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Energy density of snacking episodes and eating behaviour: A systematic review of experimental studies☆

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ABSTRACT

Snacking episodes can be defined as food and drink that are consumed between mealtimes. Snacking episodes can differ greatly in nutrient and energy content, having the potential to influence diet quality and, in turn, health. This systematic review aimed to understand the impact that the energy density of snacking episodes has on eating behaviour outcomes. Objective outcome measures included ad libitum snack intake and daily energy intake, and subjective measures included self-assessed hunger and satisfaction. Eight databases were searched based on set inclusion and exclusion criteria to identify peer-reviewed experimental studies with adult populations. Across the ten eligible studies, seven assessed hunger, five assessed fullness, one assessed overall satiety, five assessed desire to eat/prospective food consumption, and eight assessed energy intake, ad libitum intake/compensation with respect to the impact of snacking episodes' energy density. The weight of the evidence suggested that the energy density of snacking episodes has little effect on eating behaviour outcomes, with limited evidence suggesting that higher energy density snacking episodes could result in higher satiety levels and influence fullness levels but only at specific time points. Risk of confound was high, including little control over volume and sensory characteristics across studies, particularly those reporting significant effects. Overall, this literature would benefit from using standardised snacking comparisons, to confidently identify the impacts of energy density for snacking episodes on eating behaviour outcomes. Findings could inform future studies that aim to understand the formulation of snacking episode considering energy density, to benefit diet quality whilst maintaining consumer satisfaction.

1. Introduction

Energy intake consumed through snacking has risen. In the US, the prevalence of adults consuming snacks rose from 71 % in 1977 to 97 % in 2003–2006, showing a 26 % increase in engagement in snacking over the last few decades (Piernas & Popkin, 2010). Furthermore, a recent study conducted in Japan found that people spend an average of twenty-seven minutes per day snacking (Murakami et al., 2022). Snacking episodes can differ greatly in their energy density and nutrient content, meaning that they have the potential to impact diet positively or negatively (Mattes, 2018; Hess, Rao & Slavin, 2017). Energy density, as classified by Rolls (2009) is "the amount of energy (calorie or joules) in a particular weight of food. It is generally presented as the number of calories per gram of food (kcal/g)." This does not refer to the type of food consumed, but the amount of energy the food carries.

There is consistent acknowledgement throughout the eating behaviour literature that there are varying definitions for 'snacks' and 'snacking occasions' (Skoczek-Rubińska & Bajerska, 2021; Wang et al., 2012). It has been suggested that difficulties drawing conclusions in this area may be due to inconsistencies in definitions. Such definitions often relate to the nutritional content of foods, energy density and effects on energy intake, the time of day the food is consumed, and the number of eating occasions that occur (Skoczek-Rubińska & Bajerska, 2021). In some instances, participants self-define these terms. For example, one study defined snacks as food/coffee breaks, and an individual snacking episode included foods consumed within 15 min of one another (Duffey & Popkin, 2011). Overlaps were identified between foods viewed as a meal or snack, depending on whether items were consumed as a side

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dish (and a component of the meal) versus on its own (as a snack). Despite these nuances in classification, some research takes a more straight forward approach, classifying snacks as "foods/beverages consumed in between main meals" (Gage et al., 2020). Indeed, this broad and straight-forward definition is adopted for the current review.

Snacking episodes have been found to have a higher energy density than other 'main' mealtimes (Si Hassen et al., 2018; Chan et al., 2022). However, within the category of snacking there is also heterogeneity in food types (Hess, Rao & Slavin, 2017). A recent survey captured the UK's top ten favourite snack foods, varying from crisps and chocolates, to nuts, dried fruits and vegetable chips (Statista, 2021). Existing systematic reviews show that energy dense snacks are affected by contextual factors such as snacking location, timing and social context (Skoczek-Rubińska & Bajerska, 2021). A recent review by Skoczek-Rubińska and Bajerska (2021) suggested that body weight influenced what snacks were consumed, with some studies showing that those with obesity opted for snacks with a higher energy density whereas those with a normal body weight more often chose foods including fruits and vegetables. However, authors of this review note that underreporting did occur across some studies included in their review, meaning results may have only been evident before underreporting corrections were implemented.

