as being the most neglected, and *price* was identified as the most tractable priority action. Therefore, it appears that most panelists did not consider it likely that Brazil could develop a strong level of production of PBM without also dedicating resources to scaling PBM consumption within Brazil. Our findings demonstrate, perhaps unsurprisingly, that the panelists perceived production and consumption as being closely connected and interdependent. Somewhat analogously, Brazil is the world's largest beef exporter yet these exports account for only about 20% of all beef produced in Brazil, with the dominant domestic market accounting for the large majority (Zu Ermgassen et al., 2020).

4.4 Prioritization

The Importance, Neglect, and Tractability framework from the Effective Altruism movement offers a philosophy and a set of tools with which to consider the allocation of scarce resources and the prioritization of alternative actions (Todd, 2013). An Effective Altruism approach can help to guide resource allocation and could thus be of utility to stakeholders including investors, philanthropists, and funders. For example, our results could help guide philanthropic decision making by identifying important, neglected, and tractable actions that would benefit from strategic funding. Some actions, such as improving sensory profile, were identified as important and tractable for scaling consumption, but are not neglected and so may be less of a priority for funders (Figure 2). Our results could also help non-profit organizations such as the Good Food Institute and New Harvest, who advocate for alternative proteins and fund alternative protein related research, to determine where to focus their strategic endeavors and resources.

4.5 Methods: strengths and limitations

Our methodology had several strengths, which enabled us to garner expert opinion and draw interesting conclusions. First, the Delphi technique facilitated interaction between respondents, enabling a form of asynchronous dialogue that appears to have changed some panelists' minds between rounds. We found that there was greater consensus among panelists concerning the importance, neglect, and tractability rankings of most actions for promoting PBM production and consumption in Brazil in R2 than in R1. The only exception was that in R2 there was more disagreement concerning the relative importance of different production priority actions. Collectively, these findings suggest that the Delphi method was effective in facilitating interaction and dialogue between panelists. Second, our survey collected complementary quantitative and qualitative data, which enabled us to both identify priority actions and to explain some of the rationale panelists used in ranking the importance, neglect, and tractability of different actions. Third, the

method we employed in this research is a replicable way of assessing priorities. It could be applied in other geographies, with other alternative protein types and forms, and/or in relation to other emerging food technologies.

Our methodology was also subject to some caveats and limitations. First, expert opinion is generally depicted low on the evidence pyramid relative to other forms of data. That said, it is entirely appropriate for forecasting studies of an emergent technology (Feng et al., 2022) where few other forms of analysis are possible. Second, our panel was modest in size ($N = 9$) and while it had representation from several different sectors it was inevitably not perfectly balanced. The panel was too small to be able to conduct meaningful analyses that disaggregated the data according to panelist affiliations (e.g., responses from private sector vs. research panelists). Our recruitment process was constrained by our access to networks of qualified experts that could serve as panelists, and the willingness of panelists to participate in the somewhat time-intensive study. The optimal size for the Delphi method can be 10–15 (Hsu and Sandford, 2007); our final panel (following attrition) was one member smaller than this optimal range. Third, the first round of data collection lasted 4 weeks, and a further 10 days passed before we began the second round of data collection due to the time needed to process data gathered in the first round. The time lag between the two rounds of data collection could conceivably have affected how panelists thought about their responses in ways we were not able to account for in our study design. Finally, there was a limited response range in participants' action rankings (e.g., no action received a score below 50 by any panelist). This could indicate that panelists perceived all actions as being somewhat necessary, or they were hesitant to rank any action as a low priority. Previous research has found that PBM experts in Brazil tend to be generally optimistic about the future of PBM in Brazil as compared to PBM experts in Europe, perceiving a higher future consumer demand for PBM products with more optimistic outlooks about the business opportunities that the PBM sector could offer (Morais-da-Silva et al., 2022b).

Additionally, there was no clear systematic way to construct the initial list of possible actions. An alternative approach could have been to use the first round to openly solicit ideas from panelists, but this would have placed an onerous burden on respondents and would have had no greater guarantee of generating a comprehensive list. In our research, we asked panelists for suggestions of additional potential actions in the first round of data collection, but we elected not to include their suggested actions in the second round of data collection because (a) few novel actions were suggested (and none by more than one panelist), and (b) we would not have been able to employ the iterative Delphi technique for these responses. This could have been resolved by including a third round of the survey (and providing panelists with the responses to an expanded set of actions in the third round), but we were concerned about attrition because we sensed panelist fatigue even after the first round.

