

1 **Novel plant-based meat alternatives: future opportunities and health considerations**

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26 **Abstract**

27 Current food systems threaten population and environmental health. Evidence suggests reduced meat  
28 and increased plant-based food consumption would align with climate change and health promotion  
29 priorities. Accelerating this transition requires greater understanding of determinants of plant-based  
30 food choice. A thriving plant-based food industry has emerged to meet consumer demand and support  
31 dietary shift towards plant-based eating. ‘Traditional’ plant-based diets are low energy density,  
32 nutrient dense, low in saturated fat and purportedly associated with health benefits. However, fast-  
33 paced contemporary lifestyles continue to fuel growing demand for meat-mimicking plant-based  
34 convenience foods which are typically ultra-processed. Processing can improve product safety and  
35 palatability and enable fortification and enrichment. However, deleterious health consequences have  
36 been associated with ultra-processing, though there is a paucity of equivocal evidence regarding the  
37 health value of novel plant-based meat alternatives and their capacity to replicate the nutritional  
38 profile of meat-equivalents. Thus, despite the health halo often associated with plant-based eating,  
39 there is a strong rationale to improve consumer literacy of plant-based meat alternatives.  
40 Understanding the impact of extensive processing on health effects may help to justify the use of  
41 innovative methods designed to maintain health benefits associated with particular foods and  
42 ingredients. Furthering knowledge regarding the nutritional value of novel plant-based meat  
43 alternatives will increase consumer awareness thus support informed choice. Finally, knowledge of  
44 factors influencing engagement of target consumer subgroups with such products may facilitate  
45 production of desirable healthier plant-based meat alternatives. Such evidence-based food  
46 manufacturing practice has the potential to positively influence future individual and planetary health.

47

## 48 **Context**

49 Food systems have the potential to promote both human and planetary health but currently pose a  
50 significant threat to both<sup>(1,2)</sup>. Global population, expected to reach approximately 10 billion by 2050,  
51 longer life expectancy, increased income, and urbanisation will increase demand on global  
52 resources<sup>(3-6)</sup>. The projected increase in demand for food (50%) and animal-derived food (70%) will  
53 add substantial pressure to an already failing food system while animal husbandry, it is argued, also  
54 has an overall negative impact on environmental sustainability<sup>(7,8)</sup>. Some estimates suggest food  
55 production is already responsible for approximately one third of anthropogenic greenhouse gas  
56 emissions<sup>(9-12)</sup>. Meat and dairy also require more land and water use than foods of plant-based origin,  
57 potentially furthering deforestation and biodiversity loss<sup>(13-16)</sup>. Although historically considered an  
58 essential dietary component, providing vitamin B<sub>12</sub>, iron and calcium, overconsumption of meat,  
59 particularly processed meat, has been associated with certain deleterious health consequences<sup>(17-19)</sup>.

60 International recognition of this challenge has led to global strategies to accelerate transition towards  
61 a healthier, more sustainable food system<sup>(5,20)</sup>. These include the UN Sustainable Development Goals  
62 and the Paris Agreement of Climate Change<sup>(3,6)</sup>. However, the complexity and multi-faceted nature  
63 of this problem emphasises the need for strong multi-sectoral partnerships<sup>(21-23)</sup>. Extensive evidence  
64 suggests that reduced meat and increased plant-based food consumption would align with both  
65 climate change and health promotion strategies<sup>(6,17,24-26)</sup>.

66 Current animal-based protein consumption is unsustainably high<sup>(27)</sup>. In 2021, global meat  
67 consumption was estimated to be 328 million metric tons and is expected to increase approximately  
68 70% by 2050<sup>(7,8,28,29)</sup>. High intakes of red and processed meat have been associated with increased  
69 risk of non-communicable diseases including type 2 diabetes, colorectal cancer and reduced life  
70 expectancy<sup>(30-34)</sup>. Indeed, the World Health Organisation (WHO) classifies red meat as a Group 2A  
71 carcinogen (likely cause of cancer) and processed meats as a Group 1 carcinogen (known cause of  
72 cancer)<sup>(35)</sup>, with the World Cancer Research Fund recommending restriction of red meat consumption  
73 to three or less portions per week and avoidance or restriction of processed meat<sup>(36)</sup>. However,  
74 guidance does not support the total elimination of meat as a key source of energy and nutrition<sup>(18,21)</sup>.  
75 Against this backdrop, however the WHO have endorsed animal-derived foods for high-quality  
76 nutrition in children aged 6 - 23 months<sup>(37)</sup> and Adesogan *et al.*<sup>(38)</sup> challenge the notion that one-size-  
77 fits all. In many developing countries animal-sourced protein consumption is limited and nutrient  
78 intake often suboptimal, reinforcing the need to tailor recommendations to different regions to prevent  
79 exacerbating current public health challenges. Additional benefits also warrant careful consideration:  
80 the livestock sector provides increased food and nutrition security, a living income for many, and

81 contributes to national revenue, particularly in more deprived populations<sup>(16,38,39)</sup>. Nonetheless,  
82 estimates suggest that to sustainably feed 10 billion people, a significant reduction in meat  
83 consumption of ~50-75%, accompanied by increased consumption of plant-based foods (see Table  
84 1) is required<sup>(6,8,40)</sup>. It is noted that replacing 3% of daily energy intake derived from processed red  
85 meat with plant-derived sources could reduce risk of all-cause mortality by 12%<sup>(41)</sup>. Furthermore,  
86 substituting 1kg of beef-derived protein with kidney bean sources could offer an 18-fold reduction in  
87 land use<sup>(42)</sup>. Heterogeneity in modelling methods used to estimate the required intake of plant-derived  
88 proteins remains however<sup>(6,43-46)</sup>. Whilst EAT-Lancet<sup>(6)</sup> recommend a daily intake of 25g soybeans  
89 plus 50g of beans, lentils and peas, other suggested increases in legumes, beans, pulses nuts and oil  
90 seeds vary between 26-30g per day<sup>(45-47)</sup>.

91 Currently, 21% of the UK population identify as flexitarian (12.5% as meat-free) and 39% report  
92 reducing meat intake, while consumption of plant-based products between 2008-2011 and 2017-2019  
93 doubled<sup>(48,49)</sup>. Globally, 40% report reducing meat intake while 10% avoid red meat although these  
94 changes may have been accelerated by the recent Covid-19 global pandemic<sup>(49,50)</sup>. Increased  
95 consumer awareness of zoonosis, coupled with the food chain disruption during the pandemic may  
96 have facilitated a dietary shift to reduce meat consumption<sup>(50)</sup>. However, to achieve the UK climate  
97 change commitments, an additional 20% reduction in high carbon meat and dairy would be required  
98 over the next decade<sup>(48)</sup>. Novel plant-based meat alternatives (PBMAs; see Table 1) designed to  
99 replicate the preparation methods, organoleptic and nutritional qualities of meat-based equivalents,  
100 may offer a viable avenue to help facilitate the required dietary shift<sup>(7,8,11,21,51,52)</sup>. This gradual shift  
101 towards reduced meat consumption and increased engagement with plant-based foods has resulted in  
102 a reportedly thriving plant-based food industry<sup>(48)</sup>. However, accelerating this transition requires a  
103 greater understanding of the factors influencing plant-based food choice. It should be noted that there  
104 is a lack of consensus regarding a universal definition for numerous terminologies in the current  
105 review. For clarity, the current review will use the definitions outlined in Table 1.

