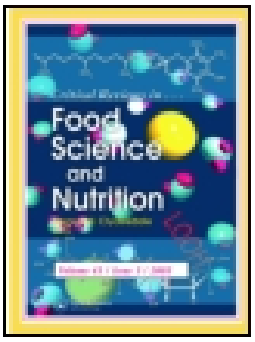

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# MODIFICATION OF APPETITE BY BREAD CONSUMPTION: A SYSTEMATIC REVIEW OF RANDOMIZED CONTROLLED TRIALS

Carolina Gonzalez-Anton[1], Reyes Artacho[2], Maria D. Ruiz-Lopez[3], Angel Gil[1,4], Maria D. Mesa[1]*

[1]Department of Biochemistry and Molecular Biology II, Institute of Nutrition and Food Technology ñJose Mataixò, Center of Biomedical Research, University of Granada, Granada, Spain

[2]Department of Nutrition and Food Sciences, Faculty of Pharmacy, University of Granada, Spain.

[3]Department of Nutrition and Food Sciences, Instiute of Nutrition and Food Technology ñJose Mataixò, University of Granada, Granada, Spain

[4]Institute of Biohealth Research, ñibs. GRANADAò, Spain

BREAD AND APPETITE

**Address correspondence and reprint requests to:**

Dr. Maria Dolores Mesa

Department of Biochemistry and Molecular Biology Molecular II, Institute of Nutrition and Food Technology, Center of Biomedical Research, University of Granada. Avda. del Conocimiento s/n, 18016 Granada, Spain, Tel: +34 958 241000 Ext. 20314; Fax: +34 958 248960, E-mail: mdmesa@ugr.es




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**Keywords**

Bread, energy intake, gastrointestinal hormones, satiation, satiety response, obesity

**Abstract**

The inclusion of different ingredients or the use of different baking technologies may modify the satiety response to bread, and aid in the control of food intake. The aim of this study was to perform a systematic search of randomized clinical trials on the effect of bread consumption on appetite ratings in humans. The search equation was ("Bread"[MeSH]) AND ("Satiation"[MeSH] OR "Satiety response"[MeSH]), and the filter `clinical trials`. As a result of this procedure, 37 publications were selected. The satiety response was considered as the primary outcome. The studies were classified as follows: breads differing in their flour composition, breads differing in ingredients other than flours, breads with added organic acids or breads made using different baking technologies. Additionally, we have revised the data related to the influence of bread on glycemic index, insulinemic index and postprandial gastrointestinal hormones responses. The inclusion of appropriate ingredients such as fiber, proteins, legumes, seaweeds and acids into breads and the use of specific technologies may result in the development of healthier breads that increase satiety and satiation, which may aid in the control of weight gain and benefit postprandial glycemia. However, more well-designed randomized control trials are required to reach final conclusions.

## Introduction

Bread, a staple food made of flour, water, and yeast, is the most common cereal-based food consumed in the world.

Bread supply varies greatly among countries. In Europe, Poland, Greece and Denmark, bread consumption has been estimated as 70 kg/capita/yr, followed by Ireland with 68 kg/capita/yr and Hungary and Holland with 60 kg/capita/yr, whereas in countries that belong to the Mediterranean area, bread consumption ranges from 44 to 46 kg/capita/yr in Spain and Italy, respectively. In the USA, bread consumption is 43 kg/capita/yr and it ranges in Latin American countries from 31 kg/capita/yr in Brazil to 96 kg/capita/yr in Chile (Figure 1, Union of International Bakeries, UIB, 2006).

Indeed, bread contributes the highest proportion of carbohydrates to the diet according to the European Prospective Investigation into Cancer and Nutrition (EPIC) study: 14-37% among men and 13-30% among women (Cust et al., 2009), and 10% in the National Health and Nutrition Examination Survey (NHANES) study (OôNeil et al., 2012). Bread is also an important source of proteins, fiber, minerals, B vitamins and bioactive compounds (Fardet, 2010).

The health-beneficial effects of the regular intake of wholegrain cereals, including bread, on the reduction of risk factors related to non-communicable chronic diseases, such as cardiovascular diseases, type 2 diabetes, certain types of cancer and gastrointestinal pathologies, have been previously reported (Slavin, 2004; Venn and Green, 2007; Gil et al., 2011). However, the influence of bread consumption on obesity and body weight regulation is unclear. Dietary patterns that include whole-grain bread do not influence weight gain and may be beneficial in




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maintaining body weight; nevertheless, dietary patterns including refined bread could be related to an excess of abdominal fat (Bautista-Castaño and Serra-Majem, 2012). The results of the PREDIMED (PREvención con DIeta MEDiterránea) study (with 4 years of follow-up in Spain) showed that decreasing total and white bread, but maintaining whole-grain bread consumption in the setting of a Mediterranean lifestyle, could help to reduce weight and abdominal fat gain (Bautista-Castaño et al., 2013). Figure 1 shows bread supply *versus* the obesity prevalence in selected European and American countries. Although a general belief holds that obesity is associated with bread consumption, this issue is controversial. A recent review has stated that there is no relationship between weight gain and bread consumption (Bautista-Castaño and Serra Majem, 2012). An examination of actual data (Figure 1) reveals that in fact, there is no relationship between bread supply and the prevalence of obesity (Organisation for Economic Co-operation and Development, OECD, 2014). In fact, it is important to establish the actual impact of bread consumption on obesity prevalence. Moreover, besides bread being one of the most restricted foods in popular hypocaloric diets, it has been observed that the inclusion of bread in a low-calorie diet designed for weight loss favored a better evolution of dietetic parameters and increased the sensation of satiety after eating, which could help foster greater adherence to those types of diet (Loria-Kohen et al., 2011, 2012).



