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Spread it on thick? Relative effects of condiment addition and slice thickness on eating rate of bread†

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Manipulating eating rate (ER) by food properties may enhance or reduce food intake. Within composite foods, such as bread with condiments, the shape of carrier food and the use of condiments are known to influence ER. However, not much is known about their quantitative impacts and interactions. This study investigates the effect of bread slice thickness and addition of condiment on oral processing (ER, chews per g, bite size). In a full factorial design, 30 participants (BMI 21.6 ± 2.0 kg m^{-2}, 23.3 ± 2.1 year) consumed two types of bread (wholewheat (WB); and sourdough (SB)), in three different slice thicknesses (1, 2, 4 cm), with three conditions of margarine addition (0, 2, 4 g per slice of 28 cm^2). The results showed that addition of margarine in both breads led to ~50% higher ER in a non-linear fashion mainly *via* less chews per g (all $P < 0.001$). Increasing bread slice thickness in both breads, resulted in ~15% higher ER, mainly *via* larger bite sizes (all $P < 0.001$). The addition of margarine reduced or overruled the effect of slice thickness on all oral processing characteristics (interaction margarine × slice thickness, all $P < 0.01$). Perceived sensory dryness showed a strong negative correlation with ER. In conclusion, this study highlighted the importance of bread slice thickness, amount of a condiment, and their interactions in controlling ER. Lubrication of the dry crumbs was a main mechanism in controlling ER in this study. These insights can help the design of products with lower ER.

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1 Introduction

Eating rate (ER) has been shown to be positively associated with overweight and obesity.[1,2] Reducing ER by food properties has been shown to reduce food intake and is therefore considered as a powerful tool to prevent overconsumption, as reviewed in.[3] Eating at a slower rate leads to earlier satiation, indicating that oral processing plays a crucial role in regulation of food intake.[4] It is considered that the duration of oro-sensory exposure and chewing leads to central feedback mechanisms that regulate consumption.[5,6] Food properties that affect oral processing duration, bite sizes, and chewing behaviour are considered to influence the process of satiation and food and energy intake.

ER is determined by (a) the food properties and (b) by the human individual oral processing. Changing food properties to manipulate ER might be easier than educating humans to consume slower in a sustained way. Textural manipulations, such as increasing viscosity in liquid foods and increasing hardness in solid foods have repeatedly been shown to reduce ER and food intake.[7–10] Besides the rheological properties of food, also surface area and morphology were shown to affect eating behaviour.[11–13]

For snack foods, it has been shown that large units usually lead to higher food intakes than small ones. For example, small cookies resulted in less intake than similar large cookies.[14] Similar effects were shown for 8 g *vs.* 32 g pieces of brownies,[15] bars *vs.* nibbles,[16] and pieces of carrot *vs.* whole carrots.[17] An explanation could be that large unit sizes are consumed faster due to greater bite sizes than small unit sizes,[16,18] and bite size strongly impact ER and food intake.[19,20] In comparable way, the food shape may also affect ER because humans will modify their bites and chewing behaviour according to the shape of the food. For example, carrots in cubes required less chewing than carrots julienne despite being similar in weights.[12] A recent unpublished study at our lab compared 10 different bread samples on oral processing and found that buns were eaten faster than slices, with texture differences between the breads having lower contribution than shape (*i.e.*, bun *vs.* slice). The higher ER in buns is likely to be explained by the larger bite sizes due to the

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height of the buns. When larger bite sizes are taken, also chewing is more efficient, because more grams of food are chewed in the same bite, which speeds up the ER.

During food consumption, the food is chewed and lubricated until it is safe to swallow. Condiments assist in lubrication and less saliva is needed to form a bolus that is safe to swallow.[21] This results in less chewing and earlier swallowing, and thereby speed up the ER.[13] For example, adding butter to toast and cake reduced oral processing time and the number of chews until swallowing.[22,23] The ER of bread increased considerably with the addition of semi-solid cheese spread and mayonnaise, but not with addition of solid firm cheese.[13] The type of condiment seems to be important facilitating oral processing. Condiments that are more liquid like and high in fat are the most effective at increasing bolus lubrication, producing the largest reductions in chews per bite, and largest increases in ER.[24] However, not much is known about how different *amounts* of condiment affect oral processing.

In many eating occasions, we consume meals or composite foods by combining food items varying in texture and composition. Bread is an example of staple food which is worldwide consumed in combination with condiments and other food items. In recent years, the design of bread structure and texture has gained attention as a mean to control oral processing behaviour and nutrients uptake.[8,25] However, these studies often focused on consumption of bread as such without addition of condiments. Consequently, not much is known about the impact of combinations of textural manipulations on ER or energy intake. Most studies investigating ER and intake behaviour by manipulating one parameter,[3] whereas it might be beneficial to change more parameters to impact oral processing.[11]

The aim of this study was to understand more complex textural changes on oral processing by systemically changing two textural parameters using bread as model food. For this purpose, two bread types with different structures and texture were selected. For each bread type three slice thicknesses and three amounts of condiment additions, *i.e.*, margarine, were investigated for their relative impacts on ER and oral processing characteristics.

