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Nudging plant-based alternatives to meat and dairy in a real-life online supermarket: A randomized controlled trial

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ABSTRACT

A shift from predominantly animal-based to plant-based consumption can benefit both planetary and public health. Nudging may help to promote such a shift. This study investigated nudge effects on plant-based alternatives to meat and dairy in an online supermarket. We conducted a two-arm, parallel-group, randomized controlled real-life online supermarket trial. Each customer transaction was randomized to a control arm (regular online supermarket) or an intervention arm (addition of placement, hedonic property and dynamic social norm nudges promoting meat and dairy alternatives). Outcomes were the aggregate of meat and dairy alternative purchases (primary outcome), the number of meat purchases, dairy purchases, meat alternative purchases, and dairy alternative purchases (secondary), and retailer revenue (tertiary). Generalized linear mixed models with a Conway–Maxwell Poisson distribution were used to estimate incidence rate ratios (IRRs). Analyzed data included 8488 transactions by participants (n = 4,266 control arm, n = 4,222 intervention arm), out of which 2,411 (66%) were aged above 45 years, 5,660 (67%) were females, and 1,970 (23%) lived in socially disadvantaged neighborhoods. Intervention arm participants purchased 10% (IRR 1.10 (95% CI 0.99–1.23)) more meat and dairy alternatives and 16% (1.16 (0.99–1.36)) more meat alternatives than control arm participants, although these findings are not statistically significant. There was no difference in dairy alternative purchases (1.00 (0.90–1.10)). Intervention arm participants purchased 3% less meats (0.97 (0.93–1.02)) and 2% less dairy products (0.98 (0.95–1.02)) than control participants. Retailer revenue was not affected (0.98 (0.95–1.01)). Online nudging strategies alone did not lead to a statistically significant higher amount of plant-based purchases, but replication of this work is needed with increased study power. Future studies should also consider nudging strategies as part of a broader set of policies to promote plant-based purchases.
Trial registration: Prospectively registered on 14th of May 2022. ISRCTN16569242 (https://doi.org/10.1186/ISRCTN16569242).

1. Introduction

Current levels of animal-based protein production and consumption are harmful to both human and planetary health. Especially excessive consumption of red and processed meats is associated with increased risks of non-communicable diseases (Han et al., 2019; Neuenschwander et al., 2023; Zeraatkar et al., 2019). Their production has negative impacts on many aspects of planetary health, such as biodiversity, water quality and climate change, through increased global greenhouse gas (GHG) emissions (Willett et al., 2019). Alternatively, production of most

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plant-based proteins requires less land, water and emits less global GHG emissions than cattle (feed) production, and higher plant-based protein consumption generally has more favorable health outcomes (Gakidou et al., 2017; Han et al., 2019; Stoll-Kleemann & O'Riordan, 2015; Zeraatkar et al., 2019).

Yet, our current food environments facilitate the formation and maintenance of habitual animal-based protein consumption since it is characterized by a high availability, accessibility and affordability of unhealthy foods including many animal-based protein products (Stoll--Kleemann & Schmidt, 2017; Swinburn et al., 2019). Strategies to change food consumption can be aimed at individual-level cognitive determinants, such as knowledge or goal-setting (Bianchi, Dorsel, et al., 2018). However, solely intervening on deliberate choices will likely not lead to substantial dietary changes since many dietary choices have a habitual (repetitive and routine-based) nature, including grocery purchasing behaviors. Habitual behaviors tend to be sensitive to being automatically elicited by situational cues in the immediate environment, such as the physical or online food environment (Stoll-Kleemann & Schmidt, 2017).

Changing aspects of food environments can be an effective strategy to change food consumption (Bianchi, Garnett, et al., 2018; Marteau, 2017; Marteau, Hollands, & Fletcher, 2012). A popular approach is changing the way a choice is being presented or positioned, i.e., 'nudging'. This concept was first introduced by Thaler and Sunstein (Thaler & Sunstein, 2008), who defined nudging as "any aspect of the choice architecture that alters people's behavior in a predictable way, without forbidding any options or significantly changing their economic incentives". Nudging tends to target the more automatic decision processes, in which decisions are presumably made less consciously and more rapidly, and are based on heuristics, biases and contextual cues and stimuli in one's environment (Kahneman, 2011). Nudging taps into this sensitivity by presenting cues and stimuli that prompt people towards certain choices. Nudging effects on various behaviors are often mixed and when present they generally have modest effects within a single individual (e.g., ~2-9% behavior change) (DellaVigna & Linos, 2022; Maier et al., 2022). Yet, they can have a substantial impact on a population level (Rose, 1985).

Supermarkets represent an important food environment where nudging could be applied to influence purchasing behaviors, being key community food suppliers. Furthermore, online supermarkets are becoming increasingly popular and can serve as an additional promising setting to promote plant-based purchases (Tyrväinen & Karjaluoto, 2022).

Nudging strategies can be classified into placement nudges or property nudges (Hollands et al., 2017). Placement nudges can increase the products salience, availability, and accessibility, and the perceived social norms in a specific environment (Pechey et al., 2021; Raghoebar, Van Kleef, & De Vet, 2020). Existing evidence on placement nudges targeting protein products predominantly stems from real-life (field) studies conducted in physical settings. These studies, for example, demonstrate that repositioning meat products and increasing the availability of plant-based alternatives can reduce meat purchases or increase plant-based purchases (Bianchi, Garnett, et al., 2018; Bucher et al., 2016; Kurz, 2018; Kwasny, Dobernig, & Riefler, 2022; Pechey, Bateman, Cook, & Jebb, 2022; Trewern, Chenoweth, Christie, & Halevy, 2022), and that prominently positioning plant-based products in meat aisles of supermarkets and butcheries can increase their purchases (Piernas et al., 2021; Vandenbroele, Slabbinck, Van Kerckhove, & Vermeir, 2021). Property nudges highlight product information or change the products design (Hollands et al., 2017). The dynamic social norm nudge is a specific type of property nudge that provides information on behaviors that others are increasingly adopting. They focus on the evolvement of behavior over time, contrasting with static social norms that reflect current behavior states. As food consumption is both influenced by social and cultural norms that dictate what is or should be eaten, dynamic social norm nudges capitalize on this influence(Nguyen & Platow, 2021).