Satiety is a process that leads to the inhibition of future eating with a decline in hunger and increased fullness after a meal has finished, whereas satiation is a process that leads to the termination of eating. Their regulation is related not only to food characteristics but also to some gastrointestinal peptides that are released following food consumption and that have a role in appetite control. These gastrointestinal hormones include the gastric peptide ghrelin, the


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pancreatic peptides insulin and amylin, as well as the gastrointestinal peptides glucagon-like peptide-1 (GLP-1), gastric inhibitory peptide (GIP), pancreatic polypeptide (PP), peptide YY (PYY) and cholecystokinin (CCK) (Blundell et al., 2010).

Bread provides an ideal matrix through which functionality could be delivered to the consumer in an accepted and convenient food (Hobbs et al., 2014). The nutritional profile of bread may be improved by the addition of different types of flours and new ingredients, by modifying its structural characteristics or by changing baking conditions (technological aspects). All these modifications may influence its traditionally high glycemic index (GI), thus optimizing the blood glucose and insulin responses (Rizkalla et al., 2007; Najjar et al., 2009), and contributing to enhanced satiety (Poutanen et al., 2014; Gonzalez-Anton et al., 2015). Therefore, promoting healthier bread formulation could be an important public health strategy in the prevention and treatment of obesity and associated metabolic disorders (Burton et al., 2011; Munsters and Saris, 2014).

As far as we know, there are no systematic reviews regarding the contribution of bread to satiety, including behavioral aspects related to gastrointestinal peptides. Therefore, the aim of the present study was to review systematically the scientific evidence regarding the effect of bread consumption on appetite ratings in humans.

**Methods**

This review was conducted in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement for Reporting Systematic Reviews and Meta-analysis of Studies that Evaluate Health Care Interventions (Liberati et al., 2009).

The research question in this systematic review was *"Does bread have a satiating effect on healthy or chronic disease populations?"* The review included all randomized controlled trials (RCTs) with prospective, parallel or crossover designs in healthy, overweight or obese, type 2 diabetics and metabolic syndrome subjects, in which the effect of different types of bread was compared with that of a control, which was mainly wheat white bread (WWB). Satiety evaluation was considered as the primary outcome, whereas the glycemic, insulinemic and gastrointestinal hormones responses were secondary outcomes. Only articles, or at minimum the abstracts, in English were considered; however, no restriction was placed on publication type or the sample size.

***Inclusion and exclusion criteria***

For a study to be considered, a dietary intervention had to be conducted with different types of bread, including the following: 1) breads evaluated without concomitant intake of any other food, except for water and 2) breads ingested together with other traditional breakfast foods (as breakfast). Studies were excluded for the following reasons: 1) the satiety of different foods other than bread was evaluated or studies in which bread was only used as a control, 2) the satiety for complete breakfasts or diets that included bread with the other foods was evaluated; however, the objectives were to analyze peptides involved in appetite regulation without evaluation of the appetite profile derived from bread consumption. The gastrointestinal peptides




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may provide supplementary information, but they are insufficient by themselves to evaluate the satiating effect of food (Health Canada, 2012).

***Participants***

Eligible participants were individuals of all ages, either healthy or affected by any chronic disease, who were mainly overweight or obese, including those with type 2 diabetes and metabolic syndrome. There were no restrictions based on gender, ethnicity, study setting or other characteristics.

***Types of intervention***

We selected postprandial RCTs that evaluated appetite scores after a single intake of the experimental bread. We also included two sustained RCTs that evaluated appetite scores after repetitive intakes of experimental breads during a specific period to observe differences in satiety between a diet including bread and without it (Bodinham et al., 2011; Loria-Kohen et al., 2011).

***Methods for measuring satiety and satiation***

Satiety and satiation are processes that affect eating behavior. **Satiety** is measured by the magnitude or duration of changes in subjective ratings of appetite-related sensations with or without the measurement of energy intake (EI, kcal or kJ) at a subsequent meal. The method commonly used is a self-reported scale, such as Visual Analogue Scales (VAS), which consist of a 100-150 mm horizontal line, anchored at each end with opposing extremes of a specific scale (for example, "not at all hungry" to "extremely hungry"). The volunteers consumed a standardized breakfast and completed appetite rating VAS every 30 min during the postprandial




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period (Flint et al., 2000). Other satiety measures employed were the rating scale (Holt et al., 1995) and the satiety index (SI) developed also by Holt et al. (1995), which is a measure of the potency of a food to satisfy hunger relative to WWB (index of 100). Foods scoring higher than 100 are more satisfying than WWB and those lower than 100 are less satisfying. The Haber scale (Haber et al., 1977) is a scoring system graded from minus 10, representing extreme hunger, to plus 10, representing extreme satiety. **Satiation** is measured experimentally through the study participant's *ad libitum* consumption of the food under investigation during an eating occasion usually four hours after the food intake, when participants are provided with a large pre-weighed *ad libitum* homogeneous meal (Blundell et al., 2010).

***Main stages of the systematic review***

Information was recovered using Medical Subject Headings (MeSH) developed by the U.S. National Library of Medicine. Neither subheadings nor entry terms were employed.

The most suitable [MeSH] terms for this systematic review were "bread", "satiation" and ñsatiety responseò. The filters used were "Clinical trials" and "Humans."

Search equations were developed to use on the MEDLINE database, via PubMed, by Boolean connectors. The search equation was adapted for the SCOPUS, EMBASE and LILACS databases, although LILACS yielded no results. The search was conducted from the beginning of the literature until February 2015.

