RESEARCH



Exploring the future of nutrigenomics: dietitians' perceptions on integration in Indian practice

Naomi Angelo Dias Do Rosario¹, Devaki Gokhale^{1*} and Manisha Gore²

Abstract

Background Nutrigenomics, the study of nutrient-gene interactions, holds immense potential for alleviating India's overburdened healthcare system and improving overall health-related quality of life. Yet, its utility remains in the nascent stages. To understand the factors affecting the implementation of nutrigenomics, we investigate the perceptions of practising dietetic professionals.

Objective The purpose of this study was to investigate the perceptions of Indian dietetic professionals related to the implementation of Nutrigenomics and to understand the factors affecting it.

Methods A total of 249 Indian dietetic professionals participated in an online survey between April 2024 - May 2024. This data was then statistically analyzed using the Chi-square test and Fisher's Exact test. Furthermore, in-depth interviews were conducted for 10 out of the 249 participants, the data collected from the interviews were analysed using reflexive thematic analysis.

Results Majority of the dietetic professionals had high awareness (97.2%) and interest (87.5%) in incorporating genetic testing into their practice. While the survey identified several barriers to its integration, such as high costs, (p-value = 0.000), lack of clinical trials (p-value = 0.013), and ethical concerns (p-value = 0.023). The in-depth interviews highlighted the need for increased education, standardization of testing panels, and collaboration among healthcare professionals to enhance the feasibility of nutrigenomics integration.

Conclusion Indian dietetic professionals express a positive outlook on integrating nutrigenomics into mainstream healthcare practice. However, successful establishment of personalized nutrition in India also requires addressing key challenges with respect to education, cost, training, development of regulatory frameworks and raising public awareness.

Keywords Nutrigenomics, Personalized nutrition, Dietetic professional, Perceptions

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Introduction

Nutrigenomics is an emerging field that integrates nutrition, molecular biology, genetics and omics technology to study how nutrients influence gene expression, enabling the development of personalized dietary recommendations [1]. By leveraging genetic data, nutrigenomics helps identify various health and nutrition risks, thereby improving health outcomes and overall quality of life [2]. This field holds the potential to revolutionize the prevention and management of non-communicable diseases (NCDs) [3], as well as optimize athletic performance through tailored dietary recommendations and individualized training adaptations [4]. Additionally, nutrigenomics enables precise identification and correction of micronutrient deficiencies by targeting genetic factors affecting nutrient absorption and metabolism [1].

The prevalence of NCDs in India has substantially grown, with an observed 36% increase in diseases like diabetes [5, 6] and 35.5% increase in hypertension [7]. Despite high awareness surrounding NCDs, the treatment and control rates remain low [8]. This necessitates improvements in prevention strategies and increased public health funding to mitigate its escalating burden and strain on the healthcare system [9]. Targeting nutritional intake is a cost-effective way to promote a healthy lifestyle and prevent NCDs [10].

Personalized nutrition recommendations, such as those guided by nutrigenomics, are found to be more effective than general guidelines in improving individuals' health and performance outcomes while eliciting sustained positive behaviour change [11]. Identifying disease predispositions allows tailored lifestyle changes that prevent or delay disease onset [12]. NCDs like obesity, type 2 diabetes, and cardiovascular disease are influenced by a complex interplay of genetic and environmental factors, the application of nutrigenomics could provide significant insights into identifying and addressing these [13]. Even in diseases like cancer and obesity, nutrigenomics demonstrates how bioactive components present in foods can be utilized to modulate gene expression and thereby prevention [14].

Personalized nutrition, akin to precision nutrition, encompasses a framework that considers factors such as genetics, lifestyle, dietary habits, microbiome, and socioeconomic status [15]. Countries like Malaysia have taken cognisance of the role of nutrigenomics and personalized nutrition in addressing health challenges. They have developed frameworks for implementating these approaches to tackle the country's triple burden of malnutrition [16].

An Indian study by Mathew and colleagues (2023) [3] among dietitians and nutritionists found that while most had heard of genetic testing for personalized diets, their knowledge about it was limited; highlighting the need

for developing professional competency and confidence in this realm [17]. Despite this, the study [3] indicated that dietitians believed understanding individual genetic needs could improve dietary recommendations for managing NCDs and their outcomes in the Indian setting. Aligning with the findings of a previous study, that undergraduates showed a strong interest in pursuing further education in nutrigenomics, although they had limited knowledge of genetic testing [18]. These studies strongly suggested improvements in education, creation of guidelines and training workshops in nutrigenomics to enhance the understanding of research methods and applications for academics and stakeholders [3, 16]. However, these and prior studies presented inconsistent results, with some lacking sufficient detail with regard to insights into the facilitators, barriers, and feasibility of nutrigenomics implementation [19].

Several barriers hinder the proper implementation of nutrigenomic testing, such as, high cost of testing, insufficient clinical data, lack of education and training opportunities for healthcare professionals and ethical considerations [20]. Despite these challenges, with the increasing awareness surrounding nutrigenomics also comes a growing demand among health professionals to pursue and implement education and training related to personalized nutrition [14]. Nonetheless, dietetic professionals, including registered dietitians (RDs) and registered dietitian nutritionists (RDNs) [21], are identified as key players [22] to bridge the translational gap between research and practice in personalized nutrition [20].

Successful implementation of nutrigenomics is dependent on evidence-based science and acceptance from health professionals and consumers [14, 23]. Understanding the perceptions of dietetic professionals about integrating nutrigenomics into nutrition practice is thus crucial to its implementation [20].

Studies have highlighted the urgent need for further training to address barriers perceived by RDs in implementing nutrigenomics, emphasizing the importance of exploring genetic testing's feasibility and cost-effectiveness while addressing challenges such as skepticism, regulatory concerns, and health inequalities, in lieu of diverse understudied genetic ethnicities like those of Southeast Asia and Maori, for instance [13, 24]. Overall, ongoing education and training programs were deemed essential to enhance healthcare professionals' understanding and effective application of nutrigenomics [19, 20, 25, 26].

The scarcity of global studies on the viewpoints of dietetic professionals, particularly in India underscores the need for further research, specifically on their perceptions of the facilitators, barriers, and feasibility of implementing nutrigenomics in practice. While studies like Mathew et al. (2023) reveal that Indian dietitians have heard of genetic testing for personalized diets, their practical knowledge remains limited [3]. This is consistent with global findings where challenges such as the high cost of testing, insufficient clinical data, and lack of education and training opportunities hinder effective implementation [13, 20]. Despite growing awareness and interest in nutrigenomics, barriers like a lack of regulatory frameworks and professional competency have limited its uptake in countries like India. For example, Malaysia has laid down frameworks for nutrigenomics training to address its triple burden of malnutrition [16]. However, India lacks these critical systems, and no studies have comprehensively explored how Indian dietitians perceive the practical challenges and benefits of nutrigenomics.