Dynamic social norms can be effective when a behavior is not yet the norm but is gradually being embraced by others, such as the current increased popularity of plant-based alternatives to meat (Sparkman, 2021; Sparkman, Macdonald, Caldwell, Kateman, & Boese, 2021; Sparkman & Walton, 2017). Dynamic social norm nudges have been found to affect meat consumption, although the evidence is mixed and not focused on a supermarket setting. For example, a set of experiments in real-life physical restaurants found promising albeit modest effects on vegetarian menu orders, whereas some other real-life studies in restaurants found no effects (Çoker et al., 2022; Sparkman & Walton, 2019; Sparkman, Weitz, Robinson, Malhotra, & Walton, 2020). Another type of property nudge, the so-called hedonic property nudge, emphasizes tastiness of products by highlighting flavor, taste or by using hedonic words. Taste is often mentioned as an important motivation to consume or avoid meat, and a negative expectation about the taste of plant-based alternatives can be an important barrier to consume these foods (Perez-Cueto et al., 2022; Stoll-Kleemann & Schmidt, 2017). Promising effects of hedonic property nudges are for example reported for vegetables, where using indulgent words to label vegetables in a cafeteria setting significantly increased their selection (Turnwald, Boles, & Crum, 2017).

Yet, focusing on online purchases may require different nudging strategies compared to physical settings due to the on-screen nature of online shopping with different sensory cues, less exposure to stimuli, and differences in type of products often being purchased as compared to physical settings (Berger, Müller, & Nüske, 2020; Pitts, Ng, Blitstein, Gustafson, & Niculescu, 2018). There are a range of previous studies investigating online nudge effectiveness in simulated experimental settings. For instance, an online meal booking study investigating a placement nudge did not report an increase in vegetarian meal bookings when meat-free options were positioned before meat options, or when default options were modified in favor of meat-free options (Stewart, Patel, & Sucharitakul, 2016). An online supermarket study on dynamic social norms found no significant effects on sustainable purchasing behaviors, using standard products with which participants were likely familiar (Berger et al., 2020). Hedonic property nudges are found to increase pro-environmental product and meal preferences and purchases (Papies, Johannes, Daneva, Semyte, & Kauhanen, 2020; Vennard, Park, & Attwood, 2019), whereas labelling plant-based dishes as meat-free are found to lead to decreased selection of those alternatives (Vennard et al., 2019). However, previous real-life online supermarkets studies predominantly focus on promoting healthier purchases – and show mixed effects – whereas real-life evidence on promoting plant-based purchases in online supermarkets is lacking (Bunten et al., 2022; Forwood, Ahern, Marteau, & Jebb, 2015; Huang et al., 2006; Sacks, Tikellis, Millar, & Swinburn, 2011; Stuber, Lakerveld, Kievitsbosch, Mackenbach, & Beulens, 2022; Valenčič, Beckett, Collins, Seljak, & Bucher, 2023; Wyse et al., 2021).

This study aims to contribute by investigating the effects of a combined nudging strategy in a real-life online supermarket to promote a shift from meat and dairy purchases to their plant-based alternatives. In comparison to a control arm, we tested the effect of a unique combination of three nudges (placement nudge, dynamic social norm nudge, and hedonic property nudge) to promote real-life online supermarket purchases of meat and dairy alternatives. As a primary outcome, we compared the total number of purchased meat and dairy alternatives. As a secondary outcome, we compared between the intervention arm and the control arm the number of purchased (a) meat, (b) meat alternatives, (c) dairy, (d) dairy alternatives. As a tertiary outcome, we evaluated retailer revenue. We explored potential interactions for nudges with neighborhood deprivation level, age, and sex on the primary outcome, as these factors have been identified as key sociodemographic factors influencing meat consumption (Graça, Godinho, & Truninger, 2019).

2. Methods

2.1. Study design

We used a parallel-arm individually randomized controlled trial (RCT) design:

Arm 1: regular online supermarket (control arm).
Arm 2: regular online supermarket with the addition of a combined nudging strategy promoting meat and dairy alternatives (intervention arm).

The trial was conducted in a real-life online supermarket in the Netherlands. This national supermarket chain delivers groceries throughout the Netherlands, using physical supermarkets as delivery hubs. Out of the 350 stores in total, 86 stores were represented in this sample serving as delivery hubs. The trial ran for eight weeks from mid-May until mid-July of 2022.

The study protocol was approved by the Medical Ethics Review Committee of VU University Medical Center (ref: 2021.0703). The trial was prospectively registered at ISRCTN Registry (ISRCTN16569242) and we used the CONSORT reporting guidelines (Schulz, Altman, & Moher, 2010).

2.2. Participants

All customers of the online supermarket ordering groceries (i.e., transactions) during the trial period were eligible for participation. Customers were requested to provide consent for data collection for scientific purposes by third parties by accepting the supermarket website's analytics cookies. According to supermarket policy, customers had to be at least 18 years to shop in the online supermarket. We excluded participants who did not purchase any meat or dairy and meat and dairy alternatives. As we aimed to investigate intervention effects among regular shoppers purchasing household groceries, we additionally excluded business-related participants and participants who were within the top 0.01% of meat and dairy alternatives related purchases, as well as the top 0.01% for the regular meat and dairy purchases, as outliers.