The search equation was: #1 ("Bread"[MeSH]) AND ("Satiation"[MeSH] OR "Satiety response"[MeSH]) using clinical trials as a filter, with 123 results without restriction on the




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publication date until the search date, yielding 41 results from Medline, 61 from SCOPUS and 25 from EMBASE.

*Data collection*

The main stages in the classification of studies for this systematic review are depicted in Figure 2. The titles, abstract sections and keywords of every record obtained (n=142) by the search in all databases were examined by two reviewers (CGA and RA) to identify potentially eligible studies. No additional records were identified through other sources. Duplicated records were eliminated (n=11). The reviewers screened all references (n=131) and excluded those evidently ineligible for inclusion (n=94). Finally, each reviewer assessed all of the remaining full texts for eligibility (n=37) independently and made a determination. In cases of disagreement, a consensus was reached on the final list after discussion among the Committee of Evaluation Members (AG, MDM and MDRL) and some full-text articles were excluded (n=11). Finally, a total of 28 RCTs, 19 from MEDLINE, 7 from SCOPUS and 2 from EMBASE were selected (Figure 1).

*Data extraction*

Two reviewers (CGA, RA) entered the data into a database and discrepancies between them were resolved by a third reviewer (MDM). Missing data were obtained from the authors whenever possible, applied on specific forms to avoid bias.

*Assessment of quality*

The quality of each publication was validated by applying the Consolidated Standard for the Reporting of Randomized Clinical Trials (CONSORT) checklist for RCTs. It ensures that publications follow quality guidelines (Moher et al., 2010; Schulz et al., 2010). We developed a modified quantitative scale by assigning a value to each item in the list, based on Rangel-Huerta et al. (2012), assigning a quality score ranging from 0 to 30 (low to excellent). Studies with scores lower than 14 were classified as low quality, from 14 to 18 as moderate quality, from 21 to 24 as good quality, from 24 to 27 as very good quality, and from 27 to 30 as excellent quality.



**Results**

Table 1 lists the 28 articles selected for inclusion in this review, grouped according to the different added flours, other ingredients, the addition of organic acids and modifications in the baking technological methods. The table also indicates the CONSORT score, type of study/participants, intervention, satiety evaluation, primary outcomes and conclusions.

***Breads differing in their flour composition***

Of the 28 selected articles, 10 reported data on the effect of different types of flours or grains by such products on breads and their satiety effects. Eight out of 10 studies were in healthy adults, one was in overweight/obese subjects and one examined type 2 diabetic patients. The sample size ranged from 10 to 104. Quality scores for these 10 studies ranged from low to moderate (10 to 18) by the CONSORT scale.

The following different products were studied: buckwheat flour (Skrabanja et al., 2001), lupin flour (Hall et al., 2005; Lee et al., 2006; Keogh et al., 2011), wholemeal bread (Holt et al., 2006), and whole-grain breads (Kristensen et al., 2010; Bodinham et al., 2011; Breen et al., 2013;

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Forsberg et al., 2014). The sustained study conducted by Loria-Kohen et al. (2011) evaluating the satiety response for a hypocaloric diet with or without WWB was also included.

The appetite profile was assessed using three different tools; six of the 10 articles used the VAS (Lee et al., 2006; Kristensen et al., 2010; Bodinham et al., 2011; Loria-Kohen et al., 2011; Breen et al., 2013; Forsberg et al., 2014). The Holt et al. scale (Holt et al., 1995) was employed three times (Hall et al., 2005; Holt et al., 2006; Keogh et al., 2011). The SI was used twice (Hall et al., 2005; Holt et al., 2006) and only one article used the scale developed by Haber et al. (1977) (Skrabanja et al., 2001). Seven of 10 articles calculated the EI after an *ad libitum* lunch.

Skrabanja et al. (2001) studied a baked bread made with 50% boiled buckwheat groats *versus* WWB as a control. The tested products provided 50 g of available carbohydrates. They reported that the postprandial satiety ratings (area under the curve, AUC) were not different after the ingestion of the buckwheat bread, whereas the GI and insulinemic index (InI) values were significantly reduced with the buckwheat bread compared with the WWB.

Hall et al. (2005), Lee et al. (2006) and Keogh et al. (2011) studied different lupin breads. Hall et al. (2005) evaluated a WWB made with 10% Australian sweet lupin flour, which is rich in fiber and proteins compared with the WWB. These authors reported that the lupin flour bread did not affect subsequent satiety or *ad libitum* EI compared with the WWB. The GI was significantly lower, whereas the InI was significantly higher for the Australian lupin flour bread compared with the WWB. Lee et al. (2006) evaluated a bread formulated by substituting 40% of the wheat flour with lupin kernel flour compared with the WWB. They conducted a crossover-designed study as follows: 1) WWB at breakfast and WWB at lunch; 2) WWB at breakfast and lupin



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bread at lunch; 3) lupin bread at breakfast and WWB at lunch; and 4) lupin bread at breakfast and lupin bread at lunch. They described higher significant variations of fullness, satisfaction and prospective consumption when subjects consumed the bread made with lupin kernel flour compared with the WWB at breakfast. Additionally, when the lupin bread was consumed at breakfast, a significantly lower EI at lunch was observed compared with the WWB. Alternatively, a significant time-by-treatment interaction for glucose was found, but not for insulin response, whereas the incremental glucose and insulin AUCs were significantly lower for the lupin bread than that for the WWB. Keogh et al. (2011) tested three different breads: lupin bread (40%), a wholemeal and seeds bread (containing wheat, rye, soy, milk, triticale, oats and barley) and WWB as a control. In this case, the lupin bread also contained wholegrain rye flour and wholegrain lupin. Higher fullness responses were registered for the lupin bread and the wholemeal and seeds bread compared with the WWB. No differences were detected in the mean energy and fat intakes (kJ) between the lupin bread and the WWB breakfasts, although the subjects consumed less food (g) following the lupin bread than the WWB. Additionally, subjects consumed significantly less energy following the wholemeal and seeds bread compared with the WWB. Moreover, postprandial glucose and insulin levels were lower after consumption of the two experimental breads compared with the WWB.



