

BMJ Open Knowledge and beliefs about dietary inorganic nitrate among UK-based nutrition professionals: development and application of the KINDS online questionnaire

Oliver M Shannon ¹, Giorgia Grisotto,¹ Abrar Babateen,¹ Andrea McGrattan,¹ Kirsten Brandt,¹ John C Mathers,¹ Mario Siervo^{1,2}

To cite: Shannon OM, Grisotto G, Babateen A, *et al.* Knowledge and beliefs about dietary inorganic nitrate among UK-based nutrition professionals: development and application of the KINDS online questionnaire. *BMJ Open* 2019;**9**:e030719. doi:10.1136/bmjopen-2019-030719

► Prepublication history and additional material for this paper are available online. To view these files, please visit the journal online (<http://dx.doi.org/10.1136/bmjopen-2019-030719>).

Received 28 March 2019
Revised 29 July 2019
Accepted 06 September 2019



© Author(s) (or their employer(s)) 2019. Re-use permitted under CC BY-NC. No commercial re-use. See rights and permissions. Published by BMJ.

¹Human Nutrition Research Centre, Institute of Cellular Medicine, Newcastle University, Newcastle upon Tyne, UK
²School of Life Sciences, The University of Nottingham Medical School, University of Nottingham, Nottingham, UK

Correspondence to

Dr Oliver M Shannon;
Oliver.Shannon@Newcastle.ac.uk

ABSTRACT

Objectives To examine knowledge and beliefs about the biological roles of dietary inorganic nitrate in UK-based nutrition professionals, and to explore potential differences by participants' education level.

Setting An online questionnaire was administered to UK-based nutrition professionals, exploring knowledge and/or beliefs across five areas: (1) health and performance effects of nitrate; (2) current and recommended intake values for nitrate; (3) dietary sources of nitrate; (4) methods of evaluating nitrate intake and (5) nitrate metabolism.

Participants One hundred and twenty-five nutrition professionals.

Primary outcome Knowledge and beliefs about inorganic nitrate.

Results Most nutrition professionals taking part in the survey had previously heard of inorganic nitrate (71%) and perceived it to be primarily beneficial (51%). The majority believed that nitrate consumption can improve sports performance (59%) and reduce blood pressure (54%), but were unsure about effects on cognitive function (71%), kidney function (80%) and cancer risk (70%). Knowledge of dietary sources of nitrate and factors affecting its content in food were generally good (41%–79% of participants providing correct answers). However, most participants were unsure of the average population intake (65%) and the acceptable daily intake (64%) of nitrate. Most participants (65%) recognised at least one compound (ie, nitric oxide or nitrosamines) that is derived from dietary nitrate in the body. Knowledge of nitrate, quantified by a 23-point index created by summing correct responses, was greater in individuals with a PhD ($p=0.01$; median (IQR)=13 (9–17)) and tended to be better in respondents with a masters degree ($p=0.054$; 13 (8–15)) compared with undergraduate-level qualifications (10 (2–14)).

Conclusions UK-based nutrition professionals demonstrated mixed knowledge about the physiology of dietary nitrate, which was better in participants with higher education. More efficient dissemination of current knowledge about inorganic nitrate and its effects on health to nutrition professionals will support them to make more informed recommendations about consumption of this compound.

Strengths and limitations of this study

- This is the first study to explore knowledge and beliefs around dietary inorganic nitrate in UK-based nutrition professionals.
- We provide a new questionnaire that may be used in future investigations to evaluate knowledge and beliefs of dietary inorganic nitrate in groups of professionals or countries.
- The sample size for this study is relatively modest.
- It is unknown how well the self-selected participants in this study reflect the wider community of nutrition professionals.

INTRODUCTION

Inorganic nitrate is a polyatomic ion naturally found in a range of foods such as green leafy vegetables and beetroot, and is also added in the form of nitrate salts (eg, sodium nitrate or potassium nitrate) as a preservative to processed meat products such as ham and bacon.^{1,2} For many years, consumption of this compound, alongside its reduction product nitrite, was believed to increase the risk of certain forms of cancer and methaemoglobinemia.³ As a consequence, acceptable daily intake (ADI) values of 0–3.7 mg/kg/day nitrate were established by WHO,⁴ and the concentration of nitrate in drinking water was restricted to 50 mg/L in the European Union and 44 mg/L in the USA.⁵ With emerging evidence, however, the negative health effects of nitrate, and the guidelines restricting consumption of this compound, have been questioned.^{1,3,6} Indeed, in 2010, WHO declared that there is 'inadequate evidence in humans for the carcinogenicity of nitrate in food'.⁷ Likewise, several investigations have demonstrated that nitrate in doses normally consumed in healthy diets does not cause

methaemoglobinaemia.^{8–10} Consequently, there has been a transition from viewing nitrate as a potentially harmful to a potentially beneficial dietary constituent, with many researchers now exploring the possible health effects of dietary inorganic nitrate. A key catalyst for this change was the discovery that nitrate is a substrate for production of the multifunctional gasotransmitter nitric oxide^{11 12} and, so, may influence a range of nitric oxide-mediated physiological processes with potentially beneficial effects. For example, several investigations have demonstrated that dietary supplementation with inorganic nitrate, typically in doses between 4 and 12 mmol/day (~250–750 mg/day), can reduce blood pressure (BP),^{13–17} improve endothelial function^{14 17 18} and, at least in recreationally active and moderately trained individuals, enhance exercise performance.^{19–24} In addition, several recent observational studies have linked increased nitrate intake with reduced risk of cardiovascular disease mortality,²⁵ atherosclerotic vascular disease²⁶ and ischaemic cerebrovascular disease.²⁷