2.3. Intervention

Nudges were designed in collaboration with the supermarket chain to match existing styles and secure technical implementation. The combination of nudging strategies was directed at product groups of meat and dairy alternatives. We defined meat and dairy alternatives as being a product that imitates animal-based meat and dairy products and can be used for similar purposes to replace meat and dairy products (e.g., vegetarian hamburgers, mock-meat bread toppings, almond milk, or soy yoghurt products) (Table 1). Cheese and butter were excluded due to a lack of plant-based alternatives (Supplementary Table S1).

Three nudging strategies were implemented: *placement nudges* adjusting the position of meat and dairy alternatives, a *dynamic social norm nudge* regarding meat and dairy alternatives providing information on behaviors that others are increasingly adopting, and a *hedonic property nudge* providing information on hedonic qualities of meat and dairy alternatives. We did not specify to participants that the products targeted by nudging strategies were plant-based or a pro-environmental choice, instead we focused on *prominence*, *taste* and *social norm* aspects of these products.

2.3.1. Placement nudge

A product navigation menu was shown when participants navigated towards the products webpage. In the intervention arm, a placement nudge was installed in this navigation menu. When participants chose the product categories 'Meat, poultry, fish and vegetarian products' or 'Dairy, butter and eggs', the categories of meat and dairy alternatives were placed more prominently. Participants in the control arm saw the regular navigation menu, where meat and dairy alternative categories were only visible after clicking on an arrow to show additional product categories (Supplementary Figs. S1–S5).

Table 1
Included products groups and product examples ($n_{total} = 1550$).

Product groups	Product subgroups	Product examples
Plant-based products (n=190)	Meat alternatives (n = 119)	Meat replacements, such as minced meat, meatball, burgers, and sausages (based on soy, wheat, or legumes). Tofu, tempeh, seitan (only plant-based). Bread toppings such as hummus, and spreads.
	Dairy alternatives (n = 71)	Long-life and fresh dairy alternatives drinks (based on soy, oats, rice or nuts). Long-life and fresh dairy products such as yoghurts, custards, desserts and ice creams (based on soy, oats, or nuts).
Animal-based products (n=1360)	Meat (n = 773)	Meat products such as minced meat, meatball, burgers, and sausages. Frozen snacks such as sausages and croquettes. Bread snacks such as sausage rolls. Bread toppings based on meat.
	Dairy (n = 587)	Long-life and fresh dairy drinks. Long-life and fresh dairy products such as yoghurts, custards, desserts and ice creams.

2.3.2. Dynamic social norm nudge

We installed a dynamic social norm nudge by placing a label stating *'Increasingly chosen'* on meat and dairy alternatives in their product categories (Supplementary Fig. S6). In total, a maximum of 234 eligible meat and dairy alternatives (meat = 161, dairy = 73) were available at the time of intervention design. We used pre-intervention sales data to select the top 50% most sold and thus popular alternatives from different categories, resulting in a total of 117 products receiving the label (meat = 81, dairy = 36).

Online supermarket orders were linked to physical supermarket locations serving as delivery hub, and the product availability varied during the intervention period. This resulted in varying numbers of meat and dairy products and meat and dairy alternatives available for label selection and data analyses. In addition, this meant participants could be exposed to a maximum amount of 117 labeled products, but the actual amount varied per participant depending on product assortment variation (Table 2).

2.3.3. Hedonic property nudge

We installed a hedonic property nudge, which consisted of 11 frames that highlighted hedonic properties (i.e., product tastiness) of meat and dairy alternatives with a label stating '*Check out these tasty products*'. The frames were placed at a prominent place (the top right side) on 11 product category overview pages (e.g., meal packages, potatoes, pasta). Therefore, the frames also functioned as a placement nudge because they changed the position of plant-based products. The frame suggested two relevant meat or dairy alternatives relevant for the product category (for example, vegetarian meatballs for pasta and processed tomatoes). Clicking on these frames directed the participants to relevant meat and dairy alternative product pages (Supplementary Fig. S7 and Supplementary Table S2).

2.3.4. Combination of hedonic property and dynamic social norm nudges

We installed three other frames, which were also placed on a prominent place (the left top side) on three main category pages (meat, poultry, fish and vegetarian products; freezer products; dairy products). The frames suggested two relevant meat and dairy alternatives and

Table 2
Overview of meat and dairy alternative categories and number of labels in each category.

Product category	Example of plant-based products	Products in category	Labels in intervention arm[a]
Total meat alternatives		**n=161**	**n=81**
Sub-categories of meat alternatives:			
Bread toppings	Plant-based salad spreads (e.g., chicken-curry salad, or pate).	n = 27	n = 11
Hummus	Hummus products.	n = 17	n = 8
Plant-based meats	Frozen and fresh plant-based meats, schnitzel, burgers, minced meats, sausage, and meatballs.	n = 78	n = 42
Bread snacks	Plant-based steamed meat buns and sausage rolls.	n = 2	n = 2
Deep fry snacks	Plant-based chicken nuggets, sausages, spring rolls, croquettes.	n = 28	n = 13
Tofu, tempeh, seitan, jackfruit	Natural and spiced tofu, seitan, jackfruit.	n = 9	n = 5
Dairy alternatives		**n=70**	**n=36**
Sub-categories of dairy alternatives:			
Ice-cream bar	Chocolate cream popsicles.	n = 3	n = 2
Plant-based milk alternatives	Soy-based, nut-based, rice-based, and oat-based drinks.	n = 46	n = 23
Plant-based yoghurts	Soy-based or nut-based yoghurts, porridge, desserts.	n = 21	n = 11

[a] The number of products with a label slightly diverges from 50%, due to uneven numbers of products in categories and single products in categories.

included both the hedonic property and dynamic social norm nudge by stating the sentences *'Increasingly chosen'* and *'Check out these tasty products*'. The frames directed the customer to relevant product pages (Supplementary Fig. S8 and Supplementary Table S3).