2 Materials & methods

2.1 Experimental design

The study consisted of a full factorial design in which the effect of bread slice thickness and the amount of margarine addition on oral processing were investigated. Three different slice thicknesses (1, 2 and 4 cm), and three different amounts of margarine (0, 2 and 4 g) on two different types of bread (wholewheat and sourdough) were investigated (Fig. 1). The bread slices were served without crust in fixed sizes of 7 cm length and 4 cm width, while varying the thickness. All participants received 18 samples randomly divided over three different sessions (explained in 2.4).

Fig. 1 Example of bread samples in three different slice thicknesses and three different amounts of margarine applied on sourdough bread (SB).

2.2 Test foods

Two commercially available breads were chosen as model foods, wholewheat bread (WB) having 221 kcal per 100 g (Hoogvliet supermarket, the Netherlands) and wholewheat sourdough bread (SB) having 205 kcal per 100 g (local bakery, Wageningen, the Netherlands). The used codes in this study, the slice thickness and the average weights are shown in Table 1. The two bread types were characterised with instrumental measures in preliminary analyses (Texture Analyser, water absorption capacity (WAC) and water content), to ensure structural differences. Sourdough bread was higher in hardness (g), chewiness (g) and lower in adhesiveness and WAC (ESI Table 1†). The choice of slice thickness was based on commercial available pre-sliced breads, which are usually between 12 mm and 14 mm in the Netherlands. Thicker bread slices up to 4 cm are often served in restaurants. Slice thicknesses were chosen of 1 cm, 2 cm and 4 cm to obtain an exponential increase in size within real life situations. The bread samples were sliced with a custom-made cutter allowing to adjust slice thickness. Sliced pieces of bread were stored in plastic bags in the freezer (−18 °C) and defrosted in the afternoon before each test day. In the morning before the test sessions, the bread slices were cut in the correct length and width by using a cardboard mould (4 × 7 cm). The samples were stored in a plastic bag until the test sessions in order to prevent dehydration. Bona margarine (Upfield, the Netherlands) was chosen as condiment for this study. The advised amount of margarine was 10 g per bread slice according to the packaging. The surface of the sample size was approximately 1/5 of a slice of bread. Therefore, 2 g and the double amount of 4 g margarine were chosen to be applied to the bread samples. Margarine was added to the bread samples shortly before the test session. All bread samples were weighed before the sessions, which was needed to calculate oral processing characteristics (ER (g min^{-1}), bite sizes (g per bite), chews per gram).

2.3 Participants

The study included 30 participants (BMI 21.6 ± 2.0 kg m^{-2}, 23.3 ± 2.1 years old). Participants were recruited from Wageningen and its surroundings, by sharing flyers and information brochures on social media. Interested participants were asked to fill in an online screening questionnaire to

Table 1 Overview of the sample codes used, thicknesses, weight, and margarine addition

Code WB samples	Code SB samples	Slice thickness (mm)	Margarine addition (g)	Weight WB samples[a] (g)	Weight SB samples[a] (g)
W1_M0	S1_M0	10	0	6.4 ± 0.6	10 ± 1.1
W2_M0	S2_M0	20	0	10 ± 1.7	16 ± 2.0
W4_M0	S4_M0	40	0	20 ± 1.8	35 ± 2.9
W1_M2	S1_M2	10	2	7.9 ± 0.8	12 ± 1.2
W2_M2	S2_M2	20	2	13 ± 1.6	20 ± 2.9
W4_M2	S4_M2	40	2	22 ± 1.8	35 ± 2.8
W1_M4	S1_M4	10	4	10 ± 0.8	14 ± 0.8
W2_M4	S2_M4	20	4	14 ± 1.7	21 ± 2.7
W4_M4	S4_M4	40	4	24 ± 2.0	37 ± 3.3

[a] Mean ± SD of the used bread samples (n = 30).

check whether they were suitable for the study. Inclusion criteria were aged between 18–55 years, regularly consume bread (>3 times per week), BMI between 18.5–30 kg m^{-2}, and have a good general and oral health (self-reported). Exclusion criteria were: dislike the test foods (<5 on a 9-point hedonic scale), having issues with chewing, swallowing and/or eating in general, smell or taste disorders, allergies or intolerances for the test foods, having braces or oral piercings, having a beard or other facial hair, smoking, following an energy restricted diet, being pregnant or lactating, drink more than 21 glasses of alcohol per week, and practicing intensive exercising (>8 hours per week). The participants were not informed about the exact study purpose; they were told that this research aimed to examine the impact of bread texture on the sensory properties of bread. The participants were informed that they were video recorded and signed a consent form at the start of the first session. After finishing the study, they were debriefed about the real aim of the study. Participants received €20 after completion of the study. The social Science Ethics Committee of Wageningen University concluded that the proposal deals with ethical issues in a satisfactory way.

2.4 Procedure

All participants received 18 samples randomly divided over three different sessions. Participants always participated in the same time slot for each session. The participants were instructed to consume the same breakfast on each of the three test sessions. In addition, participants were instructed to refrain from eating and drinking (except water) two hours before the test session.

