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Acceptance and likelihood of purchasing vitamin D-fortified foods among Irish adults aged 18–65 years: A consumer study with conjoint analysis

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ABSTRACT

Meeting recommendations for vitamin D is challenging due to limited food sources. Strategic fortification has been shown to prevent low vitamin D status. Using an online survey of Irish adults ($n = 1008$), this study assessed awareness of vitamin D deficiency, attitudes to fortification, cues-to-action and intention to consume vitamin D-fortified foods using a 7-point scale. Current consumption of supplements and fortified foods was assessed. Willingness to purchase vitamin D fortified foods was evaluated using a 9-point scale with the following attributes: food vehicle (i.e., bread, cereal, milk), fortification level (no information, with vitamin D and with vitamin D and health claim) and price, using conjoint analysis.

Conjoint analysis indicated that the food vehicle (importance = 40.6%) and claim (38.3%) exerted greater influence on purchase decisions than price (20.8%). Bread generated the highest part-worth utility (0.204), yoghurt was approximately neutral (0.039) and breakfast cereal the least preferred (−0.244), a simple 'with vitamin D' label produced a positive utility (0.177). Respondents grouped into four segments: Supplements and fortified food users (S&FF) ($n = 595$, 59.0%), supplements only (SO) ($n = 161$, 16.0%), fortified food only (FFO) ($n = 145$, 14.4%), non-users (NU) ($n = 107$, 10.6%). S&FF reported the highest positive attitudes (mean 5.6 ± 0.9), awareness (mean 5.6 ± 0.8) and intention to consume fortified foods (mean 5.2 ± 1.1), NU had lower awareness (5.2 ± 0.8) and intention (4.1 ± 1.3) but responded positively to cues to action such as health professional and family recommendations. Therefore, leveraging trusted health professionals and family-mediated cues to reach low-engagement groups could increase vitamin D intake.

1. Introduction

Vitamin D is an essential micronutrient that regulates calcium homeostasis and is critical for bone development and maintenance (Cranney and Weiler, 2008). While active metabolites have been implicated in immune and metabolic functions (Bouillon et al., 2019), cutaneous synthesis from ultraviolet B (UVB) exposure is the principal source for most people (Webb., 2006). At Ireland's latitude (51–55°N), UVB is insufficient for cutaneous synthesis between October and March (O'Neill et al., 2016), contributing to pronounced seasonal declines in status and a high prevalence of low vitamin D status across the population (Cashman et al., 2013; Kiely, O'Donovan, et al., 2016; Kiely, Zhang, et al., 2016; Scully et al., 2023a). Randomised controlled trials show that vitamin D from supplements or fortified foods increases vitamin D status (Cashman et al., 2022), and fortified staples increase intakes and status (Dunlop et al., 2021). Public-health agencies therefore recommend supplementation with vitamin D during winter to offset the UVB deficit (Food Safety Authority of Ireland, 2023; The Scientific Advisory Committee on Nutrition, 2016).

Despite these recommendations, intakes of vitamin D are substantially below targets from food and supplements across the Irish and UK populations as shown by the Irish National Adult Nutrition Survey II and the UK National Diet and Nutrition Survey (Kehoe et al., 2024; Office for Health Improvement and Disparities, 2025). This is because naturally-occurring vitamin D sources are scarce and infrequently consumed, and vitamin D fortification is not widespread or strategic (Black et al., 2015; Bird et al., 2022). To reduce micronutrient malnutrition in populations, the World Health Organization recommends a range of approaches from improving dietary diversity to implementing food fortification and/or supplementation. Dietary diversity is not useful for

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vitamin D due to the lack of rich food sources (Allen et al., 2006) and while supplementation is effective on an individual basis, it does not reach those who do not use supplements. The most recent national adult nutrition survey in Ireland determined that 18% of adults aged 19–64 years take a vitamin D supplement, a further 14% took vitamin D and Calcium, and another 27% took a multivitamin (Irish Universities Nutrition Alliance (IUNA), 2024). Data from the UK National Diet and Nutrition Survey 2019 to 2023 showed the 22% of males and 33% of females aged 19 to 64 years took a supplement containing vitamin D (Office for Health Improvement and Disparities, 2025). Well-developed and planned food fortification strategies may offer broader, more sustained, and cost-effective public health benefits (Allen et al., 2006). Fortification may be implemented voluntarily or mandatorily but its success depends on widespread uptake and consumption by a large proportion of the target population.

Systematic reviews of randomised controlled trials show that vitamin D fortification safely and effectively improves vitamin D status in children and adults (Adebayo et al., 2021; Cashman et al., 2022; Dunlop et al., 2021), supporting consideration of implementation strategies (Pilz et al., 2018). By increasing vitamin D intake through fortifying milk, yoghurt, margarines, and spreads, policy makers in Finland have reduced the prevalence of very low vitamin D status from 12% to <1% (Raulio et al., 2016; Jääskeläinen et al., 2017). Sweden mandates fortification of various milk products and margarines, while Norway allows voluntary fortification at lower levels (Itkonen et al., 2021) and while both countries improved vitamin D availability through these strategies, the reported impact has been smaller than in Finland, reflecting the lower fortification levels in Norway and more limited evaluation data in Sweden. In Canada, mandatory fortification of milk and margarine has improved vitamin D status (Calvo et al., 2004; Calvo & Whiting, 2013). While these examples demonstrate the effectiveness of vitamin D fortification in improving population status, potential for risk of excessive intakes due to mandatory fortification is a consideration. In Finland, correct monitoring of intakes using nationally representative data that accounted for contributions from foods, fortification and supplements did not reveal excessive intakes from fortification (Raulio et al., 2016; Scully et al., 2023b).

The effectiveness of food fortification requires consumer acceptance for success. Fortified foods must be integrated into dietary patterns in alignment with existing cultural norms, taste preferences, and habitual consumption of the population. For example, there is evidence that the chosen food vehicle significantly affects consumer willingness to purchase fortified products (Sandmann et al., 2015). Areal and Asioli (2024) reported that consumers preferred low-price eggs produced using the free-range production method and vitamin D fortification did not affect their perceived value. In Lebanon, Hoss et al Field and Iles (2024) evaluated vitamin D-fortified Lebanese bread and found high public acceptance with no negative effects from fortification in sensory testing. A perceived taste barrier may exist, as demonstrated by Verbeke (2005), who reported that trustworthy functional foods were perceived as being less tasty by consumers. Qualitative work with older and younger adults further emphasises taste and sensory concerns as primary determinants of acceptance, with many participants reporting off-flavours and texture changes linked to fortification (Embling et al. Field & Iles, 2024).