2.4. Outcomes

We primarily evaluated whether the combination of nudges resulted in a between-group mean-difference in the number of purchased meat and dairy alternatives. Our secondary outcomes were the number of purchases of (a) meat, (b) meat alternatives, (c) dairy, and (d) dairy alternatives. This allowed us to provide insights into which of these food groups could drive the overall between-group difference of the primary outcome, and detect potential substitution patterns (e.g., a simultaneous decrease in meat purchases with an increase in meat alternatives). For our tertiary outcome, we investigated the between-group mean difference in total revenue (i.e., Euros spent on meat and dairy products and meat and dairy alternatives) as a relevant business-related outcome.

2.5. Data collection

Collected participant data included: age (≤25 years, 26-35 years, 36-45 years, 46-55 years, 56-65 years and >65 years), sex (male, female, unknown), supermarket location, and 4-digit postal code to determine the socio-economic position (SEP) scores of the participants' neighborhood. Neighborhood SEP scores were based on national data on average household income, level of education and recent employment history (Statistics Netherlands (CBS), 2022). Participants were categorized into living in a disadvantaged neighborhood or non-disadvantaged neighborhood as being either below or above the national average SEP score. Data of participants who accepted the analytical cookies were collected by the supermarket chain and only this data was shared with the researchers. To account for the fact that individuals could make multiple transactions during the intervention period, transaction data were clustered at the level of individual participants.

2.6. Sample size

Based on a previous online supermarket experiment (Stuber et al., 2022), we expected a mean difference of 2% in purchasing behavior between the intervention arm and the control arm. To estimate a standard deviation around the mean difference, we used the formula $\sigma \sqrt{[2(1-\rho)]}$, assuming a ρ of 0.783 resulting in a standard deviation of the mean difference of 14 (Hoenink, Mackenbach, Van Der Laan et al.; Hoenink, Mackenbach, Waterlander, et al., 2020). With 80% power and a two-sided type 1 error rate of 0.05, the trial would require 768 participants in each trial arm, resulting in 1537 participants required in total. Retrospective supermarket sales in September 2021 provided by the supermarket showed that during one month, 2370 shoppers purchased at least one meat alternative product and 1308 shoppers purchased at least one dairy alternative. The supermarket provided information on the number of shoppers, with approximately 20,000 shoppers purchasing products in the online supermarket on a monthly basis (approximately 4000 shoppers per week). Therefore, a trial duration of eight weeks was considered sufficient.

2.7. Randomization and masking

During the intervention period, all participants were randomly allocated to one of two trial arms upon their first visit to the online supermarket. Randomization and allocation were concealed, as it was performed by e-commerce employees of the supermarket using a software tool (Blueconic Customer Data Platform). Randomization was based on participants' cookies. The system was set to randomize and allocate an equal percentage of participants to either the control arm or the intervention arm. Blinding of participants was not possible, but participants were not explicitly notified of the nudges and were not aware of the trial arm they were allocated to. In principle, when participants revisited the online supermarket, they remained allocated to the same trial arm based on their IP-address. However, should participants use multiple devices with the same online shopping account or delete their cookie history, this would result in varying group allocation per transaction for a unique participant.

2.8. Statistical methods

Study population characteristics are reported for unique participants by the proportion of females (n (%)), the proportions per age category (n (%)), and the proportion of participants living in socially disadvantaged areas (n (%)). Descriptive statistics on data distributions are provided for all study outcomes reported by transactions (median; quartile 1 (Q1) and quartile 3 (Q3) values; minimal and maximal values).

We expected a high number of true zero values in the purchasing data, especially in the meat and dairy alternative product groups, since not all participants will purchase products from each food group. Furthermore, we expected a highly right skewed count data distribution as most participants purchase one or two products from a specific group, whereas a smaller share of participants purchase products in bulk. Hence, the assumption of the Poisson distribution (i.e., equal variance to the mean) was expected to be violated. To determine the most suitable count model for our data, we used the *glmmTMB* R package to determine the most suitable count model fit (i.e., Negative Binomial, zero-inflated Negative Binomial, Hurdle model Negative Binomial, Conway-Maxwell-Poisson, and zero-inflated Conway-Maxwell-Poisson) (Brooks ME et al., 2017; Magnusson A et al., 2020). A generalized linear mixed model (GLMM) with a Conway-Maxwell-Poisson distribution including a zero-inflation part appeared the most suitable approach to fit our primary outcome model. The Conway-Maxwell-Poisson is a flexible

generalization of the Poisson distribution that is suitable for modelling of overdispersed as well as underdispersed count data. As such, we fitted GLMMs with a Conway-Maxwell-Poisson distribution using a random intercept at the participant level to estimate the incidence rate ratios (IRRs) and 95% confidence intervals (CI) for products purchased in the intervention arm compared to the control arm. We explored whether adding an additional random intercept and/or slope for supermarket level would improve the model. IRRs in which the 95% CI did not include 1 were considered to be statistically significant. Modelled with the *glmmTMB* package, the Conway-Maxwell-Poisson distribution is interpretable as a log-linear model (Brooks ME et al., 2017). The IRR therefore reflects the percentage difference in purchases in the intervention arm compared to the control arm. All analyses were conducted with R version 3.6.1.