When arriving at the sensory booths, participants received a brief explanation from the researcher. After that, participants were asked to consume six bread samples in a randomised, balanced block design. Each random sample series contained four samples with margarine and two without, and two samples from every thickness. This was done to balance the total food intake over the three sessions and to prevent sessions that would contain substantial amounts of bread and margarine. The bread samples were served one by one, so that participants could solely focus on the samples they were consuming. They were instructed to eat as usual and consume the whole sample without taking breaks or sips of water. After each sample, they answered questions about the textural sensory qualities on 100-unit VAS (ESI Tables 2 and 3†). In between the samples, participants were instructed to rinse their mouth with water. Qualtrics XM was used as software to guide the participants through the procedure of the sessions and to answer questions. Webcams were used to record the oral processing characteristics during consumption.

In the first session, participants were asked to spread their preferred amount of margarine on six bread samples (1, 2, and 4 cm slice thickness of both WB and SB), served in randomised order. Participants received a cup of 50 g of margarine and a knife. They were asked to spread the margarine as they would usually do on each sample. The samples were weighed before and after to determine how much margarine the participants had used. This test was performed to compare the levels of addition of margarine in the study design with the amounts applied by the participants. They started with this before the tasting session of the bread samples.

2.5 Oral processing annotation

Participants were asked not to move the laptop and watch the webcam during eating. The videos were analysed using ELAN computer software (version 6.2, the language archive, Nijmegen, the Netherlands). The first 9 of the 90 videos (10%) were analysed independently by two researchers on the number of bites, chews, and the total consumption time. Agreement between the two researchers was high >97%. Next, the differences in the annotation were determined and discussed to consensus to define a consistent methodology. After that, the remaining videos were divided between the two researchers.

For each bread type, the averaged ER per participant, (g min^{-1}) was calculated by dividing the sample weight by the total consumption time. Averaged chews per gram (chews per g) were calculated by dividing the weight of the sample by the number of chews. Averaged bite size (g) was calculated by dividing the number of bites by the weight of the sample. These characteristics were chosen to be the most relevant parameters that influence ER.[20]

2.6 Data analysis

Response surface modelling was performed with StatEase Design Expert version 22. Relative impacts of three factors (bread type, slice thickness, and margarine addition) on ER was fitted in a quadratic model with three factors. Model reduction was performed by removal of non-significant model terms ($p < 0.05$). Model hierarchy was maintained. To analyse the ER of only the bread, the same procedure was followed by calculating the ER (bread only) by subtracting the weight of the margarine (−0, −2, −4 grams for the three different margarine applications respectively) from the sample weight and dividing by the eating time.

Two-way repeated ANOVAs were conducted with IBM SPSS Statistics version 28, including slice thickness and margarine amount as independent variables and their interaction to examine oral processing characteristics, sensory ratings, and self-applied amount of margarine. Bonferroni adjustments were used for *post hoc* comparisons. Normality was assessed by histograms and Q–Q plots. All oral processing characteristics (ER, chews per gram and bite sizes) showed right-skewed distributions, therefore these data were log transformed. Means and CI range (95%) of back transformed data are shown for oral processing characteristics. Sensory ratings were normally distributed, and data are presented as estimated means and SEM. Principal component analysis (PCA) was performed with Rstudio (RStudio version 1.1.463, Inc., Boston, MA, USA) using the PCA function of the FactoMineR package (Husson *et al.*, 2022) together with Pearson correlation analysis.

3 Results

3.1 Relative impacts of bread type, slice thickness and margarine addition on ER

To explore the effects of bread type, slice thickness and margarine addition on ER, and to check whether there were non-linear relationships and interactions between the factors, response surface modelling (RSM) was applied. ER data were fitted to a quadratic model with one categorical factor (bread type) and two numerical factors (slice thickness and margarine addition). The interaction term of bread type (BT) and margarine addition (M) and the quadratic term of slice thickness (ST^2) were non-significant ($P = 0.12$ and 0.65 respectively) and these terms were removed from the model. The results of the reduced model are shown in Table 2. The fit statistics of the RSM indicate that the model fits the data well. The high signal to noise ratio (≫4) implies that the design space is well represented by the model.

These modelling results imply that ER is explained by the main effects of bread type, slice thickness, margarine addition, the interactions of bread type with slice thickness, and of slice thickness with margarine addition, and a nonlinear effect of margarine addition. From the values of the coefficient estimates (Fig. 2) the largest impact on ER is from margarine addition, followed by bread type and slice thickness both having roughly three times less impact on ER.

Surface plots of both bread types are given in Fig. 3 to visualise the modelling results. From these plots the nonlinear effect of margarine addition is larger than the linear effect of slice thickness. For SB, the effect of slice thickness on ER is lost at larger (4 g) additions of margarine, whereas for WB the effect of slice thickness on ER is reduced at highest additions of margarine.

Table 2 Significant predictors of ER and fit statistics of the reduced RSM

Source	*P*-Value
BT	<0.001
ST	<0.001
M	<0.001
BT × ST	0.012
ST × M	0.006
M^2	0.009
Fit statistics	***P*-Value**
Model p-value	<0.001
R^2	0.983
Adjusted R^2	0.974
Predicted R^2	0.955
Signal/noise	33.7

BT: bread type, ST: slice thickness, M: margarine addition, $n = 30$.