Despite the growth in nitrate-related research in recent years, it is unclear how much this new information has ‘trickled down’ to the general field of nutrition professionals; no studies have evaluated knowledge of and beliefs about inorganic nitrate among nutrition professionals (or other cohorts) to date. For example, it is unclear whether nutrition professionals consider nitrate to be primarily beneficial or harmful, whether they are aware of the key dietary sources of inorganic nitrate, understand potential ways to evaluate nitrate intake and are aware of/agree with current guidelines for nitrate consumption. Gaining a greater insight into the knowledge of, and beliefs around, inorganic nitrate among nutrition professionals could provide detailed information on the practice of these individuals and identify if there may be a need for targeted educational initiatives around inorganic nitrate physiology and its effects on health. For example, for practitioners such as dietitians and nutritionists, knowledge of, and beliefs about, inorganic nitrate and health could influence their dietary recommendations around the overall daily intake of inorganic nitrate and consumption of nitrate-rich food sources.²⁸ Likewise, for university academics, knowledge of and beliefs about, inorganic nitrate and health could inform teaching practices and curricula and have a positive influence on student’s learning.²⁹ Nutrition professionals also advise public and commercial entities about food safety and health, requiring efficient dissemination of new knowledge to ensure guidelines are updated when appropriate.^{4 5 7} Therefore, in this study, we aimed to establish the current status of knowledge related to inorganic nitrate among nutrition professionals. We also explored whether knowledge of inorganic nitrate differed depending on the education level of participants.

METHODS

Participants

The present study recruited nutrition professionals as participants. Nutrition professionals were defined as individuals working in nutrition or nutrition-related fields, students studying nutrition or nutrition-related courses, and unemployed individuals qualified or with a professional interest in nutrition.

Questionnaire development

To evaluate knowledge of and beliefs about dietary inorganic nitrate among nutrition professionals, we developed a custom questionnaire—the Knowledge of Inorganic Nitrate Dietary Survey (KINDS; online supplementary data 1). The steps involved in questionnaire development are outlined below and in [figure 1](#).

Initial development

The initial questions for the KINDS were devised by OMS, GG, AB and MS during several in-person group discussions. Questions were subsequently developed and refined for clarity in consultation with JCM and KB. There were 12 key questions, which focused on participant knowledge or beliefs across five areas: (1) potential health and performance effects of dietary inorganic nitrate (questions 1–3); (2) current and recommended intake values for dietary inorganic nitrate consumption (questions 4–6); (3) dietary sources of inorganic nitrate and factors which influence the food content of this inorganic anion (questions 7–9); (4) methods of evaluating inorganic nitrate intake (question 10) and (5) nitrate metabolism (questions 11 and 12). Additional questions were included to determine participant demographics (ie, age, gender, education and employment status). The questionnaire was built using an online survey tool (Online Surveys, Bristol, UK).

Pilot testing

Following initial development of the KINDS, a pilot version was circulated to staff in the Human Nutrition Research Centre at Newcastle University, UK. Underneath each question, a feedback box was presented such that participants could provide comments and suggestions. Further development of the questionnaire was conducted following pilot testing. This included the reordering and rewording of several questions to improve flow and clarity.

Data collection

A final version of the questionnaire was approved by the research team following pilot testing (online supplementary data file 1). Subsequently, a brief description of the study aims and a link to the questionnaire was circulated to potential participants through UK-based nutrition societies (see Acknowledgements) via email, websites and/or social media (online supplementary data file 2). Additional participants were obtained by contacting UK-based universities currently offering an undergraduate or postgraduate degree in nutrition or nutrition-related course (ie, Nutrition, Dietetics, Food Sciences,

