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Involving family and friends helps sustainable diets last longer

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Reducing animal product consumption is a necessary action to mitigate climate change and other environmental issues. We tested and compared the effectiveness of an individual and a social app-based 30-day challenge in reducing animal product consumption. Through a pre-registered field randomized controlled trial ($n = 1213$), we find both conditions reduced animal product consumption by 16–17% compared to the control group, with a lasting effect only for the social treatment (encouragement to involve family and friends) 3 months after the intervention. The effects were largest for meat consumption and those who consumed meat at the baseline. Additionally, associated greenhouse gas emissions decreased by 21–24% and are still significantly reduced 3 months after both interventions, with a larger effect for the social treatment. Our findings suggest that app-based animal product-free challenges are a cost-effective way (~€13–25 per tCO_2-eq assuming a 1-year lasting effect) to translate intentions into lasting dietary change, especially when involving the social environment and targeting meat eaters.

Animal product consumption (APC) is one of the major contributors to climate change and other environmental issues such as inefficient land and water use, biodiversity loss, and pollution[1–4]. Animal-based products account for 57% of the food system's anthropogenic greenhouse gas emissions, compared to 29% for plant-based products[5]. One crucial measure is a shift towards less animal-based diets[6–9].

We conduct a large-scale pre-registered randomized controlled trial (RCT) ($n = 1213$) of a real-life app-based 30-day challenge to reduce APC, and compare the effects of an individual and social approach at multiple timepoints. Our study is motivated by four main observations. First, social network interventions, that use or modify social networks to change behaviour (i.e., team-based or peer-support approaches)[10] could be a promising pathway for reducing APC. Fostering interactions with close social contacts can facilitate behaviour change through feelings of social support, social comparison, or new social norms and identities[11–15]. Some studies have found correlational evidence of the social network's influence on APC and related beliefs[16,17]. Moreover, social network interventions have a demonstrated impact on other health and pro-environmental behaviours[10,14,18–20]. Nevertheless, interventions leveraging the social network to reduce APC remain understudied relative to other individually focused intervention types, like nudges, educational interventions and text messages[21–26]. Second, due to limited financial resources, reliable and longer-term evidence is lacking on the effectiveness of real-life field campaigns. These are interventions organized by food advocates that aim to change behaviour and are already accessible in real life, reaching large audiences[27]. Examples are challenges organized by non-profit organizations, e.g., refs. 28–30. Third, app-based interventions to reduce APC could provide a relatively cheap, feasible and effective way to reach a large audience and make various behaviour change techniques easily accessible[31,32]. Finally, intervention studies aiming to reduce APC have mostly focused on short-term effects or one-time meal choices[24], while ideally, interventions have a lasting effect on behaviour. We therefore quantify the effect on dietary patterns up to 3 months after the intervention.

Following these considerations, we conducted a RCT to test whether individual and social app-based challenges are effective in reducing APC. Specifically, we studied the *Veggie Challenge*, developed by non-profit organization ProVeg, which challenges participants to consume less or no animal products for 30 days according to their own chosen goal, with support of an app. The app offers recipes, feedback on savings resulting from the participant's behaviour change (emissions, land, water and animals),

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informational articles, a habit-tracking feature to register daily whether they succeeded to skip certain animal products or not, and game features (i.e., quiz questions, rewards) (see Supplementary Information 1 (SI. 1)). We randomly assigned study participants to one of the three experimental arms: a control group only filling out the questionnaires sent out by the researchers, a treatment group invited to do the *Veggie Challenge* individually (VC-I), and a treatment group invited to do the *Veggie Challenge* with a social encouragement, i.e., the social intervention (VC-S). The latter entailed that on top of participating in the *Veggie Challenge*, participants were stimulated to involve their social environment in two ways. On the one hand, they were encouraged to invite family and friends to their virtual team in the app with additional app features that were not accessible to participants in the individual treatment, like an activity feed of team members, feedback on team-level savings from behaviour change (emissions, land, water and animals), and a chat group (link to WhatsApp) (see Table SI. 1.1). On the other hand, they were encouraged to involve family and friends in their behaviour change process outside the app. The study participants were 1213 adults from the Netherlands and Flanders (Belgium), mostly female (86%) and high educated (69%) with a mean age of 46.6 (SD = 15.0) (see SI. 3). To resemble the real-life Veggie Challenge audience, we targeted individuals who already had an intention to reduce APC.

We assess longer-term effects of the challenges by measuring APC at the endline, and 1 and 3 months after the intervention. The main outcome APC frequency was measured using a 3-day recall. Participants filled out for the past 3 days whether they consumed eight animal product types (chicken, beef, pork, other meat, fish or seafood, cheese, other animal dairy and eggs) or not, and subsequently with which meals (breakfast, lunch, dinner or snacks) they consumed it. The final outcome measure is the number of times (frequency) one had an animal product in the past 3 days (see SI. 4). Our study design, hypotheses and analyses were pre-registered online prior to the intervention at the Open Science Framework (pre-registration: https://osf.io/82ekc; protocol: https://osf.io/wep54). The study is designed and implemented to ensure high statistical power (see SI. 2).