Finally, we chose to keep the scope and focus of the research relatively narrow to explore a single set of alternative protein products (i.e., plant-based meat). Soliciting expert opinion on more than one type of alternative protein product could have risked expert panel confusion or the potential for responses that conflated different considerations across alternative protein product types. In principle, one could conduct multiple parallel studies, with different panels discussing the same questions in response to different types and forms of alternative protein. However, doing so would require a much larger panel of experts to include representation of the combination of different sectors and different forms or types of alternative proteins. Conducting multiple parallel studies could also be unreasonably cumbersome for panelists with expertise that relates to multiple alternative proteins or could dilute the strength of expertise on any one panel.

4.6 Future research

Our findings indicate a clear need for identifying effective pathways to reduce the cost of plant-based meat to scale up both production and consumption. There may be multiple different ways in which retail prices may be reduced, including by investing in, supporting, or subsidizing one or more different stages of the supply chain. Research that identifies the most effective ways to reduce prices for consumers may have considerable potential to help scale up the PBM sector in Brazil. From a technological point of view, the alternative protein field is rapidly developing. Alternative protein technologies are increasingly used in combination with one another depending on the desired end product formulation (e.g., fermentation technologies are used to create ingredients for incorporation into PBM products). Research and development initiatives utilizing such breakthrough technologies could be directed toward making rapid advances in improving the sensory profile of PBM products to more closely mimic their animal-based analogs. Moreover, future research could also explore the impacts of innovation and diversification of products in the PBM sector, especially as it relates to actual consumer food choice behavior rather than stated intentions. Although hamburgers, meatballs, and sausages are frequently found in supermarkets, products like local meals, ready-made meals, and blended products mixed with cultivated meats could enrich the options available to consumers and potentially increase PBM sales. Moreover, studies could also address the roles that retailers can have in stimulating PBM product adoption and sales. Finally, future research could usefully explore how regulatory landscapes or consumer food cultures present in different geographies may affect expert assessment of which priorities are most needed for scaling the production and consumption of alternative protein products.

5 Conclusion

In this research, we employed the Delphi technique to assess expert opinion concerning the relative importance, neglect, and tractability of 14 actions to scale the production and consumption of plant-based meat (PBM) in Brazil. Our panel of nine experts collectively identified reducing product costs, championing the creation of a level regulatory playing field, and identifying new crops as viable sources of plant protein as the top priority actions to scaling PBM production in Brazil. Similarly, they identified reducing product costs, improving the sensory experience of products, and championing the creation of a level regulatory playing field as the top priority actions to scaling PBM consumption in Brazil. The highest degree of consensus among panelists was that reducing the price of PBM was

the most important action to scale up consumption. With respect to production, different actions emerged as the most important (*protein sources*), neglected (*level playing field*), and tractable (*price*). Similarly, with respect to consumption, *price* was the action identified as being most important, *level playing field* was the action identified as being most neglected, and *sensory profile* was the action identified as being most tractable. Panelists evaluated *start-up support*, *manufacturing efficiency*, and *manufacturing facility capacity* as the lowest priority actions.

The findings from this research could be usefully leveraged to guide the decision-making processes of stakeholders interested in supporting the growth of Brazil's PBM sector, to determine where to focus their attention and energy. Most obviously, our research suggests a need to prioritize reducing the price of PBM for consumers, as well as creating a more equitable regulatory environment, and supporting the search for new crops for PBM production. Our findings align with previous studies that have revealed that Brazilian consumers tend to correctly perceive PBM products to be more expensive (on average) than animal products (e.g., Reis et al., 2023). Further research is needed to determine whether PBM price reductions actually affect food choice behavior and lead Brazilian consumers to purchase PBM as a substitute for animal meat. Private sector companies, governmental agencies, and non-profit organizations likely each have different tools available to them to support the pursuit of these goals, directly or indirectly.