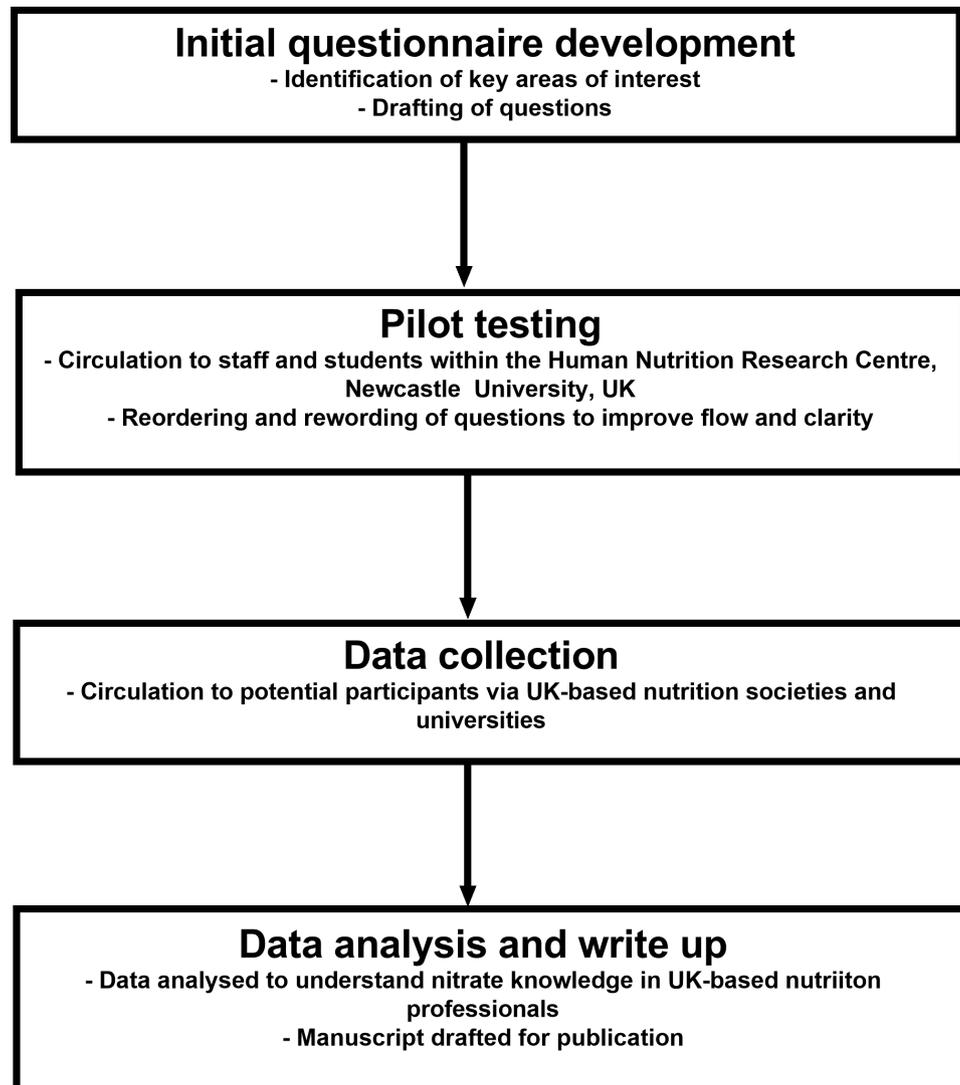


Figure 1 A schematic of the KINDS questionnaire development and analysis. KINDS, Knowledge of Inorganic Nitrate Dietary Survey.

Sport and Exercise Science), who were asked to circulate a link to the questionnaire to relevant staff and students. Data collection ran from 13 April to 31 December 2018.

Calculation of a Nitrate Knowledge Index

In addition to examining responses to individual questions on the questionnaire, we derived a 23-point index of nitrate knowledge. We identified by group consensus questions where there was clear evidence for a correct answer, and awarded one point for correct responses and zero points for incorrect responses. Questions where current evidence is ambiguous or where there is no correct response (ie, the answer reflects a belief or opinion on inorganic nitrate) were not included in the Index. Recently published systematic reviews and meta-analyses were used to inform these decisions.^{17 24 30 31}

Data analysis

All statistical analyses were conducted using SPSS V.24, and figures were produced using GraphPad Prism V.8. Statistical significance was defined as $p < 0.05$. We used the

χ^2 test to compare potential differences in questionnaire response by participant highest level of education (undergraduate degree or below, Masters degree or equivalent, PhD). Additionally, the Kruskal-Wallis test was used to compare scores between different education levels for the Nitrate Knowledge Index.

Patient and public involvement

There was no involvement of patients or the public in establishing the research questions of this study or defining the outcome measures. Likewise, patients/the public were not involved in the design, recruitment to, or conduct of this study. Patients or the public were not consulted regarding the interpretation or writing of the results. We do not have plans to disseminate the results of this study directly to participants. However, the data will be included in presentations given by the authors to a wide range of audiences.

RESULTS

A total of 125 individuals completed the KINDS online questionnaire (table 1). The majority of questionnaire

**Table 1** Participant characteristics

Participant characteristic	%
Gender	
Male	27
Female	73
Age (years)	
≤30	42
31–40	24
41–50	21
51–60	13
61–70	0
≥71	1
Highest qualification	
Undergraduate degree or below	23
Master's degree or equivalent	48
PhD	29

Data on participant highest qualification was available for n=124.

respondents were female (73%), aged ≤30 years (42%) and possessed a masters-level qualification (48%).

Overall nitrate knowledge

A summary of the results from this study is presented in [table 2](#). Overall, 71% of participants who took part in this survey had heard about inorganic nitrate, and 51% of participants believed that this polyatomic ion is primarily beneficial. Most participants were aware that inorganic nitrate can improve sports performance (59%) and reduce BP (54%), but were unsure about other physiological effects potentially associated with nitrate consumption including glucose levels (78%), lung function (73%), cancer risk (70%), cognitive function (71%) and kidney function (80%). Knowledge of nitrate intake and the ADI for this compound was generally poor. Indeed, 65% of participants were unsure of the average population intake of nitrate and 64% of participants were unsure of the nitrate ADI. Likewise, 80% of participants were unsure whether the ADI for nitrate required revision. Knowledge of dietary sources of inorganic nitrate and factors influencing the food content of nitrate was generally good, with 70%, 69%, 42% and 52% of participants correctly identifying spinach, beetroot, lettuce and radish as high in nitrate, and 46%, 51%, 43% and 42% of participants correctly identifying sausage, tomato, chocolate and bacon as low in nitrate. The majority of participants were aware that the nitrate content of food is influenced by cooking (59%), season (58%), soil conditions (79%), use of fertiliser (71%) and storage conditions (47%), all of which are consistent with current literature. However, most participants were unsure about the effect of pickling on food nitrate content (45%) and the nitrate content of drinking water (56%). There was no clear consensus on the best biomarker to monitor nitrate intake. Most participants (65%) were aware of at least one compound (ie, nitric

oxide or nitrosamines) that is derived from dietary nitrate in the body, but mixed responses were given for the mechanism involved in nitrate to nitrite conversion in the mouth. The median (IQR) score for the Nitrate Knowledge Index was 12^{7–16} out of 23 potential points.