For our secondary and tertiary outcomes, we determined whether the addition of a zero-inflation part was deemed appropriate based on the data distribution. For those outcomes including a zero-inflated part, the zero-inflated estimates are odds ratios (OR), interpretable as the odds of being a zero count (i.e., the odds for the intervention arm participants of being a structural non-purchaser of the outcome under interest).

In our pre-registration (ISRCTN16569242) we planned that the study results will reflect intervention effects within individual customers. This is however not the case since, under specific circumstances, unique participants could be allocated to both the intervention arm and control arm when shopping multiple times over the course of the intervention period. Results are now interpretable as intervention effects across single transactions, rather than intervention effects within individual customers.

Effect modification was tested in the primary outcome model by adding interaction terms between trial arms and sex, age (≤45 years or >45 years) and neighborhood deprivation level. Results would be stratified in the case of a significant interaction term ($p < 0.05$). In sensitivity analyses, we used descriptive statistics to explore whether the number of clicks and number of add-to-carts of all product groups per intervention arm were in line with our observed results. Furthermore, we repeated the main analyses with a correction for average purchase data during an 8-week pre-intervention period, to take into account regression to the mean.

3. Results

During the intervention period, 3,502 unique participants with a total of 10,798 transactions purchased products from the meat and dairy alternatives and/or meat and dairy product groups. The intervention arm consisted of 2,022 unique participants (5,440 transactions) and the control arm of 2,049 unique participants (5,358 transactions). Thus, some participants were exposed to both study arms and results are therefore presented on the transaction level. After exclusion of business-related participants, a total of 8,497 transactions remained, and after exclusion of the top 0.01% meat and dairy alternatives related purchases, 8,488 transactions remained. This sample was used for the analyses of the meat and dairy alternative related primary and secondary outcomes and the tertiary outcome. For the meat and dairy related outcomes, the top 0.01% purchases were excluded from the meat and dairy alternatives related sample resulting in an analytical sample of 8,479 transactions (Fig. 1).

Participant characteristics of transactions were equally balanced between trial arms, with approximately ~67% females, ~23% living in socially disadvantaged neighborhoods and ~66% aged above 45 years (Table 3). Data relating to all meat and dairy alternative products consisted of a high number of zero values, as the median of total meat and dairy alternative purchases was 0 (Q1-Q3: 0-0). The median of meat purchases was 3 (Q1-Q3: 1-6) and of dairy purchases was 6 (Q1-Q3: 3-

Table 3
Participant characteristics of transactions for the total sample and stratified by trial arm (n = 8,488).

	Total sample (n = 8,488)		Control arm (n = 4,266)		Intervention arm (n = 4,222)	
Sex, n (%)						
Females	5,660	(66.7)	2,946	(69.1)	2,714	(64.3)
Age categories, n (%)						
<=25 years	467	(5.5)	230	(5.4)	237	(5.6)
26-35 years	1,028	(12.1)	547	(12.8)	481	(11.4)
36-45 years	1,386	(16.3)	692	(16.2)	694	(16.4)
46-55 years	1,727	(20.3)	840	(19.7)	887	(21.0)
56-65 years	1,469	(17.3)	736	(17.3)	733	(17.4)
>65 years	2,411	(28.4)	1,221	(28.6)	1,190	(28.2)
Neighborhood SEP, n (%)						
Disadvantaged neighborhoods	1,970	(23.2)	1,001	(23.5)	969	(23.0)

SEP= Socioeconomic position.

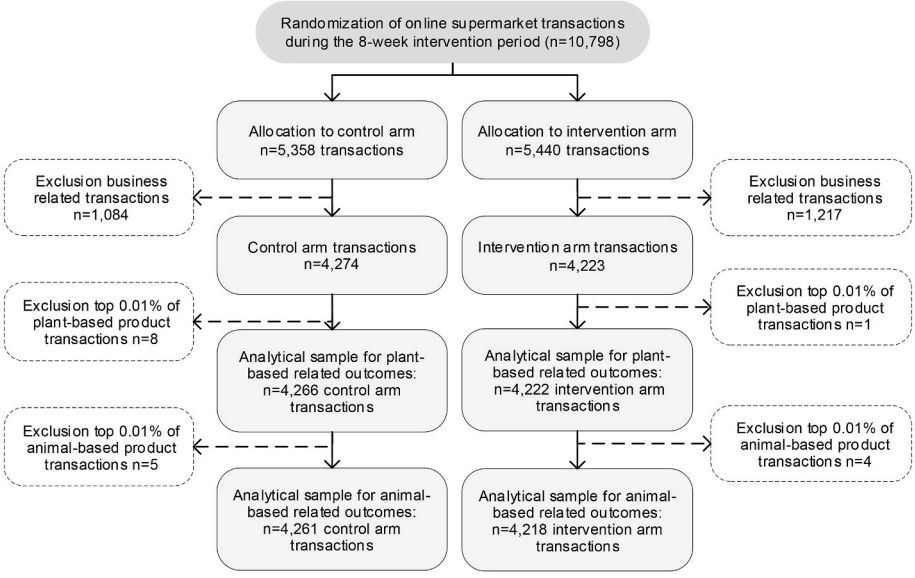

Fig. 1. Flowchart of transactions during the intervention period.

10) (Table 4).