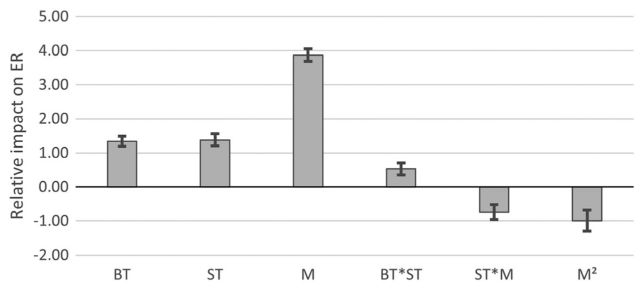

Fig. 2 Relative impact of the predictors on ER (BT: bread type, ST: slice thickness, M: margarine addition, error bars represent standard errors) ($n = 30$).

The ER is calculated using the total weight of the samples (bread + margarine addition), which indicates that adding weight to the carrier food will automatically lead to a higher ER. To see the effect on the ER when corrected for margarine addition, a separate RSM analysis was performed on the weight of only the bread of the samples (subtracting the weight of the margarine from the total weight). For the ER of the 'bread only,' the interaction terms were all non-significant (ESI Table 4†). The non-linear behaviour of margarine application remained. The relative impact of the slice thickness was almost twice as big as that of margarine addition (ESI Fig. 1†). Contrary to the observation for the total sample ER, the linear effect of slice thickness on ER for the 'bread only' was not reduced by the margarine addition (ESI Fig. 2†).

3.2 Relative impacts of slice thickness and addition of margarine on ER and oral processing per bread type

The results of all the bread samples on ER, chew per g and bite sizes are presented in Fig. 4, separated for SB and WB.

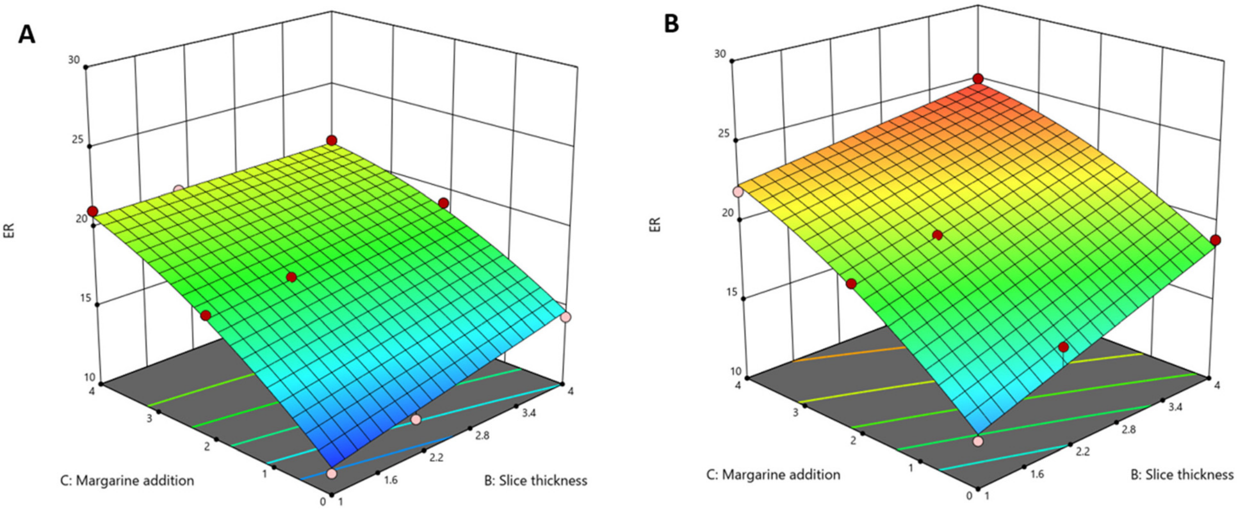

Fig. 3 Surface plots of the RSM of ER for wheat bread (A) and sourdough bread (B), (n = 30).

Increasing thickness led to a significant increase in ER in both bread types (Fig. 4A and B). Bite size obviously increased when slice thickness increases (Fig. 4E and F). Chews per g decreased by increasing slice thickness in the samples without margarine (M0) (Fig. 4C and D).

Similarly, the addition of margarine (M0, M2, M4) led to less chews per g and larger bite sizes in both breads, with most obvious differences between M0 and M2 in chews per g (Fig. 4C and D). Addition of 2 g margarine (M2) reduces effects of slice thickness on ER and chews per g, whereas addition of 4 g (M4) seems to completely overrule effects of slice thickness on ER and chews per g (Fig. 4A–D) (interaction thickness × margarine). In bite sizes, this interaction effect is still significant, but effect sizes seem to be less pronounced (Fig. 4E and F). In general, bite size was more impacted by slice thickness (increase of ∼50% from 1 to 4 cm) and relatively less by margarine (increase of ∼25% 0 g compared to 4 g). Whereas chews per g were more reduced by addition of margarine ∼30% (0 *vs.* 4 g), and less by slice thickness ∼20% (1 *vs.* 4 cm).