The aim of this study is to investigate the perceptions of Indian dietetic professionals regarding the implementation of nutrigenomics and to identify the factors influencing its feasibility, including barriers and facilitators. This study seeks to bridge this knowledge gap and contribute to the limited data on nutrigenomics in India. By adopting a mixed-methods approach, the study provides a comprehensive understanding of the factors affecting nutrigenomics implementation through both, qualitative and quantitative insights. This approach was chosen to capture the depth of the dietitians' experiences and attitudes, while also quantifying trends and key factors influencing the successful integration of nutrigenomics into Indian healthcare practice. We hypothesize that integrating nutrigenomics will significantly improve personalized dietary planning, preventive healthcare, and national health outcomes in India.

Materials and methods

Data collection

A cross-sectional mixed-methods study design was adopted to collect comprehensive evidence. To ensure a robust sample, the sample size was calculated using Cochran's formula: $n = Z^2 p (1-p) / d^2$, where Z = 1.96 (95%)confidence interval), p = expected proportion of population based on previous studies (50%) and D = 0.5 (absolute error of precision) [27]. Based on this calculation, a sample size of 461 was targeted, accounting for a 20% attrition rate [3]. Invitations were sent between April 2024 and May 2024 via various social networking platforms, utilizing a convenience sampling method. Prior to this, a pilot test was conducted to ensure reliability of the data collection process. The study included active dietetic professionals who had obtained tertiary education in nutrition and dietetics. In contrast, those who were inactive or who had completed only a 3-6 month certificate course in nutritional science were excluded to maintain the study's focus on professionals with substantial educational backgrounds. The mixed-methods approach, combining both quantitative and qualitative data, allowed for a deeper exploration of the perceptions and factors influencing the adoption of nutrigenomics in dietetic practice in India.

Questionnaire development

Survey

A self-administered online questionnaire was developed as the primary tool for quantitative data collection. It consisted of close-ended questions and included a mix of dichotomous ("yes" or "no") questions and items measured on a 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). This would assess preexisting awareness of nutrigenomics, as well as perceived motivators, facilitators and barriers, to its integration. The questionnaire was embedded as a Google Form link within the invitation message sent to potential participants. This link also included a subject information sheet and an informed consent form, presented at the beginning of the questionnaire, to ensure participants were fully informed about the study's purpose, procedures, and potential implications before providing their consent to participate. The questionnaire was carefully adapted from previous studies [3, 13] and underwent a pilot testing for refinement and improved clarity. It was also translated into English and Hindi to accommodate participants from different linguistic backgrounds across India. Additionally the questionnaire obtained a Cronbach's alpha reliability score of 0.85, indicating a high level of internal consistency and reliability [28]. The estimated time to complete the survey was approximately five minutes, making it convenient for busy professionals to participate.

Interview

Semi structured in-depth interviews were conducted to collect qualitative data, this would provide first hand insights from dietetic professionals on the implementation of nutrigenomics in India. Participants were selected based on their experience with or interest in nutrigenomics using a purposive sampling method to ensure a diverse range of perspectives and were drawn from the initial survey respondents. The interview questionnaire was reviewed by a qualitative methods expert, pilot-tested and translated into English and Hindi. It included questions related to interests, challenges, motivators, prospects and the feasibility of implementing nutrigenomics. The interview guide underwent iterative refinement based on feedback from pilot testing, ensuring clarity and relevance of the questions. The interviews were conducted via an online video communication platform to accommodate participant's schedule and locations ensuring convenience and flexibility. The estimated duration of each interview was 45-60 min. The study received ethical approval from the relevant institutional review board, and informed consent was obtained from all participants prior to the interviews. All ten in-depth interviews were transcribed verbatim to preserve the authenticity of the participants' responses.

Data analysis

Once the data collection was completed, the survey responses were downloaded from Google Sheets and exported onto the SPSS Software Version 29 where descriptive statistical analysis was done to summarize key findings. Inferential tests, including the chi-square test and Fisher's Exact Test, were conducted to identify significant relationships between categorical variables. In parallel, the in-depth interview transcriptions were analyzed using the reflexive thematic analysis, allowing for a nuanced and exploratory examination of complex themes [29]. This approach enabled identification of key themes and subthemes directly from the data. Combining both quantitative and qualitative methods provided a comprehensive understanding of the topic, with the statistical relationships complementing the depth of the themes explored through the interviews.

Results

Study population

The socio-demographic details of the subjects are presented in Table 1. Of the 452 invitations sent, 249 survey responses and 10 complete interview responses were recorded. Participants had a mean age of 27.3 ± 5.8 years, with the majority being females (91.2%, n = 227). A significant portion of respondents (92.8%, n = 231) reported having a postgraduate degree in nutritional science as

 Table 1
 Participant characteristics

their highest education qualification. Most participants were from West India (48.6%, n = 121) and South India (32.5%, n = 81). Nearly half (41%, n = 102) of the participants were employed in the private sector. The majority (75.5%, n = 188) had less than 5 years of on-field experience. Less than a third (29.35%, n = 71) of participants were nutrigenomics integrators, whereas more than half (66.6%, n = 168) were non-integrators.

Survey

As shown in Table 2, dietetic professionals were largely aware of the term 'Nutrigenomics' (97.2%, n = 242), with almost three-fourths considering personal genetic tests and having read related literature. Most (87.5%, n = 218) were keen to learn more. However, only 47.4% (*n* = 118) received nutrigenomics education as their qualification; 66.7% (n = 166) did not offer nutrigenomics counseling, compared to 33.3% (n = 83) who did. Nearly all participants (99.2%, n = 247) viewed genetic testing as important to the health industry. However, nearly half (46.6%, n = 116) felt dietetic professionals were not equipped to provide gene-based nutrition counselling. A similar proportion (46.6%, n = 116) expressed a neutral stance and only a small minority (6.8%, n = 17) felt they were equipped. A large majority (96.8%, n = 241) of dietetic professionals were open to changing aspects of their practice based on new knowledge regarding nutrigenomics. Statistically significant differences were not observed for pre-existing nutrigenomics awareness between dietetic professionals who were nutrigenomics integrators and non-integrators.

A great proportion of dietetic professionals perceived that integrating nutrigenomics would provide multiple

		Survey participants		Interview participa	Interview participants	
		n	%	n	%	
Gender (<i>n</i> = 249)	Female	217	87	10	4.2	
	Male	22	8.8	-	-	
Highest Education Qualification ($n = 249$)	Postgraduate	221	88.8	10	4	
	Graduate	18	7.2	-	-	
Geographic Zones (n = 249)	North India	34	13.7	-	-	
	South India	81	32.5	5	2	
	East India	13	5.2	1	0.4	
	West India	121	48.6	4	1.6	
Practice Setting (n = 249)	Corporate Set-Up	69	27.7	8	3.2	
	Private Set-Up	102	41	1	0.4	
	Hospital	44	17.7	-	-	
	Research Institute	24	9.6	1	0.4	
Years of Experience ($n = 249$)	< 5 years	188	75.5	10	4.1	
	> 5 years	51	20.4	-	-	
Nutrigenomics Integration $(n = 249)$	Integrators	71	28.5	10	4	
	Non-integrators	168	67.5	-	-	