106 INSERT TABLE 1 HERE

### 107 **Traditional Plant-Based Diets versus Consumption of Novel Plant-Based Meat Alternatives**

108 Consumer enthusiasm to adopt healthier, more sustainable diets has led to an increase in plant-based  
109 dietary patterns such as vegetarianism, veganism and flexitarianism<sup>(49,51)</sup>. ‘Traditional’ plant-based  
110 diets are frequently characterised as low energy density, nutrient dense, low in saturated fat and  
111 associated with a range of health benefits including healthier BMI and protection against  
112 cardiovascular disease<sup>(53-55)</sup>. A large body of evidence also recognises the role of plant-based dietary  
113 patterns in reducing risk of all-cause mortality<sup>(55-58)</sup>. Naghshi *et al.*<sup>(55)</sup> reviewed 32 prospective cohort

114 studies and reported plant-based protein consumption was significantly associated with reduced risk  
115 of all-cause mortality and cardiovascular disease mortality. Furthermore, a 3% increase in energy  
116 derived from plant proteins was associated with a 5% reduced risk of all-cause mortality<sup>(55)</sup>. While  
117 the authors reported no association between plant-based protein consumption and cancer mortality,  
118 other studies have inferred that ‘traditional’ plant-based diets may protect against cancer and  
119 mortality<sup>(56,59–61)</sup>.

120 Extensive epidemiological evidence also supports the adoption of ‘traditional’ plant-based diets to  
121 facilitate weight management<sup>(62–64)</sup>. For example, Tran *et al.*<sup>(65)</sup> systematically reviewed twenty-two  
122 studies, eight of which demonstrated significantly reduced body weight and/or BMI. Whilst most  
123 studies applied the gold-standard randomised controlled trial (RCT) study design, heterogeneity in  
124 methodology, such as restrictions on dietary fat intake, limited generalisability. Furthermore, some  
125 studies failed to consider confounding factors such as physical activity, limiting the internal validity.  
126 A more recent study, which did not emphasise restricted energy intake, involved a six-month five-  
127 arm RCT<sup>(64)</sup>. Participants were randomly assigned to a low fat, low glycaemic index; vegan (n=12),  
128 vegetarian (n=13), semi-vegetarian (n=13), pesco-vegetarian (n=13) or omnivorous (control, n=12)  
129 group dietary pattern. All intervention group participants attended dietitian-led group meetings for  
130 six months. While significant weight reduction was demonstrated across all dietary groups at six  
131 months, the vegan dietary group demonstrated significantly greater weight loss ( $-7.5\% \pm 4.5\%$ )  
132 compared to the semi-vegetarian ( $-3.2\% \pm 3.8\%$ ), pesco-vegetarian ( $-3.2\% \pm 3.4\%$ ) and omnivorous  
133 groups ( $3.1\% \pm 3.6\%$ ). However, it should be noted that no significant difference was reported  
134 between the vegan and vegetarian dietary groups.

135 Although current evidence demonstrates health benefits linked to ‘traditional’ plant-based  
136 consumption, much of the literature base relies on large-scale, historic, observational studies in  
137 restricted populations thus increasing risk of inherent methodological bias<sup>(66–71)</sup>. For example, Kwok  
138 *et al.*<sup>(69)</sup> systematic review and meta-analysis identified the positive impact of a vegetarian diet on  
139 risk of cardiovascular disease mortality based on studies of Seventh Day Adventist communities.  
140 However, it should be noted that the healthy lifestyles behaviours associated with this population  
141 typically includes regular physical activity and abstinence from alcohol and tobacco. Thus, the  
142 influence of potential confounding variables on cardiovascular outcomes limits the generalisability  
143 of findings to the wider population.

144 The fast-paced nature of contemporary lifestyles has increased demand for convenience foods as  
145 opposed to adoption of ‘traditional’ plant-based diets leading to a rapid expansion of PBMA  
146 designed to mimic sensory attributes of meat<sup>(72,73)</sup>. Unlike ‘traditional’ whole plant foods, PBMA

147 undergo considerable processing to effectively deliver tasty, convenient substitutes for meat and  
148 meat-products<sup>(52,74,75)</sup>. Such novel products may be deemed inferior to minimally processed,  
149 ‘traditional’ plant-based foods with regard to impact on sustainability and health<sup>(18,21,52,76–79)</sup>.  
150 However, PBMA s are not designed to replace whole plant foods but instead to offer a steppingstone  
151 in the transition away from meat to increased plant consumption<sup>(8,21,52)</sup>. For example, meat-eaters are  
152 more likely to replace a beef burger with a plant-based equivalent as this substitute does not require  
153 substantial dietary change. Thus future investigations focussing on the perceived benefits of plant-  
154 based meat versus meat-based equivalent products are warranted in order understand consumer  
155 demand.

## 156 **Consumer Perceptions Influencing Plant-Based Food Choice**

157 There are a wide range of complex interacting factors that influence an individual’s food-related  
158 behaviours<sup>(80,81)</sup>. Taste, cost and convenience have all been reported as primary drivers underpinning  
159 general and plant-based food choice<sup>(52,81)</sup>. Increased awareness of animal welfare, environmental  
160 sustainability and individual health has increased demand for plant-based foods more aligned with  
161 aspirational factors<sup>(14,15,18,52)</sup>.

162 INSERT FIGURE 1 HERE

### 163 **Primary Drivers**

#### 164 *Cost*

165 The perceived high cost of PBMA s presents a barrier to consumer engagement<sup>(74,82–84)</sup>. Numerous  
166 cross-sectional surveys have reported affordability as a significant determinant of current and future  
167 engagement with PBMA s<sup>(1,16,81,82,85)</sup>. Clark and Bogdan<sup>(85)</sup> reported that Canadians considered cost  
168 more important than availability and convenience (47%, 39% and 34%, respectively) and a recent  
169 European survey<sup>(86)</sup> highlighted a reluctance to pay for plant-based burgers amongst older adults.  
170 Sociodemographic factors and annual income of respondents may confound survey responses<sup>(16,87)</sup>  
171 with cost recognised as a salient product attribute amongst low-income groups and those with lower  
172 education outcomes and engagement with PBMA s reportedly being higher amongst individuals with  
173 higher socioeconomic status<sup>(76,85)</sup>. Consumer segment may also influence response: meat consumers  
174 cited cost of Quorn as a negative attribute while vegetarians were reportedly more ambivalent<sup>(84)</sup>.  
175 Whilst the interrelationship between dietary pattern and sociodemographic characteristics warrants  
176 further investigation it is clear that affordability of novel PBMA s is a key consideration when it comes  
177 to their adoption across a range of consumer segments<sup>(74,81,82,88–91)</sup>.

