Appetite, food intake, and gut hormone responses to glycomacropeptide protein ingestion in older adults: A feasibility, acceptability, and pilot study

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ABSTRACT

Glycomacropeptide (GMP) has a unique amino acid profile which may make less satiating than other dietary proteins. This study assessed the feasibility and likely acceptability of a leucine-enriched GMP drink and determined appetite response in older adults (OA). Thirteen OA (11f; 70±4 years) were recruited for sensory assessments of a leucine-enriched GMP drink when mixed with water and with fruit smoothie, compared with whey protein isolate (WHEY). Participants also partook in a single focus group exploring acceptability to protein and supplementation. Separately, a counterbalanced, double-blind study with twelve OA (8f; 69±3 years) was conducted to determine appetite and gut hormone responses. Fasting subjective appetite was recorded using visual analogue scales and a fasted venous blood sample was collected (to measures acyl-ghrelin, PYY, GLP-1, and CCK) before participants consumed either: GMP protein (27g + 3g leucine, 350mL water), WHEY (30g, 350mL water), or water. Participants rested for 240minutes, with appetite measures and blood sampling throughout. An *ad libitum* pasta-based meal was then consumed. Sensory testing revealed low pleasantness rating for GMP in water vs. WHEY (16±14 vs 31±24, p=0.016). GMP addition to smoothie reduced pleasantness (26±21 vs. 61±29, p=0.009) and worsened the aroma (46±15 vs. 69±28, p=0.014). The focus group revealed uncertainty of protein needs and a scepticism of supplements, with preference for food. Gut hormone response did not differ between GMP and WHEY (nAUC for all gut hormones p>0.05). There was no difference between conditions for lunch *ad libitum* intake (549±171 kcal, 512±238 kcal, 460±199 kcal for GMP, WHEY, and water, p=0.175), or for subjective appetite response. Leucine-enriched GMP was not less satiating than WHEY, and low palatability and scepticism of supplements question the likely acceptability of GMP supplementation. Providing trusted nutritional advice and food enrichment/fortification may be preferred strategies for increasing protein intake in OA.

Key words:

Hunger; satiety; energy intake; anorexia of ageing; undernutrition; ageing.

Abbreviations:

AEBSF – 4-(2-aminoethyl)benzenesulfonyl fluoride hydrochloride

ANOVA – Analysis of variance

BMI – Body mass index

nAUC – Net area under the curve

CCK - Cholecystokinin

EDTA – Ethylenediaminetetraacetic acid

EIA – Enzyme immunoassay

ELISA – Enzyme-linked immunosorbent assay

GLP-1 – Glucagon-like peptide 1

GMP - Glycomacropeptide

IPAQ-SF – International Physical Activity Questionnaire Short Form

METs – Metabolic equivalents

OA – Older adults

PYY – Peptide tyrosine-tyrosine

SNAQ – Simplified Nutritional Appetite Questionnaire

TER – Total energy requirements

VAS – Visual analogue scale

WHEY – whey protein isolate

INTRODUCTION

Malnutrition in later life is associated with increased morbidity and mortality (Söderström et al., 2017) and a decline in physical capacity and quality of life (Rasheed & Wood, 2013). Such consequences lead to increased healthcare utilisation, with annual health and social care costs estimated to be 3 times greater for undernourished older adults, compared with those adequately nourished (Russell et al., 2014). The prevalence of severe malnutrition is reported to be up to 55% in hospitalised older adults (Norman et al., 2008) and up to 45% in those in residential care (Ray et al., 2014), while over one third of community-dwelling older adults suffer from milder malnutrition, nutrition risk and nutritional deficiencies (van den Broeke et al., 2018). With an ageing global population, malnutrition in later life is an imposing challenge for current and future healthcare systems (Stratton et al., 2018).

Insufficient nutritional intake is underpinned by an age-related decline in appetite, termed "anorexia of ageing" (Dent et al., 2019). Impaired appetite in older adults leads, particularly, to low intakes of protein and overall lower energy intake (Lonnie et al., 2018). Compared with younger adults, older adults typically consume 30% less energy per day (Soenen et al., 2013), while over 20% of older adults fail to meet the modest dietary recommendation of $0.8 g \cdot kg^{-1}$ of protein a day (Hengeveld et al., 2020). Given that low energy and low protein intakes are risk factors for sarcopenia (Cho et al., 2020; Houston et al., 2008), frailty (van den Broeke et al., 2018) and falls risk (Westergren et al., 2014), maintaining drive to eat and prevent early decreases in food intake with ageing is vital for maintaining muscle mass, strength, physical function, and health.

A high-protein intake of 1-1.2 $g \cdot kg^{-1}$ is recommended for older adults for the maintenance of muscle mass and strength (Bauer et al., 2013; Volpi et al., 2013). However, protein is highly satiating. Protein induces fullness and suppresses hunger to a greater extent than isocaloric intakes of fat and carbohydrate (Brennan et al., 2012; Westerterp-Plantenga et al., 1999), and high protein diets reduce *ad libitum* food intake and promote weight-loss (Weigle et al., 2005). Acute protein supplementation in older adults increases satiety and reduces food intake at later meals, compared with control conditions of water or nothing (Ben-Harchach et al., 2021), while long-term supplementation strategies can effectively increase protein intake, but energy intake is either negatively affected or unaffected by supplementation (Ben-Harchach et al., 2021). This poses the challenge of trying to optimise amino acid delivery for the promotion of muscle protein synthesis, while at the same time avoiding excessive satiety that impacts negatively upon subsequent food intake.

A solution to this challenge could be the milk-derived protein glycomacropeptide (GMP). GMP's unique amino acid composition could prove well-suited to the needs of older adults. GMP has high total essential amino acid content but is free from or low in amino acids shown to have appetite-suppressive effects. These include cysteine, which has been shown to suppress the hunger hormone ghrelin (McGavigan et al., 2015); tryptophan, which has an appetite-supressing effect via reductions in the rate

of gastric emptying and stimulation of the satiety peptide cholecystokinin (CCK) (Hajishafiee et al., 2021); and phenylalanine, which is a stimulator of CCK and peptide tyrosine-tyrosine (PYY) (Fitzgerald et al., 2020). The appetite response to GMP protein remains unclear. It was thought that the high satiating effect of whey protein was a primarily driven by the GMP fraction (Luhovyy et al., 2007; Royle et al., 2008), which constitutes approximately 20% of total whey protein. However, this has not been substantiated (Burton-Freeman 2009; Chungchunlam et al., 2014) and evidence for a satiating effect of GMP is limited (Daly et al., 2020; Veldhorst et al., 2009; Hoefle et al., 2019). Indeed, high-GMP whey protein has been shown to be less satiating than GMP-free whey protein (Lam et al., 2009). However, GMP is low in leucine – the amino acid able to directly stimulate muscle protein synthesis. A leucine-enriched GMP product could achieve a desirable amino acid profile for stimulating muscle protein synthesis, while avoiding a high degree of satiety and so maintaining drive to eat.

Therefore, the aim of this study was two-fold: a) to assess the feasibility, acceptability, and palatability of a leucine-enriched GMP protein supplement to inform potential feeding or supplementation strategies for older adults; b) to determine the acute appetite response to a leucine-enriched, GMP protein supplement in older adults. It was hypothesised that a leucine-enriched GMP protein supplement would prove feasible to produce and would match a whey protein supplement for acceptability and palatability. Further, we hypothesised that the leucine-enriched GMP supplement would prove less satiating than the whey protein supplements, inducing a less anorexigenic gut hormone response.