Education-related differences in nitrate knowledge

Knowledge of inorganic nitrate was notably different between individuals with different education levels, with greater knowledge typically observed in those possessing a Masters degree or PhD compared with an undergraduate degree. Specifically, participants with a Masters degree or PhD were more likely to have heard of inorganic nitrate (undergraduate: 41%; Masters: 78%; PhD: 86%; $p=0.001$) and to perceive this compound as primarily beneficial (undergraduate: 28%; Masters: 63%; PhD: 53%; $p=0.002$), compared with those possessing an undergraduate degree or lower. More highly educated individuals were also more likely to agree that inorganic nitrate improves sports performance (undergraduate: 35%; masters: 71%; PhD: 64%; $p=0.017$) and reduces BP (undergraduate: 41%; masters: 53%; PhD: 69%; $p=0.016$). In addition, individuals with a PhD were more likely to estimate correctly the population mean nitrate intake of 50–200 mg/day (undergraduate: 3%; masters: 14%; PhD: 28%; $p=0.017$), while individuals with either a masters or PhD were more likely to correctly identify beetroot as a high nitrate food (undergraduate: 45%; masters: 76%; PhD: 81%; $p=0.020$). Participants with a PhD showed greatest knowledge of nitrate metabolism in the body and were more likely to identify correctly both compounds into which nitrate is converted in the body (undergraduate: 0%; masters: 7%; PhD: 31%; $p<0.001$). Conversely, none of the participants with an undergraduate-level degree identified both compounds which nitrate is converted into in the body. Likewise, individuals with a PhD were more likely to identify bacterial reductases as responsible for oral nitrate conversion into nitrite (undergraduate: 21%; masters: 31%; PhD: 58%; $p=0.012$). The median (IQR) scores for the Nitrate Knowledge Index for undergraduate, masters and PhD-level participants were 10,^{2–14} 13,^{8–15} 13,^{9–17} and were significantly different between groups ($p=0.01$). Post hoc analysis with Bonferroni adjustment revealed significantly greater nitrate knowledge in participants with a PhD versus undergraduate degree or below ($p=0.01$), and a trend towards greater nitrate knowledge in participants with a Masters degree or equivalent versus undergraduate degree or below ($p=0.054$; [figure 2](#)).

DISCUSSION

This study aimed to evaluate knowledge of and beliefs about dietary inorganic nitrate among nutrition professionals, and to compare knowledge and beliefs between individuals with different education levels. The key findings were that most individuals who responded to the survey had heard of inorganic nitrate, and perceived this compound to

Table 2 Nitrate knowledge in the overall cohort and when stratified by participant qualification status

Question	Overall (%)	Highest qualification (%)			P value
		≤BSc	MSc	PhD	
Health and performance effects of dietary inorganic nitrate					
1. Have you heard of inorganic nitrate?*					0.001
Yes	71	41	78	86	
No	14	31	10	2.8	
Unsure	15	28	12	11	
2. In your opinion, is dietary inorganic nitrate a primarily beneficial or harmful nutritional component?					0.002
Beneficial	51	28	63	53	
Harmful	9	10	3	17	
Unsure	35	59	32	19	
Other	5	3	2	11	
3. For each of the following variables, please specify if it is increased or decreased by dietary inorganic nitrate:					
Sports performance*					0.017
Increase	59	35	71	64	
Decrease	7	14	5	3	
Unsure	34	52	24	33	
Blood pressure*					0.016
Increase	10	7	17	0	
Decrease	54	41	53	69	
Unsure	36	52	31	31	
Glucose levels					0.409
Increase	5	3	9	0	
Decrease	17	21	15	17	
Unsure	78	76	76	83	
Lung function					0.179
Increase	23	21	28	17	
Decrease	4	10	3	0	
Unsure	73	69	69	83	
Cancer risk					0.697
Increase	18	17	14	26	
Decrease	12	14	12	11	
Unsure	70	69	74	63	
Cognitive function					0.113
Increase	27	11	37	22	
Decrease	2	4	2	3	
Unsure	71	86	61	75	
Kidney function					0.619
Increase	13	21	9	14	
Decrease	7	7	7	8	
Unsure	80	72	85	78	
Current and recommended intake values for nitrate					
4. In the general population, what is the average daily intake of dietary inorganic nitrate of an individual?*					0.017
≤10mg/day	6	7	10	0	