Table 2 Perceptions related to integration of nutrigenomics - survey

	Integrator n (%)	Non-integrator n (%)	<i>p</i> -value
Pre-existing nutrigenomics awareness			
Have you or Would you consider getting a genetic test for yourself? ($n = 249$)			0.639
Yes	61 (75.3)	125 (74.4)	
No	3 (3.7)	11 (6.5)	
Maybe	17 (21)	32 (19)	
Have you heard of the term 'Nutrigenomics' before? ($n = 249$)			-
Yes	79 (97.5)	163 (97)	
No	2 (2.5)	5 (3)	
Was Nutrigenomics taught as a part of your qualification? ($n = 249$)			0.359
Yes	46 (56.8)	85 (50.6)	
No	35 (43.2)	83 (49.4)	
Provided counselling to clients/patients related to nutrigenomics in the past year? ($n = 249$)			0.151
Yes	32 (39.5)	51 (30.4)	
No	49 (60.5)	117 (69.6)	
Read scientific literature related to nutrigenomics in the past year. ($n = 249$)		, , ,	0.191
Yes	57 (70.4)	131 (78)	
No	24 (29.6)	37 (22)	
Interested in learning more about Nutrigenomics ($n = 249$)	_ (,		0.094
Yes	75 (92.6)	143 (85 1)	0.00
Maybe	6 (7 4)	25 (14.9)	
How important do you think genetic testing is in the medical/health industry? ($n = 240$)	0 (7.1)	25 (11.5)	_
Not important	0 (0)	2 (1 2)	
	81 (100)	166 (98.8)	
How equipped are distitians/nutritionists to provide nutrigenomics counselling? $(n - 240)$	01 (100)	100 (50.0)	0 050
Not equipped	38 (46 0)	78 (16 1)	0.757
Norteal	37 (45.7)	70 (40.4)	
Fouriered	57 (+5.7)	1 (4 F)	
Likeliness to change accests of your practice due to new knowledge regarding putrigenemics?	(n - 240)	11 (0.3)	0.152
Likeliness to change aspects of your practice due to new knowledge regarding nutrigenomics:	(11-249)	72 (12 5)	0.155
Likely	45 (55.1)	7 S (43.5) OF (F6.F)	
Not likely	56 (40.9)	95 (50.5)	
Creater individualization of dist preserviction (personal putrition) (n = 240)			0.410
	2 (2 7)	4 (2.4)	0.410
Disagree	5 (5.7)	4 (2.4)	
	0 (7.4)	21 (12.5)	
Agree	72 (88.9)	143 (85.1)	0.012.8
Stronger foundations for nutrition. ($n = 249$)	1 (1 2)	2 (1 0)	0.013 -
Disagree	1 (1.2)	3 (1.8)	
Neutral	18 (22.2)	15 (8.9)	
Agree	62 (76.5)	150 (89.3)	0.064
Dietary prescriptions that would effectively manage or prevent certain diseases. ($n = 249$)	0 (0 0)	())	0.064
Disagree	8 (9.9)	6 (3.6)	
Neutral	25 (30.9)	43 (25.6)	
Agree	48 (59.3)	119 (70.8)	
Perceived Consumer Motivators Affecting the Implementation of Nutrigenomics			
Motivated by desire to prevent or manage disease. $(n = 249)$			0.011 ª
Disagree	9 (11.1)	5 (3.0)	
Neutral	23 (28.4)	37 (22)	
Agree	49 (60.5)	126 (75)	
Prevent a disease based on family history. ($n = 249$)			0.005 ^a
Disagree	4 (4.9)	0 (0)	
Neutral	17 (21)	24 (14.3)	
Agree	60 (74.1)	144 (85.7)	

Table 2 (continued)

	Integrator	Non-integrator	<i>p</i> -value
Control hoalth outcomes based on family history $(n - 240)$	11 (%)	11 (%)	0.054
	E (6 3)	6 (2 6)	0.054
Disagree	D (0.2)	0 (0.0)	
	29 (55.0)	39 (Z3.Z) 133 (Z2.3)	
Agree	47 (58)	123 (73.2)	0.200
The prove overall health-felated quality of file. $(n = 249)$	4 (4 0)	2 (1 0)	0.200
Disagree	4 (4.9)	3 (1.8)	
Neutral .	18 (22.2)	31 (18.5)	
Agree	59 (72.8)	134 (79.8)	
Perceived Barriers Affecting the Implementation of Nutrigenomics			
Cost concerns. $(n = 249)$			0.000 ª
Disagree	15 (18.5)	13 (7.7)	
Neutral	33 (40.7)	41 (24.4)	
Agree	33 (40.7)	114 (67.9)	
Not enough experts to convey professional expertise. $(n = 249)$			0.000 ^a
Disagree	8 (9.9)	1 (0.6)	
Neutral	19 (23.5)	22 (13.1)	
Agree	54 (66.7)	145 (86.3)	
Lack of Continuing Education for Healthcare Professionals. ($n = 249$)			0.003 ^a
Disagree	10 (12.3)	14 (8.3)	
Neutral	29 (35.8)	31 (18.5)	
Agree	42 (51.9)	123 (73.2)	
Lack of Continuing Education for Consumers. ($n = 249$)			0.003 ^a
Disagree	6 (7.4)	3 (1.8)	
Neutral	25 (30.9)	30 (17.9)	
Agree	50 (61.7)	135 (80.4)	
Limited access to Nutrigenomics for clients or patients. ($n = 249$)			0.000 ^a
Disagree	6 (7.4)	5 (3)	
Neutral	24 (29.6)	20 (11.9)	
Agree	51 (63)	143 (85.1)	
Confidentiality issues. ($n = 249$)			0.002 ^a
Disagree	9 (11.1)	17 (10.1)	
Neutral	27 (33.3)	24 (14.3)	
Aaree	45 (55.6)	127 (75.6)	
Moral concerns ($n = 249$)			0.044 ^a
Disagree	9 (11.1)	17 (10.1)	
Neutral	26 (32.1)	31 (18.5)	
Agree	46 (56.8)	120 (71.4)	
Too many environmental influences to give a definite connection between the effect of	nutrition on disease prog	ression $(n = 249)$	0.034 ^a
Disagree	4 (4 9)	9 (5 4)	0.00
Neutral	31 (38 3)	38 (22.6)	
Agree	46 (56 R)	121 (72)	
Lack of clinical trials to prove efficacy of personalized interventions $(n - 240)$	(0.00)	121 (72)	0.012 a
Lack of chinear thats to prove encacy of personalized interventions. $(1=249)$	7 (9 6)	4 (2 4)	0.015
	/ (0.0)	4 (2.4)	
	∠/ (33.3)	4U (ZD.0)	
Agree	47 (58)	124 (73.8)	

 ^{a}p value using $\chi 2$ or Fisher's exact tests, as appropriate, p < 0.05 considered statistically significant

benefits - greater individualization of diet prescription (86.3%, n = 215); stronger foundations for nutrition (85.1%, n = 212) and dietary prescriptions that would effectively manage or prevent certain diseases. (67%, n = 167). There was a significant difference between

integrators and non-integrators in how they perceived nutrigenomics as enhancing the foundations of nutrition (p = 0.013), with integrators more likely to agree (Table 2). Dietetic professionals agreed with the identified consumer motivators affecting the implementation of

nutrigenomics - motivated by desire to prevent or manage disease (70.3%, n = 175); prevent a disease based on family history (81.9%, n = 204); control health outcomes based on family history (68.3%, n = 170), improve overall health-related quality of life (75%, n = 193). Statistically significant differences were seen where non-integrators perceived consumer motivators such as desire to prevent or manage disease (p = 0.011); and prevention of disease based on family history (p = 0.005) more significantly (Table 2).