178 *Convenience*

179 Convenience, and its perceived influence on self-efficacy, may also restrict engagement with plant-  
180 based foods<sup>(74,81,92)</sup>. A Dutch focus group study identified that the preparation time for a desirable  
181 meal with PBMA was perceived to be significantly greater than that needed for an equivalent meat-  
182 based meal<sup>(93)</sup>. This is supported by a Finnish survey where one third of individuals perceived the  
183 preparation of plant-based meals to be more challenging compared to meat-based equivalents<sup>(94)</sup>. The  
184 availability of PBMA in UK supermarkets is also highlighted as a barrier to engagement<sup>(84)</sup> though  
185 degree of importance of convenience varies across consumer segments with flexitarians valuing  
186 convenience more than meat-avoiders<sup>(20,81,84)</sup>. Demographic factors may be important confounders  
187 here since meat-eaters and flexitarians are more likely found in households with children, thus value  
188 time-convenience more, compared to meat-avoiders<sup>(88,95,96)</sup>. Developing and marketing widely  
189 available PBMA that are easy to cook and contextually appropriate substitutes to meat may  
190 accelerate adoption of plant-based dietary patterns.

191 *Taste*

192 Novel PBMA differ from the early generation PBMA, such as soya and tofu, in that they mimic  
193 sensory attributes of meat<sup>(31,73)</sup>. Bryant<sup>(52)</sup> reported that PBMA that successfully replicated the taste  
194 and texture of processed meat have the greatest potential to replace meat-based equivalent products.  
195 Several studies have emphasised that desirable sensorial qualities, including taste, texture, appearance  
196 and smell are crucial to achieving consumer acceptance and engagement<sup>(24,31,49,81,84,97,98)</sup>. 86% of US  
197 adults cited taste as a driver of purchase intent ahead of price (68%)<sup>(99)</sup>. This supports the results of a  
198 recent Norwegian study<sup>(97)</sup> which reported 78% of consumers considered taste the most salient  
199 determinant of food purchase. However, reproducing desirable meat characteristics poses a  
200 significant challenge. For example, the higher lipid content in meat-based equivalents adds taste and  
201 texture that is limited in PBMA making them less juicy<sup>(8,13,49,100)</sup>. Furthermore, legumes as a  
202 replacement protein source may negatively impact the flavour<sup>(13,51)</sup>. Thus, taste can simultaneously  
203 also be considered as a barrier<sup>(74,83,84,101)</sup>.

204 Several studies cite lack of familiarity<sup>(40,98)</sup> and food neophobia (an individual's unwillingness to try  
205 novel foods) as playing a crucial role in the acceptance of PBMA<sup>(82)</sup>. Regular consumers of PBMA  
206 score significantly lower in the Food Neophobia Scale compared to non-users and occasional users<sup>(76)</sup>.  
207 Hence, novel products resembling familiar meat-based foods may mitigate against neophobia<sup>(31)</sup>.  
208 However, increased processing to mimic meat results in foods that are further removed from the  
209 perceived 'natural state'<sup>(83,102)</sup>. While there is no universal definition of what comprises a 'clean label'  
210 product it typically refers to consumer desire for foods that have undergone minimal processing, using

211 familiar ingredients and excluding ‘additives’<sup>(102–104)</sup>. In contrast, novelty may also be a potential  
212 motivator in people who are curious to try new foods<sup>(80)</sup>.

213 The influence of hedonic characteristics of pleasure elicited in response to *perceived* sensory  
214 characteristics may also pose a barrier to the adoption of PBMA<sup>s</sup><sup>(31,76)</sup>. Michel *et al.*<sup>(74)</sup> reported  
215 consumer associations between meat and “delicious” in contrast to PBMA and “disgust”. Although  
216 consumer perceptions offer valuable insights, they are self-reported and are not direct comparisons  
217 of consumer acceptance. Thus, it has been suggested that consumers may react differently to a novel  
218 product which they can actually taste/smell before purchasing<sup>(105)</sup>. Slade<sup>(105)</sup> conducted a hypothetical  
219 choice experiment where participants indicated their willingness to purchase a range of burger  
220 products. Despite being informed that all burgers tasted the same, 65% of respondents indicated they  
221 would purchase the beef burger in contrast to the plant-based burger and cultured meat burger (21%  
222 and 11%, respectively) with 4% stating they would purchase neither option. However, the  
223 hypothetical nature of the study design restricts findings to perceived taste not actual taste. Hedonic  
224 tests would generate a more reliable indication of actual sensorial acceptance versus perceived  
225 acceptance<sup>(40)</sup>. Schouteten *et al.*<sup>(100)</sup> conducted a sensory analysis experiment under blind, expected  
226 and informed conditions. The study again reported stronger preference for the meat burger versus the  
227 plant-based burger under all conditions and across both consumers and non-consumers. Participants  
228 attributed negative sensorial qualities, including a lack of juiciness, dryness and off flavouring, to the  
229 plant-based burger compared to the meat-based equivalent. Another sensory evaluation reported  
230 similar findings, highlighting the inability of plant-based nuggets to replicate their meat-based  
231 equivalent and critiquing the off-flavours of plant-based nuggets that included a beany aftertaste<sup>(106)</sup>.

232 *Sustained* adoption of PBMA<sup>s</sup> is also influence by taste<sup>(1,16,82)</sup>. 42% of North Americans cited  
233 perceived taste as the reason for not trying to increase purchase of protein alternatives in a recent  
234 Mintel report<sup>(85)</sup>. In addition, Collier *et al.*<sup>(87)</sup> highlighted focus group participants’ disappointment in  
235 PBMA<sup>s</sup> ability to replicate the taste of meat. In fact, missing the taste of meat has been cited as the  
236 most common factor, after health, for returning to a meat-based diet<sup>(107)</sup>. High meat attachment and  
237 high levels of food neophobia have been noted as significant barriers to adopting PBMA<sup>s</sup><sup>(1,31)</sup>. Meat  
238 attachment may also be associated with an emotional response to meat abstinence, strong enough to  
239 overcome the reported negative health impact of meat<sup>(108)</sup>. Additionally, the influence of the taste of  
240 plant-based foods as a barrier to adoption varies across different consumer segments with males more  
241 likely to reject plant-based foods as not being tasty<sup>(94)</sup> and approximately twice the number of women  
242 citing taste as a driver of regular PBMA consumption<sup>(82)</sup>. Of interest is the finding that while  
243 omnivore/flexitarian subgroups demand products mimicking sensory properties of meat, vegan and  
244 vegetarians are more likely to accept non-meat mimicking substitutes<sup>(49,76)</sup>.