Continued



Table 2 Continued

Question	Overall (%)	Highest qualification (%)			P value
		≤BSc	MSc	PhD	
11–50 mg/day	10	7	17	3	
51–200 mg/day	15	3	14	28	
201–500 mg/day	3	3	5	0	
501–750 mg/day	0	0	0	0	
Unsure	65	79	54	69	
5. Do you know what is the acceptable daily intake (ADI) of dietary inorganic nitrate?*					0.302
Currently no ADI	11	14	13	6	
0.2 mg/kg body mass/day	2	3	0	3	
3.7 mg/kg body mass/day	21	7	24	28	
14.8 mg/kg body mass/day	2	3	2	0	
29.6 mg/kg body mass/day	1	3	0	0	
Unsure	64	69	61	64	
6. In your opinion, does the ADI for dietary inorganic nitrate require revision?					0.828
Yes—it should be higher	15	10	15	18	
Yes—it should be lower	2	3	2	3	
No	3	0	3	6	
Unsure	80	86	80	74	
Dietary sources of inorganic nitrate					
7. For the following foods, do you think they typically have a low (<50 mg/100 g fresh-weight) or high (>100 mg/100 g fresh-weight) dietary inorganic nitrate content?					
Spinach*					0.094
High	70	55	74	78	
Low	11	10	9	14	
Unsure	19	35	17	8	
Sausage*					0.087
High	30	28	22	44	
Low	46	38	54	42	
Unsure	23	35	24	14	
Tomato*					0.131
High	14	14	20	6	
Low	51	38	48	64	
Unsure	35	48	32	31	
Beetroot*					0.02
High	69	45	76	81	
Low	12	21	9	8	
Unsure	19	35	16	11	
Chocolate*					0.109
High	16	10	22	8	
Low	43	38	36	58	
Unsure	41	52	41	33	
Bacon*					0.19
High	35	31	27	49	

Continued

Table 2 Continued

Question	Overall (%)	Highest qualification (%)			P value
		≤BSc	MSc	PhD	
Low	42	38	51	31	
Unsure	23	31	22	20	
Lettuce*					0.362
High	42	31	43	50	
Low	33	31	33	33	
Unsure	25	38	24	17	
Radish*					0.189
High	52	35	55	64	
Low	20	24	19	17	
Unsure	27	41	26	19	
8. Which of the following factors do you think modify the inorganic nitrate content of food?					
Cooking*					0.332
Yes	59	46	68	53	
No	8	11	7	8	
Unsure	33	43	25	39	
Season*					0.203
Yes	58	54	54	69	
No	13	7	20	8	
Unsure	28	39	27	22	
Soil conditions*					0.05
Yes	79	64	80	89	
No	1	0	0	3	
Unsure	20	36	20	8	
Use of fertiliser*					0.176
Yes	71	57	72	78	
No	4	4	7	0	
Unsure	25	39	21	22	
Storage conditions*					0.698
Yes	47	39	50	47	
No	18	14	20	19	
Unsure	35	46	30	33	
Pickling*					0.171
Yes	41	29	51	34	
No	14	11	12	20	
Unsure	45	61	37	46	
9. How much dietary inorganic nitrate is there, on average, in drinking water?*					
<50 mg/L	40	35	44	39	0.711
51–100 mg/L	4	7	2	6	
101–200 mg/L	0	0	0	0	
201–300 mg/L	0	0	0	0	
Unsure	56	59	54	56	
Methods of evaluating inorganic nitrate intake					

Continued



Table 2 Continued

Question	Overall (%)	Highest qualification (%)			P value
		≤BSc	MSc	PhD	
10. Which biomarker would you choose to evaluate dietary inorganic nitrate intake?					0.155
Urinary nitrate	32	31	36	28	
Salivary nitrite	5	7	5	3	
Plasma nitrite	27	17	34	25	
Exhaled nitric oxide	7	3	5	14	
Unsure	27	41	20	25	
Other	2	0	0	6	
Nitrate metabolism					
11. In the body, which of the following compounds is dietary inorganic nitrate converted into?*†					<0.001
0 point	23	41	22	9	
1 point	65	59	71	60	
2 points	12	0	7	31	
12. Which one of these mechanisms is involved in the conversion of nitrate into nitrite in the mouth?*					0.012
C reactive protein	2	3	2	3	
Oxyhaemoglobin	2	0	5	0	
Salivary Amylase	19	14	27	11	
<i>Bacterial reductases</i>	36	21	31	58	
Unsure	40	62	36	28	

≤BSc=highest qualification is an undergraduate degree or below, MSc=Highest qualification is a master's degree or equivalent, PhD=highest qualification is a PhD or equivalent. *Italicised* answers are those identified as correct and awarded a point on the Nitrate Knowledge Index. For question 3, only sports performance and blood pressure were included in the Nitrate Knowledge Index, as evidence was deemed to be ambiguous for other physiological effects. All other questions (2, 6 and 10) were viewed as reflecting beliefs rather than knowledge of inorganic nitrate.

*Questions which were included in the construction of the Nitrate Knowledge Index (ie, those where clear evidence exists for a correct answer).

†Potential answers were nitric oxide, nitrosamines, nitroglycerine, carbon dioxide, adrenaline, glucose and unsure. Correct answers were nitric oxide and nitrosamines. If participants identified correct and incorrect answers, their score was capped to 1 point.

be primarily beneficial. Overall, participants showed good awareness of the dietary sources of inorganic nitrate and of the factors that may influence the food content of this anion. Conversely, participants showed poor knowledge of the concentration of nitrate in drinking water. Over half of our participants were unsure of the mean population intake of nitrate, the ADI for this compound and whether the ADI requires revision. Nitrate knowledge was greater in individuals with a PhD, and tended to be greater in individuals with a masters-level qualification, compared with those possessing an undergraduate degree.