Several barriers affecting the implementation of nutrigenomics were identified (Table 2), with substantial differences between integrators and non-integrators. Cost concerns were highlighted by both groups (59%, n = 147). The statistically significant difference (p=0.000) suggested that cost poses a substantial obstacle for nonintegrators. Lack of continuing education for healthcare professionals (p = 0.003) and consumers (p = 0.003)emerged as significant barriers for non-integrators; aditionally, they reported several other barriers, including limited access to nutrigenomics for clients or patients (77.9%, n = 194, p = 0.000), concerns about confidentiality (69%, n = 172, p = 0.002), moral issues (66.6%, n = 166, p = 0.044), and the lack of clinical trials proving the efficacy of personalized interventions (68.7%, n = 171, p = 0.003). Finally, environmental influences (67%, n = 167) were cited as a barrier by both groups, a significant difference (p = 0.034) is seen with non-integrators more likely to agree.

Interview

Of the 249 dietetic professionals who completed the survey, 10 were selected to participate in an in-depth interview. To gain firsthand insights into implementing nutrigenomics in India, only those currently integrating nutrigenomics into their practice were selected. Ten themes emerged from reflexive thematic analysis of the interview data: (i) Understanding of nutrigenomics; (ii) Understanding of gene-based nutrition advice; (iii) Experiences with genetic testing in nutritional counselling; (iv) Nutrigenomics' impact on nutritional practices; (v) Practitioners' challenges in applying nutrigenomics; (vi) Consumer barriers to nutrigenomic integration in India; (vii) Challenges and motivators in integrating nutrigenomics; (viii) Feasibility and practicality of integrating nutrigenomics; (ix) Future directions for nutrigenomics in India; (x) Participant learnings on integrating nutrigenomics. An overview has been provided in Table 3.

Understanding of nutrigenomics

Dietetic professionals describe "nutrigenomics" primarily as personalized nutrition or health care tailored to individual genetic needs. One participant noted, "*Technol*ogy is so advanced, we are able to tell you what kind of meals... you are supposed to be having, just based on your genetics." (participant 8, 29 years old.). The role of genes was highlighted by five participants, with one referring to DNA as a health blueprint: "Your DNA report. is a blueprint, it is a 'Patrika,' of your own... health." (participant 7, 24 years old). The interaction between genes and nutrient absorption was also highlighted. Additionally, some participants mentioned disease prevention: "We can also try to find out diseases which can come in the future based on their susceptibility and can try to prevent them as well." (participant 2, 23 years old). These insights suggested that nutrigenomics is a developing field that aims to personalize nutrition based on an individual's genetic makeup to optimize health and potentially prevent disease.

Understanding of gene-based nutrition advice

The responses highlighted key aspects of paerticipants' understanding of gene-based nutrition advice, emphasizing personalization: "It's a customization of your diet based on your DNA...which nutrients we need to focus... which particular things we need to implement." (participant 6, 24 years old). Several participants contrasted gene-based advice with the traditional "one-size-fitsall" approach to nutrition, viewing it as a more precise: "Gene-based approach works upon precision nutrition, understanding your genotype and correlating with your phenotype. that's extremely precise and works on the root cause of the individuals, making it more systematic." (participant 4, 23 years old). While most responses were positive, some participants acknowledged the need to consider factors beyond genes: "I don't think that it is only a gene-based diet. genes are a part of the entire scenario." (participant 8, 29 years old.). Overall, participants viewed gene-based nutrition as a way to use genetic information for tailored dietary plans, while recognizing the importance of a holistic approach.

Experiences with genetic testing in nutritional counseling

Dietetic professionals shared their experiences with genetic testing in nutritional counseling, highlighting positive outcomes such as improved health conditions: "Within one or two weeks, we got a wonderful result. gastric issues and medications stopped." (participant 7, 24 years old); weight management breakthroughs: "Tve seen a lot of wonderful transformations honestly. individuals come with a stagnant weight issue... they don't understand fat mobilization, circadian rhythm, body's fat-storing tendency. So, then we understand that by the nutrigenomic test, (it) becomes very easy to work on their hormonal balance, exercise pattern... a lot of bariatric patients that we have been able to help." (participant 4, 23 years old).

A core theme was the ability to personalize nutrition plans based on genetic information, addressing macronutrient metabolism, micronutrient deficiencies, and