Additionally, snacks are often consumed when alone, later in the day, and are often high in energy density and low in nutrient content across the general population (Skoczek-Rubińska & Bajerska, 2021). There is also evidence to suggest that an adult diet that is low in energy density aids weight loss and supports weight maintenance, and that increased energy density is associated with increased weight and BMI, however evidence is mixed (Pérez-Escamilla et al., 2012; Rouhani et al., 2016).

Further, other reviews and meta-analyses have found that high energy density diets increased fullness but had no influence on hunger levels when compared to a low energy diet (Moosavian & Haghighatdoost, 2020). However, there is yet to be a systematic review that considers the influence of the energy density of snacking episodes specifically on eating behaviour outcomes. Moreover, reviews mentioned above that do focus specifically on snacking tend to be focused on the context of snacking and underpinned largely by studies that are observational in nature, limiting conclusions around causality.

Therefore, a systematic review of experimental studies was conducted to examine the differential effects that the energy density of a snacking episode has on eating behaviour outcomes, which includes objective (e.g., daily energy intake, ad libitum intake) and subjective (e.g. appetite, hunger, satiety) measures. It was hypothesised that engaging in a higher energy density snacking episode compared to a lower energy density snacking episode would differentially affect appetitive energy intake at a later meal, increase appetitive factors around satiety, and reduce appetitive factors around hunger.

2. Methods

2.1. Identifying the research question

The research question was devised using the PICO framework; population, intervention, comparison and outcome (Richardson et al., 1995). For this systematic review, the aim was to compare (comparison) how different energy densities of snacking episodes (intervention) affect eating behaviour outcomes, including appetite, hunger, and daily energy intake (outcomes) in adults (population).

2.2. Search strategy and reference management

The study was pre-registered on Open Science Framework before the title and abstract screening was complete (before any narrative synthesis or extraction took place) (https: //osf.io/yd2m8).

We searched 8 electronic databases during September 2023: PsycINFO, Web of Science, PubMed, APA PsycARTICLES, Business Source Complete, Proquest Psychology, Medline and Cochrane Library. We solicited grey literature via email of a relevant professional network, however, this failed to yield any additional papers. Searches used a query string of key terms relating to snacking, energy density and eating behaviour outcomes within titles and abstracts (please see appendix for search terms). The inclusion and exclusion were set to further refine the search (please see Table 1 for the inclusion and exclusion criteria).

Retrieved references were imported into EndNote (*EndNote* 20, 2013). Reference lists were then imported into the web-based software, Covidence (Covidence systematic review software, Veritas Health Innovation, Melbourne, Australia. Available at, 2025) where duplicated articles were removed.

2.3. Study selection, data extraction and narrative synthesis

Two reviewers (C.M & R.E) independently engaged in title and abstract screening of all articles. Reviewers were able to vote "yes", "no" or "maybe" in response to study eligibility criteria for full-text reviewing. Conflicts were flagged by the reference management software and discussed to reach agreement; where articles could not be agreed upon, a third reviewer (L.W) was introduced to deliberate). Articles voted "no" were then deemed "irrelevant" and articles voted "yes" were deemed eligible for full-text screening. The process was repeated for full-text screening by both reviewers. Please see Fig. 1 for Prisma flowchart.

Discussions between authors occurred around what data would need to be extracted from the studies in order to address the research question (please see Table 2 for data extraction plan). One reviewer extracted information from the eligible studies (C.M). A second reviewer (R.E) also carried out the extraction process in conjunction with the first reviewer (C.M) on five of the eligible studies (50 %) to ensure that sufficient and appropriate data was being extracted.

The narrative synthesis includes studies that compared snacking episodes of various energy densities. Some papers included snacking episodes of various energy densities compared to no snacking episode, where the latter acts as a control condition. We also note that within the narrative synthesis, we have referred to the energy densities as identified in the papers, however, there is variation across the literature in what is classified as high, medium, and low energy density (Rolls, 2017).

Both reviewers also used the JBI Critical appraisal tool framework as a guide to assess the strength of the studies with relation to the question being explored within this systematic review. CM and RE both independently carried out the critical appraisal on 5 of the 10 included studies using the detailed descriptions for each criterion, ranking them

Table 1
Inclusion and Exclusion Criteria.