Holt et al. (2006) studied the fullness responses and SI of different types of wheat breads supplying 238 kcal but containing different amounts of macronutrients and fiber, that is, coarse white bread (135 g of bread with 11.9 g of protein, 0.4 g of fat, 63.7 g of carbohydrates and 15.9 g of fiber), wholemeal fruit bread (109 g of bread with 10.2 g of protein, 1.7 g of fat, 51.2 g of carbohydrates and 10.2 g of fiber), protein-and-fiber-rich bread (135 g of bread with 11.9 g of


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protein, 1.2 g of fat, 63.7 g of carbohydrates and 19.9 g of fiber), high-fiber bread (148.2 g of bread with 9.6 g of protein, 1.4 g of fat, 76.5 g of carbohydrates and 33.5 g of fiber), high protein bread with 100% wholegrain (116.1 g of bread with 13.7 g of protein, 1.4 g of fat, 58.0 g of carbohydrates and 17.1 g of fiber) and low-fat, high-moisture bread with 100% wholegrain and added sesame seeds to the top crust, (162.5 g of bread with 9.6 g of protein, 1.0 g of fat, 76.5 g of carbohydrates and 23.9 g of fiber). They concluded that the SI of the high-fiber, coarse white, protein-and-fiber-rich and the low-fat, high-moisture breads were higher than those of the WWB and wholemeal fruit breads. Furthermore, the low-fat, high-moisture breadôs SI was also greater than that of the high protein bread. The subsequent EI at the *ad libitum* lunch consumed at the end of the 120 min experimental session was related negatively to the mean SI and fullness, and positively to prospective consumption. Glucose AUC was significantly higher after the intake of the coarse white bread than after the high protein, wholemeal fruit and protein-and-fiber-rich breads.

Kristensen et al. (2010) studied a wholegrain wheat bread compared with a WWB as a control, both providing 50 g of available carbohydrates. They found that wholegrain wheat bread resulted in increased satiety and fullness, and reduced hunger and prospective consumption compared with WWB. There was no significant difference on subsequent *ad libitum* EI at the lunch meal between the breads. Moreover, wholegrain wheat bread gave smaller AUCs for the desire to eat something rich in fat or something sweet, savory or salty compared with the WWB. Finally, the glucose responses were similar for the wholegrain wheat bread and the WWB. Bodinham et al. (2011) performed a sustained study in which the participants consumed a wholegrain wheat bread roll providing 48 g of whole grains per serving daily for three weeks, compared with a



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refined-grain WWB as a control. At the beginning and at the end of the 3-week intervention period, the participants underwent a postprandial test. The authors reported no significant differences between the interventions with both breads for any VAS ratings or for the EI at the *ad libitum* test meals.

Alternatively, Breen et al. (2013) tested four breads in type 2 diabetes patients who participated in an acute interventional study using a bread made of wholemeal wheat flour and buttermilk, a wholegrain wheaten bread, a pumpernickel rye bread and WWB, all providing 50 g of available carbohydrate. No significant differences in the fullness, satisfaction, hunger or prospective consumption AUCs among any of the four breads were detected. The mean AUCs for blood glucose and insulin were significantly lower for pumpernickel bread compared with the whole-grain bread, but did not differ among any of other breads. In contrast, Forsberg et al. (2014) investigated a wholegrain rye crisp bread (rich in arabinoxylan -8.2%-, ɓ-glucan -1.9%- and fructan -2.9%-) compared with WWB. These breads were served as part of a standardized isocaloric breakfast, using two different portion sizes at breakfast: a relatively high intake of bread (providing 282 kcal) and energy (592 kcal), and a lower intake of bread (providing 228 kcal) and energy (376 kcal). Participants felt less hunger and desire to eat, and higher fullness after eating the wholegrain rye crisp bread compared with the WWB. The results were more robust and/or more consistent when the test meal portion was 20% smaller, and only on that occasion was the subsequent *ad libitum* EI approximately 8% lower after the wholegrain rye crisp bread than after the WWB.



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Finally, Loria-Kohen et al. (2011) conducted an investigation that involved following a hypocaloric diet with and without WWB (with the same amount of carbohydrates). Appetite ratings were evaluated using VAS at the start of the study and after 16 weeks of the intervention. At the end of the study, they found differences in the answers to the question "How satiated do you feel right now?" The group that consumed the menu with bread experienced a greater sensation of satiety, obtaining higher significant values 60 and 90 min after eating.

***Breads differing in ingredients other than flours***

Apart from different flours, the influence of the addition of other ingredients to breads on satiety capacity has been assessed. Nine of the selected articles are included here. The different ingredients evaluated were β-glucan (Vitaglione et al., 2009), β-glucan and arabinoxylan (Hartvigsen et al., 2014), wheat fiber or oat fiber (Weickert et al., 2006), guar gum (Ellis et al., 1981; Ekström et al., 2013), fruit-derived fiber and a mix of soluble and insoluble fibers (Yuan et al., 2014), fruits, fiber and proteins (Gonzalez-Anton et al., 2015), *Ascophyllum nodosum* seaweed (Hall et al., 2012) and *Salvia hispanica* L. (popularly called chia) (Vuksan et al., 2010). Seven studies were conducted in healthy adults, one in overweight males and one in patients diagnosed with metabolic syndrome. The sample sizes ranged from 11 to 83 and the quality scores for these articles ranged from low to good quality (11 to 24) by the CONSORT scale.