The physiological effects of inorganic nitrate consumption have received considerable research interest in recent years. Strong evidence now exists showing the potential for supplemental nitrate to reduce BP^{13–17} and to enhance exercise performance^{19–24} in healthy individuals, although evidence in clinical populations is less clear.³² This growing evidence was reflected in participant responses, with over

half of participants stating that these were physiological effects of inorganic nitrate. Interestingly, in some areas, the nutrition professionals surveyed were more optimistic about beneficial effects of nitrate than justified by the present state of the knowledge. Over a quarter of participants believed that inorganic nitrate improves cognitive function, despite the lack of consistent evidence to support this notion,^{33–38} and a recent meta-analysis reporting no overall effect of nitrate on cognition or cerebral blood flow.³⁰ Similarly, almost a quarter of participants claimed that nitrate improved lung function, despite little evidence existing to support this notion.^{39–40} This illustrates the possible risk of 'overselling' the physiological benefits of any 'new' bioactives like nitrate, long before sufficient evidence is available to accurately assess the magnitudes of potential benefits for relevant population groups of short-term or long-term increases in intake.

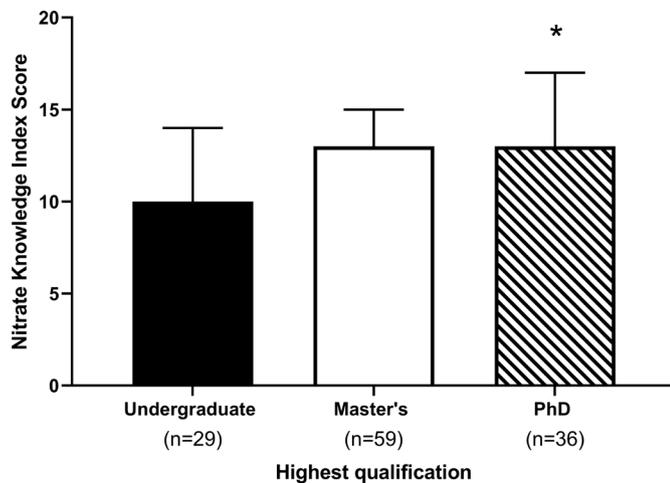


Figure 2 Overall scores for the Nitrate Knowledge Index split by participant highest qualification. Data are presented as median (IQR). *Significantly higher scores compared with undergraduate level ($p=0.01$). Information on participant highest qualification was available for $n=124$.

The current ADI for nitrate (0–3.7 mg/kg/day) has been questioned by several researchers in recent years^{13 6} so we explored participants views of this issue. We found that knowledge in this area was generally poor, with the majority of individuals surveyed unsure about the population mean intake of inorganic nitrate (65%) and the current ADI for this compound (64%). Moreover, most nutrition professionals were unsure about whether the ADI for nitrate requires revision (80%). Increasing knowledge in these areas could be valuable for two key reasons. First, it would allow more individuals to make informed contributions to the debate around nitrate consumption, and help derive consensus on whether the nitrate ADI requires revision. Second, it would help nutrition professionals (particularly those working as practitioners) make more informed recommendations around nitrate intake—something which is likely to be increasingly important in the coming years given the rising interest in nitrate among researchers and the public. Interestingly, most nutrition professionals showed good knowledge of dietary sources of nitrate and factors that influence the food content of this compound. This suggests that most nutrition professionals would be able to make recommendations as to how to increase or decrease intake of dietary nitrate. However, as discussed above, until recently such advice focused exclusively on reduction of what was considered a contamination risk. So, nutrition professionals are now faced with the much more challenging task to assess in which cases increased nitrate intake might be recommended and if so by how much.

Overall knowledge of inorganic nitrate, as reflected by the Nitrate Knowledge Index, was significantly better in individuals with a PhD and tended to be better in those possessing a Masters degree compared with those possessing an undergraduate-level qualification. Less than half of all individuals with an undergraduate-level qualification had heard of inorganic nitrate, and these participants were generally

unsure about the physiological effects, habitual consumption, sources and metabolism of nitrate. This finding is broadly consistent with previous studies which show greater knowledge of single dietary compounds such as sodium in individuals with a higher education level.⁴¹ Greater coverage of nitrate in undergraduate-level nutrition courses could be of particular value. Given the breadth of nitrate research including investigation of cellular mechanisms using in vivo and in vitro models, whole body physiology in clinical trials, epidemiology and public health, nitrate could serve as an excellent exemplar for teaching about nutrition research methodology. Increased awareness of dietary nitrate in nutrition professionals could also have implications for improving cardiovascular health in the general population given over 25% of adults in the UK possess elevated BP,⁴² and this polyatomic ion could represent a potential therapeutic intervention to target these ‘at-risk’ individuals.

Strengths and limitations

This study provides novel information on nitrate knowledge and beliefs among nutrition professionals, using a new questionnaire which could be used to evaluate nitrate knowledge and beliefs in other groups of professionals or other countries. Nevertheless, our study has certain limitations. The sample size in this investigation was relatively modest and self-selected, making it possible that our results may not be fully representative of the community of nutrition professionals. We attempted to reach as wide an audience as possible by circulating the questionnaire through several nutrition societies and universities, but it is possible that we did not reach all relevant groups of nutrition professionals. Importantly, those who responded to the questionnaire may have a greater interest in nitrate than non-respondents, potentially skewing our results to suggest greater nitrate knowledge than is present in the whole field of nutrition professionals.⁴³ We provide new information on differences in nitrate knowledge based on education level, which could be used to inform curriculum development on nutrition-related courses including Continued Professional Development. However, we were unable to compare knowledge of nitrate between individuals employed in different fields of nutrition because many participants identified simultaneously practising across a range of different nutrition areas. Therefore, potential differences in nitrate knowledge between nutrition professionals with different academic and non-academic roles remains unclear.