Cultural differences may also have an impact. Erhard et al. (2020) investigated the acceptance of vitamin D cow's milk and plant-based milk alternatives across Denmark, Iceland and the UK and reported significant between-country differences. Denmark had the lowest purchase intention with consumers concerned about naturalness, price, and taste, while Icelandic consumers had the highest intention with fewer concerns. Smith et al. (2024) also determined that acceptance of fortified foods is culturally dependent: preferred food vehicles, cooking practices and sensory expectations vary between countries and can substantially affect uptake. Consumers' perceptions of health claims, product naturalness, and trust in manufacturers further shape attitudes toward fortified products (Sandmann et al., 2015; Jahn et al., 2019). Further, these attitudes can therefore influence acceptance toward the product characteristics. These findings highlight the importance of designing fortification strategies aligned with consumer attitudes, preferences and behaviours to ensure public engagement and nutritional impact are achieved.

Psychosocial measurement is an important consideration in identifying determinants in consumer behaviour and for informing the design and targeting of fortification policies and communication strategies. Various theoretical models can be utilised to assess underlying consumer behaviour. Applicable theoretical frameworks include the Theory of Planned Behaviour, which emphasises attitudes, subjective norms and perceived behavioural control as predictors of intention and behaviour (Ajzen, 1985); and the Health Belief Model, which highlights perceived susceptibility, severity, benefits, barriers and cues to action (Rosenstock., 1974). In relation to fortified foods, attitudinal measures can capture perceived benefits and risks of fortified products, awareness and perceived susceptibility reflect knowledge of deficiency and motivation to act, and discrete cues to action such as professional advice or family recommendations represent practical levers for intervention. Cues to action, including professional advice, family recommendations and public health campaigns, operate as external triggers for initiation and maintenance of behaviour and are amenable to intervention (Krystallis & Maglaras, 2008; Jahn et al., 2019). Measurement of such constructs permits assessment of motivational processes, responsiveness to communication and facilitates segmentation by engagement and cue responsiveness. This approach supports evidence-based strategies to increase population vitamin D intake.

Previous research on functional foods using subgroup analyses has shown that acceptance, motives, attribute priorities and cue-responsiveness vary across segments. Labrecque et al. (2006) investigated functional food acceptance among young consumers in French Canada, the United States and France and reported significant between-country differences. French Canadian students expressed more favourable attitudes, higher perceived health benefits, greater trust in information and stronger purchase intention than French students, with US students generally intermediate. Further, health-related beliefs, product-related benefits and perceived credibility of information as the principal positive predictors of acceptance. Krystallis & Maglaras (2008) investigated consumer motivations for functional food purchase and found that younger consumers emphasised convenience, eating enjoyment and enhancement, whereas early-middle-aged consumers prioritised disease-prevention functionality (e.g. low cholesterol, cardiovascular risk reduction, bone health), implying different weights on taste, trust, price and functionality across age segments. Verbeke (2005) investigated consumer acceptance of functional foods in a Belgian sample and found that belief in health benefits is the strongest positive determinant of acceptance, that the presence of an ill family member substantially increases acceptance, and that high claimed knowledge can be associated with lower acceptance. Collectively, these segment-specific findings show that country, age and experience-based groupings differ in the underlying drivers of acceptance. Therefore, segmentation should be considered when investigating product preferences and for designing tailored communication strategies.

Ireland's continued reliance on voluntary fortification and individual supplementation has not sufficiently addressed population needs (Cashman et al., 2013; Cashman, 2020; Cashman & O'Neill, 2024). Effective combinations of product type, fortification levels, and communication strategies for different population groups are key (Kiely & Black, 2012). Recent research suggests that the presentation of health information can influence perceived credibility and purchase intention (Jahn et al., 2019). While health claims can enhance trust and perceived efficacy among some consumers, others may interpret them as misleading or overly commercial. This complexity highlights the need for communication strategies that are segment-specific and evidence-based. Therefore, the aim of this study was to (1) explore the

relationship between psychosocial characteristics of behaviour and perceptions of vitamin D fortified foods; (2) examine Irish consumers' likelihood of purchasing vitamin D fortified foods across different food vehicles, levels of fortification, health claims, and price points; and (3) profile users and non-users of vitamin D containing supplements and fortified foods according to their attitudes toward various vitamin D fortified foods and purchase likelihood.

2. Materials and methods

This study was an online survey among a representative sample of Irish adults aged 18–65 years.

2.1. Questionnaire design

The questionnaire composed of two sections: firstly the psychosocial determinant of fortified food consumption, and secondly consumers likelihood to purchase fortified foods varying in product type, fortification, claim and price.

2.1.1. Psychosocial characteristics

The theory of planned behaviour indicates that attitudes are strong predictors of behavioural intention when the target behaviour is clearly specified (Ajzen, 1985), and the TACT (target, action, context, time) principle emphasises the need to align measures with the specific action under study. Accordingly, the survey measured a focused set of psychosocial constructs relevant to consumer uptake of vitamin D fortified foods: positive attitudes toward fortification (7 items), negative attitudes toward fortification (6 items), awareness of vitamin D deficiency (4 items), intention to consume/purchase fortified foods (3 items). Cues-to-action are an internal or external trigger to appropriate action in relation to health behaviour (Rosenstock., 1974). These were measured using 5 items: physician advice, public health campaigns, family, social media/influencers, friends). These constructs map directly onto purchase decisions and are actionable for communication and policy. Exact item wording, references for these statements, factor loadings, reliability statistics are given in Table 1.