VAS were used by Hall et al. (2012), Vitaglione et al. (2009), Vuksan et al. (2010), Ekström et al. (2013), Hartvigsen et al. (2014), Yuan et al. (2014) and Gonzalez-Anton et al. (2015). The Holt et al. scale (Holt et al., 1995) was employed by Weickert et al. (2006), whereas Ellis et al. (1981) used the Haber scale (Haber et al., 1977). Five of the nine articles calculated the EI after




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an *ad libitum* lunch (Vitaglione et al., 2009; Hall et al., 2012; Hartvigsen et al., 2014; Yuan et al., 2014; Gonzalez-Anton et al., 2015).

Vitaglione et al. (2009) compared the satiety effect of an enriched β-glucan WWB (3%), with a WWB as a control. The results were divided by time AUC from baseline to 60 min ($AUC_{60}$) and AUC from 60 min to 180 min ($AUC_{60-180}$). There was no difference between the mean $AUC_{60}$ of the appetite scores at 60 min. However, for $AUC_{60-180,}$ a 49% reduction in hunger was obtained as well as a 25% increase in fullness and a 55% increase in satiety after consuming the β-glucan-enriched bread-compared with the WWB. The *ad libitum* lunch EI showed a significant 19% reduction after the β-glucan-enriched bread compared with the WWB. Regarding postprandial glycemia, over 180 min after the intervention, the mean blood glucose was significantly lower after the intake of the β-glucan-enriched bread than after the WWB. There was no difference in insulin response. Plasma ghrelin $AUC_{60ï180}$ was lower (23%) and PYY $AUC_{0-180}$ was higher (16%) after the β-glucan enriched bread compared with the WWB.

Hartvigsen et al. (2014) compared the appetite response of three different types of bread: WWB with concentrated arabinoxylan (24%), WWB with β-glucan (13.3% β-glucans and 1.2% arabinoxylan) and a rye bread with kernels, rich in both arabinoxylan and β-glucans (49% of rye kernels), with WWB as a control. All breads provided 50 g of available carbohydrates. The three breads induced higher postprandial satiety and lower hunger and prospective consumption AUCs than the WWB. Additionally, the arabinoxylan and the rye kernel breads resulted in higher fullness AUC than the WWB. There was no effect of the different types of bread on *ad libitum* EI. Postprandial glycemic responses were significantly lower after the β-glucan and the rye


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kernel breads consumption than after the WWB, whereas the postprandial insulin responses were significantly higher after the arabinoxylan bread, the WWB and the ϐ-glucan bread than after the rye kernel bread. Moreover, the insulin response was higher for the arabinoxylan bread compared with the ϐ-glucan bread. GIP secretion was lower after the rye kernel bread compared with the other breads. Furthermore, at the initial postprandial period (0-120 min), GIP secretion was lower after the intake of the ϐ-glucan bread compared with the WWB. Ghrelin secretion was lower after the consumption of the arabinoxylan bread compared with the rye kernel bread. In contrast, GLP-1 peak values were higher after the arabinoxylan bread than after the ϐ-glucan and the rye kernel breads, although the rye kernel bread induced higher GLP-1 responses in the late postprandial period (240ï 270 min) than the other three breads (Hartvigsen et al., 2014). In a recently published study from our research group, the consumption of a cereal-based bread, containing a variety of cereal flours (wheat, oat, and spelt), 22% dried fruits (figs, apricots, raisins, and prunes) and with both fiber (7% from wheat cross-linked maltodextrins and pea) and proteins (10ï 11% from wheat gluten and hydrolyzed wheat proteins) contributed to appetite control by reducing hunger and enhancing satiety compared with a control isocaloric and isofatty breakfast. Consumption of this bread decreased postprandial glycemia and insulinemia compared with the WWB. Additionally, we reported that the postprandial variation of plasma ghrelin, GIP and GLP-1 was lower, whereas PP release was higher after the cereal-based bread compared with the WWB (Gonzalez-Anton et al., 2015).

The addition of 10.5 g wheat fiber (insoluble fiber) or 10.6 g oat fiber (soluble ϐ-glucan fiber) per bread portion did not induce differences in postprandial hunger compared with a low-fiber bread, as assessed by time and by treatment. Furthermore, postprandial responses of PYY and ghrelin were blunted after the intake of the wheat fiber bread but not after the oat-fiber enriched bread (Weickert et al., 2006). Recently, Yuan et al. (2014) determined the satiating effects of two WWBs enriched in fruit fiber (216 g: 1.6% soluble and 8.8% insoluble) or FibreMaxÊ (216 g: 3.5% soluble and 7.3% insoluble) compared with a control WWB. There were no differences in the ratings of hunger, satisfaction, fullness, prospective consumption, or EI between the experimental and control breads. They reported that the consumption of either fiber-rich breads reduced postprandial glycemia compared with the WWB.