Regarding our primary outcome, participants in the intervention arm purchased on average 10% more meat and dairy alternatives than those in the control arm (IRR 1.10, 95%CI 0.99–1.23). The odds of being a structural non-purchaser of meat and dairy alternatives in the intervention arm was 1.25 (95%CI 0.79–1.99), compared to those in the control arm (Fig. 2 and Supplementary Table S4). We observed no significant interactions by SEP of the participants' neighborhood (p 0.09), age (p 0.74), nor sex (p 0.95). Analyses of our secondary outcomes revealed that participants in the intervention arm purchased on average 16% more meat alternatives than those in the control arm (IRR 1.16, 95%CI 0.99–1.36). There was no difference in dairy alternative purchases between both arms (IRR 1.00, 95%CI 0.90–1.10). We observed a 3% lower amount of meat purchases (IRR 0.97, 95%CI 0.93–1.02), and 2% lower amount of dairy purchases in the intervention arm (IRR 0.98, 95%CI 0.95–1.02) compared to the control arm. Regarding our tertiary outcome, transactions in the intervention arm resulted in 2% less Euros compared to those in the control arm (IRR 0.98, 95% CI 0.95–1.01) Yet, none of these findings were statistically significant. These observed results are in line with the number of clicks and add-to-carts in the online supermarket (Supplementary Table S5).

The exploratory analyses adjusting for average pre-intervention purchase data showed comparable non-significant results as the main analyses (Supplementary Tables S6–8).

4. Discussion

This novel randomized controlled trial in a real-life online supermarket found no significant effects of a combined nudging strategy on purchases of meat and dairy alternatives, nor on retailer revenue. The promising effects of placement and information nudges observed in real-life physical settings may not translate directly to online settings (Nelson & Nilsson, 2021), as food purchasing behaviors may differ from purchasing behaviors in physical settings. For example, people make less impulsive purchasing decisions and tend to buy less fresh products when shopping online versus physically (Bianchi, Garnett, et al., 2018; Huyghe, Verstraeten, Geuens, & Van Kerckhove, 2017; Piernas et al., 2021; Taufik, Verain, Bouwman, & Reinders, 2019). The latter may stem from quality concerns (e.g., distrust regarding the selection of the best products) and a preference to inspect products before purchasing them (Klepek & Bauerová, 2020).

Different nudging strategies may be required to effectively change online purchasing behavior, targeting more conscious processes and thereby taking into account the less impulsive nature of online purchasing decisions. In addition, so-called type 2 nudges may be more suitable as they are assumed to stimulate more conscious, reflective processes (Hansen & Jespersen, 2013). We did not specify information on environmental sustainability of purchases to participants, but several experimental online studies found promising effects of using eco-labels to inform participants about the environmental impact of food purchases, including personalized feedback on carbon footprint information of products (Demarque, Charalambides, Hilton, & Waroquier, 2015; Kanay et al., 2021; Potter et al., 2021; Potter et al., 2022; Potter et al., 2023; Segovia, Yu, & Van Loo, 2022).

Other promising nudges may rely on decision assistance, such as goal setting (e.g., stimulating individuals to achieve sustainable targets), for example in combination with nudges providing feedback (e.g., carbon feedback) (Kanay et al., 2021). Future studies should test these nudging strategies targeting more conscious processes on pro-environmental purchases in real-life settings. Nudges should preferably be pilot tested to ensure nudges are sufficiently attractive and salient and to ensure exposure at the right time. From a more fundamental perspective, research is needed to understand the differences in the processes underlying purchasing decisions made in online versus offline food environments, especially given the rapidly growing amount of online purchasing opportunities. Further, the development of nudges in online food environments should go beyond merely testing adapted offline nudges in online environments and should include larger-scale qualitative or mixed methods research into the wishes, needs and desires from online shoppers themselves to find inspiration for the development of online nudges.

Another explanation for our results relates to the real-life setting of this study. We studied the effects of nudges within complex real-life conditions and confirm findings from a recent systematic review reporting null results from several real-life trials (Harbers et al., 2020). Subtle nudging effects may have been attenuated by other influences, such as product availability, social norms and price perceptions (Hartmann-Boyce et al., 2018; Stoll-Kleemann & Schmidt, 2017). On the other hand, our null results build upon the growing understanding on the lack of effectiveness of nudges after controlling for publication bias (Maier et al., 2022). Moreover, in both relative and absolute terms, there were a low number of meat and dairy alternatives in our setting to be targeted resulting a relatively low intervention dosage. Furthermore, household social norms on meat consumption may be more influential on real-life purchases than hypothetical purchases.

Nudge effectiveness may differ between studies that promote healthy purchases (e.g., focusing on products that are more nutrient-dense, lower in calories or higher in fibers, vitamins and minerals compared to their less healthy alternatives) and studies that promote pro-environmental purchases (e.g., focusing on products that have less negative environmental impacts such as reduced GHG emissions or water use). Real-life evidence in online settings shows that placement and property nudges can promote purchasing of healthier foods (e.g., containing less saturated fat or sodium) (Bunten et al., 2022; Valenčič et al., 2023; Wyse et al., 2021). However, these nudges may not be as effective to increase all types of pro-environmental purchases, specifically those targeting meat products, due to different underlying processes such as values and motives involved in pro-environmental purchases. First, in comparison to healthier foods, the benefits from purchasing pro-environmental products may be perceived as more distant, long-term, and not directly benefitting oneself (White, Habib, & Hardisty, 2019). Second, meat has a socially constructed meaning and social norms on meat consumption can be either a barrier or a facilitator to spontaneously purchase an unfamiliar plant-based alternative (Stoll-Kleemann & Schmidt, 2017). Dynamic social norm nudges on plant-based product consumption may not outweigh the deeply rooted social norms regarding meat consumption. Meat is often at the center of one's plate and tied to traditions and memories, meaning people can

Table 4
Descriptive statistics of study outcomes of all transactions (n = 8,488).