Positive and negative attitudes toward vitamin D fortified foods and health, and awareness of vitamin D deficiency were measured on a 7-point Likert scale from 1 strongly disagree to 7 strongly agree, while cue-to-action and intention to consume/purchase were measured on a 7-point Likert scale from 1 extremely unlikely to 7 extremely likely. Consumers were identified as users or non-users of vitamin D supplements and fortified foods by answering "yes" or "no" to the questions: *"Do you currently take vitamin D supplements or multivitamins that contain vitamin D?"* and *"Do you currently consume food with added vitamins?"*

2.1.2. Orthogonal design

To explore likelihood to purchase, nine full-profile product concepts were generated using a fractional-factorial orthogonal design. The concepts comprised three attributes with three levels for fortification/claim (no information; added vitamin D; added vitamin D plus the long-standing EFSA-approved claim "vitamin D contributes to the maintenance of normal bones") (European Union, 2012), two levels for price (regular; 20% more expensive), and three food vehicle types (bread, breakfast cereal, yoghurt). The food vehicles were selected as they represent established or emerging fortification vehicles: dairy products and breakfast cereals are widely used for voluntary fortification and lend themselves readily to vitamin D enrichment (Calvo & Whiting, 2013; Itkonen et al., 2021), and bread is increasingly explored as a staple vehicle for fortification (Hoss et al. Field & Iles, 2024). Further, modelling and safety analyses indicate that fortifying commonly consumed staples such as milk and bread is effective and safe for increasing vitamin D intakes in older adults (McCourt et al., 2020). National consumption data support the choice of these staples in an Irish sample (approximately 93% of adults consume bread, 60% consume

Table 1
Factor analysis of attitudes, deficiency awareness and intention statements related to vitamin D fortification: item loadings, internal consistency (Cronbach's alpha), and mean scores.

	Statement mean	Item loading	Crohnbachs Alpha	Mean Construct Score
Positive attitudes toward vitamin D fortification and health				
I feel secure knowing that eating foods with added vitamins can improve my health*	5.5	0.799		
Food with added vitamins make it easier to have a healthy diet*	5.3	0.784		
I think that foods with added vitamin D are a practical and effective way to ensure my body gets the nutrients it needs*	5.5	0.778		
I feel confident that consuming foods with added vitamin D helps to maintain good health*	5.5	0.766	0.875	5.4
It is completely safe to eat food with added vitamins*	5.4	0.732		
Food with added vitamin D is healthier than food without added vitamin D*	4.9	0.71		
Food with added vitamin D tastes the same as food without added vitamin D+●	5.4	0.563		
Negative attitudes toward vitamin D fortification and health				
I worry about the risks of adding vitamins to foods*	3.4	0.71		
Vitamin D should not be added to any food*▲	3.1	0.703		
Food with added vitamin D is less natural than food without added vitamins+	4	0.702		
People with a healthy diet do not need to eat food with added vitamins*	3.9	0.659	0.754	3.9
If a certain food e.g. milk, had vitamin D added, I would like to have an option to buy it without added vitamin D▲	4.6	0.61		
I would prefer to use supplements than have vitamin D added to my food+	4.4	0.54		
Awareness of vitamin D deficiency				

(continued on next page)

Table 1 (*continued*)

	Statement mean	Item loading	Crohnbachs Alpha	Mean Construct Score
Vitamin D is essential to maintain a healthy immune system*●	5.6	0.83		
Vitamin D is essential for healthy bones*●	5.9	0.775	0.618	5.5
Most of the Irish population has low vitamin D intakes*+	5.6	0.715		
Few foods contain vitamin D*	4.5	0.412		
Intention to consume and purchase vitamin D fortified foods				
I am committed to eating foods with added vitamin D every day as part of my healthy diet*	4.8	0.865		
I will replace some of my regular foods with vitamin D alternatives to boost my vitamin intake this month*	4.8	0.885	0.85	4.9
Next time I do my food shop, I will look out for foods with added vitamin D to purchase●	5	0.881		

Statements were measured on a 7-point Likert scale from 1 strongly disagree to 7 strongly agree.
Statements were adapted from: *(Jahn et al., 2019), +(Erhard et al., 2020), ● (Vassallo et al., 2009), and ▲ (Bromage et al., 2019).

breakfast cereals, 38% consume yoghurt (Irish Universities Nutrition Alliance (IUNA), 2024)), making them relevant targets for population-level interventions. The primary analytic interest was whether the presence of any fortification statement or health claim (versus no information) influenced purchase likelihood, rather than comparing multiple, more complex claims. Price had two levels (regular; +20% premium) based on a supermarket review of lead retailers in Ireland; the 20% premium represents a modest retail markup for fortified staples and allows a clear test of price importance.

The orthogonal design was generated using the Orthoplan procedure (generate orthogonal design) to produce a fractional-factorial set of nine concepts with independent variation across attribute levels (SPSS Orthoplan). All nine product cards (Fig. 1) were presented to each participant, who rated each concept's likelihood to purchase on a 9-point Likert scale (1 = extremely unlikely to 9 = extremely likely); participants did not choose between cards but evaluated each independently. A rating-based (metric) conjoint approach was chosen as it permits direct estimation of part-worth utilities from a compact set of full-profile ratings using the SPSS Conjoint procedure and is appropriate when the principal interest is estimating level utilities and attribute importance. The 20% premium for the higher price level was selected following a market review of retail differentials for fortified versus non-fortified staple products and was intended to represent a plausible, modest premium consumers might face; including this premium also allowed assessment of the relative importance of price compared with food vehicle and fortification/claim attributes. Participants with dietary restrictions (e.g., vegan, coeliac, lactose intolerant) were instructed to assume that all products met their dietary needs.

2.2. Participant recruitment

In order to achieve a population-representative sample, 1008 participants aged 18–65 years from the Republic of Ireland completed the online survey in January 2025. In order to achieve a population-representative sample, 1008 participants aged 18–65 years from the Republic of Ireland completed the online survey in January 2025. This sample size is commonly used in national nutrition surveys (e.g., the Irish Universities Nutrition Alliance (IUNA) (2024) Irish National Adult Nutrition Survey which had 1000 participants and it allows scope for subgroup comparisons. This sample size yields a 95% confidence margin of error of approximately ±3.1 percentage points for proportions near 50%, which is typical precision for national consumer surveys. Participants were recruited through Empathy Research, a market research agency based in Ireland using quota sampling to achieve representativeness for age, gender and social class. The agency collected socio-demographic information to facilitate coding of social class, aligned



Fig. 1. The product concepts by food vehicle (bread, breakfast cereal, and yoghurt), price (regular, 20% more expensive) and fortification level/claim (no fortification or health claim, with added vitamin D, and with added vitamin D and health claim ('vitamin D contribute to the maintenance of normal bones')).

with Irish population standards (e.g., Irish central statistics office standards), focusing on socioeconomic factors that divide the population into categories ranging from professional/managerial to manual/unskilled workers. The sample was representative of the Irish population for age, gender, and social class when compared to census data. Participants received a modest incentive administered by the recruitment agency (Empathy Research) in line with standard market-research panel remuneration for a survey of this length; incentives were handled by the agency and were not provided directly by the research team. The agency applied the study eligibility criteria and removed incomplete or ineligible questionnaires before supplying the analytic dataset to the research team. On receipt of the dataset, the research team identified flatliners and these were removed and additional participants were recruited through Empathy Research. No further exclusions were made by the research team, and all analyses were performed on the complete cleaned dataset ($n = 1008$). Education was not quota-controlled; as a result, the sample contains a relatively high proportion of respondents with undergraduate or postgraduate qualifications. This is reported in Table 2 and is acknowledged as a limitation (see Limitations). Inclusion was on the basis of having consumed yoghurt/yoghurt drinks/plant-based alternatives, bread, and breakfast cereal in the past month as these products were assessed as food vehicles for fortification in the conjoint task. The participants had to be responsible for at least some of the shopping. Ethical approval for this study was granted through the Teagasc Social Research Ethics Committee (approval number: 2024AFBSA006).