METHOD

To achieve our aim, we conducted a two-part study, adopting a convergent mixed-methods approach (Creswell & Clark, 2017). Part 1 assessed feasibility and palatability of a leucine-enriched GMP protein drink through taste testing, and assessed likely acceptability through conducting a focus group to explore attitudes towards and experiences of protein intake and supplementation. Part 2 assessed appetite and gut hormone responses to the leucine-enriched GMP protein drink.

Part 1

Drink Development

A vanilla-flavoured, leucine-enriched GMP protein powder was produced (Milk Specialties Global, MN, USA), containing 27g GMP and 3g leucine. The powder proved suitably soluble in water, fruit juices, and milk (as potential methods of ingestion). The powder remained in solution at temperate (room temperature, ~20^{o}C and cold temperatures (~4^{o}C). A comparator whey protein isolate (30g per dose) powder was also provided (Milk Specialties Global, MN, USA).

Study Design and Participants

To assess palatability and likely acceptability, thirteen older adults were recruited to attend taste testing and a focus group session at the Human Nutrition Suite at Newcastle University (11 female and 2 male, age: 70±4 years, Simplified Nutritional Appetite Questionnaire (SNAQ) score: 15.4±2.8, 4/13 classified as low appetite (score < 15, Lau et al., 2020)). Participants were recruited through poster distribution at institutions in the Newcastle area (e.g., libraries and community centres), and via the public engagement platform VOICE Global. Participants were aged 65 years or older, were free from cardiometabolic disease, and self-reported healthy senses of taste and smell. Participants were reimbursed for travel expenses and offered a £20 gift voucher to thank them for their participation. They also received lunch after the session.

Palatability of protein supplements

The sensory properties of drinks made with either GMP powder (GMP) or whey protein powder (WHEY) were compared in four taste tests. Tests 1 and 2 assessed analytic and hedonic ratings of GMP and WHEY mixed with water. Participants were given a 30mL sample of GMP mixed with water and a 30mL sample of WHEY mixed with water in a randomised order. Drinks were prepared in stock, according to manufacturer instructions (30g protein mixed with 350mL of water). Tests 3 and 4 assessed analytic and hedonic ratings of GMP and WHEY mixed with fruit smoothie. In a randomised order, participants received three 30mL samples: a commercial smoothie (Tesco 'Pineapple Paradise' smoothie, consisting of pineapple juice (31%), apple juice, banana puree (20%), apple puree, creamed coconut (5%) and lemon juice); GMP mixed with smoothie; and WHEY mixed with smoothie. The preparation of drinks was as with water (30g protein to 350mL of liquid). Participants were blinded to the contents of drinks throughout.

The participants were asked to rate each sample for 5 properties in each test. Properties were identified before the trial by three researchers (KB, AH, RS), informed by previous studies investigating taste and sensory properties of food and drink products with older adults (Norton et al., 2020; Tsikritzi et al., 2015) and adapted for a simplified taste and sensory profile for participants untrained in taste and sensory testing. Tests 1 and 3 addressed the analytical properties, while tests 2 and 4 asked about hedonic properties, in a design intended to optimise the power of the final (preference) question, by supporting the untrained panellists to communicate what they like and dislike about each product'. The properties and questions are detailed in **Table 1**. The tests were conducted with Qualtrics^{TM}XM software, using the 'Slider' option to create unmarked visual analogue scales (VAS), approximately 12 cm long on the screen of a tablet computer. The responses were recorded as the position on the scale, with the left end of the line as 0 and the right end as 100, and the cursor initially placed at the midpoint (value 50).

Table 1. Taste test questions.

Property	Left limit (0)	Right limit (100)
Analytical (how much or little), first and third test		
Texture: Take a small sip of each product and give your impression of their texture/mouthfeel	*Creamy and smooth*	*Grainy or lumpy*
Sweetness: Give your impression of how sweet the taste is, take another sip if needed	*Not sweet at all*	*Extremely sweet*
Aroma/smell: Give your impression of how strong the aroma and smell are	*Completely bland, no smell*	*Extremely strong aroma/smell*
Savoury/cheesy taste: Assess if there is a savoury or cheesy element to the taste	*Not savoury at all*	*Distinctly savoury*
Bitterness and off-taste: Were there any flavours that should be avoided in a product like this?	*Clean taste, no off-flavours*	*Very bitter, metallic taste or other strong off-flavours*
Hedonic (how pleasant or unpleasant), second and fourth test		
Texture: Take a small sip of each product and give your impression of their texture/mouthfeel	*Feels pleasant and smooth on tongue*	*Unpleasant texture: sticky, sandy or slimy*
Sweetness: Give your impression of how sweet the taste is, take another sip if needed	*Not sweet at all*	*Much too sweet*
Aroma/smell: Give your impression of how pleasant the aroma and smell are	*Disgusting smell and aroma*	*Extremely pleasant aroma/smell*
Savoury/cheesy taste: Assess if there is a savoury or cheesy element to the taste	*Too bland*	*Too 'cheesy'*
Pleasantness of product: Give your impression of your preference for each of the products	*I'll never have it again!*	*I'd want more of this every day!*

Assessing acceptability of protein supplementation

One in-person focus group was carried out with all thirteen participants immediately after the taste testing procedure. A topic guide was developed through discussions within the research team. The guide was then aligned to the Theoretical Domains Framework (TDF). The TDF serves as a

framework in behavioural science, offering a theoretical perspective for examining the influences of cognitive, affective, social, and environmental factors on behaviour (Atkins et al., 2017).

The focus group was facilitated by researcher RS and three other members of the research team. It was audio recorded, and lasted 45 minutes. It was determined that data reached saturation (Saunders et al., 2018) at around 40 minutes. Inductive thematic saturation was also identified during analysis, indicating that no further concepts or themes were being identified through analytical engagement with the data. Qualitative feedback was obtained from participants after the focus group, with positive responses indicating that all voices were heard during the session. The audio file was transcribed verbatim by an approved transcription service, anonymised, then imported into NVivo (version 12) software to aid data management and retrieval. Data analysis followed the principles of thematic analysis (Braun et al., 2006), providing an interpretive exploration of participant attitudes and beliefs about protein supplementation. The transcript was reviewed and coded by a single researcher (RS), granting them a comprehensive insight into the data. Another author independently coded a section of the transcript. The team collaboratively discussed the developing codes and themes. This established coding framework was then iteratively applied to the analysis of the full transcript.

Part 2

Study Design

In a double-blind, within-subject design, participants completed three experimental conditions in a counter-balance order: glycomacropeptide drink (GMP), whey protein drink (WHEY), and a water placebo drink (WATER). Outcome measures were subjective appetite, lunch *ad libitum* intake, and circulating concentrations of acyl-ghrelin, PYY, glucagon-like peptide 1 (GLP-1) and CCK. The study adhered to the ethical guidelines as outlined in the Declaration of Helsinki and gained ethical approval from the Newcastle University Faculty of Medical Sciences Research Ethics Committee (LREC #: 2525/30107).

Participants

Fourteen, low-to-moderately active, older adults (OA) living without obesity were recruited through poster distribution at institutions in the Newcastle area (e.g., libraries and community centres), advertisement through social media sites (e.g., Facebook interest groups), and via the public engagement platform VOICE Global. Inclusion criteria were an age of 65 years or older, a score of < 3000 metabolic equivalent of task (MET) mins · week^{-1} on the International Physical Activity Questionnaire Short Form (IPAQ-SF; Craig et al., 2003), body mass index (BMI) of < 33

231 $kg \cdot m^{-2}$ (Winter et al., 2014), non-smoker, not attempting to change bodyweight or composition, not
232 taking medication likely to impact on appetite, and free from metabolic disease and any known
233 food allergy. As laboratory *ad libitum* test meals can promoting over-consumption (Blundell et al.,
234 2010), those who had an average consumption of > 40% of estimated total energy requirements
235 (TER; estimated using the Mifflin-St Joer equation (Mifflin et al., 1990)) across trials were
236 excluded as over-eaters. This value of >40% TER represents a substantially greater intake than the
237 typical lunch energy intake of ~27% of TER in UK mid-life adults (Pot et al., 2014).