## 245 **Aspirational Drivers**

246 While primary drivers of cost, taste and convenience are important, animal welfare, environmental  
247 impact and health have a significant influence on food choice<sup>(81)</sup>.

### 248 *Animal Welfare*

249 Animal welfare has long been a driver of meat-avoidance though concerns regarding differing global  
250 meat rearing standards and live animal transportation issues continue to influence the gradual  
251 reduction in meat consumption in both the UK and worldwide<sup>(26,32,109)</sup>. The reported degree of its  
252 relative importance as a driver of both meat-avoidance and adoption of PBMA varies however, with  
253 some studies suggesting it to be a key factor (amongst ~45-65% of respondents)<sup>(82,83,110)</sup> and others  
254 suggesting it is of lesser importance<sup>(81,111,112)</sup>. Neff *et al.*<sup>(112)</sup> found as few as 12% of respondents in  
255 the US cited animal welfare as the reason for reduced meat consumption in contrast to other factors  
256 such as cost and health. Inconsistency in findings may be the result of variation across consumer  
257 subgroups<sup>(74,76)</sup>, with rural consumers less influenced than urban consumers<sup>(98)</sup>, and personal  
258 experience of animal husbandry or limited access to large supermarkets also influencing this  
259 phenomenon<sup>(85,98)</sup>. Vegetarian and vegan consumers also tend to place greater value on the welfare  
260 of animals<sup>(54,58,63,89-92)</sup>.

### 261 *Environment*

262 Estimates of the extent to which environmental awareness influences the popularity of and  
263 engagement with plant-based food varies<sup>(48,80,81,105,116)</sup>. A recent cross-sectional survey<sup>(82)</sup> found over  
264 80% of respondents cited environmental reasons as the primary driver behind regular PBMA  
265 consumption. In contrast, Circus and Robison<sup>(83)</sup> reported only 21.6% of respondents reduced meat  
266 for environmental reasons. In addition, a recent Food Standards Agency survey<sup>(117)</sup> reported 36% of  
267 respondents were willing to try plant-based proteins for sustainability reasons compared to health  
268 (39%) and safety (44%). This supports the findings which suggest that personal health has a greater  
269 influence on the adoption of plant-based eating compared to environmental sustainability amongst  
270 omnivores and semi-vegetarians (32.9% and 20.3%, respectively)<sup>(118)</sup>. Thus, personal health gains  
271 may outweigh altruistic factors when it comes to reducing meat and consuming more plant-based  
272 foods.

273 Historically low levels of public awareness of the environmental impact of meat consumption may  
274 partially explain the so far limited dietary shift towards plant-based<sup>(31,40,92,101)</sup>. Macdiarmid *et al.*<sup>(119)</sup>  
275 highlighted a substantial lack of awareness in focus groups regarding the impact of meat consumption  
276 upon climate change and a mutual perception that personal consumption was negligible in addressing  
277 environmental sustainability. However, socio-economic status has been shown to influence

278 awareness<sup>(9,85)</sup> and, more recently following publication of EAT-Lancet and media coverage of the  
279 issue, awareness has been heightened<sup>(1,6)</sup>. Estell *et al.*<sup>(110)</sup> reported over 80% of survey respondents  
280 agreed that following a plant-based diet is environmentally friendly. Despite increased awareness  
281 however, only a small minority of consumers are willing to change meat consumption  
282 behaviour<sup>(49,115,120)</sup>. Demographic characteristics of study respondents predicts consumer  
283 behaviour<sup>(40,108)</sup> with age and gender noted to influence both degree of awareness and importance of  
284 environmental impact of meat consumption, appearing to be greatest amongst younger adults,  
285 Millennials and females compared to older adults and males<sup>(9,40,74,82,113)</sup>.

286 While it appears altruistic drivers of animal and environmental welfare are important to consumers,  
287 they are consistently identified as secondary to health<sup>(20,40,97,105,108,113,114,121,122)</sup>. Parry and Mitchell<sup>(123)</sup>  
288 highlight that perceived importance of altruistic factors was at least 20% lower than other attributes  
289 including taste and health when purchasing plant-based products (see Table 1). Furthermore, concern  
290 for the environment (12%) and animal welfare (12%) was substantially lower than health (50%) as a  
291 driver for reduced meat consumption<sup>(112)</sup>. This emphasises the salient role of health in driving meat  
292 reduction and increased engagement with plant-based foods.

### 293 *Health*

294 Excessive red and processed meat consumption has been associated with deleterious health  
295 consequences such as increased risk of type 2 diabetes, colorectal cancer and reduced life  
296 expectancy<sup>(30–34)</sup>. In contrast, ‘traditional’ plant-based dietary patterns are noted to maintain  
297 cardiovascular health, reduce obesity and prevent or improve the management of type 2  
298 diabetes<sup>(48,49,98,120)</sup>. Increased consumer awareness of putative health benefits may therefore have  
299 fuelled a dietary shift to reduce animal-sourced food products and increase engagement with plant-  
300 based foods<sup>(20,31,32,40,48,80,81,84,97,103,118,122)</sup>.

301 The perceived health benefits of consuming plant-based foods relate to their predicted nutritional  
302 composition (low energy density, low saturated fat content, rich micronutrient profile), and the likely  
303 associated physiological effects of dietary adoption (altered cardiometabolic risk and reduced risk of  
304 overweight / obesity)<sup>(76,84,93,111,113,118,124–126)</sup>. Elzerman *et al.*<sup>(93)</sup> highlighted that PBMA were  
305 perceived as healthier than meat amongst Dutch consumer focus groups. This supports the  
306 conclusions of cross-sectional surveys where the term ‘nutritious’ was associated with plant-based  
307 eating and plant-based burgers were considered healthier than their meat-based equivalent<sup>(127,128)</sup>.  
308 While the online nature of these studies restricts validity of findings, a recent sensory evaluation  
309 reported meat-based burgers were deemed ‘unhealthy’ compared PBMA<sup>(129)</sup>. Once again,

310 demographic differences exist with females and middle aged-older consumers more likely to be  
311 influenced by health drivers<sup>(16,68,75)</sup>.

312 When it comes to weight control there are contrasting findings. Hoek *et al.*<sup>(76)</sup> identified weight  
313 control as a motive to try PBMA across consumers and non-consumers. However, weight loss was  
314 not a strong health-related motive for plant-based product adoption amongst plant-based food and  
315 beverage product consumers and non-consumers in the UK and Republic of Ireland<sup>(98)</sup>. Moreover,  
316 Culliford and Bradbury<sup>(9)</sup> concluded that weight loss was perceived to be substantially less influential  
317 compared to health when determining food choice (76% and 12%, respectively).