	Total sample (n = 8,488)		Control arm (n = 4,266)		Intervention arm (n = 4,222)	
Total number of meat and dairy alternatives						
Median, [Q1, Q3]	0	[0, 0]	0	[0, 0]	0	[0, 0]
[min, max]		[0, 14]		[0, 14]		[0, 14]
Number of meat alternatives						
Median, [Q1, Q3]	0	[0, 0]	0	[0, 0]	0	[0, 0]
[min, max]		[0, 12]		[0, 12]		[0, 10]
Number of dairy alternative products						
Median, [Q1, Q3]	0	[0, 0]	0	[0, 0]	0	[0, 0]
[min, max]		[0, 13]		[0, 13]		[0, 13]
Number of meat products[a]						
Median, [Q1, Q3]	3	[1, 6]	3	[1, 6]	3	[1, 6]
[min, max]		[0, 96]		[0, 63]		[0, 96]
Number of dairy products[a]						
Median, [Q1, Q3]	6	[3, 10]	6	[3, 10]	6	[3, 11]
[min, max]		[0, 97]		[0, 65]		[0, 97]
Total Euros spent						
Median, [Q1, Q3]	21	[12, 32]	21	[12, 32]	21	[12, 32]
[min, max]		[1, 578]		[1, 433]		[1, 578]

Q = Quartile.

[a] n = 9 transactions missing due to exclusion of top 0.01% of animal-based protein purchases.

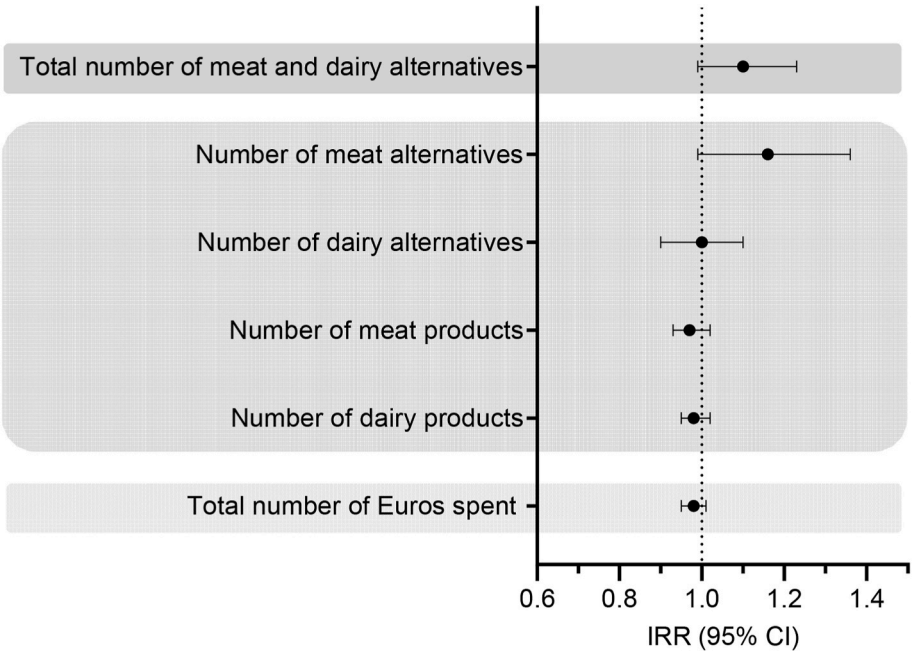

Fig. 2. Effect of a combined nudging intervention compared to a control arm (n_{total} = 8,488 transactions).

have a broad affective bond with and dependency towards meat (meat attachment) (Graça, Calheiros, & Oliveira, 2015). Meat's special status can make it more difficult to shift to plant-based alternatives compared to a shift from more neutrally perceived products (e.g., from refined to whole-grain bread). The same could be the case for social norms regarding milk consumption, which is deeply rooted into to Dutch culture and also reflected in the relatively high median purchase of milk products. Third, taste claims such as those used in our hedonic property nudge, may elicit associations with prior experiences of eating the products (Wilson, Buckley, Buckley, & Bogomolova, 2016). However, many participants in our study did not purchase any meat and dairy alternatives at baseline, suggesting no taste associations were elicited as they may have been unfamiliar with these types of products and their taste. Alternatively, it could also be that the used sentence for our hedonic property nudge was too short, due to the limited available space for text. Future research could investigate hedonic labels with more words to describe taste or social norm labels describing who changed their behavior by how much (Berger et al., 2020; Demarque et al., 2015; Papies et al., 2020; Sparkman et al., 2020).

4.1. Strengths and limitations

This study was the first to test a novel combination of nudging strategies to promote meat and dairy alternative purchases in a real-life online supermarket. A key strength of this study was that participants were actual customers shopping for groceries with their own money, who did not receive any specific instructions, securing high external validity. Another key strength is the large study sample and inclusion of data on both transactions and clustering of transactions within individual participants. The additional exploratory analyses using pre-intervention data to correct for baseline purchases of participants allowed for stronger methodological underpinning of our findings.