238

239 ***Enrolment and Familiarisation***

240 Participants visited the Human Nutrition Suite, Newcastle University for enrolment and
241 familiarisation. The study was verbally explained, and the participants were afforded the
242 opportunity to ask any questions prior to informed written consent being obtained. Height and
243 weight were recorded, and body composition was assessed by bioelectrical impedance (SECA
244 mBCA 515 Body Analyser). Habitual physical activity was record, habitual appetite was assessed
245 using the Simplified Nutritional Appetite Questionnaire (SNAQ, Wilson et al., 2005), and
246 participants were screened for any known food allergies. Participants were then familiarised with
247 the test meals to be consumed on the experimental visit. Samples of the breakfast drinks and lunch
248 meal were provided to confirm palatability. All participants confirmed that the pasta-based lunch
249 meal was sufficiently palatable to eat until full.

250

251 ***Procedures***

252 Participants arrived at the Human Nutrition Suite in a fasted state, between 08:00 and 09:00.
253 Participants had consumed a standardised, nutrient-balanced evening meal of beef hash, yoghurt
254 and orange juice (691 kcal; 47% energy from carbohydrate, 29% fat, 23% protein) a minimum of
255 12 hours prior to arrival and had drunk 300mL of water upon waking. They had also been instructed
256 to abstain from exercise, caffeine and alcohol on the day before each experimental visit. Adherence
257 to dietary and exercise controls was confirmed prior to commencing the experimental trial.

258 Subjective appetite was then assessed using the VAS method (Flint et al., 2000). A cannula was
259 inserted into the antecubital vein of one arm and a fasted, rested blood sample was obtained ten
260 minutes after insertion. Participants then consumed one of the three test breakfast drinks within
261 five minutes.

262 Upon completion of breakfast drink and 30 minutes after the cannulation, subjective appetite was
263 measured, and a second blood sample was obtained. Participants then rested for a further 210
264 minutes, with appetite measured every 30 minutes and blood samples obtained at 60, 90, 120, 180

and 240 minutes (see **Figure 1**). Participants remained seated and were free to read, watch television or use a laptop computer. Activity was monitored to minimise exposure to food cues in reading and viewing material. At 240 minutes, the cannula was removed and participants were provided with an *ad libitum* lunch meal. Upon completion of the meal, the trial was complete.

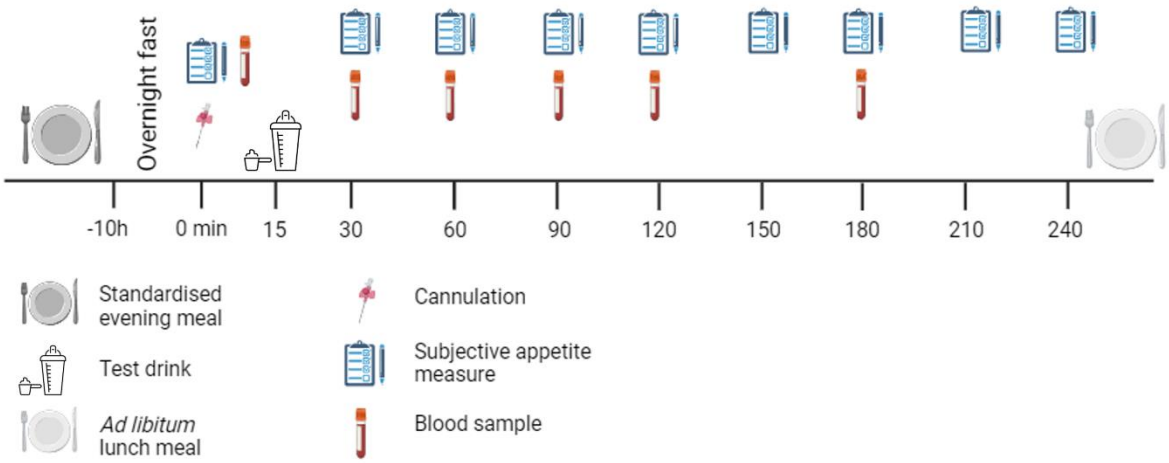

Figure 1. Schematic of study protocol

Test Breakfast Drinks

The WHEY test drink consisted of 30g of vanilla-flavoured whey protein isolate. The GMP test drink consisted of 27g of vanilla-flavoured GMP protein, fortified with 3g of leucine. Each was made with 350mL of water and additionally flavoured with strawberry flavour drops (10 drops). The water test drink consisted of 350mL of water with 10 strawberry flavour drops and four vanilla flavour drops. Each drink was made with temperate temperature water and mixed thoroughly, before being chilled in a fridge at 4°C for 15 minutes.

Outcome Measures

Ad libitum food intake

Food intake was assessed using homogeneous pasta-based *ad libitum* test meal (Astbury et al., 2011; Gonzalez et al., 2013). The nutrient-balanced meal consisted of pasta (Napolina penne pasta), Bolognese sauce (Sainsbury's Tomato & Herb), grated cheddar cheese (Sainsbury's Grated Mature British Cheddar), and olive oil (Sainsbury's) (energy density = 1.79 kcal·g^{-1}. 50% energy from carbohydrate, 15% protein, 35% fat). Participants were instructed to eat until they felt "satisfyingly full." To avoid an empty bowl providing a cue to stop eating prior to satiation, the "bottomless bowl" method was adopted whereby each bowl of pasta was replaced with a fresh, full bowl before

the participant cleared the bowl (Deighton et al., 2016). Food was consumed in isolation, free from distractions (such as a mobile phone) and food cues, and with no time limit. Each bowl was weighed before and after serving, with the difference in weight indicating the mass consumed. As the energy density of the meal was known, caloric content was calculated from the total mass consumed by the participant.

Subjective appetite

Measures of subjective appetite perceptions were obtained using the 4-item VAS method, assessing hunger, fulness, desire to eat and expected consumption (Flint et al., 2000). Each item was answered with participants placing a vertical mark on an ungraded, 100mm horizonal line anchored on both ends with extreme answers to the question posed ("How hungry are you?", "How full are you?", "How strong is your desire to eat?" and "How much would you expect to eat right now?"). A score was obtained by measuring the distance from the left-hand side anchor to the mark. A single composite score was calculated from the four items as: (hunger score + (100-fullnessscore) + desire to eat score + expected intake score) / 4 (Holliday & Blannin, 2017). As well as monitoring appetite profile over the 240-minute experimental period, the time period from consuming the breakfast drink to the point at which appetite rating returned to the baseline value was recorded. If appetite rating remained lower than baseline value at 240 minutes, the time to returning to baseline was estimated by extrapolating the data from the final three appetite measures.

Plasma concentration of acyl-ghrelin, total PYY, GLP-1, and CCK

Blood was collected in EDTA-treated blood collection tubes for the measure of total PYY, GLP-1 and CCK. For acyl-ghrelin, blood was collected in EDTA tubes pre-treated with AEBSF protease inhibitor as a concentration of $1 g \cdot mL^{-1}$ of whole blood (Deschaine & Leggio, 2020). Whole blood was centrifuged at 2000 *g* and 4°C for 15 minutes to separate plasma. Plasma was aliquoted into 0.5mL sample cups and stored at -80°C for later analyses. Plasma aliquots for the measure of acyl-ghrelin were treated with 0.2mL of 1M hydrochloric acid.