Inclusion Criteria	Exclusion Criteria
Intervention studies (i.e. studies including an experimental manipulation)	Observational studies
Participants who have not had surgery or medication for weight management	Participants who have had surgery or medication for weight management
Human studies	Animal studies
Studies including participants with no history of disordered eating behaviour	Studies including participants with a history of disordered eating behaviour
Adult participants (18+ years of age)	Studies that included children as participants
Conditions that explored solid food items as a snack.	Conditions that explored the impact of liquids as a snack (e.g., a condition that stated drinks such as tea, coffee or milk were the snacks being explored)
Studies including the comparison of 2+ snacking episodes	Studies with less than 2 comparable snacking episodes
Peer Reviewed papers and Grey Literature	Non-peer reviewed reports / write ups

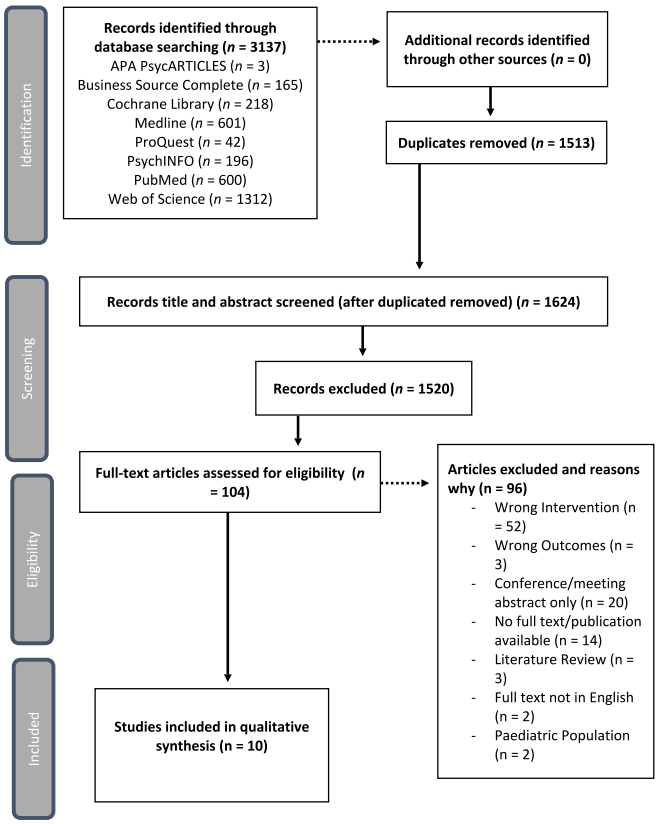

Fig. 1. PRISMA flowchart.

as either strong, moderate or low. Once in agreement on the appraisal, the primary reviewer continued to carry out the critical appraisal on the remaining 5 papers.

3. Results

3.1. Literature search and data analysis

Across the selected 8 databases, 3137 articles were exported into Covidence, with 1513 duplicated articles being removed. 1624 papers were title and abstract screened. Full text screening was conducted on 104 papers. The final review included 10 articles. (Please see Fig. 1 for PRISMA flowchart).

All studies were published between 1999 and 2023. Participants within the studies were recruited in the UK ($n = 4$), USA ($n = 2$), New Zealand ($n = 1$), Mexico (n = 1), Netherlands (n = 1), and Australia (n = 1). There was a large range in sample size across studies with the lowest number of participants being 13 and largest being 100. The lowest number of female participants per study was 7 and the highest was 75, and the lowest number of male participants per study was 5 and the highest was 36. Across studies, 173 participants were male and 272 female (1 study did not report gender). Participants ranged from age 18 to 65 years. There was a large range in BMI with participants ranging between lean, overweight, and obese classifications. Please see extraction Table 2 for participant characteristics for each study.

Of the 10 studies included, five compared snacking episodes of 2 energy densities, two compared snacking episodes of 3 energy densities (one of which was a 3 × 3 design, meaning there were three low, three moderate and three high conditions), one compared snacking episodes of 4 energy densities, one compared snacking episodes of 5 energy densities, and one compared snacking episodes of 6 energy densities. Of these studies, two also included a no snack condition as a comparison. Considering this variation in comparisons, the narrative synthesis is organised in terms of the outcome measures (see below), as these allowed for consensus building. Please see Table 3 for study details.

Table 2
List of information extracted from each study.