Our results demonstrate that both interventions, individual (VC-I) and social (VC-S), effectively reduced APC by 16–17%. The effect of the social intervention, i.e., being encouraged to involve family and friends, lasted at least 3 months post intervention, while the individual one did not, showcasing the importance of involving the social environment for maintenance of behaviour change. Both interventions were most effective among baseline meat consumers (compared to non-meat consumers). The results additionally suggest estimated reductions of more than 20% in 3-day APC-related greenhouse gas emissions (kg CO_2-eq) directly after the intervention, which remain significant over time for both treatments, but reduce in size for the individual treatment. Translating the findings to cost-effectiveness, we find that the challenges cost €13–25 per avoided ton CO_2-eq under the assumption that the average treatment effect lasts for a year.

We discuss implications and conclude that app-based animal product-free challenges represent a low-cost and effective way to translate intention into reduction of APC among a broad audience (everyone with a smartphone). As suggested by our main results and heterogeneity analysis, this finding is particularly true when involving the social environment or targeting meat eaters.

Results

Main effects

The Veggie Challenge significantly reduced 3-day APC frequency by 1.31 (SE = 0.29; p value = 0.000; q value = 0.000), in the individual treatment (VC-I) and by 1.17 (SE = 0.31; p value = 0.000; q value = 0.000) in the social intervention (VC-S), compared to the control group with an APC frequency of 7.57 at the endline (see Table 1 and Fig. 1). VC-I reduced APC by 17.3%, and VC-S by 15.5% compared to the control group at the endline. The effect sizes are 0.34 and 0.31 Cohen's d comparing the treatment groups VC-I and VC-S to the control group, respectively. Both challenges reduced APC compared to the control group. We did not find a significant difference between VC-I and VC-S directly after the intervention (0.14; SE = 0.26; p value = 0.593; q value = 0.593).

To study the longer-term effect, we tested the effects of the interventions at 1- and 3-month follow-ups (see also Table 1 and Fig. 1). One and 3 months after the intervention, the effect of VC-I disappeared. However, the difference between the VC-S participants and the control group remains significant, with a reduction of 0.93 (SE = 0.31; p value = 0.003; q value = 0.009; d = 0.24) and 0.81 (SE = 0.31; p value = 0.008; q value = 0.024; d = 0.21) after 1 and 3 months, respectively. These are 12.7% and 11.3% reductions compared to the control group (APC frequency 7.32 after 1 month and 7.16 after 3 months). Comparing the individual (VC-I) to the social (VC-S) treatment, we observed that APC was 0.55 lower (SE = 0.25; p value = 0.030; q value = 0.060; d = 0.14) in VC-S compared to VC-I at the 1-month follow-up. Similarly, 3 months after the intervention, VC-S participants show significantly lower APC compared to VC-I (0.61; SE = 0.26; p value = 0.020; q value = 0.040; d = 0.16). The lower APC in social treatment participants after 1 and 3 months emphasizes the importance of involving the social environment to achieve longer-lasting reductions in APC.

To assess the impact of the Veggie Challenge over the period of 140 days (~4.5 months) from the beginning of the intervention until the end of the study, we use panel data analysis on pooled data from all measurements (n = 939; observations = 3756) further boosting statistical power. We find an average treatment effect of −0.42 ($SE_{clustered}$ = 0.14; p value = 0.002; q value = 0.004) for VC-I and −0.71 ($SE_{clustered}$ = 0.14; p value = 0.000; q value = 0.000) for VC-S (Table 1). Finally, the difference between the average treatment effects of VC-I and VC-S is −0.290 ($SE_{clustered}$ = 0.12; p value = 0.017; q value = 0.017).

Food categories

The outcome variable APC was divided into three different food categories: meat consumption, fish and seafood consumption and dairy and egg consumption (see SI. 6.3). The interventions were most effective in reducing meat consumption. For meat consumption, the results are significant for both treatments right after the intervention (reduction of 22–27% compared to control group) and lasting up to 3 months after the intervention for the VC-S group (25% reduction). For dairy and egg consumption, significant effects are found right after both treatments (15–11%), but no lasting effects are found at follow-up. We do not find a statistically significant effect on fish and seafood consumption. Panel analyses also only show significant effects for each comparison for meat consumption.

Heterogeneity

We assess treatment heterogeneity using a generic machine learning approach[33] and subsequently test the presence of interaction effects using linear regression (see SI. 7). Most importantly, we find that the reduction in both treatments both after 1 and 3 months is significantly larger for those who ate meat at the baseline, see Fig. 2 and Table SI. 7.8. Namely, we find a significant interaction effect between the VC-I treatment and baseline meat-eater status of 1.98 (SE = 0.61; p value = 0.001) 1 month after the intervention and of 1.61 (SE = 0.63; p value = 0.01) 3 months after the intervention. Similarly, we see a significant interaction effect between the VC-S treatment and baseline meat-eater status of 1.89 (SE = 0.61; p value = 0.002) 1 month and of 1.98 (SE = 0.62; p value = 0.001) 3 months after the intervention. Additionally, those who chose the vegetarian or vegan goal experienced a significantly lower reduction of APC than those who chose the 'meatless days' goal (see Table SI. 7.10). Finally, having vegetarian or vegan friends is associated with a smaller effect of the interventions 1 and 3 months after (see Table SI. 7.11).