CONCLUSION

This study provides novel information on knowledge of and beliefs about inorganic nitrate among nutrition professionals. Our findings suggest that while many nutrition professionals have good awareness of dietary sources of this inorganic anion and of the factors affecting the food content of nitrate, knowledge of health-related effects of nitrate are more variable, which may reflect the rapidly evolving state of the knowledge in this nascent

research area. Knowledge of current and recommended values for nitrate intake was generally poor, and knowledge was overall much lower in those with an undergraduate versus masters or PhD-level qualification. Increasing education about inorganic nitrate and its impact on health, with an emphasis on recent developments in the scientific consensus, particularly at undergraduate level, but also as among graduates, may be advantageous to empower nutrition professionals to make more informed recommendations about this compound and adapt appropriately to new developments.

Correction notice This article has been corrected since it was published.

Twitter Oliver M Shannon @Oli_Shannon

Acknowledgements The authors thank the following nutrition societies for circulating the questionnaire to their members: the Association for Nutrition (AfN), the British Association for Parenteral and Enteral Nutrition (BAPEN), the British Dietetics Association (BDA), the Need for Nutrition Education Program (NEdPRO) and the Sport and Exercise Nutrition Register (SENR).

Contributors MS conceived the study and designed the study alongside OMS, GG, AB, AM, JCM and KB. OMS conducted the statistical analysis, with guidance from MS. OMS and MS drafted the manuscript. All the authors participated in the interpretation of the results and critical revision of the manuscript and approved the final version. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests All authors have completed the ICMJE uniform disclosure form at www.icmje.org/doi_disclosure.pdf. MS and JCM report grants from Alzheimer's Research UK during the conduct of the study. All other authors report no conflict of interest. All authors report no financial relationships with any organisations that might have an interest in the submitted work in the previous three years and no other relationships or activities that could appear to have influenced the submitted work.

Patient consent for publication Not required.

Ethics approval The study was approved by the Newcastle University Ethics Committee (4961/2018).

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement No data are available.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: <http://creativecommons.org/licenses/by-nc/4.0/>.

ORCID iD

Oliver M Shannon <http://orcid.org/0000-0001-8208-6837>

REFERENCES

- Hord NG, Tang Y, Bryan NS. Food sources of nitrates and nitrites: the physiologic context for potential health benefits. *Am J Clin Nutr* 2009;90:1–10.
- Blekkhorst LC, Prince RL, Ward NC, et al. Development of a reference database for assessing dietary nitrate in vegetables. *Mol Nutr Food Res* 2017;61. doi:10.1002/mnfr.201600982. [Epub ahead of print: 03 May 2017].
- Benjamin N. Nitrates in the human diet - good or bad? *Annales de Zootechnie* 2000;49:207–16.
- European Food Safety Authority. Nitrate in vegetables scientific opinion of the panel on contaminants in the food chain. *Efsa J* 2008;689:1–79.
- World Health Organization. Recommendations; nitrate and nitrite. In: *Guidelines for drinking water quality*. Geneva, Switzerland: WHO, 2004: 417–20.
- Fewtrell L. Drinking-Water nitrate, methemoglobinemia, and global burden of disease: a discussion. *Environ Health Perspect* 2004;112:1371–4.
- World Health Organization/International Agency for Research on Cancer. *IARC monographs on the evaluation of carcinogenic risks to humans. Volume 94: ingested nitrate and nitrite, and cyanobacterial peptide toxins*. Lyon, France: IARC, 2010.
- Cornblath M, Hartmann AF. Methemoglobinemia in young infants. *J Pediatr* 1948;33:421–5.
- Avery AA. Infantile methemoglobinemia: reexamining the role of drinking water nitrates. *Environ Health Perspect* 1999;107:583–6.
- Powlson DS, Addiscott TM, Benjamin N, et al. When does nitrate become a risk for humans? *J Environ Qual* 2008;37:291–5.
- Benjamin N, O'Driscoll F, Dougall H, et al. Stomach NO synthesis. *Nature* 1994;368:502.
- Lundberg JO, Weitzberg E, Lundberg JM, et al. Intra-gastric nitric oxide production in humans: measurements in expelled air. *Gut* 1994;35:1543–6.
- Larsen FJ, Ekblom B, Sahlin K, et al. Effects of dietary nitrate on blood pressure in healthy volunteers. *N Engl J Med* 2006;355:2792–3.
- Webb AJ, Patel N, Loukogeorgakis S, et al. Acute blood pressure lowering, vasoprotective, and antiplatelet properties of dietary nitrate via bioconversion to nitrite. *Hypertension* 2008;51:784–90.
- Vanhatalo A, Bailey SJ, Blackwell JR, et al. Acute and chronic effects of dietary nitrate supplementation on blood pressure and the physiological responses to moderate-intensity and incremental exercise. *Am J Physiol Regul Integr Comp Physiol* 2010;299:R1121–31.
- Siervo M, Lara J, Ogbonmwan I, et al. Inorganic nitrate and beetroot juice supplementation reduces blood pressure in adults: a systematic review and meta-analysis. *J Nutr* 2013;143:818–26.
- Jackson JK, Patterson AJ, MacDonald-Wicks LK, et al. The role of inorganic nitrate and nitrite in cardiovascular disease risk factors: a systematic review and meta-analysis of human evidence. *Nutr Rev* 2018;76:348–71.
- Siervo M, Scialò F, Shannon OM, et al. Does dietary nitrate say no to cardiovascular ageing? Current evidence and implications for research. *Proc Nutr Soc* 2018;77:112–23.
- Bailey SJ, Winyard P, Vanhatalo A, et al. Dietary nitrate supplementation reduces the O₂ cost of low-intensity exercise and enhances tolerance to high-intensity exercise in humans. *J Appl Physiol* 2009;107:1144–55.
- Lansley KE, Winyard PG, Bailey SJ, et al. Acute dietary nitrate supplementation improves cycling time trial performance. *Med Sci Sports Exerc* 2011;43:1125–31.
- Porcelli S, Ramaglia M, Bellistri G, et al. Aerobic fitness affects the exercise performance responses to nitrate supplementation. *Med Sci Sports Exerc* 2015;47:1643–51.
- Shannon OM, Barlow MJ, Duckworth L, et al. Dietary nitrate supplementation enhances short but not longer duration running time-trial performance. *Eur J Appl Physiol* 2017;117:775–85.
- Shannon OM, McGawley K, Nybäck L, et al. 'Beet-ing' the mountain: a review of the physiological and performance effects of dietary nitrate supplementation at simulated and terrestrial altitude. *Sports Med* 2017;47:2155–69.
- McMahon NF, Leveritt MD, Pavey TG. The effect of dietary nitrate supplementation on endurance exercise performance in healthy adults: a systematic review and meta-analysis. *Sports Med* 2017;47:735–56.
- Liu AH, Bondonno CP, Russell J, et al. Relationship of dietary nitrate intake from vegetables with cardiovascular disease mortality: a prospective study in a cohort of older Australians. *Eur J Nutr* 2019;58:2741–53.
- Blekkhorst LC, Bondonno CP, Lewis JR, et al. Association of dietary nitrate with atherosclerotic vascular disease mortality: a prospective cohort study of older adult women. *Am J Clin Nutr* 2017;106:207–16.
- Bondonno CP, Blekkhorst LC, Prince RL, et al. Association of vegetable nitrate intake with carotid atherosclerosis and ischemic cerebrovascular disease in older women. *Stroke* 2017;48:1724–9.
- Williams L. Research in dietetic practice and education: insights from the sociological perspective. *Nutr Diet* 2016;73:217–9.
- Kane R, Sandretto S, Heath C. An investigation into excellent tertiary teaching: emphasising reflective practice. *High Educ* 2004;47:283–310.
- Clifford T, Babateen A, Shannon OM, et al. Effects of inorganic nitrate and nitrite consumption on cognitive function and cerebral blood flow: a systematic review and meta-analysis of randomized clinical trials. *Crit Rev Food Sci Nutr* 2019;59:2400–10.