Themes	Illustrative Quotes
Understanding of Nutrigenomics	"Technology is so advanced, we are able to tell you what kind of meals you are supposed to be having, just based on your genetics." (participant 8, 29 years old.)
-	"We can also try to find out diseases which can come in the future based on their susceptibility and can try to prevent them as well." (participant 2, 23 years old)
Understanding of Gene-Based Nutrition Advice	"It's a customization of your diet based on your DNAwhich nutrients we need to focuswhich particular things we need to imple- ment." (participant 6, 24 years old)
	"Gene-based approach works upon precision nutrition, understanding your genotype and correlating with your phenotype. that's extremely precise and works on the root cause of the individuals. Making it more systematic more precise." (participant 4, 23 years old).
Experiences with Genetic Testing in Nu- tritional Counselling	"I've seen a lot of wonderful transformations honestly. individuals come with a stagnant weight issue they don't understand fat mobilization, circadian rhythm, body's fat-storing tendency. So, then we understand that by the nutrigenomic test, (it) becomes very easy to work on their hormonal balance, exercise pattern a lot of bariatric patients that we have been able to help." (participant 4, 23 years old).
	"Genetic testing today so advance right from nutrition it also gives you your risk to diabetes, cardiovascular health a lot of other things that I was never aware of - when it comes to sports specifically,- your injury risk, your flexibility and everything." (participant 1, 23 years old).
Nutrigenomics' Impact on Nutritional	"There is no scope for trial and error. because this is what your genetic report is. it gives more precise and, uh, good results. if we com- pare to the normal practice." (participant 7, 24 years old).
Practices	"This is not out of thin air. it's, again, very, very data-driven. In a long run, they (clients) definitely see good results. in terms of how they feel overall." (participant 9, 23 years old).
Practitioners' Chal- lenges in Applying Nutrigenomics	"People get so panicked because there are certain risks that are mentioned in the report but they need to realize that it's a predictive report." (participant 6, 24 years old).
	"This whole thing takes around almost 4–5 weeks to get processed Not all clients agree with how this whole algorithm is built. they just keep asking you a lot of counter questions." (participant 9, 23 years old).
Consumer Barriers to Nutrigenomic Integra- tion in India	"The main reason.the test not being cost-effectiveThe larger part of India, being India II and India III (middle and lower income households), they can't afford paying for a preventative health care model." (participant 4, 23 years old).
	"When we tell people that there is genetic testing and all available in our state, people are still surprised to hear that it's even possible." (participant 5, 26 years old).
Motivating Dietetic Professionals to Em-	"It could be introduced at the college level first.in a way of making people understand that what more it (Nutrigenomics) has to offer, what are the different scopes, that one can envision after choosing a career in Nutrigenomics." (participant 1, 23 years old).
brace Nutrigenom- ics: Challenges and Opportunities	"Start using the power of social media to create an awareness. it can be viewed by anyone from anywhere on the internet. If there is a consistencyyour audiencewill start correlating that psychological impact is going to be there." (participant 7, 24 years old).
Integrating Nutrig- enomics: Navigat-	"Feasibility. I don't know. Not sure, like we can, we can convince a person about this, butwill they take it? I don't know." (participant 2, 23 years old).
ing Feasibility and Practicality	"So, once the awareness is there, once people start talking about the same, automatically the DNA labs, the, feasibility, affordability, will fall into the place." (participant 7, 24 years old).
Future Directions for Nutrigenomics in India	"I believe that a lot of nutritionists and a lot of dietitians have been trying to incorporate nutrigenomics. A lot of younger nutritionists, a lot of budding nutritionists understanding the importance of nutrigenomics. trying to apply that in their practices, I definitely see the whole regime. changing into towards precision nutrition." (participant 4, 23 years old).
	"This has to have a mediator, right?. We have to be the ones that"II be carving it out; the entire journey of Nutrigenomics. to explain to them that this (genes) is just the loaded gun; you have to pull the trigger to fire it. So, this thing has to go through a dietitian or a nutritionist only. to devote that time to give out that information in an absorbable way." (participant 8, 29 years old)
Participant Learn- ings on Integrating Nutrigenomics	"I have understood that, a lot of people are still not aware of what Nutrigenomics is and how it could be applied in real life. with lot of people still having an understanding that genes will define your future.genes, play are very small part." (participant 4, 23 years old).
	"It is an actual problem, that the entire fraternity is facingit is very much important to understand that in terms of a greater popu- lation.the more suggestions that will come up from nutritionists who are practicing in the field. they have the best insights about, what could have improved. more of such studies needs to be participated in by qualified nutritionists. it is a real-time problem and there should be real-time solutions. Until and unless facts and data speak up for it. Nobody is going to take action." (participant 8, 29
	vears old).

Table 3 Perceptions related to integration of nutrigenomics - interview

intolerances. Prevention was another key point, with genetic tests detecting disease predispositions: "Genetic testing today so advance... right from nutrition it also gives you your risk of diabetes, cardiovascular health... a lot of other things that I was never aware of - when it comes to sports specifically,- your injury risk, your flexibility and everything." (participant 1, 23 years old). However, interpreting client-provided reports remained a challenge: "Sometimes clients would come in with their own genetic reports. There's so much information in the genetic reports. It is very difficult to counsel them." (participant 8, 29 years old). The responses suggest that incorporating genetic testing can significantly improve client health outcomes, but effective communication and understanding are crucial for success.

Impact of nutrigenomics on nutritional practices

Participants' responses reveal that nutrigenomics is seen as a transformative approach in dietetics, moving away from trial-and-error methods to provide targeted recommendations: *"There is no scope for trial and error. because this is what your genetic report is. it gives more precise and, uh, good results. if we compare it to normal practice."* (participant 7, 24 years old); highlighting its data-driven nature: *"This is not out of thin air. it's, again, very, very data-driven. In the long run, they (clients) definitely see good results. in terms of how they feel overall."* (participant 9, 23 years old).

Other impacts included client empowerment and addressing public health issues related to genetics: "I'm currently in the public health sector, I can see a lot . of genetic issues, which has not been addressed and there are so many taboos...when I tell them (patients) ... This might be genetic, because this, this is there in the family tree, people are very surprised to know ... there's even a genetic element to it. that (genetic) kind of counseling can be really helpful." (participant 5, 26 years old). The role of ongoing education for dietitians was also emphasized: "We don't have the first basic understanding. Nutrigenomics is such an untapped resource... it would dramatically change the results." (participant 8, 29 years old). The responses suggested that although nutrigenomics promises a more personalized and evidence-based approach to nutrition, challenges in education, and access to reliable information persist.

Practitioners' challenges in applying nutrigenomics

Dietetic professionals faced several challenges while integrating nutrigenomics into their practices. A significant hurdle was the complexity of genetic concepts, with difficulties in understanding reports and the need for improved education: *"There are conditions which basically sometimes even the dietitian is unaware.sometimes I think that would. put the dietitian in the back seat. that level of communicating . should be a part of curriculum... More of practicality, should be you know, inculcated.*" (participant 1, 23 years old).

Educating clients about nutrigenomics and its benefits was another challenge: "People get so panicked because there are certain risks that are mentioned in the report... but they need to realize that it's a predictive report." (participant 6, 24 years old). Skepticism about genetic testing algorithms also surfaced: "This whole thing takes around almost 4–5 weeks to get processed... Not all clients agree with how this whole algorithm is built. they just keep asking you a lot of counter questions." (participant 9, 23 years old). Lack of awareness among both lay people and doctors was noted: *"The awareness among lay people is as important as the awareness among doctors. the first contact of illness . is directly to the doctor in our society."* (participant 7, 24 years old).

Additional barriers included, the cost of genetic testing: "Nutrigenomics tests, yet, are not very cost efficient. So, helping them (clients) understand that this (genetic testing) is still an investment." (participant 4, 23 years old); and limited availability of testing equipment: "Less number of genetic, uh tests, you know, kind of apparatus available here in India." (participant 9, 23 years old). Concerns about test accuracy and the interpretation of gene variants were also raised: "There is no systematic information available." (participant 4, 23 years old). Effective communication, ongoing education and addressing affordability and accessibility issues will be crucial for the successful integration of nutrigenomics into mainstream nutritional practice.

Consumer barriers to nutrigenomic integration in India

Dietetic professionals identified several barriers hindering the widespread adoption of nutrigenomics in India. The high cost of genetic testing was a major concern: *"The main reason.the test not being cost-effective...The larger part of India, being India II and India III (middle and lower income households), they can't afford paying for a preventative health care model."* (participant 4, 23 years old). This limits accessibility for many consumers.

Lack of public awareness was another significant barrier: "When we tell people that there is genetic testing and all available in our state, people are still surprised to hear that it's even possible." (participant 5, 26 years old). Other challenges included concerns about data privacy and resistance to change traditional healthcare practices: "When it comes to the word 'DNA', 'gene' and all people can get confused and flustered. people go to the hospital or take diet plans at the end, when they are really sick." (participant 2, 23 years old). The responses suggested that addressing the high cost, raising awareness, and building practitioner knowledge are critical steps for enabling the successful integration of nutrigenomics into the Indian healthcare landscape.