Acyl-ghrelin, PYY, GLP-1, and CCK concentrations in plasma were measured by enzyme-link immunosorbent assay (ELISA) using commercially available kits (Human Ghrelin (active) ELISA kit, Merck Millipore; Human PYY (total) ELISA kit, Merck Millipore; Mulit Species GLP-1 Total ELISA kit, Merck Millipore; Cholecystokinin EIA kit, Merck). Sensitivity of acyl-ghrelin, PYY, GLP-1, and CCK kits were 8 $pg \cdot mL^{-1}$, 1.4 $pg \cdot mL^{-1}$, 1.5 $ng \cdot mL^{-1}$, and 0.2 $pg \cdot mL^{-1}$ respectively. Coefficients of variation were 4.45%, 4.18%, 4.82% and 9.7%.

The decision was made to measure total PYY, rather than the more bioactive form, PYY3-36 (Chelikani et al., 2005; Sloth et al., 2007). PYY3-36 accounts for ~65% of total PYY and total PYY and PYY3-36 exhibit comparable responses to feeding (Batterham et al., 2006). As such, it is believed that changes observed in total PYY are representative of changes in PYY3-36, while also

accounting for the less anorexigenic but still active PYY1-36 form (Chelikani et al., 2005; Sloth et al., 2007).

Statistical Analyses

All values are presented as mean ± SD (mean ± SEM in figures). Differences in sensory test scores of the taste test were determined using paired t-test when comparing GMP and whey in water and using a repeated-measures analysis of variance (ANOVA) when comparing GMP, whey and pure smoothie. To assess acyl-ghrelin, PYY, GLP-1, and CCK responses to feeding, change-from-baseline concentration was calculated. Differences between conditions in gut hormone responses and in subjective appetite were assessed using a factorial (condition x time) repeated measures ANOVA. Net area-under-the-curve (nAUC) was calculated for each of these variables using the trapezium method. Differences in nAUC values were assessed using a one-way repeated measures ANOVA. Differences in lunch energy intake were also determined using a one-way repeated measures ANOVA. Throughout, significant interactions and main effects were explored further using Bonferroni-corrected pairwise comparisons. Partial η^2 (η^2_p) effect sizes were calculated for main effects and interactions, while Cohen's d (*d*) effect sizes were calculated for pairwise comparisons. Outliers were identified from fasted appetite scores and hormone concentrations as >1.5 x interquartile range above the third quartile or below the first quartile. Statistical significance was determined at an alpha level of 0.05. All statistical analyses were conducted using Statistical Package for Social Sciences (SPSS, Version 29.0.1.0).

An *a priori* power calculation was conducted to determine the sample size required to provide adequate statistical power to detect a large effect for gut hormones based on previous studies determining meaningful gut hormone changes with feeding in older adults (Giezenaar et al., 2018; Giezenaar et al., 2017). With statistical power of 0.8 and an alpha value of 0.05, a sample of at least 12 participants per group was required to detect a large difference (d = 1.2).

RESULTS

Part 1

Taste Testing

Analytic ratings of texture, sweetness, aroma, savoury, and bitterness, and hedonic ratings of texture, sweetness, aroma, savoury, and pleasantness for test drinks are shown in **Table 2** and **Table 3**. When GMP and WHEY were added to water (Table 1), pleasantness rating was significantly lower for GMP, compared with WHEY (p = 0.016. d = 0.763). There were no differences in any analytical ratings, or

hedonic ratings of texture, sweetness of savoury taste (all $p > 0.1$), while there was a trend for a difference in rating of aroma, ($p = 0.077$).

When GMP and WHEY were added to a fruit smoothie (Table 2), there was a condition main effect for pleasantness ($p = 0.004$, $\eta_p^2 = 0.522$). Post hoc pairwise comparisons showed that GMP score significantly lower than pure smoothie ($p = 0.009$, $d = 1.382$). There was no difference in pleasantness score between GMP and WHEY ($p = 0.102$). There was also a condition main effect for hedonic ratings of sweetness ($p = 0.014$, $\eta_p^2 = 0.300$) and aroma ($p < 0.001$, $\eta_p^2 = 0.447$). Pairwise comparisons showed a trend for a higher hedonic sweetness score for WHEY compared with pure smoothie, indicating lower preference and a perception of it being "too sweet". Both GMP and WHEY scored lower than pure smoothie for hedonic rating of aroma ($p = 0.012$, $d = 0.604$ and $p = 0.042$, $d = 0.332$, respectively). There was also a significant condition main effect for analytical rating of texture ($p = 0.040$, $\eta_p^2 = 0.236$), with tends for higher ratings for both GMP ($p = 0.060$) and WHEY ($p = 0.092$) compared with smoothie, indicating a more grainy or lumpy texture. However, this did not affect hedonic rating of texture, where no condition main effect was observed.

Qualitative data showed that participants perceived the GMP, both in water and when added to smoothie, to have an "artificial" and "metallic" taste, and an "unpleasant" and "off" smell.

Table 2. Mean ± SD analytical and hedonic ratings for GMP and WHEY added to water.

Analytic Assessment					
	Texture	**Sweetness**	**Aroma**	**Savoury**	**Bitterness**
GMP	19±14	62±34	54±32	21±26	50±30
WHEY	26±21	60±32	64±30	20±31	47±33
p	*0.241*	*0.681*	*0.302*	*0.853*	*0.562*
Hedonic Assessment					
	Texture	**Sweetness**	**Aroma**	**Savoury**	**Pleasantness**
GMP	42±31	63±30	51±23	48±26	16±14
WHEY	33±31	68±23	61±19	42±23	31±24
p	*0.229*	*0.309*	*0.077*	*0.306*	***0.016***

Table 3. Mean ± SD analytical and hedonic ratings for GMP and WHEY added to smoothie, and for pure smoothie.

Analytic Assessment					
	Texture	**Sweetness**	**Aroma**	**Savoury**	**Bitterness**
GMP	47±34	58±31	50 ±28	20±21	44±31
WHEY	39±36	65±29	58±19	33±32	46±26
Pure smoothie	21.8±20.3	52±25	64±17	20±21	40±38
p	***0.040***	*0.159*	*0.091*	*0.161*	*0.788*
Hedonic Assessment					

	Texture	Sweetness	Aroma	Savoury	Pleasantness
GMP	46±33	64±23	46±15 *	43±19	26±21 *
WHEY	35±25	67±22	53±19 *	41±21	36±26
Pure smoothie	27±29	46±26	69±28	38±15	61±29
p	*0.066*	***0.014***	***<0.001***	*0.611*	***0.009***

* = significantly different to pure smoothie.

Focus Group: Attitudes towards nutritional interventions and protein supplements

Findings are presented across three themes:

(1) **distrust**, with sub-themes of (a) distrust of government and (b) distrust of official guidance;
(2) **confusion and unawareness**, with sub-themes of (a) uncertain of which information sources are best and (b) unawareness of protein benefits;
(3) '**natural is better'**, with sub-themes of (a) a traditional, whole-food diet is best and (b) protein powders are unnatural.

Theme 1. Distrust

Sub-theme 1.1. Distrust of government

Many participants expressed their distrust of various official bodies related to diet and nutrition. Scepticism about the health-related decisions that the Government make, and in turn, dietary guidance produced by official bodies associated with the Government, was evident throughout the focus group (See **Table 4** for supporting quotations).