Information	Description
Sample Characteristics	Sample gender, age, recruitment type, and the country where the study was conducted
Control Measures	Standardisations and factors controlled for
Study Design	Between-subjects, within-subjects or mixed design
Study Setting	Laboratory or field study
Study Intervention	A comparison between snacking episodes of different energy densities (e.g. snack (high/ medium/ low energy density)
Study Outcome	Appetite, satiety/satisfaction, hunger, energy intake, fullness, compensation
Analysis used	Tests and statistics
Quality Assessment	Assignment to conditions, control conditions, measurements of outcomes, extraneous and additional variables control for during analysis

*1. Conversations with an author of paper allowed results as a function of energy density to be obtained.

*2. Information not found within paper.

**3. Recruitment not explicitly stated within paper but does indicate where recruitment took place (e.g., ethics granted).* Of the ten studies included, 7 assessed hunger, 5 assessed fullness, 4 assessed desire to eat and/or prospective food consumption, 1 assessed overall satiety, and 9 assessed energy intake (with relation to the impact that the energy density of a snacking episode has on such outcomes). Please see extraction Table 2 for the study characteristics of included papers.

3.2. Narrative synthesis

3.2.1. Hunger, Fullness and Satiety

Seven of the ten studies included hunger as an outcome measure, and 5 of the 10 studies explored fullness, all of which used a 100 mm Visual Analogue Scale for assessment. One study explored overall satiety (a quotient score for combined measures of hunger, fullness and satiety).

A recent study by Escobedo et al. (2023) showed that there was no significant difference in hunger levels when consuming a high versus low energy density cooked-bean based snack. Both snacking episodes did however result in reduced hunger levels and higher fullness levels compared to a moderate energy density snacking episode of white bread. These results were only evident in a normal weight sample and not in an overweight sample.

Other studies found that the energy density of a snacking episode had no significant impact on hunger or fullness (Guo et al., 2018). Clark, Dewey and Temple (2010) found that there were no significant differences in post-consumption hunger or fullness levels as a function of energy density. Similarly, Green et al. (2000) also found no significant difference in hunger levels between high and low energy density snacking episodes, with both conditions reducing hunger levels after snack consumption and rising until the next meal. Additionally, at the end of a twelve-week study, Zaveri and Drummond (2009) did not find a significant difference in hunger ratings per day between two snacks of different energy densities (cereal bars compared to almonds).

Some studies did highlight that energy density impacts hunger levels; however, such results tended to have limitations that affected interpretation. Brown et al. (2021) found no significant differences in 2-h area under the curve for fullness or satiety quotient between the lower energy density snacking episode of biscuits compared to the higher energy density snacking episode of almonds. Despite this, a difference was found with relation to hunger. Biscuits resulted in lower hunger levels at 90 min post-consumption (no statistically significant differences at other time points), compared to raw almonds. However, both snack foods could be considered as high energy density in other areas of the literature (Rolls, 2017). Furthermore, despite the foods being different energy densities, the amount provided was likely different for

Table 3
Study Information.