2.3. Data analysis

The recruitment agency supplied a cleaned, complete dataset with no missing or partially completed questionnaires; incomplete records were removed prior to delivery and no imputation was required. Analyses are reported by survey component: psychometric analyses (factor analysis, reliability testing and between-group comparisons of multi-item constructs) are presented in Sections 2.3.1 and 2.3.3, while the conjoint/orthogonal design are described in Section 2.3.2.

2.3.1. Factor analysis

A targeted set of items was selected from the literature to capture constructs hypothesised to relate to intention and purchase of fortified foods (see Table 1 for sources). Exploratory factor analysis with Varimax rotation was used to confirm the dimensionality of the selected items and to generate multi-item constructs; statements loading on each factor were averaged to produce construct scores. Internal consistency was assessed with Cronbach's alpha (acceptable reliability $0.5 < \alpha < 0.8$; good reliability $\alpha > 0.8$); factor loadings, alpha values and mean construct scores are reported in Table 1. It was expected that higher positive-attitude and awareness scores, and greater responsiveness to action cues, would be associated with stronger intention to purchase fortified products. Cue-to-action items were retained and analysed individually rather than aggregated to preserve nuanced information about different external prompts that could drive behaviour change.

2.3.2. Conjoint task

The fractional-factorial orthogonal plan was generated using SPSS Orthoplan and nine full-profile concepts were presented to each participant (Fig. 1). Rating-based conjoint estimation was performed with the SPSS CONJOINT procedure on the profile ratings (CARD1–CARD9); part-worth (utility) scores and attribute importance values were estimated via the CONJOINT "estimate utilities" routine (specified using the .setup/.data subcommands) and saved (Supplementary File S1). The estimated part-worths quantify the relative desirability of each attribute level (higher utility = greater preference), and attribute importance was computed by the range method (importancej = rangej / Σ ranges) and is reported in Table 4. Discrete attributes (product, claim) are reported with level utilities that sum approximately

Table 2
Percentage distribution of socio-demographic profile for the total population and for the segments: supplements & fortified foods (S&FF), supplements only (SO), fortified foods only (FFO), and non-users (NU).

	Total (n = 1008)	S&FF (n = 595)	FFO (n = 145)	SO (n = 161)	NU (n = 107)	Pearson Chi Squared
	%					*p-value*
N	100.0	59.0	14.4	16.0	10.6	
Gender						
Female	57.8	60.8	51.7	57.1	50.5	
Male	41.8	38.7	48.3	42.2	49.5	0.064
Other	0.4	0.5	0.0	0.6	0.0	
Age						
18–24 years old	13.6	13.1[a]	17.2[a]	11.2[a]	15.0[a]	
25–34 years old	23.1	25.2[a]	24.1[a]	18.6[a]	16.8[a]	
35–44 years old	25.9	27.7[a]	20.7[a]	25.5[a]	23.4[a]	0.013*
45–54 years old	21.3	20.3[a]	24.1[a]	18.6[a]	27.1[a]	
55–65 years old	16.1	13.6[a]	13.8[a]	26.1[b]	17.8[a,b]	
Occupation						
Working full time	62.1	63.0	55.9	62.7	64.5	
Working part-time	19.0	20.2	20.7	15.5	15.9	
Retired/stay at home partner/ unemployed	14.3	13.3	14.5	18.6	13.1	0.086
Full time student	4.6	3.5	9.0	3.1	6.5	
Diet						
Omnivore (eats plants, meat and animal products)	92.6	91.1	93.1	93.8	98.1	0.069
Pescatarian, vegetarian or vegan	7.4	8.9	6.9	6.2	1.9	
Shopping responsibility						
All or most of the shopping	70.3	75.6[a]	57.2[c]	68.9[a,b]	60.7[b,c]	<0.001*
Half or less of the shopping	29.7	24.4[a]	42.8[c]	31.1[a,b]	39.3[b,c]	
Locality						
Rural	21.5	19.7	24.1	24.2	24.3	
City	19.3	20.8	19.3	18.0	13.1	
Suburban	18.9	18.0	15.9	18.0	29.9	0.219
Large Town	18.5	19.3	17.2	19.9	13.1	
Small Town	15.0	15.5	15.2	15.5	11.2	
Village	6.7	6.7	8.3	4.3	8.4	
Household						
Family: parents & children/teens	44.9	46.9	45.5	39.8	41.1	
Couple	18.6	18.7	17.9	19.3	17.8	
Family: parents and adult children	18.5	17.0	16.6	25.5	18.7	0.154
Single occupant	11.9	12.3	9.0	11.2	15.0	
House share - independent adults	6.2	5.2	11.0	4.3	7.5	
Education						
Undergraduate/ postgraduate qualification	72.5	73.4	66.9	75.1	70.1	0.101
Secondary	26.9	26.1	32.4	23.0	29.9	
No formal/primary	0.7	0.5	0.7	1.9	0.0	

(*continued on next page*)

Table 2 (*continued*)

	Total (n = 1008)	S&FF (n = 595)	FFO (n = 145)	SO (n = 161)	NU (n = 107)	Pearson Chi Squared
	%					*p-value*
Of those with an undergraduate or postgraduate qualification, is it a nutrition, health or food related qualification?						
No	81.9	77.4[a]	86.5[b]	85.9[b]	96.0[c]	<0.001*
Yes	18.1	22.6[a]	13.5[b]	14.1[b]	4.0[c]	

*The mean difference is significant at the 0.05 level.
[a,b]Within a row: means with a different superscript are significantly different at $p < 0.05$: differences between segments were tested using Pearson's Chi-squared test for categorical variables.

to zero, consistent with effects-style representation in which level coefficients represent deviations from the attribute mean; price was specified as LINEAR in the CONJOINT call and was therefore estimated as a numeric coefficient. The CONJOINT plan file and the exact CONJOINT syntax are provided as Supplementary File S1 to enable replication. Assumption diagnostics for the pooled OLS representation of the conjoint model were performed on the respondent-level mean ratings. Multicollinearity was assessed using variance inflation factors (all VIFs<5; maximum VIF = 2.433). Influence diagnostics (Cook's distance) and residual inspections were also examined; no excessively influential observations were identified (maximum Cook's D = 0.093).