Greenhouse gas emissions

To estimate the associated effect on greenhouse gas emissions, we approximated 3-day APC-related kg CO_2-eq using portion sizes derived from the Dutch nutritional centre[34] and kg CO_2-eq per portion based on a meta-analysis[4], see Table SI. 6.2. At the endline, the findings show an estimated 1.40 (SE = 0.44; p value = 0.002; q value = 0.004; d = 0.27) and 1.68

Table 1 | Linear regression of animal product consumption at endline, 1 and 3 months after intervention, and average treatment effect

Outcome	*N*	Control vs VC-I	Control vs VC-S	VC-I vs VC-S
APC (endline)	1043	−1.307*** (0.290)	−1.170*** (0.306)	0.137 (0.257)
p value		0.000	0.000	0.593
q value[a]		0.000	0.000	0.593
Cohen's *d*[b]		0.34	0.31	–
% change[b]		17.3	15.5	–
APC (1 month after)	1045	−0.380 (0.312)	−0.930*** (0.312)	−0.551** (0.253)
p value		0.224	0.003	0.030
q value		0.224	0.009	0.060
Cohen's *d*		–	0.24	0.14
% change		–	12.7	7.9
APC (3 months after)	1011	−0.203 (0.306)	−0.811*** (0.308)	-0.609** (0.261)
p value		0.508	0.008	0.020
q value		0.508	0.024	0.040
Cohen's *d*		–	0.21	0.16
% change		–	11.3	8.8
APC (panel)[c]	939	−0.422*** (0.139)	−0.712*** (0.143)	−0.290** (0.121)
p value		0.002	0.000	0.017
q value		0.004	0.000	0.017

Estimates are derived from linear regression analyses including control variables baseline APC, intention, goal and dietary label. Robust standard errors in parentheses.
APC Animal Product Consumption, *VC-I* Individual Veggie Challenge, *VC-S* Social Veggie Challenge, in which participants were encouraged to involve their social environment.
** and *** denote significance at the 5 and 1 percent levels, respectively.
[a]Holm–Bonferroni corrected for multiple comparisons.
[b]Cohen's *d* and % change only included for significant effects. Based on adjusted means and standard deviations reported in SI. 6.1.
[c]Time modelled as fixed effects and standard errors clustered at the level of individuals.

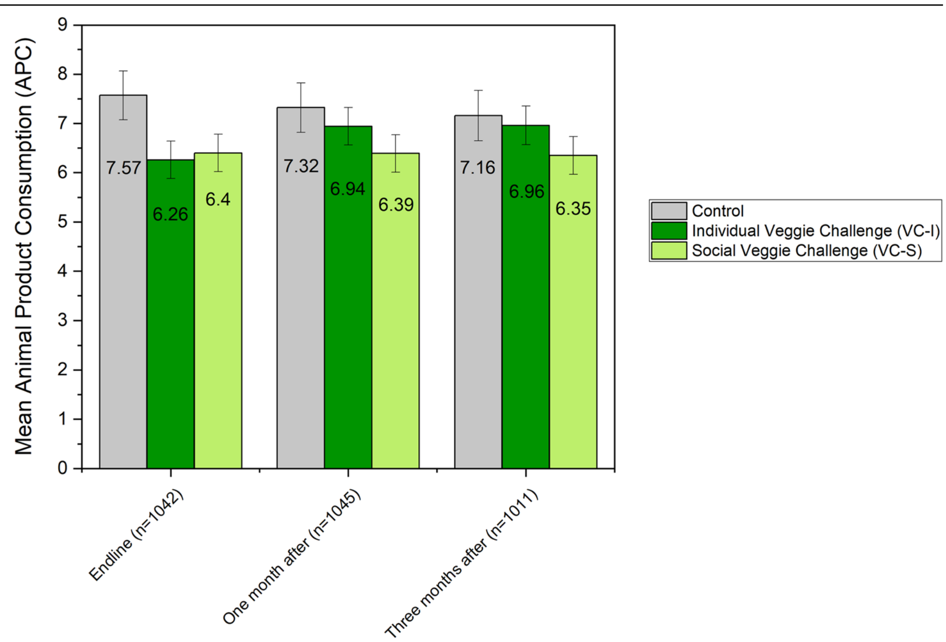
(SE = 0.42; p value = 0.000; q value = 0.000; d = 0.33) kg CO_2-eq reduction per 3 days for VC-I and VC-S respectively. That is an estimated reduction of 21% and 25% in 3-day animal product-related kg CO_2-eq compared to the control group. Both the estimated effects of VC-I and VC-S prevail 3 months after the intervention with a decrease of respectively 1.06 (SE = 0.48; p value = 0.022; q value = 0.044; d = 0.18) and 1.55 (SE = 0.49; p value = 0.001; q value = 0.000; d = 0.27) kg CO_2-eq compared to the control group. Over the entire study period, VC-I significantly reduced estimated greenhouse gas emissions with 0.69 ($SE_{clustered}$ = 0.21; p value = 0.001; q value = 0.002) per 3 days, and VC-S with 1.01 ($SE_{clustered}$ = 0.21; p value = 0.000; q value = 0.000) compared to the control group. There was no significant difference in estimated average treatment effect on greenhouse gas emissions between the two treatments. Throughout the treatment (30 days), VC-I participants reduced an estimated 14.02 APC-related kg CO_2-eq per person, and VC-S participants an estimated 16.78 APC-related kg CO_2-eq. Over the entire study time (140 days), this amounts to an estimated 32.15 and 47.27 APC-related kg CO_2-eq per person, respectively.