Title	Authors	Year	Country of Recruitment	Number of Participants	Participant Age	Participant Gender	Participant BMI
Snacking on Almonds Lowers Glycaemia and Energy Intake Compared to a Popular High-Carbohydrate Snack Food: An Acute Randomized Crossover Study	Brown, R., Ware, L., Gray, A.R., Chisholm, A., & Tey, S.L.	2012	New Zealand	100	18–65 years of age (m = 29)	Male = 25; Female = 75	M = 23.1 kg/m^2
Low glycemic index common bean snack increased satiety without modifying energy intake in adults with normal weight: randomized crossover trials	Escobedo, A., Esquivel-Hurtado, M., Morales-Hernández, N., Rodríguez-Reyes, S. C., Rivera-León, E. A., & Mojica, L.	2023	Mexico	Study 1 = 18 (normal weight) Study 2 = 18 (overweight)	Study 1 = 25–27 years of age (median = 26) Study 2 = 25–35 years of age (median = 27)	Study 1: Male = 5; Female = 13 Study 2: Male = 11; Female = 7	Study 1: M = 21.9 +/− 0.4 kg/m^2 Study 2: M = 27.1 +/1 0.4 kg/m^2
Comparison of high-fat and high-carbohydrate foods in a meal or snack on short-term fat and energy intakes in obese women	Green, S. M., Wales, J. K., Lawton, C. L., & Blundell, J. E.	2000	UK	13 (+2 excluded)	25–56 years of age (m = 38)	All female	M = 39.2 kg/m^2
Effect of Midmorning Puree Snacks on Subjective Appetite, Food Intake, and Glycemic and Insulin Responses in Healthy Adults	Guo, Q., Totosy de Zepetnek, J., Chang, J., Hayden, J., Crozier, S. J., Mongia, G., … & Bellissimo, N.	2018	USA	23	M = 23.7	Male = 14; Female = 9	M = 22 +/− 0.5 kg/m^2
Effects of Snack Intake on Appetite, Affect and Attention	Hetherington, M. M., & Macdiarmid, J. I.	1999	UK	30	*2	All male	Normal weight
Exploring relationships between satiation, perceived satiety and plant-based snack food features	Ni, D., Gunness, P., Smyth, H. E., & Gidley, M. J.	2012	Australia*3	10	M = 45	*2	M = 25.57 kg/m^2
Effects of daily snack food intake on food reinforcement depend on body mass index and energy density*	Clark, E. N., Dewey, A. M., & Temple, J. L.	2010	USA	53	18 to 50 years of age	All female	Obese (n = 23): BMI in kg/m^2 ≥ 30; overweight (n = 15): BMI in kg/m^2 < 30 and ≥ 25; lean (n = 15) BMI in kg/m^2 < 25
Food characteristics and dietary intake the role of taste, eating rate and energy density (Chapter 6)	Viskaal-van Dongen, M., Kok, F. J., & de Graaf, C. (Chapter 6)	2010	Netherlands	82	M = 21.9	Male = 16; Female = 66	M = 20.7 kg/m^2
Effects of two weeks' mandatory snack consumption on energy intake and energy balance	Whybrow, S.; Mayer, C.; Kirk, T. R.; Mazlan, N.; Stubbs, R. J.	2007	UK	72	Lean Male: M = 33.6; Lean Female: M = 31.9; Overweight Male: M = 36.9; Overweight Female: M = 37.8	Lean Male = 18; Lean Female = 18; Overweight Male = 18; Overweight Female = 18	Lean BMI: 19–25 kg/m^2; Overweight BMI: 26–35 kg/m^2
The effect of including a conventional snack (cereal bar) and a nonconventional snack (almonds) on hunger, eating frequency, dietary intake and body weight	Zaveri, S.; Drummond, S.	2009	UK	36 (+9 incomplete)	25–50 years of age (M = 39.6)	All male	M = 29.8 kg/m^2

each food in order to control for caloric intake. Moreover, sensory properties were not matched, and the aim of the paper was less about energy density and more about the potential benefits of eating almonds.

Hetherington and Macdiarmid (1999) also found that a snacking episode of a higher energy density (724 kcal) resulted in lower hunger levels compared to snacking episodes of a lower energy density (124 kcal), with post-hoc tests revealing significance between the lowest energy and highest energy condition. This was also evident for fullness as the higher energy density condition resulted in higher fullness levels than the lowest energy density snack. However, the snack foods used in this study were melba toast or melba toast with chocolate spread, with the amount of chocolate spread being increased to change the energy density of each condition. Considering this, there lacked control of the effects of the increasing volume of the chocolate spread.

Ni et al. (2021) assessed fullness and satiety across seven different foods all differing in energy density, including cut apple, carrot, and banana, whole chickpeas, avocado, and macadamia. Energy density did impact fullness and satiety though dependent on time (20- or 180-min post-consumption) and whether volume or caloric load was being measured. Aggregated results showed that satiety was associated with energy density, with the higher energy density snacking episodes associated with higher perceived satiety levels, however fullness was not associated with energy density.

3.2.2. *Desire to eat/consume and prospective food consumption*

Four of the ten studies measured desire to eat/consume and/or prospective food consumption, with the weight of the evidence showing that the energy density of a snacking episode had little effect on

consumption.

Guo et al. (2018) found no significant difference in desire to eat or prospective food consumption across snacking episodes of different energy densities. Escobedo et al. (2023) found no significant difference between the highest and lowest energy density snacking episodes (both bean-based), however both reduced food consumption more than a moderate energy density snacking episode of white bread. Again, this was only prevalent in the normal weight sample compared to the overweight sample. Similarly, Brown et al. (2021) found no significant difference in 2-h areas under the curve or satiety quotient for prospective food consumption and desire to consume between the lower energy density snacking episode of biscuits or the higher energy density snacking episode of almonds. Though again, we note limitations of this study as discussed above.