2.3.3. Segement characteristics

Consumer segments were defined a-priori using respondents' self-reported current use of vitamin D supplements and/or foods with added vitamins (two binary items; yes/no). The four a-priori consumer segments were as follows: supplements and fortified food users (S&FF) ($n = 595$), supplements only users (SO) ($n = 161$), fortified foods only users (FFO) ($n = 145$) and non-users (NU) ($n = 107$). Crosstabs were used to compare the socio-demographic distributions across segments and for the total population. Significant differences in categorical socio-demographic data between the segments were determined using Pearson Chi Squared Analysis. The multi-item constructs (scale means) were treated as continuous variables for analysis, similar to previous published literature and reviews supporting the treatment of this data as continuous (Carifio & Perla, 2008; Field & Iles, 2024; Norman., 2010). Mean scores for attitudinal statements, likelihood to purchase, and utility values were calculated across each of the segments and tested for significant differences using One-way ANOVA with Tukey Post Hoc tests.

Data analyses were conducted using SPSS v29 (SPSS Inc., Chicago, IL).

3. Results

3.1. Demographics

Socio-demographic distribution for the total sample and the consumer segments (and the differences between these segments) are shown in Table 2. There was a higher proportion of females (60.8%) than males (36.7%) in the total survey sample likely due to the requirement that participants had to be responsible for at least some of the shopping. Participants working full time made up 62.1%, while students were the lowest category (4.6%). Almost half of participants lived in households consisting of parents and dependent children or teenagers with the lowest proportion living in house shares (6.2%). The sample were well educated; 72.5% of participants had an undergraduate degree at minimum, of which 18.1% had a nutrition, health or food related qualification. Over 90% of participants were omnivores and 70.3% having all or most of the shopping responsibility.

3.1.1. Segment characteristics

The sample was divided into four consumer groups: S&FF ($n = 595$, 60.8% female), FFO ($n = 145$, 51.7% female), SO ($n = 161$, 57.1% female), and NU ($n = 107$, 50.5% female). In all groups, the largest proportion of participants lived in families with children or teens. While differences in gender, occupation, diet, household composition, and locality were not statistically significant, some patterns were noticeable: FFO had the highest proportion of full-time students (9.0%), NU had the highest proportion of omnivores (98.1%) and suburban residents (29.9%), and SO had the highest proportion of families with adult children (25.5%) among the groups. Significant differences between segments were observed for shopping responsibility, age, and nutrition related education (Table 2). For shopping responsibility, S&FF had the highest proportion reporting responsibility for all or most household shopping, followed by SO. Both of these segments had significantly higher shopping responsibility than FFO and NU ($p < 0.001$). For age, the SO group had a significantly higher proportion of adults aged 55–65 years than S&FF and FFO ($p = 0.013$). Regarding education, S&FF participants were most likely to hold a nutrition, health, or food-related qualification (22.6%; $p < 0.001$), whereas NU participants had the lowest proportion (4%; $p < 0.001$). This suggests that consumers who use both supplements and fortified foods are more likely to be nutritionally informed and to take primary responsibility for food shopping, whereas non-users and those consuming only fortified foods tend to be less engaged or informed in these areas.

3.2. Vitamin D: psychosocial characteristics

Table 3 presents mean scores for attitudes, deficiency awareness, cue-to-action and intention to consume or purchase vitamin D fortified foods for the total population and for the four segments. Significant differences were observed for all constructs across the segments. For attitudes toward fortification, both supplements and fortified foods users (S&FF) and fortified foods only (FFO) expressed more positive attitudes toward vitamin D fortification than supplements only (SO) and non-users (NU) and were less likely to agree with negative fortification statements ($p < 0.001$). Regarding deficiency awareness, S&FF and SO demonstrated a stronger understanding of the importance of vitamin D for health compared with NU ($p < 0.001$). For cues-to-action, S&FF reported higher responsiveness to most prompts (e.g., public health campaigns, social media, and peer influence) compared with the other groups. SO and NU were less responsive, particularly to social and media-based cues, although differences were smaller for doctor advice. In terms of intention to consume or purchase, S&FF had the highest intention across all statements, followed by FFO, while SO and NU showed significantly lower intention scores ($p < 0.001$). Overall, participants who already used fortified foods and/or supplements were more positive, aware, and motivated to act on vitamin D related behaviours, whereas non-users and supplement-only participants were comparatively less engaged across all psychosocial dimensions.

3.3. Likelihood to purchase

Fig. 2 shows mean likelihood to purchase ratings for the total population and the four consumer segments. For the total population, products with added vitamin D and/or a health claim were rated significantly higher than those with no fortification and/or claim. Across consumer segments no significant differences were observed in likelihood to purchase for products without fortification and claims i.e. breakfast cereal (regular price), yoghurt (20% more expensive), and bread (regular price). However, segments did differ significantly for products with fortification and claims. For these products, S&FF users consistently reported the highest likelihood to purchase, followed by FFO users. SO users reported lower likelihood to purchase than FFO, whereas NU generally reported the lowest likelihood, with significant differences compared to FFO observed for yoghurt with vitamin D ($p =$

Table 3
Mean construct scores (±SD) for attitudes, deficiency awareness, and intention to consume/purchase, and mean item scores for behavioural cues-to-action for increasing vitamin D intake across four segments: supplements & fortified foods (S&FF), supplements only (SO), fortified foods only (FFO), and non-users (NU).