We additionally calculated the returns on investment in terms of saved kg CO_2-eq per euro and carbon abatement costs in terms of euro per metric ton CO_2-eq. The details are reported in SI. 8. Two cost types are distinguished: total costs for developing, maintaining, expanding and promoting the app (~ €1.4 million or €2.50 per participant from 2018 to 2023) and promotion costs separately (~€1.2 million or €2.00 per participant from 2018 to 2023). In case of total costs, saving a metric ton CO_2-eq costs €64 considering the duration of the study (140 days; ~4.5 months) and €25 if the average treatment effect lasts a year. For promotion costs, this decreases to €52 for 140 days and €20 for a lasting effect of a year. Focusing solely on the social challenge and/or on baseline meat eaters further decreases costs (€16–21 for total costs and €13–17 for promotion costs in case of a year-long effect).

App usage

Table 2 reports objective app usage data (number of activities, number of recipes viewed, and days using the habit-tracking feature) of the 483 treatment participants who downloaded the app in the correct manner (~50% of the 970 treatment participants). A comparison between VC-I and VC-S participants shows that participants in the social intervention used the mobile application significantly more frequently. For instance, on average VC-S participants viewed 71% more recipes (~23) compared to those in the

Fig. 1 | Bar chart of mean animal product consumption by experimental arm per timepoint. Means are adjusted for control variables baseline animal product consumption, intention, goal and dietary label. Control = control group only filling out surveys, VC-I = Individual Veggie Challenge group; VC-S = Social Veggie Challenge group which received the encouragement involve their social environment.



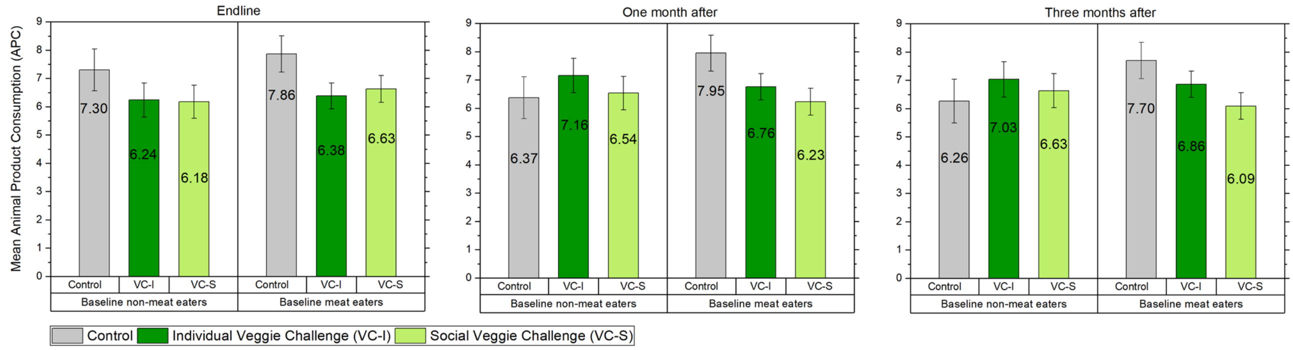


Fig. 2 | Baseline meat eaters are more affected by the intervention than baseline non-meat eaters. The plots represent the interactions between experimental arm and baseline meat consumption (meat eater vs non-meat eater). The mean animal product consumption (*y*-axis) is displayed for each experimental arm (*x*-axis) and baseline meat consumption category (adjacent plots) per timepoint. Control = control group only filling out surveys, VC-I = Individual Veggie Challenge treatment group, VC-S = Social Veggie Challenge group which received the encouragement involve their social environment. Means are adjusted for control variables baseline APC, intention, goal and dietary label. Error bars represent 0.95 confidence intervals.

Table 2 | App usage statistics (*n* = 483)

	VC-I (*n* = 249)	VC-S (*n* = 234)	*p* value[a]	*q* value[b]
No. of activities in app				
Mean (SD)	74.97 (84.34)	105.83 (99.6)	0.001***	0.004***
Median	40	107.5		
Min–max	0–526	0–573		
No. of recipes viewed				
Mean (SD)	13.26 (26.13)	22.71 (40.47)	0.002***	0.004***
Median	3	6.5		
Min–max	0–211	0–319		
Days habit tracking				
Mean (SD)	14.67 (13.51)	17.88 (13.25)	0.009***	0.009***
Median	12	25.5		
Min–max	0–30	0–30		

The sample in this table is smaller than the full sample because it represents people that both complied to participate in the challenge and signed up correctly through our designated sign-up page. Self-reported data (see SI. 10) suggests that at least 551 people (285 VC-I and 266 VC-S) signed up for the challenge.

VC-I Individual Veggie Challenge, *VC-S* Social Veggie Challenge, in which participants were encouraged to involve their social environment.

*** denotes significance at the 1 percent level.

[a]*P* values are derived from *t*-tests.

[b]Holm–Bonferroni corrected for multiple comparisons.

individual treatment (~13) (p value = 0.002; q value = 0.004). The total amount of app activities was also significantly higher among social treatment participants (~106) compared to individual treatment participants (~75), a difference of 41% (p value = 0.001; q value = 0.004). Finally, the VC-S group used the habit-tracking roadmap of the app significantly more days (18 out of 30) than the VC-I group (15 out of 30). There are even more pronounced differences in the medians, with a higher than double median in the social treatment compared to the individual treatment in each activity category. Altogether, this suggests that the social treatment activated the participants more compared to individual participants who did not receive the encouragement to involve family and friends.