By contrast Hetherington and Macdiarmid (1999) found that the highest energy snack of melba toast and chocolate spread reduced desire to eat when compared to a snack of a lower energy density, melba toast, again noting that in order to manipulate energy density, volume of chocolate spread provided was also changed (0 units, 0.5 units, 1 unit, and 2 units).

3.2.3. *Energy intake, ad libitum intake, and energy compensation*

Eight of the ten studies explored the influence that the energy density of a snacking episode had on either energy intake or ad libitum intake, and/or compensation of energy. Some studies found no difference in energy intake when comparing snacking episodes of different energy densities (Viskaal-van Dongen, Kok and de Graaf, 2010).

Similarly, but for ad libitum consumption, Escobedo et al. (2023), Green et al. (2000), Guo et al. (2018), and Zaveri and Drummond (2009) found no difference in consumption as a function of energy density. For example, Green et al. (2000) showed no significant differences between the higher energy density condition compared to the lower energy density condition, with relation to energy consumed at test dinners or the remainder of the day.

When measuring at daily energy intake, Brown et al. (2021) showed that a higher energy density snacking episode of almonds resulted in lower energy intake (when combining the ad libitum lunch consumption and the remainder of energy consumed through the day) when compared to the lower energy density snacking episode of biscuits. By contrast,

Ni et al. (2021) did show that the higher energy density snacking episode resulted in higher energy intake.

With respect to compensation, results were extremely mixed. Guo et al. (2018) found no difference in caloric compensation as a function of energy density. Brown et al. (2021) showed that there was no significant difference in ad libitum lunch or energy intake consumed through the remainder of the day. The only significant difference identified was when the lunch and remainder of the day energy intake were combined, with the higher energy density snacking episode of almonds resulting in lower energy intake compared to the lower energy density snacking episode of biscuits.

Whybrow et al. (2007) found that across all conditions, gender, and weight status, regardless of energy density, as snacks were introduced into the diet energy intake increased (with men consuming more than women and participants with overweight consuming more than lean). Partial compensation did occur by 54 % for the low energy snacking episode conditions and by 64 % in the high energy density snacking episode conditions, however there was not a significant difference across conditions.

3.3. *Quality assessment checks*

Using the JBI Critical Appraisal tool (see Fig. 2), it was determined that 7 of the studies had an overall rating of 'strong' and 3 had an overall rating of 'moderate' with relation to the quality of the studies. The moderate to low factors mainly included confounding factors and descriptive statistics not being reported. For example, some studies did not control for liking of the test foods or other potential confounding factors (e.g., other sensory differences between test foods) and a lack of control of volume albeit minimal but present.

4. Discussion

This systematic review explored the impact that the energy density of snacking episodes has on eating behaviour outcomes. Ten articles were reviewed with various methodologies, comparing snacking episodes of different energy densities. The weight of the evidence within this review suggested that for snacking episodes, there is little effect of energy density on eating behaviour outcomes, including hunger, desire to eat, prospective food consumption, and energy intake. However, there was limited evidence to suggest that higher energy density snacking episodes could result in higher satiety levels, and energy density may influence