	Mean Construct Score (S·D)								Significance
	Total		S&FF		FFO		SO	None	
	(n = 1008)		(n = 595)		(n = 145)		(n = 161)	(n = 107)	(p-value)
Positive attitudes toward vitamin D fortification and health	5.4 (0.9)		5.6 (0.9)	a	5.5 (0.8)	a	4.8 (1.1) b	4.9 (0.8) b	<0.001
Negative attitudes toward vitamin D fortification and health	3.9 (1.1)		3.8 (1.1)	a	3.6 (1.0)	a	4.2 (1.1) b	4.1 (0.8) a, b	<0.001
Awareness of vitamin D deficiency	5.5 (0.8)		5.6 (0.8)	a	5.4 (0.8)	a, b	5.5 (0.9) a	5.2 (0.8) b	<0.001
Intention to consume and purchase vitamin D fortified foods	4.9 (1.2)		5.2 (1.1)	a	4.9 (1.1)	b	4.2 (1.4) c	4.1 (1.3) c	<0.001
Behavioural Cues-to-Action for Increasing Vitamin D Intake									
If a doctor advised me to increase vitamin D intake	6.0 (1.2)		6.1 (1.2)	a	6.0 (1.1)	a, b	5.8 (1.4) a, b	5.7 (1.5) b	0.005*
If I saw a public health campaign highlighting the benefits of vitamin D consumption	5.3 (1.3)		5.5 (1.2)	a	5.2 (1.3)	a, b	5.0 (1.5) b, c	4.8 (1.5) c	<0.001*
If a family member had vitamin D deficiency	5.3 (1.4)		5.4 (1.4)	a	5.6 (1.1)	a	5.0 (1.5) b	5.0 (1.4) b	<0.001*
If I saw a social media post/influencer recommending vitamin D intake	4.0 (1.7)		4.3 (1.7)	a	4.0 (1.6)	a	3.3 (1.6) b	3.2 (1.6) b	<0.001*
If a friend was taking supplements or consuming food with added vitamin D	4.9 (1.3)		5.2 (1.2)	a	4.9 (1.2)	a	4.6 (1.4) b	4.2 (1.3) b	<0.001*

*The mean difference is significant at the 0.05 level using ANOVA and Tuley Post Hoc tests.
[a,b]Within a row: means without a common superscript differ ($p < 0.05$).
Statements for each construct are shown in Table 1.
Statements were measured on a 7-point Likert scale from 1 strongly disagree to 7 strongly agree.

0.003), bread with vitamin D ($p < 0.001$), yoghurt with vitamin D and claim ($p = 0.043$), and breakfast cereal with vitamin D and claim ($p < 0.001$). However, segments did differ significantly for products with fortification and claims.

3.4. Conjoint and utility analysis

Table 4 shows the importance scores and utility scores (relative desirability of a specific level within a product attribute, with higher scores indicating greater preference) for the attributes (food vehicle, fortification and claim, and price) and attribute levels. For the four segments Food vehicle was the most important attribute to consumers with an importance score of 40.6, this was closely followed by claim with an importance score of 38.3. Price was the least important attribute relative to the other two with an importance value of 20.8. Consumers preferred the regular price products, and this did not differ across the different segments. Regarding food vehicle, bread had the highest utility score (0.204), yoghurt had a neutral utility score (0.039), and breakfast cereal had the lowest utility score (−0.244) for the total survey population. With the exception of yoghurt, responses differed across consumer segments. For bread, S&FF had higher utility scores than SO. For breakfast cereal, the SO segment showed a less negative utility (−0.05) than the S&FF (−0.286) and FFO (−0.312) segments, indicating a relatively greater, but still low, preference for this food vehicle. Across the total population, vitamin D fortification alone was the most preferred claim attribute, whereas products with no fortification information or with both vitamin D and a claim were less preferred. Segment-specific differences were observed: NU showed higher preference for products with no fortification information compared with other segments, while both NU and SO participants had lower utility scores for vitamin D fortification alone relative to the other groups. The SO segment showed higher preference for products combining vitamin D with a claim compared with the other segments. Overall, food vehicle and claim were the most influential attributes in product choice, followed by price, which had minimal impact on preference. Among food vehicles, breakfast cereal and bread showed the largest effects on utility, while yoghurt had limited influence.

4. Discussion

In order to inform a national framework for vitamin D fortification and including the important consideration of consumer acceptance of vitamin D fortified products, this study surveyed a representative sample of Irish adults and evaluated the likelihood of purchasing vitamin D fortified foods. Further psychosocial characteristics were explored across four groups in Ireland: users of fortified foods and supplements, supplement-only users, fortified food–only users, and non-users. By segmenting the population based on current use of supplements and fortified foods, the study profiled four distinct consumer segments with meaningful differences in demographics, psychosocial determinants, and behaviours. The present findings reinforce the need for targeted strategies that account for these consumer differences when designing effective vitamin D fortification policies.

4.1. Consumer segment profiles and behavioural patterns

While the total population showed broad support for vitamin D fortification, analysis revealed subtle differences in attitudes, deficiency awareness, and purchase behaviour among the segments. Segment analyses revealed clear and policy-relevant heterogeneity. The S&FF consumer segment (largest) combined high positive attitudes, the strongest deficiency awareness and the highest intention to purchase fortified products; this group also reported greater shopping responsibility and a higher prevalence of nutrition-related qualifications, characteristics consistent with greater engagement in dietary decision-making (Labrecque et al., 2006; Ares et al., 2008).

The SO group, which included a larger share of older adults (55–65 years), displayed high supplement uptake and comparatively lower intention to use fortified foods; this pattern may reflect clinical or practitioner-led supplementation and a preference to obtain nutrients via supplements rather than altered food choices. Qualitative work has shown that older adults frequently describe supplement use as a