Sub-theme 1.2. Distrust of official guidance

Some participants made a concerted effort to keep up to date with latest dietary advice, however advice from trusted, non-governmental sources was preferred. Several highlighted websites and books from individuals such as Dr Tim Spector, who they felt was more open and honest than official sources.

Participants were often sceptical of the claims made by food supplement (and other health related) products aimed at older adults. They felt that this sector was monetized specifically to tap into, and exploit, the health-related concerns of older adults. Food supplement products were seen as making untrue promises of the benefits they could offer them.

Theme 2. Confusion and unawareness

Sub-theme 2.1. Uncertain of which information sources are best.

Participants expressed confusion over dietary guidance, often with exasperation. They felt that official sources of dietary guidance moved the goalposts of what they were 'meant' to stick to so frequently, that ultimately they were inclined to attend to other trusted sources instead. Protein intake guidance in particular was felt to be confusing, with many unaware of current guidance, or were unsure of how to personalise guidance to their own diet and living situations. The source of this confusion was ultimately blamed on changing and unclear guidance, with participants feeling frustrated.

After being presented with research findings indicating that protein supplementation may help to stall certain health issues in the future, many felt that there should be more awareness raised. Participants wanted a personalised, straightforward approach which detailed what they could take and the benefits of doing so.

Sub-theme 2.2. Unawareness of protein benefits

Some took supplements regularly, after reading various 'official' (NHS-related) and 'unofficial' sources. These primarily consisted of pre- and pro-biotics and products containing vitamins and fibre. The decision to take these supplements were based on tackling current health problems, such as poor sleep, rather than to help stave off any health issues in the future. Taking supplements, such as protein, with a view to limit future health problems was not a particular consideration for any of the participants in our sample.

Theme 3. 'Natural is better'

Sub-theme 3.1. A traditional, whole-food diet is 'best'.

There was a unanimous agreement amongst participants that whole food, natural sources of vitamins and other food/dietary components should be preferred over anything else in the first instance. Some felt that the advent of processed foods was partly to blame for the need to consider food supplementation, and reflected on 'naturally balanced', yet sometimes restricted, diets from their childhood. There was a feeling that if individuals ate sensibly and intuitively, that food supplementation was unnecessary.

However, there was pushback from other members of the focus group who highlighted that supplementation is necessary in certain cases, and that attaching value and blame to the 'laziness' of society and their consumption of processed foods was an unhelpful stereotype. This also extended to the concept of potentially using supplementation as a replacement for a naturally healthy lifestyle.

Sub-theme 3.2. Protein powders are unnatural.

The feeling that food supplementation is an unnatural and therefore undesirable method of increasing protein intake was enhanced by the artificial tasting nature of many protein supplements on the market, including some of the powders tested by this group in the session. The taste of the product was very important to participants.

Ultimately, many would only take a protein powder to supplement their diet as a last resort, after exploring all natural options.

452 **Table 4.** Selected quotations from the focus group to support the identified themes and key themes.

Theme and sub-theme	Selected Verbatim Quotations
Sub-theme 1.1 Distrust of government	*People in parliament who lobby against sugar content of drinks and all that stuff, and contribute to the Tories and whatever - and a big profession of parliamentary lobbyists who are there to do exactly what they're saying they're doing. [P3].* *But the government is different from large health organisations such as the WHO and maybe they're more trustworthy…[P4].* *Well, WHO is dependent on government… [P3].*
Sub-theme 1.2 Distrust of official guidance	*I've read Tim Spector's book about food mix, and he's a researcher at Kings College in London. He said that a lot of food research is actually funded by food companies, and if they don't like the results it would be hard to get it published. [P1]* *What you read on the packets everything tells you you're going to be a super woman or a superman having this product - but how long do you take it for? Does it really help you? Does it get into the psyche, and you think 'I'm taking this and I do feel better'? I think that's the hardest thing and there's a lot of monetising that's happening for the older generation trying to give us a quality life – a healthy life and that's what concerns me. [P7].* *The cost [of protein supplements]! I'm not convinced it's a necessary thing. I think perhaps it's just a method of making money. [P4].* *I think it's an excuse to charge more because if you eat sensibly with all of the vegetables it's already included. [P10].*

Sub-theme 2.1. Uncertain of which information sources are best.	*ny sources of information [about diet] that sometimes you just think, 'Go away!' [P3].* *I think loads of people are aware of how you should eat good fats and some protein. And I'm like that. So, I'll make sure I'll get some - and I've got absolutely no idea how much I take in. You know when you're talking about kilograms per body weight [to dose protein]? I really don't know! And I didn't know that elderly people or some elderly people become deficit in protein. So that's where I am. I suspect that's where a lot of people are. [P2].* *There's so much on tv, on social media, everywhere you look. Magazines, books, we've all mentioned them this morning, sources about food and nutrition. That's what we think about all day long. We're buying food, we're cooking food, we're looking at diets, whether it's to lose weight or put weight on. There's so much information out there. I think if [protein supplementation] was presented in the right way, in the right medical or research recommendations, then I think something like that could be useful. [P1].* *I'm concerned that we're bombarded with so much information it's just coming from so many different directions… [P7].* *So many contradictories as well… [P4].* *Contradictory. You really don't know. You look at a magazine, you look at Saga website or something which is supposedly for our generation and you think okay, they're talking about accredited organisations that are giving us this information then you go into women's magazines and then the newspapers and on tv. There's so much you just don't know and that's what's frightening. [P7].*
Sub-theme 2.2. Unawareness of protein benefits Sub-theme 3.1. A traditional,	*I thought, if it would help me to maintain my independence for longer, I would definitely consider doing something like that [take protein supplements]. I mean, I take probiotics and soluble fibre because it helps my problems, so I'll definitely take something that helps me to maintain what I do now. [P1].* *Maybe there's not enough information out there, saying that this is what's going to happen to older people. Older people are going to lose all this muscle but if you started to take protein earlier on it could help. [P8].* *Well, I was brought up I think like a lot of people in my generation with reasonably well balanced meals because we had breakfast, we had lunch – light lunch and then we had dinner. We didn't snack in between, so we didn't talk about proteins, carbohydrates. We*

whole-food diet is 'best'.	*just ate sensibly and we ate good portions so I find it now very complicated to have to listen to all these proteins, amino acids, whatever, etcetera. I think we've complicated the whole situation. If we could just go back to eating sensibly in moderation, the way we were brought up, I think it would be so much more simpler. [P7].* *I would only consider anything like that [protein supplementation] if I had some sort of illness or maybe something that would stop me from eating. I'm thinking like oesophageal cancer or something like that where it's very difficult to actually intake the food sometimes to actually keep you healthy. [P12].* *What about the other side of the thing which is exercise? Is it effective just to take the supplements and sit on your backside all day or…? [P3].* *You probably need to do both. [P10].* *Exactly, yeah that's what I was thinking. Is there any point just taking supplements if you don't change your lifestyle? … To me, people think 'I'll take this and not change [my] lifestyle'. [P3].*
Sub-theme 3.2. Protein powders are unnatural.	*What would you think about enriching your diet with more protein? [F1]* *As long as it didn't take like powder. [It was] horrible. [P9].* *I didn't like some of them. [P2].* *The first couple were okay and then after that they just got… [P9].* *I thought they were all rather sweet. Very sweet. [P11].* *[Agreement]* *But there's a peculiar thing that some of them have where the taste of them was alright but the smell was disgusting. [P11].* *If you published [information on protein supplementation], the first thing I would wonder is, 'can I get this protein from ordinary food sources'? Because I'd just eat more protein. And at [the age of] 40 I guess people are not having appetite problems, you know? So, I would certainly do that. [P2].*

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Part 2

Participant Characteristics

Of fourteen participants recruited, one withdrew due to discomfort of the cannula and one participant was excluded as over-eaters (consuming 43% and 55% of TER at the *ad libitum* lunch meal). As such, twelve participants completed the study and were included in the analyses (4m and 8f; age 69 ± 3 years; weight 67.9 ± 13.8 kg; BMI 23.5 ± 3.7 $kg \cdot m^{-2}$; fat mass 24.5 ± 9.1 kg; percentage body fat 35.3 ± 9.8%; fat free mass 43.5 ± 9.1 kg; SNAQ score 15 ± 2, 6/12 classified as low appetite (score < 15, Lau et al., 2020); IPAQ-SF score 1804 ± 1112 $METSs \cdot day^{-1}$).