Discussion

We assessed the effectiveness of an individual (VC-I) and a social (VC-S) app-based animal product-free challenge, targeting individuals that already had an intention to reduce APC. The results show that both app-based challenges are effective and decrease the frequency of consuming animal products by 16–17% with effects sizes of Cohen's d 0.31–0.34 compared to the control group. The effects are sizable, considering that the average effect size of field experiments focused on pro-environmental consumption is estimated to be $d = 0.20$ (CI: 0.179; 0.217) with changes of 2–12% points[20].

Remarkably, the effect lasts over time for the social challenge with a reduction of 11% 3 months after the 30-day intervention, but not for the individual challenge, revealing the crucial role the social environment played. We offer two complementary explanations. First, our app usage data (Table 2) demonstrated that social treatment participants were more active in the app during the intervention than individual participants. This suggests that involving the social environment led to more active participation in the challenge, and therefore resulted in more persistent behaviour change. Second, involving the social environment could have led to a more socially supportive environment outside the app to start and maintain dietary change during and after the intervention. Qualitative feedback from VC-S participants confirmed that involving the social environment fostered discussions and inspiration (see SI. 14). Psychological literature also suggests that the social environment fosters behaviour change maintenance through increased social support, social comparison, and the creation of social norms and identities[11–14]. A side note is that only ~12% of the social treatment participants actually invited someone to their virtual team. Leaving those who invited someone out of the analysis decreases but does not defeat the difference between the individual and the social treatment effects (see SI. 12.6). We can therefore conclude that the encouragement to involve family and friends, even without forming a virtual team on the app, led to a longer-lasting effect.

Heterogeneity analyses of the treatment effects showed that it is more fruitful to focus on reducing meat consumption rather than other APC categories, as the interventions were most effective for meat consumption and for baseline meat consumers. This is in line with findings by Lohmann et al.[21] and Sleboda et al.[35] that show that labelling strategies had the largest effects on those who did not prefer vegetarian meals and those who were red meat eaters. In fact, in our study, those who did not consume meat at the baseline and those who chose vegetarian or vegan goals, did not experience significantly reduce their APC compared to the control group at the follow-up measurements. A plausible explanation is that those who are just starting to reduce APC benefit more from the new knowledge and ideas in the app, while vegetarians do not gain many new skills or information.

Translating the outcome from animal product frequency to animal product-related kg CO_2-eq resulted in similar effects (~23% reduction at endline, and after 3 months 22% for the social treatment and 15% for individual). Notably, the effect of the individual intervention on estimated kg CO_2-eq was significant after 3 months (though smaller than the effect of the social intervention), while the effect on frequency was not. This may be explained by that the individual treatment group ate less beef as a proportion of total APC than the control group 3 months after the intervention (see SI. 13), and beef has by far the largest impact on estimated kg CO_2-eq among the studied products (6.4 kg CO_2-eq per portion, see SI. 6.2). The estimated savings (~0.12–0.17 kg CO_2-eq per meal) are in the same range as a carbon footprint labels intervention of Lohmann et al.[21] (0.14 kg CO_2-eq per meal), and are lower than an educational intervention by Jalil et al.[23] (0.35 kg CO_2-eq per meal) see SI. 6.2. Our design might offer lower bounds on potential reductions in greenhouse gas emissions as we included only participants that already had a limited APC (because of the interest in reducing APC), included all animal products rather than only meat consumption (e.g., replacing pork or chicken by cheese actually leads to increased greenhouse gas emissions) and measured dietary pattern rather than meal choice.

In terms of cost-effectiveness, the social cost of carbon is an important benchmark to decide whether an intervention is worth to invest in or not. The estimates in the literature vary from about US $31–200 per metric ton depending on methods and assumptions[36–38]. Conservatively considering the lower bound (US $31) and comparing to other interventions, the Veggie Challenge is at first sight expensive when considering exclusively the study duration of 140 days with €52–64 per ton CO_2-eq (an educational intervention cost €30 per ton CO_2-eq for an effect of a year and a labelling nudge €36 per ton CO_2-eq[21,23]), see SI. 8. However, the campaign becomes beneficial in the case that the average effect on greenhouse gas emissions lasts longer, for instance a year (€20–25/tCO_2-eq). Counting only promotion costs and/or focusing on the social challenge or baseline meat eaters is even more beneficial (€13–21/tCO_2-eq). It should be considered that in the 1st years an app like the Veggie Challenge requires increasing development and maintenance costs, which will decrease over time as the app is mature and established. Altogether, app-based challenges represent a low-cost way to reach a large audience, especially after the initial development phase and when many individuals are reached.