- 31 Babateen AM, Fornelli G, Donini LM, *et al.* Assessment of dietary nitrate intake in humans: a systematic review. *Am J Clin Nutr* 2018;108:878–88.
- 32 Blekkenhorst LC, Bondonno NP, Liu AH, *et al.* Nitrate, the oral microbiome, and cardiovascular health: a systematic literature review of human and animal studies. *Am J Clin Nutr* 2018;107:504–22.
- 33 Gilchrist M, Winyard PG, Fulford J, *et al.* Dietary nitrate supplementation improves reaction time in type 2 diabetes: development and application of a novel nitrate-depleted beetroot juice placebo. *Nitric Oxide* 2014;40:67–74.
- 34 Thompson KG, Turner L, Prichard J, *et al.* Influence of dietary nitrate supplementation on physiological and cognitive responses to incremental cycle exercise. *Respir Physiol Neurobiol* 2014;193:11–20.
- 35 Thompson C, Wylie LJ, Fulford J, *et al.* Dietary nitrate improves sprint performance and cognitive function during prolonged intermittent exercise. *Eur J Appl Physiol* 2015;115:1825–34.
- 36 Kelly J, Fulford J, Vanhatalo A, *et al.* Effects of short-term dietary nitrate supplementation on blood pressure, O₂ uptake kinetics, and muscle and cognitive function in older adults. *Am J Physiol Regul Integr Comp Physiol* 2013;304:R73–83.
- 37 Bondonno CP, Downey LA, Croft KD, *et al.* The acute effect of flavonoid-rich apples and nitrate-rich spinach on cognitive performance and mood in healthy men and women. *Food Funct* 2014;5:849–58.
- 38 Shannon OM, Duckworth L, Barlow MJ, *et al.* Effects of dietary nitrate supplementation on physiological responses, cognitive function, and exercise performance at moderate and very-high simulated altitude. *Front Physiol* 2017;8:401.
- 39 Behnia M, Wheatley CM, Avolio A, *et al.* Influence of dietary nitrate supplementation on lung function and exercise gas exchange in COPD patients. *Nitric Oxide* 2018;76:53–61.
- 40 Cumpstey AF, Hennis PJ, Gilbert-Kawai ET, *et al.* Effects of dietary nitrate on respiratory physiology at high altitude - Results from the Xtreme Alps study. *Nitric Oxide* 2017;71:57–68.
- 41 Patel D, Cogswell ME, John K, *et al.* Knowledge, attitudes, and behaviors related to sodium intake and reduction among adult consumers in the United States. *Am J Health Promot* 2017;31:68–75.
- 42 Forouzanfar MH, Alexander L, Anderson HR, *et al.* Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks in 188 countries, 1990–2013: a systematic analysis for the global burden of disease study 2013. *Lancet* 2015;386:2287–323.
- 43 Kelley K, Clark B, Brown V, *et al.* Good practice in the conduct and reporting of survey research. *Int J Qual Health Care* 2003;15:261–6.