Blinding of test drinks was assessed qualitatively. No participants were able to distinguish between protein conditions. Differences in texture were reported, with four participants confidently identifying the water condition.

Energy Intake

Energy intake at the *ad libitum* lunch meal for the three test conditions is shown in **Figure 2**. There was no difference in energy intake (549 ± 171 kcal vs. 512 ± 238 kcal vs. 460 ± 199 kcal for GMP, WHEY and WATER, respectively, $p = 0.175$, $\eta_p^2 = 0.147$). Data was also analysed for a trial order effect. There was a significant main effect for trial order (Trial 1 = 458 ± 209 kcal, Trial 2 = 476 ± 199 kcal, Trial 3 = 588 ± 190 kcal; $p = 0.019$, $\eta_p^2 = 0.366$), with post hoc pairwise comparisons revealing that intake was significantly greater on trial 3 (588 ± 190 kcal) then trial 2 (467 ± 199 kcal, $p = 0.012$), with a trend of a greater intake on trial 3 than trial 1 (458 ± 209 kcal, $p = 0.090$).

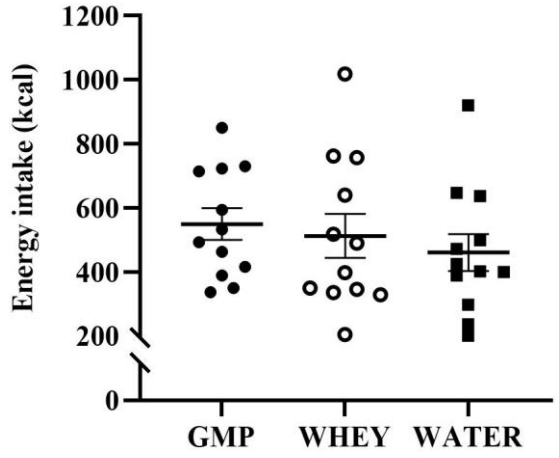

Figure 2. Mean ± SEM lunch *ad libitum* energy intake for WATER, WHEY and GMP.

Subjective Appetite

The subjective appetite response to each of the three breakfast drinks are shown in **Figure 3**. There was no condition x time interaction (p = 0.251, η_p^2 = 0.111), nor group main effect (p = 0.360, η_p^2 = 0.089). Net AUC for appetite response did also not differ across conditions (p = 0.349, η_p^2 = 0.091). We also assessed the time period from consuming the drink until appetite rating had returned to the baseline value. There was a trend for a group main effect for time taken for appetite score to return to baseline (145 ± 93 mins vs. 118 ± 83 mins vs. 76 ± 63 mins for GMP, WHEY and WATER, respectively; p = 0.081, η_p^2 = 0.229). Post hoc pairwise comparison showed a trend for a difference between WHEY and WATER (p = 0.065, d = 0.574), with no difference between GMP and WHEY.

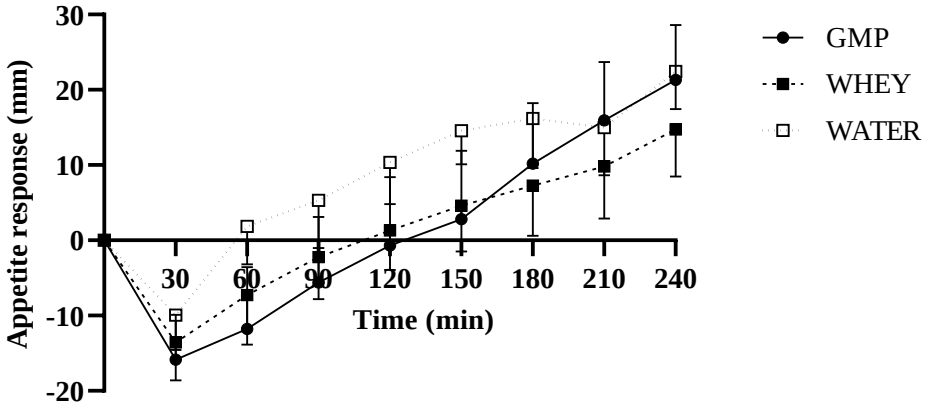

Figure 3. Mean ± SEM subjective appetite response for WATER, WHEY and GMP.

Gut hormone responses

Blood samples were not obtained for one participant due difficulties with cannulation. All hormone analyses were conducted for 11 participants. Responses of acyl-ghrelin, PYY, GLP-1, and CCK to GMP, WHEY, and WATER are shown in **Figure 4a - 4d**.

Acyl-ghrelin

There was no condition x time interaction (p = 0.572, η_p^2 = 0.065), nor condition main effects for acyl-ghrelin response (p = 0.431, η_p^2 = 0.070). There were also no differences in nAUC (p = 0.417, η_p^2 = 0.074).

PYY

There was no condition x time interaction effect for PYY response (p = 0.404, η_p^2 = 0.091). There was a group main effect (p = 0.046, η_p^2 = 0.265); however, post hoc analyse revealed no pairwise differences (all p > 0.1). There was also a condition main effect for nAUC (p = 0.047, η_p^2 = 0.263), with no significant pairwise differences (all p > 0.1).

GLP-1

For GLP-1 response, there was a significant condition x time interaction ($p = 0.038$, $\eta_p^2 = 0.237$). Post hoc analysis showed a greater increase in GLP-1 concentration in both GMP and WHEY compared with WATER at 30min, 60min, 90min, and 120min (all $p < 0.05$, $d > 1.081$). A greater increase in WHEY compared with WATER was also observed at 180min (15.3 ± 7.1 ng·mL^{-1} vs. 3.6 ± 10.8 ng·mL^{-1}, $p = 0.034$, $d = 1.408$), with a trend for a difference between GMP and WATER at this time (9.2 ± 8.4 ng·mL^{-1} vs. 3.6 ± 10.8 ng·mL^{-1}, $p = 0.087$, $d = 0.647$). There was a group main effect ($p < 0.001$, $\eta_p^2 = 0.551$), with post hoc analyse identifying differences between GMP and WATER ($p = 0.006$, $d = 1.404$) and between WHEY and WATER ($p = 0.006$, $d = 2.093$). There was no difference between GMP and WHEY ($p = 0.382$). There was also a condition main effect for nAUC ($p < 0.001$, $\eta_p^2 = 0.544$), with significantly greater nAUC value in GMP compared with WATER ($p = 0.007$, $d = 1.367$) and WHEY compared with WATER ($p = 0.007$; $d = 2.050$). There was no difference between GMP and WHEY ($p = 0.390$).