Interestingly, for all oral processing characteristics, there was a significant interaction of slice thickness × margarine (Fig. 4). The addition of margarine clearly reduces the effect of slice thickness on the oral processing characteristics.

3.3 Self-application of margarine

Fig. 5 shows the amounts of margarine by self-application of the participants on the two types of bread differing in slice thickness. The type of bread did not significantly influence the addition of margarine (P_{bread} = 0.064). Increasing slice thickness showed increasing addition of margarine ($P_{\text{thickness}}$ < 0.001). On average, the self-application showed that about 1.5–2 g of margarine were added to the bread samples of 1 and 2 cm, which is similar to what is used in the present study, which was based on packaging instructions (explained in 2.2). Overall, the result of the self-application indicated that the study design properly covered ranges of margarine addition by naïve consumers, including excessive use.

3.4 Relation between sensory perception and oral processing

Slice thickness and addition of margarine significantly affected the sensory perception (ESI Tables 2 and 3†). In general, increasing thickness led to higher ratings for hardness, denseness, and chewiness regardless of the bread type, while dryness and crumbliness scores increased only for WB. Addition of margarine led to lower ratings of all sensory texture parameters, regardless of bread type.

In order to better understand the relation between the textural sensory perception of breads and the oral processing behaviour, scores for sensory attributes, ER, bite size and chews per g were analysed all together using PCA (Fig. 6). The first two principal components (*i.e.*, PC_1 and PC_2) accounted for over 90% of the variance, thus providing a particularly good representation of the differences among samples.

With regards to sensory scores, samples were mainly differentiated along PC_1 for dryness, crumbliness, and adhesiveness and on PC_2 for denseness and hardness. Within each PC, sensory attributes were highly correlated with each other (Fig. 6). SB samples without condiments were generally perceived as harder and denser than WB samples without condiments, with the scores increasing with thickness for both breads (ESI Tables 2 and 3†). Without condiments, WB samples were generally perceived drier than SB ones, with limited influence of thickness. Margarine addition resulted in a substantial reduction in the scores for dryness (PC_1). A reduction in dryness was significantly correlated to an increase in ER, with the highest correlation observed among sensory attributes in PC_1 (Fig. 6). Interestingly, hardness, chewiness and denseness did not show any relation with ER. Overall, differences in sensory perception between bread types and thicknesses were largely retained for similar amounts of condiment. The addition of margarine substantially shifted samples