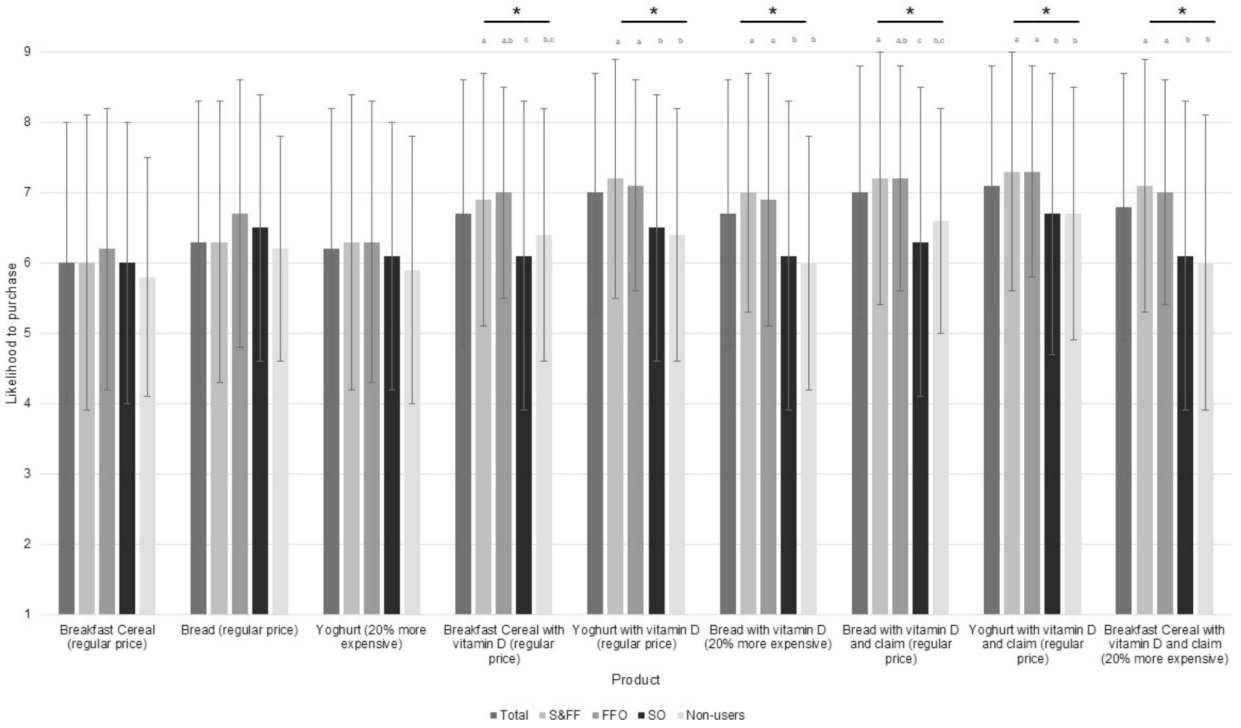


Fig. 2. Mean likelihood to purchase with Anova and post hoc analysis for the four segments: supplements & fortified foods (S&FF), supplements only (SO), fortified foods only (FFO), and non-users (NU) (*The mean difference is significant at the 0.05 level, means without a common superscript differ ($p < 0.05$)).

Table 4
Overall importance scores and utility scores for the total population with ANOVA and Tukey post hoc tests for the four segments: supplements & fortified foods (S&FF), supplements only (SO), fortified foods only (FFO), and non-users (NU).

Attribute	Importance scores	Attribute level	Utility Scores										Significance
			Total	*S&FF*		*FFO*		*SO*		*NU*			(p-value)
			(n = 1008)	*(n = 595)*		*(n = 145)*		*(n = 161)*		*(n = 107)*			
		Breakfast cereal	−0.244	−0.286	a	−0.312	a	−0.05	b	−0.205	a,b		0.010*
Food vehicle	40.6	Bread	0.204	0.262	a	0.217	a,b	0.026	b	0.138	a,b		0.002*
		Yoghurt	0.039	0.025		0.095		0.024		0.066			0.581
		No information	−0.08	−0.093	a	−0.075	a,b	−0.135	a	0.07	b		0.033*
Claim	38.3	With vitamin D	0.177	0.278	a	0.175	a,b	−0.015	b,c	−0.092	c		<0.001*
		With vitamin D & health claim	−0.097	−0.185	a	−0.100	a	0.15	b	0.023	a,b		<0.001*
Price	20.8	regular price	0.019	0.002		0.032		0.058		0.039			0.537
		20% more expensive	−0.019	−0.002		−0.032		−0.058		−0.039			0.537

*The mean difference is significant at the 0.05 level.
[a,b]Within a row: means without a common superscript differ ($p < 0.05$).

prescribed or treatment-focused practice rather than as a dietary behaviour, with many reporting use in response to specific medical advice or diagnoses (Embling et al., 2024). This framing of supplements as a medicinal or clinical response is consistent with the SO segment's pattern of high supplement uptake and lower interest in fortified foods. The FFO group (younger, more students) showed receptivity to fortified products and to clear fortification claims despite lower shopping responsibility, suggesting that claim-based messaging and low-effort product options may resonate with younger consumers which is in line with previous research (Krystallis et al., 2008; Areal & Asioli, 2024).

The NU group exhibited the lowest awareness, least positive attitudes and weakest overall intention to purchase fortified foods. Perceptions about naturalness, product processing and potential cost may partly explain low engagement low engagement with fortified foods and supplements in this group (Cashman, 2024). In the present study, certain cues to action such as GP and family advice increased likelihood to consume vitamin D fortified foods for the NU group; this pattern indicates limited intrinsic engagement but potential responsiveness to trusted messengers (Niva, 2007; Verbeke, 2005). This finding is in line with those from Verbeke (2005) who found an increased likelihood of functional food acceptance with the presence of an ill family member. These differences argue for segment-tailored interventions.

4.2. Importance of key food vehicles, claims, and Price

Across the total population, food vehicle preferences showed a clear pattern: bread was the most preferred for vitamin D fortification, followed by yoghurt (neutral) and breakfast cereal, which had the lowest and a negative utility. Vitamin D without health claims had the highest utility overall, while vitamin D with claims received negative utility among more informed segments. This finding perhaps reflects scepticism about manufacturer-driven claims, also reflected in earlier studies (Williams & Ghosh, 2008). Conversely, the SO group assigned relatively more favourable utility to claims, implying that efficacy cues can increase perceived equivalence between fortified foods and supplements in some subgroups. Verbeke (2005) highlighted the role of trust and product familiarity in shaping response to health claims while Areal and Asioli (2024) found that willingness to pay increased when claims were linked to health outcomes.

Price was ranked as the least important attribute for all segments. While previous research by Baker et al. (2022) found that health-motivated consumers are generally willing to pay a premium for functional foods, the current findings show that for NU, price is not the barrier, it is awareness, engagement, and motivation that are lacking. Together, these findings imply that food vehicle selection and labelling should be considered in policy design.

4.3. Public attitudes and motivation to change

The total population showed broad support for voluntary fortification, with all segments agreeing on the right to choose non-fortified options. This result and the “right to choose”, is important when considering mandatory fortification. Despite differing behaviours, all segments disagreed with the statement that *vitamin D should not be added to any food*, suggesting overall openness to fortification as a public health measure. Alignment between policy attitudes and behaviour was strongest among engaged consumers (S&FF, FFO), whereas disengaged consumers (NU) exhibited low awareness and weak responsiveness to broad campaigns. Lower engagement in the NU segment aligns with concepts of amotivation and precontemplation including low self-efficacy, unfavourable outcome, and/or effort, and/or value beliefs and strong cue-driven habits reduce willingness to adopt new health behaviours (Hardcastle et al., 2015). However, the NU segment were comparatively receptive to personalised recommendations from health professionals and family. This underscores the value of trusted messengers in targeted outreach and supports combining population-level measures with tailored interpersonal communication to reach harder-to-engage groups.