CCK

There was no condition x time interaction ($p = 0.438$, $\eta_p^2 = 0.084$), nor condition main effects for CCK response ($p = 0.395$, $\eta_p^2 = 0.081$). There were also no differences in nAUC ($p = 0.440$, $\eta_p^2 = 0.069$).

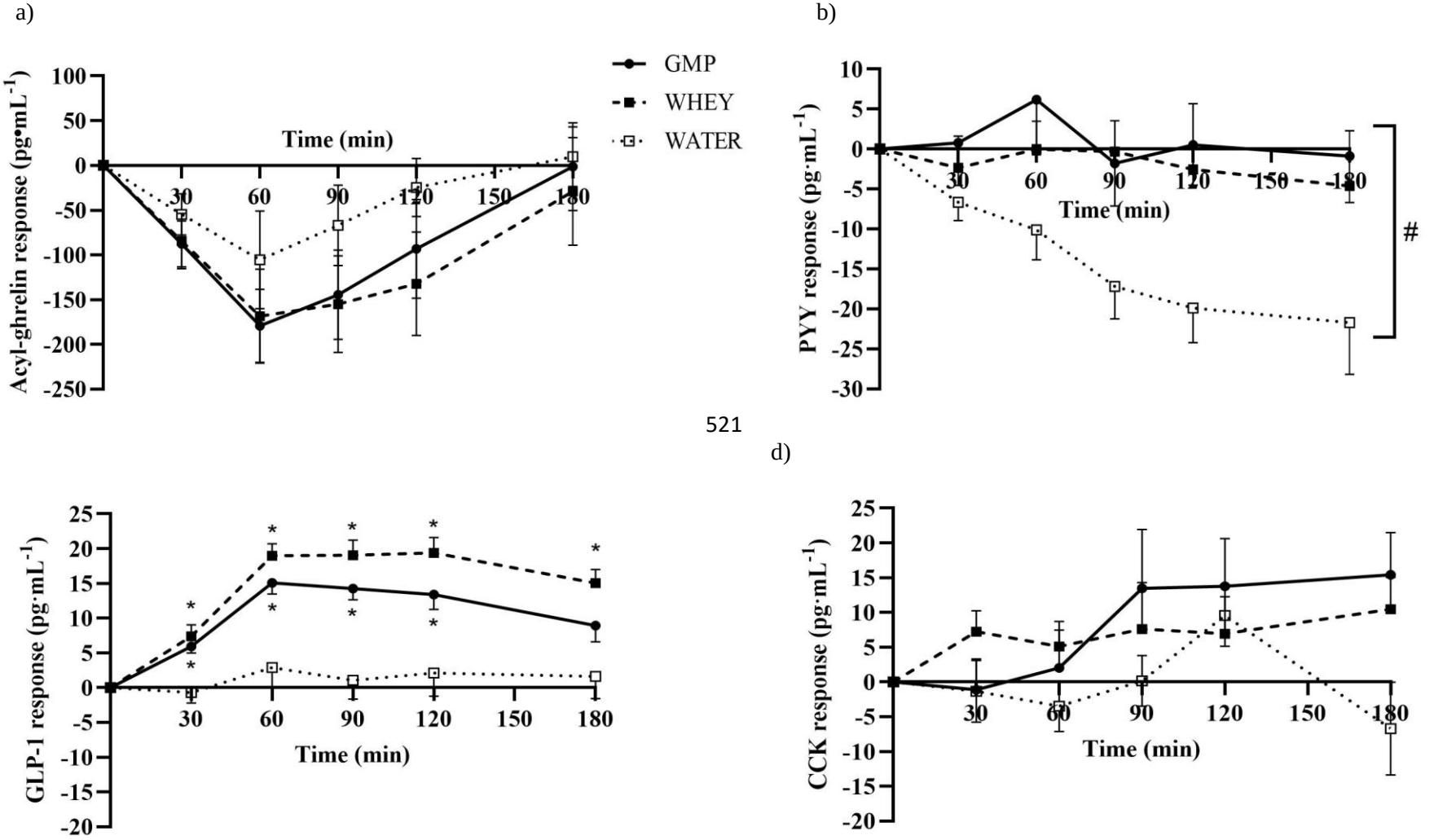

Figure 4 – Mean ± SEM plasma concentrations of acyl-ghrelin (a), PYY (b), GLP-1 (c) and CCK (d) is response to water, whey protein and GMP protein ingestion. # significant condition main effect, $p < 0.05$. * significantly different to WATER, $p < 0.05$.

DISCUSSION

The aim of this study was to determine the feasibility and acceptability of developing a GMP-based protein product to meet the needs of older adults. Our findings suggest that: a) leucine-enriched GMP is not less satiating than whey protein; b) low palatability of a GMP-based supplement and negative attitudes towards protein supplementation would make effective adoption of such a supplement challenging in older adults; c) future study and interventions to increase protein intake in older adults may benefit from providing trusted nutritional advice and oping for food enrichment/fortification approaches.

It was hypothesised that the amino acid profile of GMP would favour a less anorexigenic hormonal response. This was not the case. There was no difference between the two protein drinks for acyl-ghrelin, PYY, GLP-1 or CCK response. Our rationale was informed largely by studies investigating appetite and gut hormones responses to isolated amino acids. It is perhaps unsurprising that gut hormone response to intact, whole protein differs to the that of individual amino acids or amino acid mixtures (Gwin et al., 2020). MacLeod and colleagues (2010) showed greater ghrelin suppression after the ingestion of intact GMP, compared with the ingestion of an essential amino acid mix, despite very comparable amino acid profiles. Studies determining gut hormone secretion in response to GMP are scarce, and this is the first study to identify responses or a range of gut hormones in older adults. Hoefle et al. (2019) showed no difference in GLP-1 response after consuming a 50g dose of GMP compared with 50g of whey in prediabetic adults, while Veldhorst et al. (2009) observed no difference in GLP-1 or ghrelin response between ingestions of whey and GMP-free whey. Keogh et al. (2010) assessed CCK response to ~40g doses of different protein fractions, observing no difference in response between GMP and GMP-free whey protein in males living with overweight and obesity. Our findings echo these observations in younger cohort, with a modest intake of 30g of protein – one likely ecologically valid for older adults. Burton-Freeman (2008) did show a lower CCK response to GMP ingestion compared with GMP-free whey protein, in younger and mid-life adults. However, CCK concentration was measured for only 75 minutes after ingestion; our data indicate a more rapid CCK release in response to whey protein, with a delayed release after GMP. As such the data of Burton-Freeman (2008) may be representative of a delayed, rather than attenuated, CCK response to GMP.

In line with no difference in gut hormone response, subjective appetite and *ad libitum* energy intake did not differ between conditions. Subjective appetite profiles for GMP and whey protein were very comparable, while the mean energy intake at the lunch meal differed by just 37 kcal. It is noted that there was an order effect for energy intake. However, the counterbalancing of condition order should have negated such an effect. Poppitt et al. (2014) and Keogh et al. (2010) had previously shown no differences in subjective appetite and acute *ad libitum* feeding after consuming GMP and whey protein drinks in lean, young men, and mid-life males living with obesity, respectively. Our data suggest a similar comparative response between the two types of protein in older adults. As such these findings

do not support the efficacy of leucine-enriched GMP as a low-satiety alternative protein source for older adults.

Our data also suggest low likelihood of acceptability of a GMP protein supplement. While low pleasantness scores for both protein powders mixed with water indicates that participants clearly did not like the taste of either, GMP was deemed less pleasant in taste than whey protein. When mixed with a fruit smoothie, the addition of both proteins reduced the rating of pleasantness, with this reduction in pleasantness score significant for GMP. The GMP-smoothie drink was also rated lower than pure smoothie for aroma, with participants reporting an "unpleasant" or "off" smell. Condition main effects also pointed towards both protein drinks being perceived as "too sweet" and of less-desirable a lumpy and grainy texture.