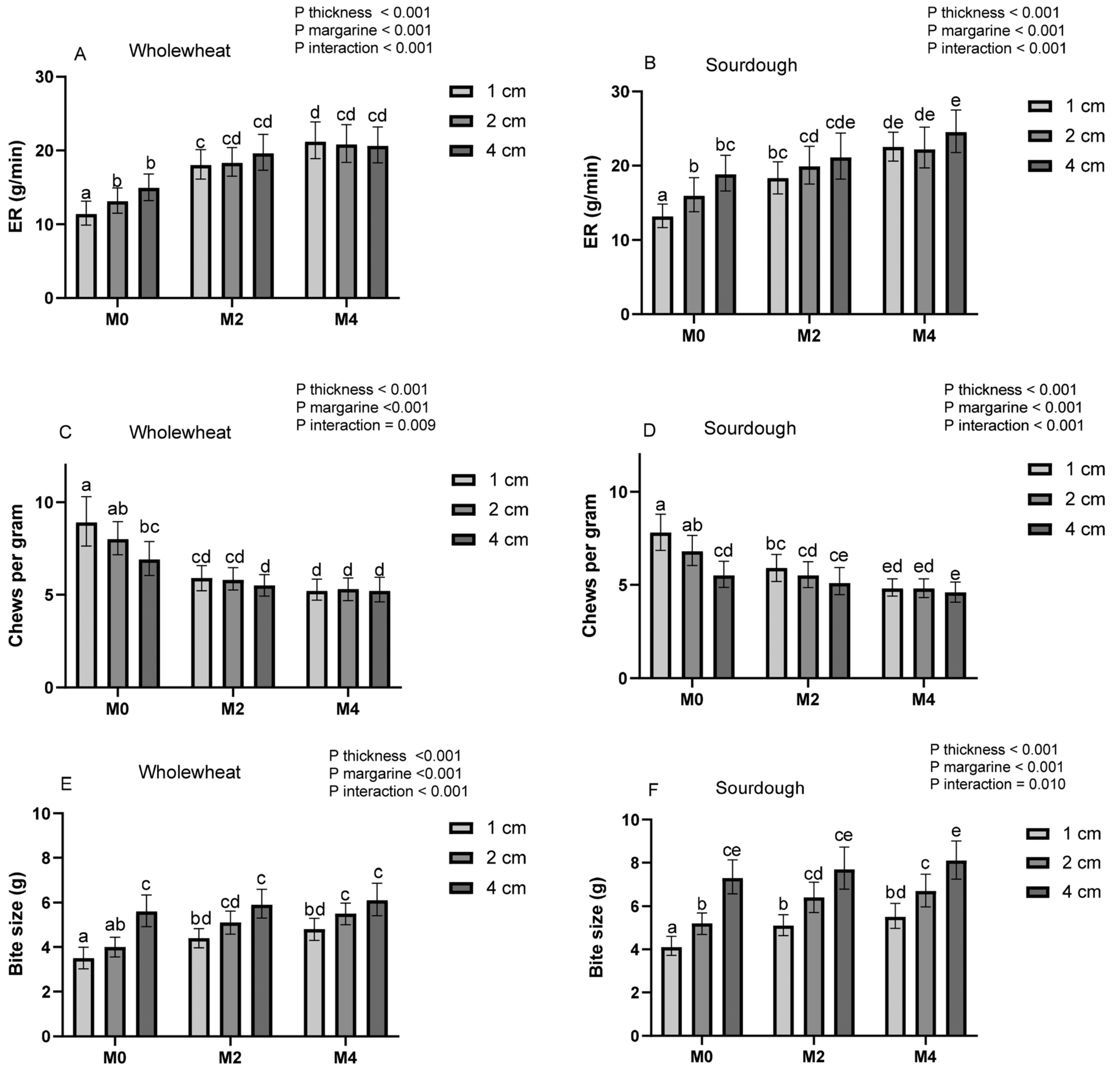

Fig. 4 Means and CI of oral processing of WB (A, C and E) and SB (B, D and F) in different slice thicknesses and addition of margarine (M = Margarine, M0 = 0 g, M2 = 2 g, M4 = 4 g) (n = 30). The P-values of the main effects and interactions are shown in the left corners of the figures. Different letters mean significant differences with *post hoc* Bonferroni correction.

to an increased ER parallel to its vector, with a concomitant reduction in chews per g due to reduced dryness (Fig. 6). Along the PC_2, differences in hardness among bread samples were correlated to an increase in bite size (Fig. 7), the relation being mainly driven by the weight of the samples. ER was also highly correlated with bite size (Fig. 7).

4 Discussion

In recent years, the importance of eating rate (ER) and oral processing on energy intake has been increasingly acknowledged.[3,26,27] The effect of bread texture on oral processing behaviour has been extensively reviewed,[25] but less is known about the interplay of carrier and condiment on ER, as in the case of the addition of condiments on bread slices. The results show that addition of margarine increased ER by ~50% in non-linear fashion. Increasing bread slice thickness resulted in ~15% higher ER. All oral processing characteristics showed an interaction effect of margarine and slice thickness, where margarine reduced or overruled the effects of slice thickness.

There is only limited literature on ER of composite foods where the interplay of shape, texture and condiment addition are systematically investigated. The present study shows that both slice thickness and condiment addition influence ER, however, *via* different mechanisms in oral processing.

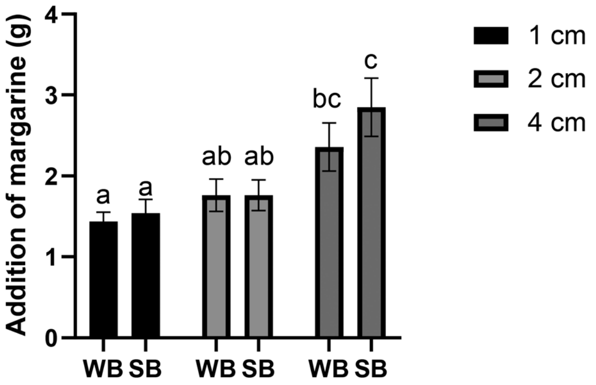

Fig. 5 Mean (SEM) of the amount of margarine that participants applied on the bread samples differing slice thickness, WB = wholewheat bread, SB = sourdough bread, (n = 30).

Increasing the slice thickness clearly increased bite sizes, whereas margarine addition speeded up ER *via* a steep decrease in chews per g. Increased thickness is considered to automatically increase bite size. Previous research on food bars showed food bite size is not controlled by weight nor volume, but by bite length.[18] In this study it is considered that increasing thickness logically leads to larger bite sizes, because the length of the bread samples and not the thickness were the limiting factors that determined bite sizes. The addition of margarine added weight to the bread sample while it hardly added height or volume since most margarine will enter the pores in the bread slice. Consequently, the bite size (g) further increased with margarine addition at the same bite length. Consumption with larger bites consequently lead to less chews per gram (Fig. 4C, D and 7), and therefore a more efficient oral processing per gram food, which has been illustrated earlier for carrots.[12]

The perceived sensory texture also changed with increasing slice thickness whereas the structure of the breads remained similar. Hardness perception is generally dependent on the thickness of food.[28] The present study confirmed that in general, thicker slices were perceived as harder, denser, and chewier compared to thinner slices, especially in wholewheat bread. Compared to wholewheat bread, sourdough breads had higher crumb density and were perceived harder, denser, and chewier. Such differences in sensory perception of crumb texture can be explained by the exponential dependency of crumb hardness on crumb density.[29] On the contrary, dryness perception was less affected by thickness but clearly had a key role in controlling the eating behaviour, mainly affecting chews per gram and ER, as showed by PCA and correlation analysis (Fig. 6 and 7). Plain bread without condiment requires a substantial amount of saliva to make a bolus that is safe to swallow. Bread is a dry and porous product which requires 5 times more saliva for oral processing compared to moist food like cooked pasta.[30] Excretion of saliva is stimulated by chewing,[31] therefore relatively many chewing cycles are needed to consume plain bread.