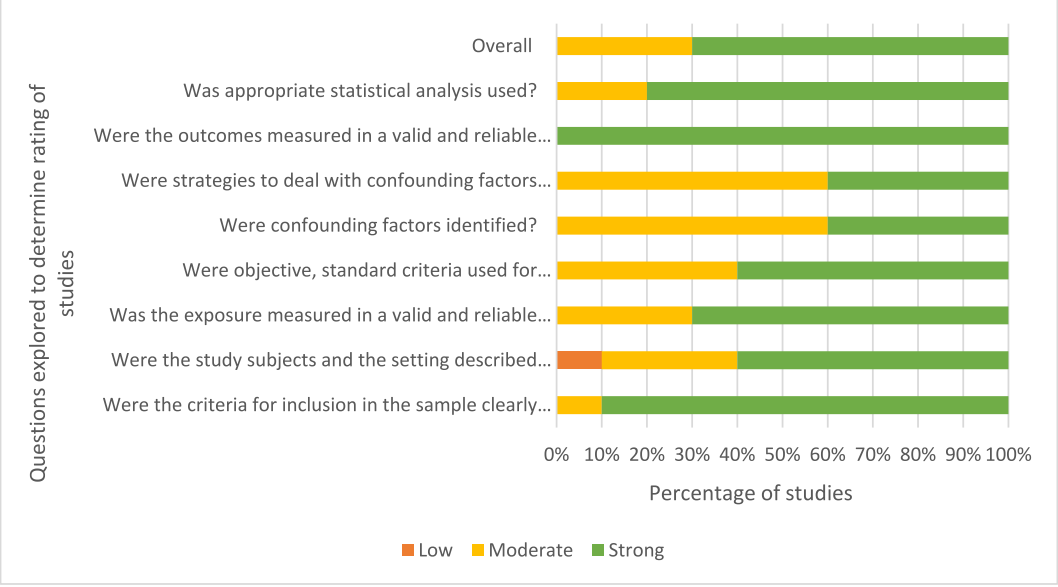

Fig. 2. Quality Assessment Checks: JBI Critical Appraisal Tool.

fullness but only at specific time points.

There were limited studies available to examine effects, and of those available, study designs were not always suitable to distinguish between effects of energy density and confounding factors. For example, volume was not optimally controlled for in some studies and snack foods often differed considerably in their sensory properties. This shows the need for studies in this area of research to compare standardised snack foods, with all confounds controlled. Studies need to find a balance between evaluating the impact of more comparable test foods and realistically manipulated products. Furthermore, in order to better understand the role that energy density has on behavioural outcomes studies may also consider controlling for familiarity and considering outcomes post-ingestion.

As mentioned in the introduction, there are various definitions relating to what classifies as a snack and engaging in snacking behaviour. Our focus was on "snacking episodes" as a whole, meaning the consumption of food/foods in a single sitting between mealtimes. The literature would undoubtedly benefit from a universal definition that allows standardisation across studies. Such a definition would also help us to understand more about the role of snacking in the diet as a whole for example via consistent classification of entries in a food diary as a snack (or not) and indeed the energy density of those snacks relative to other foods consumed (e.g., as meals).

When exploring the ten included studies, it became apparent that the literature would benefit from more studies in this area that have a more central focus around snacking, with comparable foods that standardise volume and sensory features, have consistent agreement around what is considered a "high energy density" snack, with adequate power, that also follow the open science approach (Open Science Collaboration, 2015). Furthermore, there is limited research exploring the impact that the energy density of a snacking episode has on energy compensation, a pivotal part to this topic which is underrepresented within the existing literature. A reduction in the heterogeneity of methodologies would strengthen the literature by allowing more definite conclusions to be drawn based on robust studies with relation to energy density, snacking episodes and eating behaviour outcomes.

The results from the current systematic review highlight a potential opportunity to explore snack energy density as an intervention for promoting a healthy and nutritionally rich diet. As noted, there is little difference between the impact that the energy density of a snacking episode has on eating behaviour outcomes with relation to fullness, hunger and appetite. Considering this, there is scope for future studies to create snacking episodes which consider the modulation of energy density to target other food choice drivers, such as pleasure, and satisfaction. Future research investigating how lowering the energy density of an overall snacking episode would add to the current literature, with relation to how this impacts eating behaviour outcomes such as those explored in the current review, including hunger, fullness, desire to eat, and energy intake.

Our findings add to a broader literature around the influence of energy density on eating behaviour, however many existing studies have focused on meals or diet as a whole, whereas the focus of this systematic review was on snacking episodes. Such studies have highlighted the existing discrepancies across the literature with relation to whether humans can adequately detect energy density and adjust for it appropriately (Finlay et al., 2024; Flynn et al., 2022; Brunstrom et al., 2018). Research from Flynn et al. (2022) and Brunstrom et al (2018) posed the idea that humans use a volume heuristic to guide their consumption of lower energy density foods up until a breakpoint, following this, an energy density heuristic guides consumption. By contrast, Finlay et al. (2024) conducted a study which suggested that when foods of a higher energy density were consumed, overall energy intake increased and more of this food was consumed in comparison to those of a lower energy density. This is consistent with the passive over-consumption theory; such findings suggests that the energy density of the food is not detected and that there is little compensation and adjustment elsewhere in the diet (Blundell & MacDiarmid, 1997). As noted, many of the studies included in this current systematic review also highlighted that there was little difference in hunger, desire to eat, prospective food consumption, and energy intake. Though, some evidence showed that fullness and satiety are influenced by energy density. Future studies considering snacking behaviour may draw on this meal/diet related discourse.