4.4. Policy implications and communication strategies

Given Ireland's persistent low vitamin D intakes and status, these findings support the case for exploring a mandatory vitamin D fortification policy. Bread presents the most viable route for widespread implementation, mirroring previous findings that demonstrated the success of bread as a vehicle for vitamin D fortification in Lebanon (Hoss et al., 2024). However, any fortification strategy must be supported by targeted public health messaging, especially for disengaged consumers. Simple, messages endorsed and disseminated by trusted professionals such as GPs are likely to be most effective. When investigating the determinants and longitudinal changes in vitamin D status in Northern Finland, Ikonen et al. (2021) found that in addition to a national food fortification policy, health information campaigns communicating the beneficial effects of vitamin D aided in decreasing deficiency. Findings from the present study suggest that younger consumers and those with lower shopping responsibility, may benefit from passive consumption through mandatory fortification of staple products.

Passive consumption raises ethical concerns among some, particularly regarding personal autonomy. Fanzo and Glass (2018) argue that technological solutions to complex societal problems, such as fortification, often provoke ethical debate. Nevertheless, it is important to recognise that mandatory fortification is not an untested approach. Long-standing public-health interventions such as salt iodisation and water fluoridation demonstrate that population-wide nutrient delivery

can be safe and effective when supported by appropriate dose-setting, monitoring, and transparent governance. Well-designed mandatory programs can enhance health equity for groups less likely to engage in voluntary preventive behaviours, while still managing risks through continual surveillance. In the case of vitamin D, the possibility of excessive intakes needs to be considered, particularly among those consuming high-dose vitamin D supplements. Excessive vitamin D intakes are uncommon as evidenced by national data from Finland following implementation of vitamin D fortification (Raulio et al., 2016; Scully et al., 2023b). Nonetheless, a mandatory vitamin D fortification strategy must design and implement regular monitoring of intakes and status across the population. This is usually achieved through properly designed nutrition surveillance systems. Overall, a combined strategy that includes mandatory fortification, clear food vehicle selection, and tailored communication is likely to yield the highest public health benefit in safely reducing the prevalence of vitamin D deficiency.

4.5. Limitations and future research

There are several limitations to the present study:

1. The sample in the present study has a higher proportion of participants with undergraduate or postgraduate qualifications than national estimates. This likely reflects panel recruitment and the study eligibility criteria (participants needed to have shopped for/consumed the assessed food vehicles). Higher educational attainment is associated with greater nutrition knowledge and interest in fortified/functional foods and therefore may bias results toward more positive attitudes and higher reported uptake.
2. Participants were required to have consumed bread, breakfast cereal or yoghurt in the previous month to ensure familiarity with the food vehicles and to obtain meaningful conjoint ratings; participants with dietary restrictions were instructed to assume that products met their needs. Although these food vehicles are commonly consumed in Ireland (IUNA, 2024: ≈93% bread, ≈60% breakfast cereals, ≈38% yoghurt), this inclusion criterion limits generalisability because it excludes non-consumers and may bias the sample toward groups more likely to consume these items (for example, women, families, adults aged 25–54 and health-oriented individuals), which could inflate measures of awareness and favourable attitudes toward fortified products. These recruitment effects are acknowledged and caution is advised when extrapolating results to the wider population.
3. It is worth noting that not all consumers may be aware that some of the foods they consume ((e.g., butters, breads, and cereals) are fortified with a range of vitamins and minerals. The study objective was to identify consumers who intentionally use vitamin D sources (supplements and/or fortified products) and to compare psychosocial profiles and purchase preferences between those who report active use and those who do not. The single yes/no item ("Do you currently consume food with added vitamins?") was therefore selected as an explicit measure of self-reported, intentional consumption behaviour, which aligns directly with the segmentation approach and the study's primary focus on willingness/acceptance of vitamin D fortified foods rather than on total vitamin D intake.
4. While segmentation revealed key attitudinal and behavioural differences, self-report bias precludes causal interpretation. Additionally, cultural attitudes toward fortification were not explored in depth and could vary within population subsets.
5. Price levels in the conjoint were specified as a modest relative premium an additional 20% price increase in comparison to a non-fortified product based on a targeted retail scan. Base prices used therefore reflect lower end or own brand staples. As a consequence, the conjoint may underestimate consumer sensitivity to larger absolute price differences or to premium product tiers. Likewise, several attribute contrasts (for example, the distinction between 'added vitamin D' and a short, authorised health claim) were intentionally modest and policy relevant but may have been insufficiently salient to capture the full range of consumer responses. Taken together, these design choices could attenuate observed effects for price and claim. Future work should test a wider and product specific range of price levels (including larger absolute differences and willingness to pay) and evaluate alternative claim phrasings and fortification dosages.

This study provides insights on consumer preferences but to achieve success in ensuring adequate vitamin D intake, the perspectives of other stakeholders including policymakers and industry need to be taken into account. Future research should focus on sensory evaluation of vitamin D fortified food products in Irish consumers, randomised control trial to determine the effect of adding vitamin D to different staple foods, modelling fortified food consumption behaviour and co-designing a vitamin D fortification strategy in Ireland with all stakeholders to ensure a successful implementation.

5. Conclusion

This study demonstrates that Irish consumers can be segmented based on their use of vitamin D supplements and fortified foods, with clear differences in demographics, product preferences, and psychosocial characteristics. Food vehicle choice is a key determinant of acceptance of fortification, with bread preferred over breakfast cereal. Interestingly, fortification without health claims was generally more acceptable. Segment-specific attitudes indicate that supplement and fortified food consumers are highly engaged, while non-consumers exhibit the lowest level of vitamin D deficiency awareness, intention to consume or purchase vitamin D fortified foods, and responsiveness to cues. Public health strategies to increase vitamin D intake should be tailored by segment, leveraging trusted health professionals and family-mediated cues to reach low-engagement groups. While voluntary fortification may appeal to some segments, a mandatory fortification policy for staple foods could ensure population-wide improvements in vitamin D intake, particularly among those not currently engaging with supplements or fortified foods, provided monitoring of excessive intakes is implemented.

CRediT authorship contribution statement

Lauren McGuinness: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mary McCarthy:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Mairead E. Kiely:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Sinéad N. McCarthy:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization.

Ethical approval

Ethical approval for this study was granted through the Teagasc Social Research Ethics Committee (approval number: 2024AFBSA006).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodqual.2026.106038.

Data availability

Data will be made available on request.

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