Ellis et al. (1981) studied the effect 50, 100 and 150 g guar gum/kg bread, incorporated as a replacement for wheat flour into WWB. They reported no significant differences in postprandial appetite ratings between the tested breads and the control WWB. The highest satiety score was obtained for the 150 g guar gum/kg, although this bread appeared to be unacceptable for volunteers. No significant differences in postprandial blood glucose were observed between the control and the guar gum breads, apart from the 100 g guar/kg bread at 30 min, whereas at 60 min after the guar-containing breads, serum insulin levels were significantly lower than after the control breads at all three guar gum levels. Alternatively, Ekström et al. (2013) studied four WWB bread products containing 24% Hi-maize® whole-grain corn flour (with elevated amylose and insoluble fiber content) without or with 3%, 6% and 9% added medium-molecular-weight guar gum, compared with a WWB as a control. In this study, the replacement of 24% of refined wheat flour with whole-grain corn flour alone did not modify appetite and the glycemic responses compared with the WWB. All the tested products containing medium-molecular-weight guar gum promoted a higher feeling of fullness than the control. Furthermore, the two breads with the highest amount of guar gum induced a lower feeling of hunger compared with the WWB, whereas the desire to eat was lower after ingestion of the bread with 9% of guar gum than after the WWB. A linear increase in the feeling of fullness with increasing content of medium-molecular-weight guar gum was found, as was a linear decrease in the feeling of hunger and the desire to eat. Indeed, the addition of medium-molecular-weight guar gum to breads containing whole-grain corn flour significantly improved the course of glycemia and insulinemia compared to WWB; however, in these cases, 6% and 9% of guar gum provoked similar results. These authors hypothesized that 6% of medium-molecular-weight guar gum was sufficient to affect glycemic responses and that higher levels did not cause any further reduction.

Hall et al. (2012) evaluated the satiety effect of a wholemeal bread containing added *Ascophyllum nodosum* seaweed (4%) compared with a standard wholemeal bread (0% *A. nodosum*). In this study, the volunteers consumed a breakfast consisting of scrambled eggs on 100 g of either the *Ascophyllum nodosum* enriched bread or standard wholemeal bread. Consumption of the enriched bread led to a significant reduction (16.4%) in EI at a test meal 4 h later; however, no differences in the postprandial appetite scores or in EI were observed during the 24-h free-living period after the intake of both breads. Moreover, no significant differences were observed in postprandial glycemia.

Vuksan et al. (2010) studied the effect of adding different doses of *Salvia hispanica* L. (chia; 0 g, 7 g, 15 g and 24 g) to WWB. They used a control WWB and provided 50 g of available carbohydrates in all breads. As observed by time-course, the appetite ratings decreased at 60 min after the high dose of chia, at 90 min after high and intermediate doses and at 120 min after the intake of the three experimental breads; however, the appetite ratingsô AUC differences did not reach significance. A dose-response reduction in postprandial glycemia was observed with all three doses of chia with decreasing incremental AUCs (21%, 28% and 41%, respectively) and time-point-specific blood glucose values compared with WWB. Additionally, they reported significant correlation between incremental blood glucose and incremental appetite values.

***Breads with added organic acids***

Five of the articles selected in the present review addressed the effect of adding organic acids to breads and investigated beneficial properties such as satiety, glycemic and insulinemic responses. All of these five studies were conducted in healthy adults and the sample sizes ranged from 11 to 20. Their quality scores ranged from low to moderate (9 to 15) by the CONSORT scale.

The organic acids or their corresponding salts were added in different doses: lactic acid 0.18 mol/kg dry weight (Liljeberg et al., 1995) or 0.17 mol/kg dry weight (Liljeberg and Björck,1996); calcium lactate 0.19 mol/kg (Liljeberg et al.,1995); sodium propionate 0.213 mol/kg, 0.61 mol/kg (Liljeberg et al., 1995) or 0.56 mol/kg (Liljeberg and Björck, 1996) and propionate-rich sour made with 3% Domani starter culture containing 0.048 mol of propionate/kg (Darzi et al., 2012). Acetic acid was added as vinegar providing 18, 23 and 28 mmole of acetic acid in the respective bread portions (Ostman et al., 2005) or 23 mmole acetic acid in each test meal (Hlebowicz et al., 2008).

The appetite profile was assessed four times (Liljeberg et al., 1995; Liljeberg and Björck, 1996; Ostman et al., 2005; Hlebowicz et al., 2008) using the Haber scale (Haber et al., 1977), and only once with VAS (Darzi et al., 2012). Darzi et al. (2012) were the only authors who determined *ad libitum* EI.

Liljeberg et al. (1995) and Liljeberg and Björck (1996), evaluated the possible influence of acids formed during sourdough fermentation on the postprandial appetite sensations in healthy subjects by the addition of acid or their corresponding salts into bread. They used breads made with 80% wholemeal barley flour and 20% white wheat flour as a basic recipe, which was used as a reference. In the first study, they evaluated the influence of lactic acid formed during the sourdough fermentation (0.18 mol/kg dry weight) or breads supplemented with lactic acid (0.18 mol/kg dry weight), calcium lactate (0.19 mol/kg dry weight) or two doses of sodium propionate (0.21 and 0.61 mol/kg dry weight, respectively) on satiety. They reported no differences between the bread with lactic acid and the reference bread. Moreover, the higher satiety scores corresponded to the two breads with sodium propionate compared with the reference wholemeal bread at 45 min during the time-course. However, only the bread containing the high dose of sodium propionate induced a higher postprandial satiety AUC and obtained the worst acceptability score (Liljeberg et al., 1995). In a second study, they used the basic wholemeal barley bread to which lactic acid (0.17 mol/kg dry weight) or sodium propionate (0.56 mol/kg dry weight) were added. Similarly, in this case, they reported higher satiety scores for the bread with added sodium propionate compared with the reference bread and no differences between the bread with added lactic acid and the reference wholemeal bread (Liljeberg and Björck, 1996). Both studies reported significantly lower blood glucose and insulin increments at the initial postprandial phase (0-45 min) after consumption of the sourdough bread and the breads with lactic acid or sodium propionate compared with the reference, but not in the later postprandial




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phase (Liljeberg et al., 1995; Liljeberg and Björck, 1996). These effects were more pronounced for the propionate breads than for the lactic acid bread. No lowering of postprandial glycemia was found after the ingestion of the bread with calcium lactate.