It is important to note that the research included in this systematic review focuses solely on intervention studies exploring snacking episodes in an adult population ($n = 10$), however there is much literature that adds to this discussion that did not fit the inclusion criteria of this study. For example, Temple et al. (2008) found that after two-weeks of consuming a 200–300 cal food, the reinforcing value of the food decreased. Although slightly out of scope for the purpose of this review, due to the presentation of results being focused on a reinforcement task rather (i.e, the impact that the reinforcing value of liked foods has on eating behaviour outcomes) than comparisons between energy densities, these results do indeed highlight how snacking can influence behaviour through factors such as reinforcement.

The focus of the current systematic review centred around energy density, with one of the key findings being a need for studies with higher comparability between the snack products used. Future studies might also consider micronutrient intake in addition to energy density as this may also play an influential factor when exploring eating behaviour outcomes such as daily energy intake, fullness and satiety. For example, studies would benefit from considering the carbohydrate to fat ratio of snacks. Indeed, Rogers et al. (2024) found that foods with equal amounts of carbohydrate and fat (in terms of energy) scored higher on liking and food reward. By contrast, energy density and level of processing did not predict these outcome variables. Interestingly, Mantzavinou and Rogers (2023) attempted to decouple energy density by manipulating food volume and calories separately. They found that hunger was affected by both food volume and calories, but fullness was affected by volume alone. Again, such observation may benefit future studies considering conflicting findings around the relationship between energy density and eating behaviour outcomes of snacks.

There are both strengths and weaknesses to the current systematic review. As stated in the inclusion criteria, studies needed to be written in English, this may have biased our results. Previous studies have noted the differences in eating behaviour between Western and non-Western cultures (Randall et al., 2024), indeed, the current systematic review likely does not adequately represent non-Western diets. Nevertheless, the current review engaged in open science with the pre-registration of our approach. We also used a systematic approach aided by Covidence software, which ensured the independence of the two reviewers.

Energy density is only one element to understanding snacking episodes and eating behaviour outcomes. For example, Gatzemeier et al. (2024) found that a range of self-identified management and coping strategies were utilised to control the intake of tempting foods (often snacks). Moreover, Phan Thuy (2015) found that health and weight control were driving factors for mid-morning and mid-afternoon snacking, whereas pleasure and visual appeal drove late-night snacking behaviour. Finally, Higgins et al. (2022) discussed the importance of portion size and snacking frequency. Future studies would benefit of a holistic approach that explores energy density in conjunction with such factors. Such research is likely to benefit both public health and the food and drink industry product development, with relation to meeting consumer demands for sensory and pleasurable factors such as taste while responsibly benefitting health (Mattes, 2018; Belc et al., 2019; Durack, Alonso-Gomez and Wilkinson, 2008).

CRediT authorship contribution statement

Chloe Mellor: Writing – review & editing, Writing – original draft, Visualization, Investigation, Conceptualization. **Rochelle Embling:** Writing – review & editing, Investigation. **Menna Price:** Writing –

review & editing, Conceptualization. **Milena Rundle:** Writing – review & editing. **Alexandra Meynier:** Writing – review & editing, Conceptualization. **Sophie Vinoy:** Writing – review & editing, Conceptualization. **Laura Wilkinson:** Writing – review & editing, Supervision, Conceptualization.

Ethics approval and consent to participate

Ethical approval was not required for this study as it was a review of existing literature.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Laura Wilkinson reports financial support was provided by Mondelez International UK Ltd. Laura Wilkinson reports financial support was provided by Biotechnology and Biological Sciences Research Council. Sophie Vinoy reports a relationship with Mondelez International Inc. that includes: employment. Alexandra Meynier reports a relationship with Mondelez International Inc. that includes: employment. Milena Rundle reports a relationship with Mondelez International UK Ltd. that includes: employment. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Appendix

A.1. Search terms

Used Search terms relating to snacking - Snack* or “snacking episode*” or “snacking occasion*” or “snacking between meals” or “graz*” or “between meals eating”

A.2. Search terms

relating to energy intake and appetite - Appetite or satisf* or satiation or hunger or hungry or nutriti* or “nutrient dense” or “energy content” or “energy intake” or “daily energy intake” or “mealtime energy intake” or “meal energy intake” or “energy dens*” or overeating or “energy balance” or “diet quality” or “ad libtium intake” or “meal size” or “portion size” or consumption or “food intake” or “food consumption” or “food content” or “eating occasion*”

Data availability

No data was used for the research described in the article.

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