Our research extends the literature on alternative proteins in three ways. First, our study engages with the reality that decision-makers (e.g., funders) have finite resources to invest in the scaling up of alternative proteins. It focuses not on *characterizing* the various technological, policy, and market barriers but on *prioritizing* the potential actions that decision-makers could take in the hope of informing a more strategic and efficient approach to overcoming the most pressing barriers to scaling up PBM. Second, our study adopts an established framework to differentiate 'priority' in the context of scaling up PBM into three distinct traits (importance, neglect, and tractability), which more clearly identifies whether and why any given action should be a priority for decision-makers. Third, our study is methodologically novel in this topic area. Our use of the Delphi technique was successful in facilitating panelist dialogue between rounds of data collection, suggesting that the methodology used could be applied in other geographies, to evaluate other alternative protein types and forms, and/or in relation to other emerging food technologies.

Data availability statement

The quantitative datasets generated for this study and the code used to analyze these data are included in the Supplementary Material of this paper.

Ethics statement

The studies involving humans were approved by University of Colorado Boulder Institutional Review Board (Protocol: 21-0543). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

PN: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Visualization, Writing – original draft, Writing – review & editing. WE: Conceptualization, Formal analysis, Investigation, Methodology, Visualization, Writing – review & editing. MH: Conceptualization, Formal analysis, Investigation, Methodology, Visualization, Writing – review & editing. RM-d-S: Investigation, Methodology, Writing – review & editing. MSH: Writing – review & editing. AH: Writing – review & editing. GR: Writing – review & editing.

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Conflict of interest

AH was employed by the Brazilian Agricultural Research Corporation (Embrapa).

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1303448/full#supplementary-material

SUPPLEMENTARY TABLE S1
Aggregated quantitative results from two rounds of an online survey using the Delphi method to assess expert opinion of the relative importance, neglect, and tractability of 14 possible priority actions to scale up the production and consumption of plant-based meat in Brazil. Scores represent the mean ± standard deviation across the panel of nine experts for round one (R1) and round two (R2).

SUPPLEMENTARY TABLE S2
Aggregated quantitative results from two rounds of an online survey using the Delphi method to assess expert opinion of the relative importance, neglect, and tractability of 14 possible priority actions to scale up the production and consumption of plant-based meat in Brazil. Scores represent the median value across the panel of nine experts for round one (R1) and round two (R2).

SUPPLEMENTARY TABLE S3
Aggregated quantitative results from two rounds of an online survey using the Delphi method to assess expert opinion of the relative importance, neglect, and tractability of 14 possible priority actions to scale up the production and consumption of plant-based meat in Brazil. Values represent the change in standard deviation between round one (R1) and round two (R2), as a measure of the change in consensus among panelists. A negative value indicates less agreement (red) in the second round (R1_sd-R2_sd < 0; R2_sd >R1_sd). A positive value indicates more agreement (green) in the second round (R1_sd-R2_sd >0; R2_sd < R1_sd).

SUPPLEMENTARY TABLE S4
Aggregated quantitative results from two rounds of an online survey using the Delphi method to assess expert opinion of the relative importance, neglect, and tractability of 14 possible priority actions to scale up the production and consumption of plant-based meat in Brazil. Values represent those actions deemed to be of greatest priority by the expert panel, derived by averaging the importance, neglect, and tractability scores, separately for round one (R1) and round two (R2).

SUPPLEMENTARY NOTE S1
The search terms used to identify relevant literature.

SUPPLEMENTARY NOTE S2
The Qualtrics survey used in round one (R1) to determine the expert opinion of panelists on the relative priority of 14 potential priority actions to scale up the production and/or consumption of plant-based meat in Brazil.

SUPPLEMENTARY NOTE S3
The Qualtrics survey used for R2 to determine if the opinion of panelists changed after reading the opinions of other experts from R1.

SUPPLEMENTARY DATA S1
Anonymized quantitative data from round one (R1) of an online survey using the Delphi method to assess expert opinion of the relative importance, neglect, and tractability of 14 possible priority actions to scale up the production and consumption of plant-based meat in Brazil.

SUPPLEMENTARY DATA S2
Anonymized quantitative data from round two (R2) of an online survey using the Delphi method to assess expert opinion of the relative importance, neglect, and tractability of 14 possible priority actions to scale up the production and consumption of plant-based meat in Brazil.

SUPPLEMENTARY DATA S3
R code to replicate the figures and tables from this paper, using Data S1 and Data S2.

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