The study performed by Darzi et al. (2012) compared the effects of including propionate-rich sour, made with 3% Domani starter culture, and WWB on appetite scores. They provided a breakfast including the experimental bread (0.048 mol of propionate/kg of bread) or the control WWB; the hedonic properties of the experimental breads were previously evaluated to verify their acceptability. This study did not report differences in postprandial appetite ratings or in EI between both types of breakfasts. Additionally, postprandial glycemia and insulin sensitivity were not affected by adding propionate.

Ostman et al. (2005) investigated a WWB served with 18, 23 or 28 g white vinegar (equivalent to 18, 23 and 28 mmole acetic acid in the respective servings) compared with a control WWB. All meals contained an identical portion of WWB providing 50 g of available carbohydrates. They reported a linear dose-response relationship between acetic acid and satiety rating, although satiety was only significantly higher after consuming the bread with the higher amount of acetic acid. Similarly, an inverse dose-response relationship between the level of acetic acid and glucose and insulin responses was also reported, whereas only the highest amount of acetic acid significantly lowered the glucose and insulin levels.

Hlebowicz et al. (2008) studied the effect of maintained botanical structure and dietary fiber present in wheat-based bread products in combination with vinegar on satiety. They prepared a whole-kernel wheat bread, a wholemeal bread made from milled wheat kernels and a WWB. The three test meals contained one of the three types of test bread dipped in 28 g white wine vinegar (equivalent to 23 mmole acetic acid in each test meal) and provided 50 g available carbohydrates from the bread. A WWB without vinegar was used as the control. These authors showed that the addition of vinegar to WWB or wholemeal bread did not influence satiety; however, the addition of vinegar to the whole-kernel wheat bread significant increased the satiety sensation compared with the other breads. Moreover, this study did not demonstrate any effect of the inclusion of wheat kernel and vinegar on postprandial blood glucose.

***Breads made using different baking technological methods***

Four of the selected articles studied the effect of modifying bread-manufacturing technological methods on the satiety response. Two of them investigated whether extrusion or cereal-milling processing modifies the food structure and thus the satiety response (Johnson et al., 2005; Isaksson et al., 2009; 2011). Another study concerned the influence of bread volume on its satiety effect (Burton and Lightowler, 2006). The studies were conducted in healthy subjects and the sample size ranged from 10 to 24. Their quality scores ranged from low to moderate (11 to 15) by the CONSORT scale.

The appetite profile was assessed with two different tools. Isaksson et al. (2009 and 2011) used a computerized VAS, Johnson et al. (2005) and Burton and Lightowler (2006) used the Holt et al. scale (Holt et al., 1995) and SI was used by Burton and Lightowler (2006). Only Johnson et al. (2005) measured EI.

Burton and Lightowler (2006) evaluated the influence of manipulation of the WWB dough proving time, resulting in lower loaf volume, on the satiety response. They tested bread volumes of 1100, 1700, 2400, and 3000 ml. They observed an increase in satiety with the decrease in loaf volume. Additionally, a significant effect of bread volume on glycemic response was observed with the reduction in bread volume leading to significant reductions in GI values.

Isaksson et al. (2009) investigated subjective appetite ratings during an 8-h period after the intake of isocaloric rye bread breakfasts that varied in rye dietary fiber composition and content. In the first part of the study, they compared the satiating capacity of three rye milling fractions used for the manufacturing of the following breads, provided as part of isocaloric breakfasts (260 kcal): rye bran bread (20% of the total grain, 13.6 g of fiber from rye per portion), an intermediate rye fraction bread (obtained from the fourth brake roll in the milling process, 5.6 g of fiber from rye per portion), and a sifted rye flour bread (80% of the total grain, 0 g of fiber from rye per portion). The breads were compared with a WWB as a control. After the milling process, they obtained larger particles of rye bran than particles present in the intermediate rye fraction and the sifted rye flour. To avoid any effects of structure/particle size, the rye bran was milled to a fine flour, similar to that of the intermediate rye fraction and sifted rye flour, and it contained the same proportionate amount of energy and was similar in protein, fat and available carbohydrates. In the morning (08:30-12:00), the rye bran bread breakfast induced the strongest effect on satiety, stronger than that of the intermediate rye fraction and the sifted rye flour bread breakfasts. Furthermore, each of the three rye bread breakfasts resulted in increased satiety, decreased hunger and a decrease in the desire to eat compared to the WWB breakfast. In the afternoon (12:30-16:00), after a standardized lunch, hunger and the desire to eat was lower after consumption of each of the three rye bread breakfasts compared with the WWB breakfast. The type of bread did not affect satiety, and no differences were observed among the rye breads in




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any of the appetite scores during the afternoon. The second part of the study was a dose-response analysis designed to investigate the satiating capacity of rye fiber, using four rye bread breakfasts with rye bran and an intermediate rye fraction, each in amounts providing 5 or 8 g of rye dietary fiber/portion compared with WWB. The results indicated that the rye breads increased postprandial satiety even at the lower fiber content, and no differences among the rye breads were found, despite differences in the rye amount and composition (Isaksson et al., 2009). In 2011, Isaksson et al. investigated the effect of kernel structure on 8-h subjective appetite. They used whole rye kernel bread and milled rye kernel bread in comparison to the WWB included in a breakfast. Both rye breads resulted in increased satiety and a reduced desire to eat compared with the control WWB. Hunger ratings did not differ significantly during the morning; however, the bread with whole rye kernels also reduced hunger in the afternoon (12:30-16:00) compared with the control. Comparisons between the two rye breads revealed no significant differences in any appetite measure in either the morning or afternoon. Alternatively, Johnson et al. (2005) assessed the appetite response of a chickpea bread and an extruded chickpea bread. Both chickpea breads did not exert any differences on the AUC for satiety compared with the WWB used as a control, nor were any differences observed by time-course. The chickpea bread led to a significantly lower blood glucose level at 90 min compared with the WWB, and this effect was observed for the extruded chickpea bread at 120 min. The glucose AUC tended to be significantly lower for the chickpea bread compared with the WWB. The insulin concentration 60 min after the intake of the chickpea bread was significantly higher than that for both the extruded chickpea bread and the WWB. Higher insulin AUC was observed for the chickpea