Challenges and motivators in integrating nutrigenomics

Dietetic professionals highlighted various strategies to motivate dietitians and nutritionists to integrate nutrigenomics into their practices. Education and awareness campaigns were seen as essential: "Definitely education and webinars... The more they are done, the more people will have that awareness." (participant 3, 23 years old). Notably, social media was seen as an effective tool for raising awareness: "Start using the power of social media to create awareness . it can be viewed by anyone from anywhere on the internet. If there is a consistency... your audience ...will start correlating... that psychological impact is going to be there." (participant 7, 24 years old). Showcasing practical benefits through case studies and real-world examples was also emphasized: "Doing proper clinical studies or case studies on clients will bring in the proof. the testimonies... will be really helpful." (participant 5, 26 years old). Client interest in advanced tools like nutrigenomics further highlighted the need: "One time, I had this one client who just came to me, and I had to walk him through how the technology is so advanced, he was so intrigued. The next day, I'm sending him the genetic test kit, he is ready to do the test. So, people... actually want to invest in health." (participant 9, 23 years old).

Standardization of genetic testing and interpretation was also a concern: "If it's standardized, we will still have to take a look at the individual level... At this point, it may not be possible because there are very few companies working in it. But as it will go ahead, definitely you need to incorporate some standard guidelines to make our life easier with Nutrigenomics." (participant 6, 23 years old). Education was deemed essential for successful integration: "It could be introduced at the college level first.in a way of making people understand that what more it (Nutrigenomics) has to offer, what are the different scopes, that one can envision after choosing a career in Nutrigenomics." (participant 1, 23 years old). Overcoming challenges in standardization, education, and affordability, while addressing ethical implications is crucial for integrating nutrigenomics into nutrition practice. The potential for personalized nutrition and improved client outcomes underscores its significance in modern dietetics.

Feasibility and practicality of integrating nutrigenomics

Dietetic professionals expressed nuanced views of the practicality and feasibility of incorporating nutrigenomics into mainstream practice. They acknowledged its practicality in precision nutrition and long-term health: "I think it should be introduced early in life... making yourself strong enough right from childhood to improve your quality of life, increase your chances of having a disease-free life. It's a one-time investment and it's for life. It doesn't change." (participant 1, 23 years old). However, feasibility concerns were also prevalent, with cost as a major barrier: "There should be people who are ready to pay...People are not open to it. So, the reason is lack of awareness. I think it will need a whole support...when they get the correct education... awareness, I think Nutrigenomics is something everybody should accept." (participant 3, 23 years old). Lack of standardized testing panels were additional hurdles: "If we prepare standardization in terms of gene panels or ... costing, that can definitely make it more practical and feasible to everyone." (participant 6, 23 years old).

Participants suggested raising awareness among public and practitioners: "So, once the awareness is there, once people start talking about the same, automatically the DNA labs, the feasibility, affordability, will fall into the place." (participant 7, 24 years old). Bridge courses for practitioners and training for nutrigenomics counselors were also highlighted: "If you are more equipped at the basic level... then we are probably at an advantage. I have a stronger resonance now that we need to have bridge courses." (participant 8, 29 years old). Data confidentiality was another concern: "Based on the confidentiality issues, though there are negatives. it should be improved. seeing the benefits of the testing. it's very evident for their personalization. we have to focus more on the positive details." (participant 10, 25 years old). These responses indicate that while significant challenges exist, focusing on education, cost reduction, and practitioner knowledge development is required for making nutrigenomics a feasible and practical tool for improving health outcomes.

Future directions for nutrigenomics in India

Participants envisioned a future where nutrigenomics empowers personalized dietary plans based on individual genetic profiles, aligning with the concept of precision nutrition: "I believe that a lot of nutritionists and a lot of dietitians have been trying to incorporate nutrigenomics... I definitely see the whole regime. changing into towards precision nutrition." (participant 4, 23 years old). Collaboration among healthcare professionals was seen as crucial: "There has to be meaningful collaboration, where we actually get to learn from each other. and have respect for each other's profession." (participant 8, 29 years old).

Dietitians and nutritionists were identified as key players in advancing nutrigenomics by educating themselves and the public: "Awareness. needs to be created. the best marketing strategy till date is the word-of-mouth publicity. until, a single client gets a good result, they understand its value... We are marketing science." (participant 7, 24 years old). They can bridge the gap between the science of nutrigenomics and the public: "This has to have a mediator. We have to be the ones that'll be carving it out. this thing has to go through a dietitian or a nutritionist only. to give out that information in an absorbable way." (participant 8, 29 years old).

Dietetic professionals also emphasized advocating for the integration of nutrigenomics into mainstream practice, including corporate settings: "As a Nutrigenomics counselor, we can actually suggest the company to start something... when it comes to Nutrigenomics testing. it's just a matter of connections." (participant 2, 23 years old). Through education, collaboration, and advocacy, they can help create a more personalized, preventive, and collaborative approach to healthcare in India.

Participant learnings on integrating nutrigenomics

Participants' responses revealed valuable insights and heightened awareness of nutrigenomics: "I definitely understand that there can be different perspectives to what we have been studying so far. I went into introspection - 'What challenges can come? What barriers can come?' it made me think a lot deeper." (participant 6, 24 years old). They acknowledged the vastness and complexity of the field while recognizing the need for ongoing education and public awareness campaigns. One participant stressed correcting misconceptions about genetic influence: "A lot of people are still not aware of what Nutrigenomics is and how it could be applied in real life... genes, play are very small part." (participant 4, 23 years old).

The study motivated dietetic professionals to further explore nutrigenomics into practice: "I would be willing to know more about this field." (participant 1, 23 years old). There was optimism about the field's future: "It is necessary that we start working on Nutrigenomics as much as we can, and let's take this field forward, it will grow." (participant 7, 24 years old). Practical applications and community growth of nutrigenomics integrators were also discussed: "I'm really happy that there are not just a handful of us now, but there are so many more people out there." (participant 5, 26 years old).

Another participant emphasized the importance of practitioner insights informing research: "It is very much important to understand. the more suggestions that will come up from nutritionists who are practicing in the field. they have the best insights about what could have improved. more of such studies needs to be participated in by qualified nutritionists. Until and unless facts and data speak up for it. Nobody is going to take action." (participant 8, 29 years old). The responses conveyed a deeper understanding, enthusiasm, and need for education and collaboration to unlock the full potential of nutrigenomics in healthcare in India.

Discussion

The present study explores the perceptions among practicing dietetic professionals in India regarding the integration of nutrigenomics. Findings indicate a strong awareness of nutrigenomics (97.2%) among participants, with a positive outlook on its application. A large proportion (87.5%) expressed interest in learning more about nutrigenomics, although only 47.4% received nutrigenomics education as part of their qualifications, revealing a gap in formal education and training [17]. While nearly all participants viewed genetic testing as important to the health industry (99.2%), only a third provided nutrigenomics counseling, highlighting the limited practical application despite awareness [20]. Dietetic professionals with postgraduate education showed significantly higher awareness compared to those with undergraduate qualifications, reflecting the growing emphasis on nutrigenomics in postgraduate programs [17]. Moreover, newer professionals (those with qualifications within the last 5 years) were more likely to have received such education, indicating a recent shift towards incorporating nutrigenomics into the curriculum [17]. These findings suggest that while awareness is high, structured education and training remain critical for widespread implementation, a conclusion also supported by global studies [18, 20].