318 Health concerns have been described as a ‘double-edged sword’<sup>(81)</sup>. Particularly restrictive plant-  
319 based dietary patterns (e.g., veganism) may be associated with nutrient deficiency or insufficiency<sup>(31)</sup>.  
320 Thus, a lack of awareness regarding the health benefits of regular consumption of PBMA may  
321 enhance the perception that they are nutritionally inferior and limit consumer engagement<sup>(31,109)</sup>.  
322 Elzerman *et al.*<sup>(93)</sup> reported that although most focus group participants perceived PBMA to be  
323 healthy (e.g., high in protein and low in saturated fat), concerns were raised regarding digestibility,  
324 suitability for children (particularly regarding nutritional needs) and a lack of clarity in relation to  
325 their health value. The reported perception that meat is a necessary component of the diet and thus its  
326 avoidance raises health concerns may be a key reason for meat-excluders returning to meat  
327 consumption<sup>(76,94,107,125)</sup>.

328 Leroy and Cofnas<sup>(130)</sup> emphasised the juxtaposition between consumer health-related motivations and  
329 the arguably ultra-processed nature of PBMA<sup>(31,48,131)</sup>. Excessive consumption of, so-called ‘ultra-  
330 processed’ foods (UPF; see Table 1) has been argued to elevate risk of obesity and associated  
331 comorbidities such as cardiovascular disease<sup>(131)</sup>. This may explain the findings of Mullee *et al.*<sup>(118)</sup>  
332 who reported nearly a quarter of respondents perceived habitual consumption of vegetarian foods to  
333 be ‘unhealthy’. Jahn *et al.*<sup>(31)</sup> also identified degree of processing, even processes that are  
334 paradoxically designed to enhance nutritional quality (such as fortification), as an important factor in  
335 consumer product evaluation and reduced product desirability.

336 While clearly many factors are associated with engagement with plant-based foods, health plays a  
337 salient role in consumer decisions and behaviour<sup>(103,122)</sup>. More research is needed regarding the  
338 specific health-related drivers beyond weight loss. Furthermore, the current evidence base highlights  
339 variation in drivers and barriers associated with plant-based food engagement amongst different sub-  
340 groups of consumers. This reinforces the need for a strong, evidence-based, whole systems approach  
341 to facilitate effective and sustainable dietary behaviour change. It also reinforces the fact that a one-  
342 size-fits all approach is not sufficient to accelerate engagement with PBMA. Instead an increased

343 understanding of the specific needs and barriers within different subgroups of consumers is required  
344 to effectively tailor new product development and marketing strategies to meet those needs.  
345 Application of segmentation theories to divide populations into smaller subgroups based on  
346 similarities, can enable consumer segments to be targeted with a more customised strategy. Studies  
347 within the current research field have segmented according to sociodemographic factors, dietary  
348 patterns and product usage<sup>(9,76,84,97,98,110,112,123,125,126)</sup>. However, using models of behaviour change to  
349 identify sub-groups more pre-disposed to engage with innovative PBMA has the potential to  
350 accelerate adoption<sup>(81)</sup>. For example, Roger's Diffusion of Innovation identifies predisposition to  
351 change while the Transtheoretical Model describes the process of intentional behaviour  
352 change<sup>(132,133)</sup>. Together these models would enable investigation of perceptions of, drivers of and  
353 barriers to the adoption of novel PBMA relative to specific population subgroups.

### 354 **Novel Plant-Based Meat Alternatives: Health Considerations**

355 Despite the paucity in evidence regarding the impact of novel PBMA on health, a limited number of  
356 published studies have indicated their adoption may be associated with a range of health benefits.  
357 Notably, a systematic review and meta-analysis of RCTs investigating the impact of plant-protein  
358 consumption on lipaemia proposed that protein itself may be responsible for the health-associated  
359 benefits<sup>(134)</sup>. Hence, processing whole-plant food into protein isolates may not necessarily  
360 compromise their health value. A RCT<sup>(135)</sup> comparing the impact of PBMA with animal-derived  
361 meat across a range of health risk factors in thirty-six healthy omnivorous adults randomised  
362 participants to either plant-animal or animal-plant sequence and instructed them to consume  $\geq 2$   
363 servings of the intervention meat product per day while ensuring consumption of other (non-study)  
364 foods was comparable in each phase (8-weeks each). PBMA consumption was associated with  
365 cardioprotective changes including significantly lower trimethylamine-N-oxide concentrations  
366 (PBMA mean =  $2.7\mu\text{M} \pm 0.3$  v meat mean =  $4.7\mu\text{M} \pm 0.9$ ; mean difference =  $-2.0$  [95% CI  $-3.6, -$   
367  $0.3$ ]), LDL-cholesterol concentrations (PBMA mean =  $109.9\text{mg/dL} \pm 4.5$  v meat mean =  $120.7 \pm 4.5$ ;  
368 mean difference =  $-10.8$  [95% CI,  $-17.3, -4.3$ ]) and weight (PBMA mean =  $78.7\text{kg} \pm 3.0$  v meat mean  
369 =  $79.6\text{kg} \pm 3.0$ ; mean difference =  $-1.0$  [95% CI  $-1.5, -0.5$ ]) compared to meat consumption. It should  
370 be noted that the level of dietary control was limited as participants were able to consume chicken or  
371 fish in the plant-arm and self-selected all other dietary components. However, this in turn increases  
372 the generalisability and external validity of the study findings. A recent RCT<sup>(136)</sup> also demonstrated  
373 positive changes in the gut microbiome when substituting several meat-based meals per week for  
374 PBMA meals, resulting in a significant increase in butyrate-production pathways and significant  
375 decrease in the Tenericutes phylum; attributes associated with a healthy gut microbiome. Zhou *et*

376 *al.*<sup>(137)</sup> also reported higher levels of dietary fibre from the digestion of PBMA compared to meat  
377 that may increase satiation after consumption of the PBMA.