Surprisingly, sourdough bread was perceived harder than wholewheat bread but was consumed with a higher ER. From literature, it was expected that the hardest foods would be consumed slower than the softer foods.[7] However, the samples that were served to the participants were controlled by volume but differed in weight. Sourdough bread has a higher density, so the samples were higher in weight (Table 1). This means that participants took automatically larger bites in terms of weight, which speed up the ER. In this case, the rheological

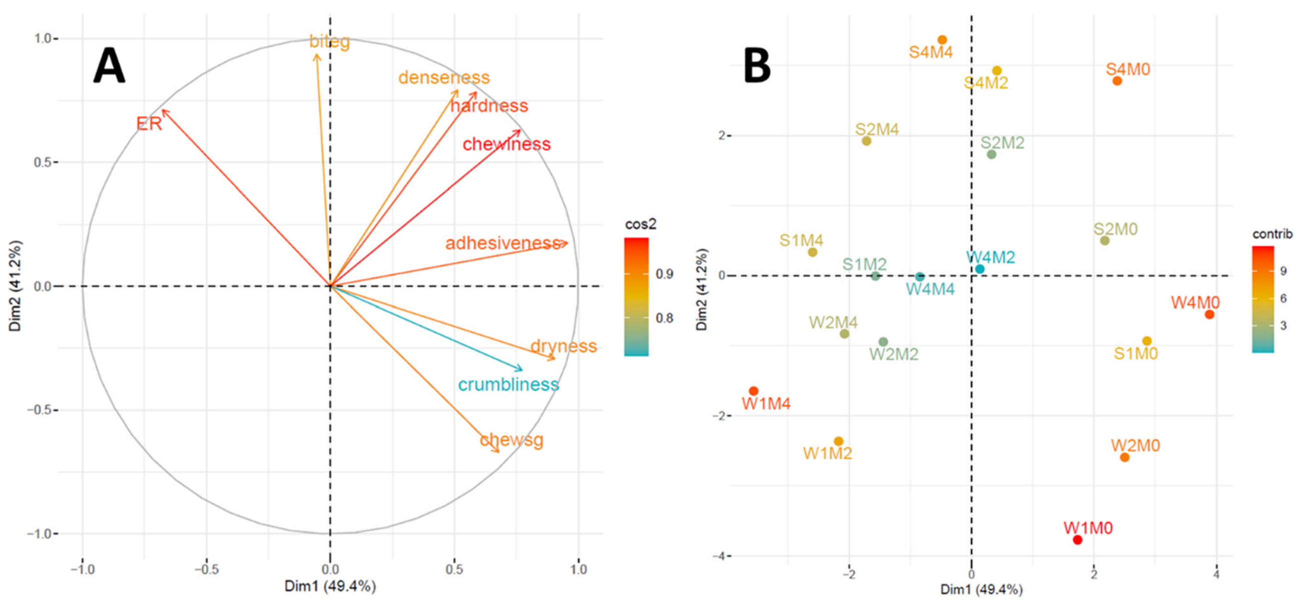

Fig. 6 PCA with loading plot of sensory scores and oral processing parameters (A) and sample scores (B). Sample codes are explained in Table 1. In the PCA plots, oral processing parameters are ER = eating rate (g min^{-1}), chew per g = chews per gram and biteg = bite size (g) (n = 30).

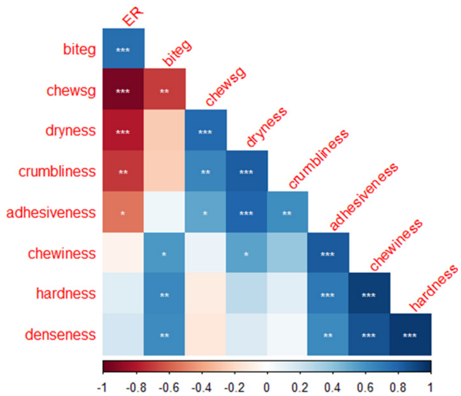

Fig. 7 Correlation analysis between sensory scores and oral processing parameters. Oral processing parameters are ER = eating rate (g min^{-1}), chewsg = chews per gram and bite = bite size (g) (n = 30). Significance level: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

and related sensory properties were less important compared to the density (g cm^{-3}) of the food to determine the ER (g min^{-1}). It should be also noted that sourdough breads were perceived less dry than wholemeal breads. Therefore, the combination of density and moistness together contributed to the ER of sourdough bread. The density of food, in terms of either gram or kcal is a highly effective strategy to influence ER and energy intake. Adding air or water to food to dilute the density in weight and/or kcal has been shown to reduce energy intake.[32,33]