Our study also has some limitations. First, we did not reach the entire sample at the endline and follow-up measurements. Yet, we still reached more than 83% of participants each time. More importantly, the sample remained balanced across treatments on baseline participant characteristics in each survey period. Moreover, as we anticipated some level of attrition, we employed several estimation strategies to mitigate the risk of attrition bias following study protocol—accounting for predictors of unbalanced attrition with a double lasso procedure in our main specification, reweighting estimates utilizing intensively tracked sample of initial attritors, and a bounding approach (see SI. 12). The results remain robust across these estimation strategies. Second, food behaviour is period-sensitive. Both follow-up measurements were recorded during Summer time, and several participants reported to have eaten more animal products due to vacations abroad. To overcome temporal influence, the research would have to be repeated in different periods across the year with different participants. Third, not all individuals included in the analysis took part in the challenge (~65–70% of treatment participants in the analyzed samples reported to have taken part in the challenge, see SI. 10). The conclusions about the intervention effects thus rather reflect the effect of the encouragement to participate rather than the effect under perfect participation in the challenge. This means that the effect of the intervention is likely larger when participation is stimulated more thoroughly or systematically, e.g., ref. 39. Fourth, the study was directed at individuals who already had an intention to reduce their APC to match the real-life Veggie Challenge participants, of whom the majority is female and high educated. While this strategy is relevant for policy practice, it limits the generalizability to the general population and in particular to those who do not have any intention of or awareness about reducing APC. We argue however that individuals at different stages of change react better to different types of interventions[40]. In our case, a self-regulation strategy like the Veggie Challenge may be more useful for individuals that are already willing to take action. Other strategies like information provision or nudges may be more appropriate for those without motivation[41]. Future studies could test whether and how animal product-free challenges can help those in the pre-contemplation stage or in the wider population. Finally, the aggregate measures of animal product and meat consumption do not account for the possible shift in product types that have varying effects on greenhouse gas emissions, such as a shift from beef to chicken or pork. We aimed to account for this by translating the consumption score to greenhouse gas emissions. Future studies could focus on the shift between various products in a more detailed fashion. It should however be kept in mind that even if a shift between various meat products reduces emissions, it could worsen other issues, like animal suffering or zoonotic risk[42].

The results lead to some key takeaways for non-profit organizations, food advocates and governments. First and foremost, the study demonstrates the importance of involving the social environment in behaviour change. Behaviour change interventions could benefit from the cost-free encouragement to seek support in the social surroundings so that the change is longer lasting. Second, we recommend to target meat consumers by reaching beyond the already interested vegetarian/vegan audience of non-profits. Finally, as individual treatment showed a disappearing effect over time, repeating or extending the challenge through maintaining a 'streak' after the 30 days could be beneficial. Altogether, app-based animal product-free challenges, in particular those involving the social environment, provide a readily available and effective way to contribute to the much-needed shift towards more plant-based diets.

Methods

Setting

Our field partner was ProVeg, an international non-profit organization stimulating the transition to plant-based diets. In particular, we tested our hypotheses (see SI. 2) with support of their Dutch department, through a specific case of an animal product-free challenge—the Veggie Challenge. The Veggie Challenge, and the recently developed social extension of the app, are available in different countries adapted to language and culture. Here we focus on the Dutch version. The entire study (e.g., experiment, data collection, data management and analysis) was conducted objectively and independently from ProVeg. The collaboration with ProVeg consisted of supporting the implementation strategy, leveraging their large network and social media reach for recruitment, and making use of their mobile application for the intervention.

Design

The experiment is three-armed, including a control group that does not partake in the Veggie Challenge, a treatment group with individual participation in the standard Veggie Challenge (VC-I), and a treatment group in which the participants are additionally encouraged to invite peers (friends, family, etc.) to join their virtual team or be non-virtually involved in their challenge (VC-S). The invited peers are only part of the treatment, and are not study participants. A summary of the design (research questions, hypotheses, required sample sizes and methods) is given in Table SI. 2.1 in the Supplementary Information. The hypotheses, sample sizes, methods and all used materials (e.g., for advertising) were pre-registered online on OSF (pre-registration: https://osf.io/82ekc; protocol: https://osf.io/wep54).

Participants

Participants were recruited in the Netherlands and Flanders (Belgium) in April and May 2023, both via our own networks and via paid social media advertisements (Facebook and Instagram). Out of 2745 registrations, 1606 were eligible and received the baseline survey. We excluded participants who did not speak Dutch, did not have a smartphone, were already (almost) vegan or had already done the Veggie Challenge before. Additionally, we only targeted individuals who already had an intention to reduce APC, in order to resemble the real-life audience that would partake in the Veggie Challenge, and because self-regulation strategies are most useful when there is already an intention to change the behaviour[41]. The final sample to be randomized consists of the 1213 participants who filled out the baseline survey. According to our a priori power analysis (see pre-registration and SI. 2), this is sufficient to reach a statistical power of 0.80 with a minimum detectable effect size of $d = 0.3$ for the control vs treatment comparisons and $d = 0.2$ for the VC-I vs VC-S comparison, adjusting for multiple comparisons with a conservative Holm–Bonferroni correction. In our a priori power calculations we conservatively assumed effect sizes to be lower than effect sizes found by previous studies (see sampling plan in the online available study protocol: https://osf.io/wep54).

Data collection

Data were collected by the principal investigator through four surveys: a baseline measurement, an endline measurement right after the intervention, and two follow-up measurements 1 and 3 months after the intervention. ProVeg had no access to the collected survey data.