378 There is conflicting evidence regarding the impact of plant-based foods upon appetite<sup>(138–140)</sup>.  
379 Williamson *et al.*<sup>(141)</sup> conducted a three-way crossover study in overweight subjects (n = 42)  
380 investigating the satiating efficacy of a mycoprotein pasta preload and a tofu pasta preload compared  
381 to an isocaloric chicken pasta preload, closely matched for protein and organoleptic characteristics.  
382 The authors concluded pre-loading with mycoprotein and tofu led to significantly lower food intake  
383 compared to chicken preloading (138.7g, 135.2g and 158.3g, respectively). A similar study<sup>(138)</sup>  
384 reported plant-based protein (beans/peas) to be significantly more effective than energy and protein  
385 matched animal-based protein (veal/pork) on subjective markers of appetite in a healthy cohort of  
386 male participants (n = 43). In contrast, no differences were found between plant-based (fava  
387 beans/split peas) and meat-derived (veal/pork) protein meals, matched for energy, macronutrient and  
388 fibre, in a single-blinded RCT<sup>(139)</sup>. Similarly, a recent double-blind RCT<sup>(142)</sup> also reported no  
389 significant differences regarding markers of appetite between a lamb burrito and a plant-based meat  
390 burrito meal. However, it should be noted that the study meals were not matched for protein which  
391 may have influenced the results. In addition, Neacsu *et al.*<sup>(143)</sup> suggested plant-based and meat-based  
392 high protein diets had a similar impact on gut-peptide hormones and subjective appetite responses.  
393 However, a randomised crossover study demonstrated increased peptide YY, glucagon-like peptide  
394 1, amylin and thalamus perfusion following consumption of a plant-based meal compared to an  
395 energy and macronutrient matched meat-based meal<sup>(140,144)</sup>. Proposed satiating mechanisms include  
396 high dietary fibre content (promoting short chain fatty acid production) in addition to modification of  
397 gastric hormone secretion and gastric emptying related to appetite suppression<sup>(145,146)</sup>. Grundy *et*  
398 *al.*<sup>(147)</sup> also described how dietary fibre encapsulates macronutrients to regulate digestion, while  
399 soluble dietary fibre increases viscosity in the gastrointestinal tract which in turn may slow  
400 macronutrient digestion. However, extensive processing is associated with nutrient loss and UPFs are  
401 noted to be limited in appetite-regulating nutrients such as dietary fibre and protein<sup>(148,149)</sup>. Thus, the  
402 influence of processing on the capacity of commercial PBMA to elicit fullness needs further  
403 investigation. Furthermore, while the RCT study design is considered the gold standard method, there  
404 is an urgent need for longitudinal data to evaluate the long-term consequences of habitual  
405 consumption of PBMA on appetite and health.

#### 406 *Ultra-Processed Foods*

407 Many novel PBMA are typically classified as ultra-processed, according to the NOVA  
408 definition<sup>(96,131)</sup>. While processing improves safety and, shelf-life and fortification enhances nutrient

409 content, deleterious health consequences have been associated with ultra-processing. For example,  
410 so-called UPFs are noted to contain less appetite-regulating nutrients such as dietary fibre and protein.  
411 Additional concerns relate to higher levels of saturated fat, salt and free sugar content and inclusion  
412 of additives such as artificial colours, flavours and preservatives<sup>(131,150–152)</sup>. Moreover, a recent  
413 systematic review and meta-analysis by Suksatan and colleagues<sup>(153)</sup> demonstrated a significant dose-  
414 response association between UPF consumption and risk of all-cause mortality.

415 Gehring *et al.*<sup>(96)</sup> noted greater UPF consumption within meat reduction or avoidant diets compared  
416 to omnivorous diets in the French NutriNet-Santé cohort. This supports the notion that while novel  
417 PBMA facilitate reduced meat consumption, their health value needs further consideration<sup>(48)</sup>.  
418 However, there is a lack of consensus as to whether all UPFs can be labelled ‘unhealthy’. In fact,  
419 Derbyshire<sup>(154)</sup> argued that some UPFs demonstrate ‘healthy’ nutritional profiles. For example, the  
420 authors<sup>(154)</sup> highlighted fifty ‘ultra-processed’ food products (characterised according to the NOVA  
421 classification system) that were identified as ‘healthy’ food products according to the 2011 and 2018  
422 Nutritional Profiling tool. This and similar findings have led to criticism of NOVA as an ambiguous  
423 classification system<sup>(155–159)</sup>. Additional concern relates to the use of one umbrella term of “ultra-  
424 processed” to describe a diverse range of processing techniques which have distinct functions<sup>(156)</sup>.  
425 Nonetheless, there is a paucity of evidence supporting the detrimental health consequences associated  
426 with ultra-processing upon both the nutritional and mechanistic quality of foods, specifically in  
427 relation to PBMA<sup>(4,150,151)</sup>.

## 428 **Nutritional Profile of Novel Plant-Based Meat Alternatives**

429 Limited published scientific evidence is inconclusive regarding the health value of novel PBMA and  
430 their capacity to replicate the nutritional profile of meat-equivalents. Curtain and Grafenauer<sup>(160)</sup>  
431 reported that most PBMA demonstrated a healthier nutrient profile than meat-based equivalents in  
432 their audit of Australian supermarkets. For example, PBMA were significantly lower in energy  
433 density, total fat, saturated fat and significantly higher in dietary fibre. However, the sodium content  
434 of PBMA was particularly high, with only 4% of products classified as ‘low in sodium’. In fact,  
435 plant-based mince had six-fold higher sodium content than the meat-based equivalent while meat  
436 sausages had significantly greater sodium than PBMA. A similar study in the UK<sup>(161)</sup> also reported  
437 significantly higher sodium levels in all categories except sausages and reinforced concerns by  
438 identifying approximately three-quarters of products having salt content greater than their maximum  
439 salt reduction target. The authors also reported significantly lower protein content in four out of six  
440 PBMA categories. However, although the study targeted fourteen UK retailers for PBMA, Covid-

441 19 restrictions meant that only one supermarket was targeted for meat-equivalent products.  
442 Consistency in search method for both product types would increase rigour in future research.

443 Tonheim *et al.*<sup>(162)</sup> recently conducted a similar survey investigating PBMA's available on the  
444 Norwegian market. Again the Covid-19 pandemic restricted the range of suppliers and data collection  
445 was undertaken in two phases. The authors compared PBMA's to their meat-based equivalents in two  
446 categories: 'regular' meat and 'healthy' meat (identified with a Keyhole symbol, a labelling scheme  
447 identifying healthier food products)<sup>(163)</sup>. These 'healthy' meats were typically reduced fat alternatives  
448 to 'regular' meats. PBMA's were typically lower in energy content compared to 'regular' meat, though  
449 they contained more energy than their 'healthy' meat comparator. PBMA's were generally lower in  
450 saturated fat and higher in dietary fibre than either category of meat comparator. There was also  
451 between product variation in salt content. While salt content was more favourable in the plant-based  
452 meatballs versus both meat-equivalents, it was greater than both meat-equivalents in other product  
453 categories with plant-based mince demonstrating a ten-fold greater salt content than the 'healthy'  
454 meat comparator. In contrast, Boukid and Castellari<sup>(164)</sup> reported no significant difference in sodium  
455 content between the four burger products (vegetarian, red meat, fish and poultry based) in their survey  
456 of the EU burger market.