Corporate dietitians were more likely to provide nutrigenomics counseling compared to those in hospitals or research institutes, likely due to better funding and resources in corporate settings [20]. This aligns with the notion that private sector autonomy can facilitate early adoption of innovative practices, as previously observed [20].

The perceived benefits of integrating nutrigenomics include greater individualization of dietary prescriptions (86.3%) and improved disease management (67.1%), supporting the view that nutrigenomics enhances the foundations of nutrition. Both integrators and non-integrators agreed on the potential of nutrigenomics to strengthen nutrition practice, a finding mirrored by previous studies [14, 19]. Consumer motivators, such as the desire to prevent or manage disease and improve health-related quality of life, were also acknowledged as key drivers for nutrigenomics testing [12, 14]. This reflects global trends, where consumers increasingly turn to nutrigenomics for personalized health solutions [30].

Barriers to the integration of nutrigenomics were substantial, particularly cost concerns (59%), lack of expert knowledge (70.2%), and insufficient continuing education for both professionals and consumers [3, 19, 20]. Nonintegrators reported these barriers more frequently than integrators, particularly in areas such as cost and education, consistent with findings from other studies [19, 26, 30–32]. Concerns about confidentiality and the absence of clinical trials to prove efficacy were also prevalent, underscoring the need for robust evidence and ethical considerations [30, 32, 33, 34].

Mixed perceptions were reported regarding the feasibility of integrating nutrigenomics. While participants recognized its potential benefits in precision nutrition, challenges such as cost, limited practitioner knowledge, and a lack of standardized testing panels were identified as significant obstacles [20]. These findings reflect the broader challenges faced in implementing nutrigenomics in clinical practice globally, where cost and education remain critical barriers [19]. Participants suggested raising awareness, standardizing testing panels, and offering bridge courses to enhance practitioner knowledge and improve feasibility [13].

Despite these challenges, there was optimism about the future of nutrigenomics in India. Participants envisioned a shift towards personalized dietary plans based on genetic profiles, emphasizing the importance of collaboration between nutritionists, nutrigenomics counselors, and general practitioners to optimize client care [3]. Dietitians and nutritionists were identified as pivotal in driving the adoption of nutrigenomics, with a key role in educating both professionals and the public [20, 33].

The strengths of this study include a substantial data set of 249 survey responses and 10 in-depth interviews, providing comprehensive insights into the perceptions and challenges of integrating nutrigenomics in India. The mixed-method approach allowed for both quantitative and qualitative analysis, identifying practical obstacles and potential solutions [3, 26]. However, a potential bias exists, as those with an interest in nutrigenomics may have been more likely to participate, and the uneven geographic distribution of responses limits the generalizability of the findings [3, 20].

Conclusion

The study reveals that dietitians and nutritionists in India had a favorable attitude towards nutrigenomics. Major barriers such as high cost, insufficient continuing education, limited public awareness and ethical concerns were identified. To overcome these, participants suggest solutions like raising awareness on social networking platforms, improving accessibility towards bridge courses, strengthening data protection policies and engaging with other healthcare professionals in improving and advocating for nutrigenomics. Future recommendations for advancing studies in this domain should include broader participation across various practice settings and geographic zones of India. Additionally, it is advisable to assess knowledge scores regarding nutrigenomics and delve into its branches such as sports nutrigenomics, and gut microbiome to name a few.

Abbreviations

NCD Non-Communicable Disease

- RD Registered Dietitian
- RDN Registered Dietitian Nutritionist

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Author contributions

N.A.D.D.R conceptualized the study, reviewed related literature, collected, recorded and transcribed data from the survey and interviews, conducted statistical and thematic analysis and interpreted results. D.G conceptualized and supervised the study and interpreted the quantitative data. M.G. supervised and interpreted the qualitative data. D.G and M.G provided

iterative critical feedback. All authors read and approved the submitted manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

This study protocol was reviewed and approved by the Institutional Research Committee of Symbiosis Institute of Health Sciences and Institutional Ethics Committee (No. SIU/IEC/758), Symbiosis International (Deemed University), Pune. Written informed consent was obtained from the participants. Ethical consideration and confidentiality were strictly maintained throughout the research process. This study was performed in accordance with the principles of the Declaration of Helsinki and fully abides by the norms laid by the university.

Consent for publication

Written informed consent was obtained from all participants for the publication of this study.

Competing interests

The authors declare no competing interests.

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References

- Kiani AK, Bonetti G, Donato K, Kaftalli J, Herbst KL, Stuppia L. Polymorphisms, diet and nutrigenomics. J Prev Med Hyg. 2022;63(2 Suppl 3):E125–41. https:// doi.org/10.15167/2421-4248/jpmh2022.63.2S3.2754.
- Lagoumintzis G, Patrinos GP. Triangulating nutrigenomics, metabolomics and microbiomics toward personalized nutrition and healthy living. Hum Genomics. 2023;17(1):109. https://doi.org/10.1186/s40246-023-00561-w.
- Mathew MR, Medithi S, Muley A. Dietitians' and nutritionists' knowledge of nutritional genomics and perception toward genetic testing for a personalized approach in noncommunicable diseases (NCDs) prevention and management in India: a cross-sectional survey. Int J Nutr Pharmacol Neurol Dis. 2023;13:123–31.
- Guest NS, Horne J, Vanderhout SM, El-Sohemy A. Sport Nutrigenomics: Personalized Nutrition for athletic performance. Front Nutr. 2019;6:8. https://d oi.org/10.3389/fnut.2019.00008.
- Anjana RM, Unnikrishnan R, Deepa M, Pradeepa R, Tandon N, Das AK. Metabolic non-communicable disease health report of India: the ICMR-INDIAB national cross-sectional study (ICMR-INDIAB-17). Lancet Diabetes Endocrinol. 2023;11(7):474–89. https://doi.org/10.1016/S2213-8587(23)00119-5.
- International Diabetes Federation.IDFDiabetesAtlas.10thed.Brussels:InternationalDiabetesFederation. 2021.Availablefrom:https://www.diabetesatlas.org
- Amarchand R, Kulothungan V, Krishnan A, Mathur P. Hypertension treatment cascade in India: results from National Noncommunicable Disease Monitoring Survey. J Hum Hypertens. 2023;37(5):394–404. https://doi.org/10.1038/s4 1371-022-00692-y.
- Mathur P, Leburu S, Kulothungan V. Awareness, Treatment and Control of Diabetes in India from the Countrywide National NCD Monitoring Survey. Front Public Health. 2022;10:748157. https://doi.org/10.3389/fpubh.2022.748 157.
- Habeeb S, Thankappan KR. Metabolic non-communicable diseases in India: time to act. Lancet Diabetes Endocrinol. 2023;11(12):897–8. https://doi.org/1 0.1016/S2213-8587(23)00298-X.
- Lee Y, Mozaffarian D, Sy S, Huang Y, Liu J, Wilde PE. Cost-effectiveness of financial incentives for improving diet and health through Medicare and Medicaid: a microsimulation study. PLoS Med. 2019;16(3):e1002761. https://doi.org/10.1 371/journal.pmed.1002761.