Margarine addition speeded up ER of the bread slices mainly *via* a steep decrease in chews per g. Previous studies showed similar effects of condiment addition on of a carrier food on ER, which were also explained by a decreased number of chewing cycles.[11,24,34] Condiments moistens and softens the food in the oral cavity.[35] Adding a condiment, especially a fat-based one like margarine, requires less saliva to form a compact bolus that is safe to swallow and this will speed up the ER[21] and explains the steep decrease in chews per g when adding margarine in this study. The perceived sensory texture attributes in this study confirmed that the breads with margarine were indeed perceived as less dry compared to bread without margarine, facilitating oral processing and consumption. On the other hand, texture differences among bread samples were largely retained for similar level of margarine addition with regards to perceived hardness, denseness, and chewiness. Taken together, these results suggest that for bread slices the lubrication of the dry crumbs was a main mechanism in controlling ER. However, it should be noted that the effect of condiments may differ depending on the specific texture perception of the carrier food. A recent study investigated effects of hardness, thickness, unit size, and condiment addition (with and without mayonnaise) on ER in both carrots and crackers. Both foods showed that hardness had the most impact on ER, followed by thickness (only investigated in carrots), followed by condiment addition and unit size, respectively.[11] In the present study, we showed that condiment addition overruled the effect on thickness, whereas in the study of Janani *et al.*,[11] the thickness of the carrots was more important in determining the ER of carrots than the addition of mayonnaise. This might be due to distinct differences in textural properties and oral processing that is needed for carrots *vs.* bread.

It should be also noted that the margarine weight added to the bread was an additional factor for increasing the ER in this study, since this increases the density (g cm^{-3}). Since the bite size is controlled by the bite length,[18] the bite size (g) increased with margarine addition. Therefore, it was decided to analyse the effect of the ER when corrected for margarine addition (subtracting the added margarine from the total sample) to investigate whether margarine affected the ER of the carrier. The data clearly showed that the effect of margarine addition has a significant impact on the oral processing of the carrier itself (ESI Fig. 1†). The effect of the additional weight of the condiment was not taken into account in a study on the effect of mayonnaise addition on the ER of carrots.[12] The fact that ER is increased by adding condiments does not necessarily imply that the carrier food itself is consumed faster than without addition of condiments. The ER of the total sample increased by adding condiments but this is relatively less carrot compared to samples of only carrot.[12] Advice to increase vegetable intake by adding condiments to vegetables to speed up ER should be reconsidered, although the sensory appeal may increase and possibly stimulate vegetable intake.

As far as we know, the *amount* of condiment addition on oral processing has not been studied before. In this study, we showed that the addition of margarine from 0 to 2 g resulted in a steep increase in ER, while the effect seemed to level off when doubling the amount of margarine to 4 g (Fig. 4). Also, for the perceived texture, the largest effects of textural changes related to food softening were observed when comparing 0 g *vs.* 2 g margarine. It makes sense that from "no margarine" to "margarine" leads to the most obvious changes in perception and oral processing and further additions do not cause major changes, and this might explain the non-linear relationship found in the RSM. However, the amount of condiment, especially fat containing condiments, is crucial for the energy density of the food. The results of this study suggest that above a certain amount of condiment, a further, increase in condiment addition only slightly affects the sensory and oral processing characteristics while having major consequences in terms of caloric intake. Excessive use of fat containing condiments leads to higher energy intake rates (kcal min^{-1}: ER (g min^{-1}) × energy density (kcal g^{-1})) which is a risk factor for overconsumption and weight gain.[36,37]

When participants applied margarine to the bread slices themselves, the amount was on average around 1.5 g for slices of 1 cm in thickness. This amount increases when slice thickness increases but not proportional to the increased weight of the bread. This means that thinner slices will probably lead to more condiments per gram food, and therefore a higher energy density. The variation between participants was quite large (ranging from a participant that applied 0.5 g on all types of bread, to maxima of 5 g and 9 g for the 2 and 4 cm breads, respectively), this may indicate that people differ substantially in their habits to use condiment. Future research may clarify how these habits connect to the individual oral processing characteristics, food preferences and energy intakes.

In conclusion, bread slice thickness increased the ER primarily by increasing bite sizes while margarine addition increased ER by a steep decrease in the number of chews per gram. When looking at the composite food, *i.e.*, bread with margarine, condiment addition had a dominant effect on ER due to increased sample density (*i.e.*, increasing bite size) and lubricating effect (*i.e.*, decreasing chews per g), consequently diminshing the effect of slice thickness. Therefore, for foods that are dry and porous such as bread, geometrical aspects on oral processing and ER may disappear when a fat-based condiment is added. To provide dietary advice to moderate ER of a bread-based meal, thinner slices are recommended, but condiment additions should be moderate to prevent an excessive number of calories. This study showed that this is not done automatically, since participants used relatively larger amounts of margarine on thin slices. Overall, this study highlights the importance of bread slice thickness, amount of a condiment and their interactions in controlling ER. These insights can help the design of products that either moderate ER or stimulate ER for vulnerable populations to increase the energy intake.

Author contributions

Dieuwerke P. Bolhuis: conceptualization, methodology, supervision, formal analysis, writing – original draft, review & editing. Matthijs Dekker: conceptualization, methodology, supervision, formal analysis, writing – review & editing. Stefano Renzetti: conceptualization, methodology, supervision, formal analysis, writing – review & editing.

Conflicts of interest

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

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