457 Heterogeneity both within and between product categories was also demonstrated in other similar  
458 studies<sup>(160,165-167)</sup>. Fresán *et al.*<sup>(10)</sup> reviewed 56 PBMA's according to their protein source and  
459 concluded that despite some between product variation, the nutritional profile demonstrated no  
460 substantial differences. Meanwhile, Bohrer<sup>(166)</sup> reported the nutritional composition of a plant-based  
461 burger to be similar to that of a McDonald's® beef patty but found differences in meatballs where  
462 the plant-based version was lower in energy, saturated fat and higher in dietary fibre compared to the  
463 meat-based equivalent. In addition, *safe*food<sup>(167)</sup> identified chicken alternatives to be less favourable  
464 on a number of nutritional components including energy density, protein, saturated fat, sugar and salt  
465 in their audit of PBMA's in Irish supermarkets. However, the method of product categorisation may  
466 have influenced the findings<sup>(167)</sup>. For example, while other studies<sup>(160-162,168)</sup> typically selected an  
467 equivalent meat-based product as a comparator, the authors<sup>(167)</sup> compared all chicken alternatives,  
468 including breaded, battered and plain alternative products, to a skinless, grilled chicken breast.  
469 Similarly, while other studies<sup>(160,161,168)</sup> compared plant-based mince to beef mince, the authors<sup>(167)</sup>  
470 compared plant-based alternative steaks, mince, meatballs and Bolognese to beef mincemeat. This  
471 method of categorisation limits the reliability of study findings as the selected meat product does not  
472 reflect a suitable comparator. This highlights a substantial challenge for research conducted within  
473 this area. For example, a robust feeding trial, would require an appropriate comparator arm which  
474 includes an element of blinding across a range of factors including sensory attributes, cooking

475 technique and nutritional profiling. However, a major limitation in the above studies is the omission  
476 of micronutrient analysis. As meat is considered a valuable vehicle of vital micronutrients such as  
477 vitamin B<sub>12</sub>, zinc, iron and calcium, vitamin and mineral content should be considered when  
478 evaluating nutritional value of PBMA<sup>s</sup>(<sup>17,18,160</sup>).

479 More recent studies have considered micronutrient alongside macronutrient composition in their  
480 evaluation of PBMA<sup>s</sup>(<sup>168–170</sup>). These studies used similar methods, identifying PBMA<sup>s</sup> via a search  
481 of defined supermarkets and extracting nutritional information from product packaging, front of pack  
482 information and both supermarket and manufacturer websites. While there was substantial between  
483 product variation, the studies generally reported PBMA<sup>s</sup> to be lower in saturated fat, richer in dietary  
484 fibre and substantially higher in sodium than their meat-based comparator. However, despite  
485 reporting an intention to analyse micronutrient content of PBMA<sup>s</sup>, D'Alessandro *et al.*(<sup>169</sup>) failed to  
486 present data for these variables. While Bryngelsson *et al.*(<sup>168</sup>) reported that a large proportion of  
487 PBMA<sup>s</sup> lacked micronutrient information, the limited data highlighted a wide variation between  
488 product categories. For example, while PBMA<sup>s</sup> were typically richer in iron and folate compared to  
489 their meat-equivalent, vitamin B<sub>12</sub> was noted to be higher in plant-based sausages, lower in bacon,  
490 and similar within the nugget product range. However, these data were derived from a very limited  
491 number of products as information for iron, folate and vitamin B<sub>12</sub> were provided on 13%, 6% and  
492 6% of products, respectively.

493 Cole *et al.*(<sup>170</sup>) restricted their analysis to burger categories (imitation burger, vegetarian burger and  
494 conventional beef burgers) and highlighted variation in vitamin and mineral content. For example,  
495 although the imitation burger demonstrated comparable levels of iron, it was significantly richer in  
496 vitamin A, C and D, potassium and calcium compared to the meat-based equivalent. However, the  
497 authors were unable to obtain information regarding a range of vitamins and minerals that are key  
498 components of beef, including zinc, vitamin B<sub>12</sub>, phosphorus and magnesium. This may reflect that  
499 in the EU labelling of vitamin and mineral information on packaged food labelling is at the discretion  
500 of the manufacturer and highlights a limitation of evaluating micronutrient value through Nutrition  
501 Facts labelling(<sup>171</sup>). Meanwhile, Harnack *et al.*(<sup>172</sup>) used food ingredient information alongside  
502 Nutrition Facts labelling to develop recipes and estimate nutritional value of selected beef alternative  
503 products in contrast to meat counterparts. They reported plant-based ground beef to be a rich source  
504 of dietary fibre with comparable levels of iron compared to ground beef but highlighted a shortfall in  
505 protein, zinc, and vitamin B<sub>12</sub> alongside substantially higher sodium content. Again, the authors  
506 acknowledged that inaccurate labelling and limitations in the Food and Nutrition Database used to  
507 develop recipes increased the risk of inaccurate calculations of nutritional value.



508 Two studies<sup>(173,174)</sup> have investigated nutritional composition using laboratory analysis techniques.  
509 Although it wasn't reported, it could be inferred that the associated time and cost-burden may have  
510 resulted in restricted focus of these studies<sup>(173, 174)</sup> to single product categories (burger products). Both  
511 studies<sup>(173,174)</sup> concluded that the plant-based burger products were able to demonstrate a comparable  
512 nutritional profile and richer content of certain minerals although there was again variability between  
513 products. However, in contrast to other studies where PBMA's were reported to be lower in saturated  
514 fat content but contain substantially more sodium, De Marchi and colleagues<sup>(174)</sup> reported no  
515 significant difference in sodium or saturated fat content between plant-based and meat-based burgers.  
516 However, the comparable levels of saturated fat may be attributed to use of particular ingredients in  
517 the selected products such as coconut oil in the plant-based burgers<sup>(175)</sup>.