It must be emphasised that most or all the participants had no direct experience with this type of product, so their responses to the flavours were primarily first impressions, not affected by any post-ingestive rewarding effects of the proteins (Berthoud et al., 2012). The result might have been different had the participants been asked to consume the products regularly (e.g., at least once per day for a week) before the taste testing took place. In particular if any of the participants habitually did consume less protein (specifically less leucine) than their individual requirement (Gietzen & Aja, 2012), such familiarisation could have given the post-ingestive effect of the more balanced amino acid profile of GMP opportunity to overcome the flavour's negative initial impression.

Previous studies have also shown low pleasantness and likeability ratings of GMP protein when mixed with milk. Our data show that such effects of GMP on beverage taste persist when mixed with a more flavoursome fruit smoothie and are prevalent for an older adult pallet. Studies have highlighted that compliance to supplementation strategies is low amongst older adults (Jobse et al., 2015) and the systematic review of Hubbard et al. (2012) found that compliance to oral nutritional supplements is negatively associated with age. Further, taste and palatability are important factors influencing compliance (Darmon et al., 2008; Lester et al., 2022). As such, efforts should be made to improve the palatability of protein supplements, particularly if adopted for older adults suffering from or at risk of undernutrition.

The focus group revealed other significant challenges in promoting protein supplementation among older adults, beyond palatability. Findings highlighted a pervasive distrust of 'official' dietary guidance, a widespread sense of confusion and unawareness about the benefits of protein supplementation, and a strong preference for natural, whole-food diets. Participants expressed deep-rooted scepticism and distrust towards 'official' sources of dietary guidance. This sentiment was particularly strong in relation to protein supplementation. Participants' apprehensions were rooted in a perceived lack of transparency and potential conflicts of interest within government and health organisations. The scepticism extends

to the commercialisation of health products targeted at older adults, with participants questioning the validity and motivations behind the marketing of such products.

A significant level of confusion and unawareness regarding the benefits of protein and its supplementation was evident among participants. This confusion was compounded by the perceived ever-changing landscape of dietary recommendations, leading to frustration and a reliance on varied and sometimes contradictory information sources. The lack of clarity in official guidelines is a critical issue, as it impedes the ability of older adults to make informed decisions about their dietary needs. Interestingly, even when presented with research findings about the potential benefits of protein supplementation, participants expressed a desire for more straightforward, personalised advice. This suggests a gap in the current dissemination of dietary information, particularly regarding protein, where the personalisation and simplification of guidance could play a role in improving understanding and adherence. Our data echo recent calls to provide education and increasing awareness of the benefits of protein consumption amongst older adults in order to promote greater protein intake (Linschooten et al., 2021; Norton et al., 2022).

The study participants overwhelmingly preferred natural dietary sources over supplementation. This preference is not just a matter of taste or habit; it also reflects a philosophical stance about what constitutes a healthy lifestyle. Preference for whole food rather than oral nutritional supplements has been shown previously (Jacobs et al., 2014; Griffiths et al., 2023), with van der Zanden et al. (2014) also identifying old adults' distrust of certain products they perceived to be supplements and not food. Our discussion about supplementing diets with protein powders revealed a reluctance to use such products unless as a last resort, with a notable emphasis on taste and naturalness. It perhaps should be considered that raising the awareness of the importance of protein for health ageing may lead to a greater willingness to try protein supplementation amongst older adults; but this is somewhat speculative. Nonetheless, our finding suggests that nutritional interventions targeting this demographic should perhaps be food-focused. Indeed, fortification of commonly-consumed foods with protein has proved an effective means of increasing protein in those in residential care (Beelen et al., 2017a), those in hospital (Mills et al., 2018) and those recently discharged (Beelen et al., 2017b). Our data support such approaches and suggest greater likely acceptability, compared with the use of supplements.

The present study is not without limitations. An optimal protein source for older adults would have a low satiety effect while also providing a range of amino acids, particularly essential amino acids and the anabolic amino acid leucine. While we did ensure leucine content reached 3g per 30g dose of GMP, a limitation of the present study was that we did not determine amino acid delivery through the measure of postprandial plasma amino acid concentration. In addition, the study sample size was determined to power the study to detect large differences in gut hormones. Consequently, the study may have been under-powered for the measure of subjective appetite and *ad libitum* food intake. However, the magnitude of difference in these two measures, particularly between the two protein conditions, were

sufficiently small to be confident of no type II statistical error. It is pertinent to also acknowledge the order effect for *ad libitum* food intake. As mentioned earlier, the counterbalancing of the study conditions should negate the order effect and as such, the current findings can be considered valid. Nonetheless, the observation of a greater intake in trial 3 is not easily explained, as a*d libitum* test meals have been shown to exhibit good reproducibility in younger adults (Gregersen et al., 2008; Horner et al., 2014). It is possible that participants underate due to observer bias (Robinson et al., 2015) in the early trials, and that this diminished with repeated trials. However, this cannot be confirmed.

We also acknowledge that a thorough assessment of all sensory responses to taste testing would require a larger sample size. Nonetheless, it is felt that the inclusion of both the sensory tests and the focus group in their present form strengthen this exploratory study by providing a mixed methods and interdisciplinary insight into the likely feasibility and acceptability of a GMP-based product for older adults. We are confident that our data, despite a small sample size, robustly indicates that more targeted product development is needed to attain more acceptable sensory properties. Future iterations of product development would require more thorough, adequately-powered, sensory assessment. Finally, we acknowledge that the cohort who took part in the focus group was predominantly female. A more balanced representation of men and women may have resulted in different attitudes towards supplement use, as men have been shown to be more receptive of supplements than women in cohorts of younger adults (Aguilar-Navarro et al., 2020)

CONCLUSION

This study would indicate that leucine-enriched GMP is unlikely to prove an effective protein source to meet the protein needs and preferences of older adults. It proved no less satiating than the more commonly-adopted and cost-effective whey protein. Low palatability ratings and negative attitudes towards protein supplementation suggest poor likely acceptability of a GMP-based drink for community-dwelling older adults. Indeed, our data is supportive of alternative means to supplementation for promoting protein intake in older adults. Providing trusted education on the importance of protein for healthy ageing and fortifying commonly-consumed “healthy” foods with protein should be pursued.

ACKNOWLEDGEMENTS

We would like express huge gratitude to our participants for taking part, and for making data collection such an enjoyable experience for the research team. We would like to thank our students Vicky Catterall, Beth Minion, Joe Ashworth, Monty Hardcastle, and Anna Brooks for supporting data collection. We also thank Agropur Ingredients (Eden Prairie, MN, USA) for providing GMP.

AUTHOR CONTRIBUTIONS

A.H., D.RC., and L.O. conceived the research question. A.H., D.R.C., K.B., R.S., and E.S. designed the study. A.H., K.B., R.S., and J.W. collected data. A.H., K.B., R.S., and J.W. conducted data analyses. A.H., K.B., R.S., and J.W. wrote the manuscript. D.R.C., E.S., and L.O. edited the manuscript. All authors approved the final version.

FUNDING

This work was supported by a Pump-Priming Award from the Food 4 Years Network. Milk Specialties Global provided a non-monetary contribution in the form of test drinks.

CONFLICT OF INTEREST

L.O. is an employee of Milk Specialties Global. L.O. contributed to the conception of the research question, but did not contribute to data collection, analyses, or interpretation.

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