Yet, some limitations should be acknowledged. While there are dual health and environmental benefits for many products targeted in nudging studies (for example fruit, vegetables, and legumes) (18), it is important to recognize that not all food items offer these mutual advantages. Meat alternatives, for example, can have lower environmental impacts than meat products, but they may not always be a healthy alternative to meat due to a high level of processing and salt content (Pointke & Pawelzik, 2022). In this experiment, targeted meat and dairy alternatives were mostly not in line with the Dutch dietary guidelines due to a lack of available healthy alternatives (i.e., only the targeted tofu, tempeh and soy-based dairy including micronutrient fortification are recommended in the guidelines). However, to facilitate the shift towards plant-based products by small steps, we focused mostly on meat substitutes that were similar to meat products (e.g., vegetarian hamburgers) and did not focus on legumes as a (healthy) plant-based alternative. We expected the meat substitutes to be more acceptable to customers in terms of options to replace animal-based products (Onwezen, Bouwman, Reinders, & Dagevos, 2021; Schösler, De Boer, & Boersema, 2012). Second, a methodological limitation is that we were unable to investigate a shift in the ratio of meat and dairy alternatives versus meat and dairy purchases within a participant, because many individuals did not purchase meat and dairy alternatives. Operationalizing outcomes as a ratio measure would have led to a U-shape data distribution, including an extremely high number of 0 values (0% meat and dairy alternative purchases), some 100 values (100% meat and dairy alternative purchases), and little nuance between those two values (participants purchasing both meat and dairy alternatives and meat and dairy). Third, the high number of zero values may have contributed to low study power as we did observe a relevant effect size of 10% more meat and dairy alternative purchases, yet not significant. This observation highlights the need for replication of this work with increased study power. Fourth, we did not have access to data on how many, and which type of, customers did not accept the supermarket website's analytics cookies. This might have led to some unobserved selection bias. Fifth, collaborating with a supermarket chain with a profit motive inhibited nudging strategies that discourage meat purchases. Sixth, we planned to use individual-level data for analysis as described in the preregistration of the study. Unfortunately, this data could not be used due to the unexpected varying group allocation per transaction for some participants that revisited during the intervention period and probably used different devices or deleted their cookie history. A limitation of utilizing transaction-level data is the possibility of spill-over effects from nudges in the intervention group onto participants who were initially assigned to the intervention group but later reassigned to the control group. In addition, we collected transaction data during an 8-week post-intervention period to investigate post-intervention effects on

purchases but we were unable to use these data since transaction-level data did not contain information about prior trial arm allocation. Last, nudge type and design were limited by technological boundaries within the existing online supermarket ICT-landscape. A planned pricing intervention and mixed-placement nudge that placed labeled meat and dairy alternatives between animal-based products were not possible. The absence of the latter may have resulted in low intervention exposure. We were limited to one set of nudges for all customers and future studies should investigate tailored nudges or focusing on specific customer groups (Potter et al., 2021). Nudges may work best if targeted at a behavior that people are already motivated to do, such as people who already buy less meat or more meat alternatives.

4.2. Implications

This study suggests that nudging online supermarket purchases on itself is insufficient to enable the protein transition, although the positive non-significant effect size of 16% for meat alternatives suggest that effects may substantially impact purchasing patterns when combined with additional strategies. Additional strategies are especially needed when implemented in a food system where meat products are predominantly available, promoted and intertwined in daily meals. There are multiple reasons why these additional strategies should target food systems and food environments, next to individual-level measures. First, consumer decisions take place at the end of a larger chain of factors influencing food-intake. Solely focusing on the last-mile is insufficient to change food consumption at the scale needed (Bianchi, Dorsel, et al., 2018). Second, there is evidence that individual-level interventions can draw away support for more systemic changes (Hagmann, Ho, & Loewenstein, 2019). Opponents of interventions aimed at individuals state that these interventions signal personal responsibility for behavior change, while higher level factors (e.g., regulation, corporate incentives) are making it difficult to take this responsibility and also contribute to inequalities when lower SEP populations rely on more limited resources (Adams, Mytton, White, & Monsivais, 2016; Chater & Loewenstein, 2022, pp. 1–60). Third, behavior can be captured as resulting from interaction between individuals and their environment. Advances in modelling techniques can shed light on these interactions and are increasingly allowing to test how, in complex systems, systemic interventions affect behavior (Scalco, Macdiarmid, Craig, Whybrow, & Horgan, 2019). A large scale protein transition thus requires systemic changes on a policy level (Marteau, 2017). Additional strategies can for example be financial policies that subsidize meat and dairy alternatives production or policies requiring a minimum percentage of meat and dairy alternatives within the food retail sector and other food outlets. Moreover, policy measures can promote meat and dairy alternative reformulation since many alternatives currently contain too high amounts of salt and saturated fats. Such additional strategies on a policy level can create a level playing field for industry and food retailers and can ultimately make meat and dairy alternatives more widely available and accessible to all (Ferrari, Cavaliere, De Marchi, & Banterle, 2019; Poore & Nemecek, 2018). Nudging may help in creating and maintaining such a food system, but policy makers should be aware that there is no one-size-fits-all nudging strategy and that effects of additional strategies should ideally first be tested and monitored over time.

4.3. Conclusion

This study observed no significant effects of a combined nudging strategy (placement nudges, a dynamic social norm nudge, and a hedonic property nudge) on purchases of meat and dairy alternatives in a real-life online supermarket. These findings suggest that additional strategies are needed to shift purchasing patterns from predominantly animal-based proteins towards predominantly plant-based proteins. Future real-life studies should evaluate effectiveness of nudging strategies on food purchases as part of a broader policy strategy enabling higher availability, accessibility and healthiness of plant-based products.

Ethical statement

The study protocol was approved by the Medical Ethics Review Committee of VU University Medical Center (ref: 2021.0703). Customers were requested to provide consent for data collection for scientific purposes by third parties by accepting the supermarket website's analytics cookies.

The trial was prospectively registered at ISRCTN Registry (ISRCTN16569242).

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CRediT authorship contribution statement

Nina van der Vliet: Conceptualization, Data curation, Investigation, Methodology, Project administration, Validation, Writing – original draft. **Josine M. Stuber:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Visualization, Writing – review & editing. **Sanne Raghoebar:** Conceptualization, Data curation, Investigation, Methodology, Validation, Writing – review & editing. **Eline Roordink:** Conceptualization, Data curation, Investigation, Methodology, Validation, Writing – review & editing. **Koen van der Swaluw:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing.

Declaration of competing interest

All authors declare that they have no conflicts of interest.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.appet.2024.107278.

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