518 A more recent study conducted a comprehensive nutritional analysis of a large range of PBMA's (hot  
519 and cold categories) versus their meat-based counterparts using four national nutrient databases and  
520 laboratory analyses<sup>(176)</sup>. The authors support previous study findings<sup>(160,161,168,170)</sup> where despite  
521 substantial variation between PBMA product ranges, PBMA's were demonstrated to have lower  
522 energy density, total and saturated fat but considerably higher sugar and sodium levels compared to  
523 their meat-equivalent. In addition, analysis of micronutrients demonstrated similarities to other  
524 reports where PBMA's were notably higher in calcium, phosphorus and iron<sup>(168,170)</sup>. In contrast to  
525 other studies, the authors analysed a greater range of micronutrients and highlighted substantial  
526 between product heterogeneity. For example, while levels of micronutrients, such as folate, vitamin  
527 B<sub>6</sub>, E and K, were either comparable or superior to their meat-based comparator, others demonstrated  
528 a significant shortfall, in particularly vitamin B<sub>12</sub> and zinc. Similarly, the study was unable to detect  
529 vitamin D within PBMA's; highlighting the need for manufacturers to consider fortification of certain  
530 products to ensure sufficient nutrient content. This supports previous studies that have raised concern  
531 regarding the level of and/or bioavailability of nutrients such as vitamin B<sub>12</sub>, zinc and iron in plant-  
532 based diets and the need to consider meal plans and supplementation to avoid nutrient  
533 deficiency<sup>(172,177-179)</sup>. For example, plant-foods are a primary source of non-haem iron, which has  
534 much lower bioavailability compared to haem iron, the predominant form present in animal-derived  
535 foods; reinforcing the need for PBMA fortification<sup>(175,177,180,181)</sup>. However, fortification of PBMA's  
536 with vitamin B<sub>12</sub>, iron and zinc is inconsistent with under a quarter of products fortified with these  
537 nutrients<sup>(160,168,181)</sup>. Tso and Forde<sup>(18)</sup> recently compared a model omnivorous reference diet to model  
538 diets replacing animal-derived products for either 'traditional' plant-based foods or novel plant-based  
539 products (e.g., PBMA's). Acknowledging the variability in fortification of plant-based products, the  
540 authors excluded fortified products from their reference diets. The findings highlighted that novel  
541 plant-based products were unable to meet dietary requirements for a range of nutrients including zinc

542 and vitamin B<sub>12</sub> in contrast to the omnivorous reference diet. While this study was a hypothetical  
543 comparison, it yet again reinforces the need to consider fortification methods to protect against  
544 deficiency for diets incorporating PBMA.

545 Ultimately, these findings demonstrate the inconsistent nutrient profile of PBMA and highlight the  
546 challenge of successful replication of meat-equivalents. There are multiple confounding variables that  
547 may have influenced the heterogeneity of the reported findings including geographical location,  
548 product search methods and measurement tools used. For example, despite being deemed a reliable  
549 tool, questions have been raised regarding the ability of the UK Nutrient Profiling Index to reflect  
550 current consumption behaviour and recent revisions have been made to the model to address such  
551 limitations<sup>(182)</sup>. Furthermore, while the Healthy Star Rating system has been praised for inclusivity  
552 and understandability, it is contextualised to Australia and New Zealand<sup>(183)</sup>. However, a key  
553 limitation of these tools is that they fail to consider the potential impact of degree of processing on  
554 the nutritional and mechanistic quality of food products and there is a need for greater understanding  
555 of the possible impact of this on the health benefits associated with particular ingredients. For  
556 example, processing can increase or decrease the bioavailability, digestibility, nutritional and  
557 functional characteristics of particular foods and ingredients<sup>(184)</sup>. Furthermore, the potential impact of  
558 antinutrients commonly present in PBMA, such as phytate and tannins, requires further  
559 understanding, particularly regarding possible positive or negative interactions within the food matrix  
560 in addition to their potential inhibition of the absorption of other key vitamins and minerals<sup>(184)</sup>. In  
561 addition, despite some inconsistency, the majority of studies highlighted considerably higher levels  
562 of sodium in PBMA and some authors attributed this to ultra-processing<sup>(96,131)</sup>. This is concerning  
563 given the association between high sodium intake and increased risk of non-communicable disease  
564 such as cardiovascular disease<sup>(185,186)</sup>.

565 Thus, without further clarification on the impact of processing, categorising UPFs as ‘healthy’ may  
566 inflate the so-called ‘health halo’ surrounding PBMA<sup>(131)</sup>. Current paucity in knowledge, coupled  
567 with the rapid expansion of the PBMA market means there is a growing urgency for more scientific  
568 evidence to address this ambiguity and a strong rationale to improve consumer literacy of  
569 PBMA<sup>(110,131)</sup>.

## 570 **Conclusion**

571 The equivocal nature of the limited published findings, specifically in relation to the health value of  
572 novel PBMA, raises concern as to whether consumers are using historic evidence related to  
573 ‘traditional’ plant-based dietary patterns to make assumptions. While such products may not align

574 with aspirational, ‘traditional’ plant-based food consumption, one must consider whether these novel  
575 products do offer a healthier alternative to meat-based equivalents. With the exception of sodium and  
576 possibly some micronutrients, the current evidence suggests this may be the case. If so, this raises the  
577 question whether accelerating the adoption of these products will create a good compromise with  
578 incremental benefits to public health and climate change targets while meeting consumer demand.

579 Food manufacturers are now recognising the urgency to deliver products with healthier nutrient  
580 profiles, emphasising the need for rigorous studies which consider a range of variables such as level  
581 of processing and nutritional composition. Understanding the impact of extensive processing on  
582 health effects may help to justify the use of innovative methods designed to maintain health benefits  
583 associated with particular foods and ingredients. In addition, furthering knowledge regarding the  
584 nutritional value of PBMA s will identify opportunities to enhance their health profile and promote  
585 consumer capacity to make informed food choices.

586 Finally, a clearer understanding of factors influencing engagement of target consumer subgroups with  
587 PBMA s may support production of desirable healthier plant-based foods. Such evidence-based food  
588 manufacturing practice has the potential to positively influence future individual and planetary health.

589

590

591 **Figure Legends**

592 Figure 1: Key factors influencing individual plant-based food choice adapted from Szejda and  
593 Parry<sup>(187)</sup>.

594

595 **Tables**

596 *Table 1: definitions of key terminology referred to in the current review*

<b>Terminology</b>	<b>Defined as</b>
<b>Traditional Plant-Based Diet</b>	A diet based on minimally processed plant foods that are low energy density, nutrient dense and low in saturated fat. Examples include fruit and vegetables, wholegrains, pulses, legumes, nuts and unsaturated oils.
<b>Plant-Based Food</b>	Any food or food product derived from plants. Examples include whole foods (e.g., fruit and vegetables) and commercially available products (e.g., tofu, plant-based meat and plant-based dairy alternatives). Commercially available novel food and beverage products, derived from plants.
<b>Plant-Based Products</b>	Many of these are designed to mimic the preparation methods, sensorial qualities, and nutritional profile of animal-based equivalents (e.g., plant-based meat alternatives and plant-based dairy alternatives). This could also include commercially available vegan food products designed to appeal to those following plant-based diets. Examples include nut butters, pulse-based ready meals and vegetable burgers.
<b>Plant-Based Meat Alternative</b>	Commercially available novel food products, derived from plants, that are designed to mimic the preparation methods, sensorial qualities, and nutritional profile of meat-equivalents. The term 'plant-based meat alternative' is often used interchangeably with 'plant-based meat analogue' and 'plant-based meat substitute'. Examples include plant-based burgers and plant-based sausages.
<b>Ultra-Processed Food</b>	Defined by NOVA as: "Products involving formulations of ingredients, most of exclusive industrial use, typically created by a series of industrial techniques and processes" <sup>(188,189)</sup> .

597

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