- Adams SH, Anthony JC, Carvajal R, Chae L, Khoo CSH, Latulippe ME. Perspective: Guiding principles for the implementation of Personalized Nutrition approaches that benefit health and function. Adv Nutr. 2020;11(1):25–34. htt ps://doi.org/10.1093/advances/nmz086.
- Ferguson L, Barnett M. Nutrigenomics and Nutrigenetics Research in New Zealand, and its relevance and application to Gastrointestinal Health. Nutrients. 2022;14(9):1743. https://doi.org/10.3390/nu14091743.
- Kassem NM, Abdelmegid YA, El-Sayed MK, Sayed RS, Abdel-Aalla MH, Kassem HA. Nutrigenomics and microbiome shaping the future of personalized medicine: a review article. J Genet Eng Biotechnol. 2023;21(1):134. https://doi. org/10.1186/s43141-023-00599-2.
- Horne JR, Nielsen DE, Madill J, Robitaille J, Vohl MC, Mutch DM. Guiding global best practice in personalized nutrition based on genetics: the development of a nutrigenomics care map. J Acad Nutr Diet. 2022;122(2):259–68. https://doi.org/10.1016/j.jand.2021.02.008.
- Dhanapal ACTA, Wuni R, Ventura EF, Chiet TK, Cheah ESG, Loganathan A, Quen PL, Appukutty M, Noh MFM, Givens I. Implementation of Nutrigenetics and Nutrigenomics Research and Training Activities for Developing Precision Nutrition Strategies in Malaysia. Nutrients. 2022;14(23):5108. https://doi.org/1 0.3390/nu14235108.
- YaelJoffe. Heléne Herholdt; what will it take to build an Expert Group of Nutrigenomic Practitioners? Lifestyle Genomics 19 May. 2020;13(3):122–8. htt ps://doi.org/10.1159/000507252.
- Horne J, Madill J, O'Connor C. Exploring knowledge and attitudes of personal nutrigenomics testing among dietetic students and its value as a component of dietetic education and practice. Canad J Clin Nutr. 2016;4(1):50–62.
- Greyvensteyn D, Walsh CM, Nel M, Jordaan EM, Nutrigenomics. Perceptions of South African dietitians and General practitioners. Lifestyle Genomics. 2023;16(1):11–20. https://doi.org/10.1159/000526898.
- Abrahams M, Frewer LJ, Bryant E, Stewart-Knox B. Perceptions and experiences of early-adopting registered dietitians in integrating nutrigenomics into practice. Br Food J. 2018;120(4):763–76. https://doi.org/10.1108/BFJ-08-2 017-0464.
- Sekar P, Ventura EF, Dhanapal ACTA, Cheah ESG, Loganathan A, Quen PL, Appukutty M, Taslim NA, Hardinsyah H, Md Noh MF. Gene–Diet interactions on metabolic disease-related outcomes in southeast Asian populations: a systematic review. Nutrients. 2023;15(13):2948. https://doi.org/10.3390/nu15 132948.
- Wildish DE, Evers S. A definition, description, and framework for advanced practice in dietetics. Can J Diet Pract Res. 2010;71(1):e4–11. https://doi.org/10 .3148/71.1.2010.24.
- Mustapa MAC, Amin L, Frewer LJ. Predictors of stakeholders' intention to adopt nutrigenomics. Genes Nutr. 2020;15(1):16. https://doi.org/10.1186/s12 263-020-00676-y.

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- Beckett EL, Jones PR, Veysey M, Lucock M. Nutrigenetics—Personalized Nutrition in the genetic age. Explor Res Hypothesis Med. 2017;2(4):109–16. https:// doi.org/10.14218/ERHM.2017.00027.
- Mlodzik-Czyzewska MA, Chmurzynska A. The state of Nutrigenomic Education in Poland. Lifestyle Genomics. 2019;11(2):90–8. https://doi.org/10.1159/0 00494332.
- Cormier H, Tremblay BL, Paradis AM, Garneau V, Desroches S, Robitaille J, Vohl MC. Nutrigenomics - perspectives from registered dietitians: a report from the Quebec-wide e-consultation on nutrigenomics among registered dietitians. J Hum Nutr Diet. 2014;27(4):391–400. https://doi.org/10.1111/jhn.1 2194.
- Heinisch O, Cochran WG. SamplingTechniques,2nded.JohnWileyandSons,Ne wYork,London1963.BiomJ.1965;7:203.https://doi.org/10.1002/bimj.19650070 312
- Taber KS. The use of Cronbach's alpha when developing and reporting research instruments in science education. Res Sci Educ. 2018;48:1273–96. htt ps://doi.org/10.1007/s11165-016-9602-2.
- Braun V, Clarke V. To saturate or not to saturate? Questioning data saturation as a useful concept for thematic analysis and sample-size rationales. Qual Res Sport Exerc Health. 2019;13(2):201–16. https://doi.org/10.1080/2159676X.201 9.1704846.
- Tutty E, Hickerton C, Terrill B, McClaren B, Tytherleigh R, Stackpoole E. The expectations and realities of nutrigenomic testing in Australia: a qualitative study. Health Expect. 2021;24(2):670–66. https://doi.org/10.1111/hex.13216.
- Vallée Marcotte B, Cormier H, Garneau V, Robitaille J, Desroches S, Vohl MC. Nutrigenetic testing for Personalized Nutrition: an evaluation of public perceptions, attitudes, and concerns in a Population of French canadians. Lifestyle Genom. 2018;11(3–6):155–62. https://doi.org/10.1159/000499626.
- Nacis JS, Galang MR, Labrador JPH, Gonzales MS, Dablo AMFD, Domalanta-Ronquillo DGA. Right diet for the right person: a focus group study of nutritionist-dietitians' perspectives on nutritional genomics and gene-based nutrition advice. J Community Genet. 2022;13(1):49–57. https://doi.org/10.10 07/s12687-021-00560-1.
- Kaufman-Shriqui V, Salem H, Boaz M, Birk R. Knowledge and Attitudes Towards Nutrigenetics: Findings from the 2018 Unified Forces Preventive Nutrition Conference (UFPN). Nutrients. 2020;12(2):335.https://doi.org/10.339 0/nu12020335
- Ceriani F, Montalvan M, Quintero B, Suárez R, Bautista-Valarezo E, Frias-Toral E. Ethics of the clinical practice of nutrigenetics and nutrigenomics. Clin Nutr Open Sci. 2023;49:58–66. https://doi.org/10.1016/j.nutos.2023.04.006.

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