The primary outcome APC was measured through a 3-day recall focused on animal products, consisting of several steps. Respondents were asked which animal product types they consumed with which meals (breakfast, lunch, dinner, snacks) in the past 3 days before today. The final outcome variable APC is the sum of the number of times an animal product was eaten with a meal across the 3 days. Hence, the maximum possible range of the variable is 0 (no animal products on any of the 3 days) to 96 (all 8 animal products in all 12 meals across the 3 days). The broad range allows various gradations in APC, and hence takes account of people who reduce but not fully avoid APC, such as flexitarians or semi-vegans[43,44]. An extensive account of the recall questions and measure selection is given in SI. 4. Beside the 3-day APC recall, we assessed their *dietary identification label* (omnivore, flexitarian, etc.) at every timepoint, *intention to reduce animal product consumption* in the first two measurements (baseline and endline), and socio-demographics at the baseline. A full account of the relevant questions is provided in SI. 9.

Additionally, we gathered qualitative feedback about the study and intervention through open-text boxes in the surveys (see examples in SI. 14). Finally, ProVeg provided us with app usage data of our participants. These were pseudonymous data that ProVeg could recognize through a registration marker and we could link to the survey data through pseudonymized e-mail addresses (i.e., ProVeg did not have access to personal data of the participants).

Procedure

Randomization, data collection and analysis were performed blindly for everyone involved, except for the principal investigator who was responsible for managing the experiment, randomization, sending out surveys and pseudonymizing the data.

After the baseline survey, the 1213 participants were randomized into the three arms using the 'randomizr'-package in R (probability allocation 1:2:2, based on the pre-registered sample size calculation). Considering balance, there are no significant differences between the experimental arms on any characteristic (see SI. 3), meaning that randomization was successful. Before the start of the intervention, all participants, including control participants, received information via e-mail and kick-off meetings stating that we aim to track their food consumption habits through four surveys. The treatment participants also received information about the start date of the Veggie Challenge (1st of June, 2023) and instructions on how to sign up for the challenge through a webpage specifically created for our study, download the app and log in. Additionally, VC-S participants were encouraged to add friends, family members or other social contacts to their virtual team. They were also stimulated to involve family and friends offline throughout their challenge.

Throughout the month of June, the complying treatment participants partook in the VC-I or VC-S. For 30 days, both VC-I and VC-S participants tried to reduce their APC according to their own chosen goal (meatless days, vegetarian or vegan). The app helped the participants through offering recipes, informative articles, the possibility of habit-tracking (filling out every day whether they succeeded to skip certain products), and giving feedback on how many animals, land, water and emissions they saved. Additionally, the VC-S participants who added someone to their virtual team could see an activity feed of the team members, access a WhatsApp group with the team members, and received group-level feedback on the savings. SI. 1 contains a full account of the intervention features. At the end of the intervention, participants received the endline survey. To track long-term effectivity, we sent follow-up surveys after 1 and 3 months. The procedure is also summarized in Fig. 3.

Participants were incentivized by small gifts (reductions to web shops), lotteries of gifts/vouchers from sponsors and a final lottery of 200 euros for those who filled out all the surveys. At every timepoint, we put effort into reminding the participants multiple times to fill out the survey by approaching them both via e-mail and WhatsApp or text. Moreover, we used intensive tracking of a randomly selected attritor sample to boost the effective response rate in robustness checks[45,46], see SI. 12.1.

Compliance

In SI. 10, descriptive statistics on compliance are reported (e.g., who signed up, invited someone, app usage). Self-reported data shows that about 69.5% of the VC-I participants downloaded the app and 65.9% tried to participate. For the VC-S participants this was 65.0 and 68.0%, respectively. Within the VC-S treatment, 12% reported to have invited others to their team. Analyzing the app usage data provided by ProVeg's database (not self-reported), it appears that VC-S participants had a significantly higher number of activities, higher number of recipes viewed, higher number of days they tracked their habits, and a higher number of badges earned.

Statistical analysis

All analyses were conducted in RStudio, using R version 4.2.2. The analysis plan was registered online prior to the intervention (https://osf.io/82ekc). Throughout the analysis, we adhered to an intention-to-treat approach (ITT), meaning that we analyze all participants randomized to a certain arm, regardless of whether they complied to the treatment or not[47]. In the main analysis, we conducted linear regression analyses to compare means at each timepoint. We control for baseline APC and other relevant covariates, selected by a post-double lasso approach at the endline measurement[48]. Together with the selected covariates, accounting for baseline behaviour further boosts statistical power[49]. Next to p values, we report q values adjusted for multiple-hypothesis testing with a Holm–Bonferroni procedure. To determine an average treatment effect over time, we applied panel linear regression with time modelled as a fixed effect, and standard errors clustered by individual to control for the dependence between observations. The models used in the main analyses are presented and explained in SI. 11.

Before the main analyses, we assessed balance and selective attrition using ANOVA and linear regression techniques (see SI. 5)[49]. The sample remained balanced on baseline characteristics across all measurements. We mitigate possible bias due to selective attrition by using a post-double lasso to select covariates that could either explain the outcome variable or treatment[48]. Additionally, robustness checks mitigating selective attrition in various ways show stable results: reweighting using an intensively tracked non-responder sample[46], checking heterogeneity on specific variables related to selective attrition (educational level at the endline), and the calculation of Lee bounds[50] (see SI. 12).

The assumptions of linear regression (normality of errors, constant variance of errors, independence of errors and linearity) were investigated for each of the three timepoints. While the normality assumption was slightly violated, non-normality is not likely to impact the results with a large sample like ours[51]. On top of that, a robustness check with bootstrapped confidence intervals (see SI. 12.3) showed that the results prevail without distributional assumptions.

In additional analyses, linear regression analysis was applied to different outcome variables (see SI. 6). Furthermore, we explored heterogeneous treatment effects by applying a generic machine learning approach[33] and introducing interactions (see SI. 7). Finally, robustness checks and risk assessment and mitigation strategies are reported in SI. 12.

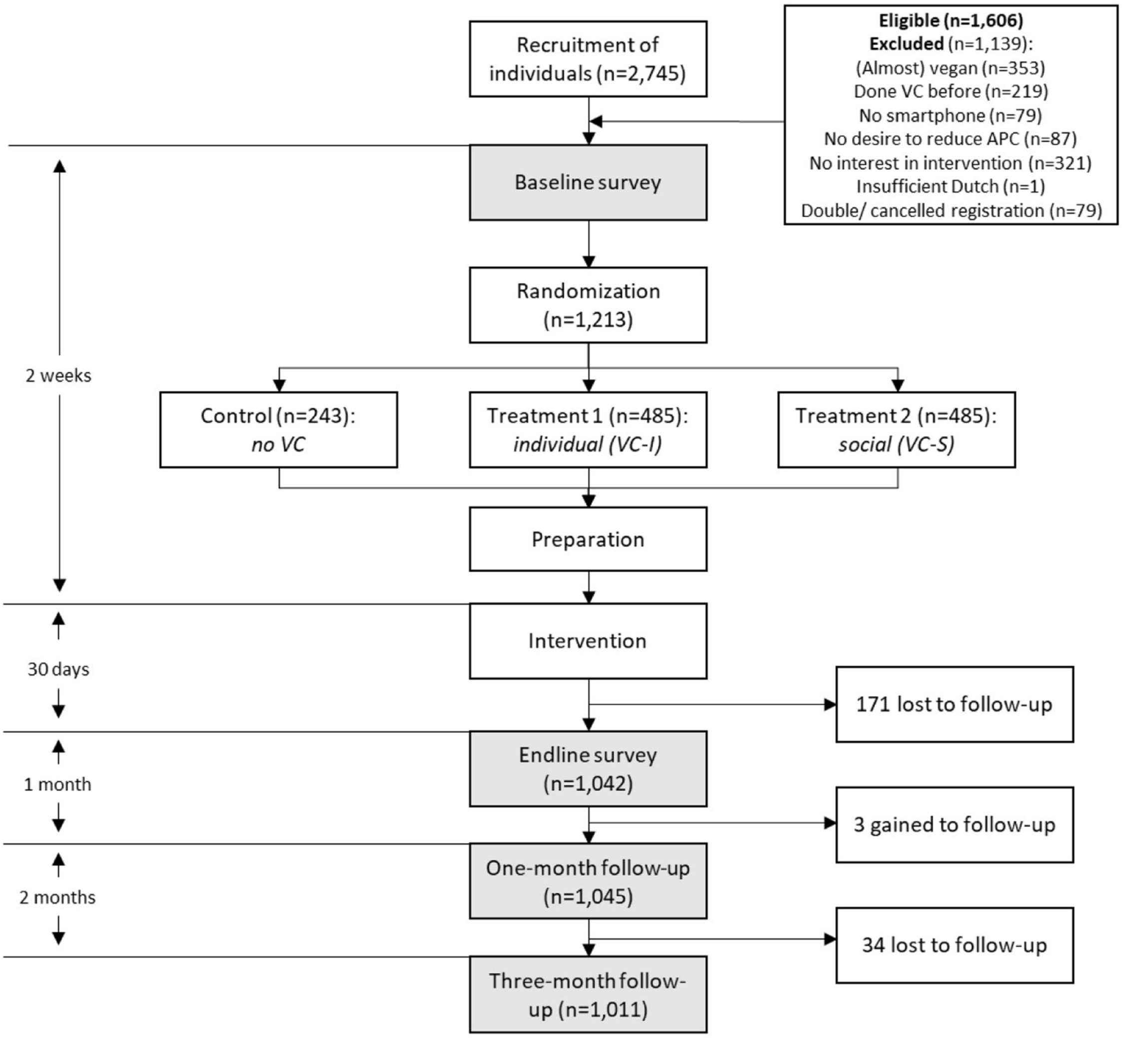


Fig. 3 | Flowchart of experiment. Control = control group only filling out surveys, VC-I = Individual Veggie Challenge treatment group, VC-S = Social Veggie Challenge group which received the encouragement to invite family or friends to their team.

Data availability

The pseudonymized data that support the findings of this study are available from the corresponding author upon reasonable request.

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Author contributions

Rosaly Severijns: conceptualization, methodology, formal analysis, investigation, writing—original draft, project administration. Igor Asanov: conceptualization, methodology, writing—review and editing. Sandra Streukens: writing—review and editing, supervision. Stephan B. Bruns: methodology, writing—review and editing. Pablo Moleman: resources, writing—review and editing. Jasperina Brouwer: writing—review and

editing, supervision. Joey van Griethuijsen: software. Sebastien Lizin: conceptualization, writing—review and editing, supervision, project administration, funding acquisition.

Competing interests
The authors declare no competing interests.

Ethics approval
The study was approved by the Social and Societal Ethics Committee (SMEC) of Hasselt University (REC/SMEC/2021-22/32).

Informed consent
Informed consent was obtained from the participants at every measurement.

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