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bread compared with the WWB. Furthermore, the InI of the chickpea bread was significantly higher than that of the WWB.

## Discussion

The studies included in the present systematic review show that the satiating effect of wholegrain breads depends on the flour origin, the integrity of the bran and the bran amount included in the bread. The inclusion of 40% lupin flour enhanced satiety and reduced *ad libitum* EI at lunch (Lee et al., 2006 and Keogh et al., 2011), whereas lower amounts did not have any effect (Hall et al., 2005). Boiled buckwheat groats (Skrabanja et al., 2001), chickpea flour or extruded chickpea flour (Johnson et al., 2005) did not show any effect on appetite scores. The presence of seeds in a wholemeal bread induced higher fullness and a lower EI (Keogh et al., 2011), whereas wholegrain wheat bread increased satiety and fullness, and reduced hunger and prospective consumption without affecting the subsequent EI (Kristensen et al., 2010). However, the two latter studies did not describe the amount of wholegrain included in the breads. Furthermore, the inclusion of 40-50% of rye fiber increased satiety (Isaksson et al., 2009; 2011).



Wholegrain rye bread induced more satiety and satiation compared with the WWB; however, the results were more consistent when the volunteers ate lesser amounts of food (Forsberg et al., 2014). Additionally, similar results were found with breads enriched in β-glucan (Vitaglione et al., 2009; Hartvigsen et al., 2014), and arabinoxylan and rye kernel (Hartvigsen et al., 2014). In contrast, Weickert et al. (2006) did not observe any effect of added β-glucan on appetite. Medium-molecular-weight guar gum contributes to promoting a higher fullness in a dose-

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dependent manner when incorporated into a WWB containing whole-grain corn flour (Ekström et al., 2013). However, other authors did not observe the same results with the same amounts of guar gum (Ellis et al., 1981). Alternatively, the inclusion of high amounts of fiber and proteins increases satiety and satiation (Gonzalez-Anton et al., 2015) and may influence the subsequent EI (Holt et al., 2006).

Related to insoluble fiber included alone or with small amounts of soluble fiber, the addition of wheat fiber, wholegrain corn flour, fruit-derived fiber or FibreMaxÊ did not show beneficial effects on postprandial appetite scores (Weickert et al., 2006; Holt et al., 2006; Ekström et al., 2013; Yuan et al., 2014) or after a daily consumption over three weeks (Bodinham et al., 2011). Finally, only one study reported that the inclusion of bread into a hypocaloric diet may affect satiation positively (Loria-Kohen et al., 2011), which may aid in the adherence to these types of diets.

Arriving at final conclusions is limited by the diversity of breads studied and the lack of information found in the articles, primarily because they did not describe bread ingredients or their amounts correctly, omitting important details that may influence the interpretation of the results (Holt et al., 2006; Keogh et al., 2011). Additionally, Holt et al. (2011) supplied fixed 238 kcal portions of each bread, but varied the amount of macronutrients and fiber, without considering the different contributions to satiety exerted by fiber, proteins or fats. Similarly, Keogh et al. (2011) did not consider that the lupin wholegrain plus seed bread evaluated also included wholegrain rye flour and other ingredients. Alternatively, Yuan et al. (2014) decided to match the breads by serving size rather than by available carbohydrates and therefore the WWB



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enriched in fiber was less energy-dense than the control WWB. These facts may be the reason for the wide range of responses in postprandial satiety studies. Another limitation in many studies is the reliance on the manufacturersô information to calculate available carbohydrates, which are usually calculated as total carbohydrate minus dietary fiber. Moreover, few well-described RCTs that are based on the CONSORT guidelines exist; according to those guidelines, most of the studies included in this systematic review were not of high quality. Furthermore, a substantial limitation of these types of crossover studies is that hunger scores may be affected by the order of bread administration or by the size of the breakfast (Forsberg et al., 2014). Therefore, although it appears clear that the inclusion of whole grains, wheat and rye flours or seeds, or certain types and amounts of fibers positively affect satiety and satiation, well designed studies that are conducted following standardized protocols are needed to confirm these data.

Contrarily, in patients with type 2 diabetes, no differences in appetite scores were observed after the consumption of wholemeal, wholegrain wheat or pumpernickel breads (Breen et al., 2013). In that study, the servings of the test breads were weighed to provide 50 g of available carbohydrates, which resulted in differing bread volumes served with varying energy and fiber content, factors that potentially influence satiety and which were not addressed in the study. Additionally, it is important to consider that this type of patient has altered appetite control due to the altered carbohydrate metabolism. Therefore, these results should be analyzed from a different perspective.

Few studies analyzed the effect of other ingredients incorporated into breads. *Ascophyllum nodosum* did not affect postprandial appetite scores but did influence the subsequent EI (Hall et




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al., 2012), whereas *Salvia hispanica* positively affected appetite ratings (Vuksan et al., 2010). Some studies have proposed that the inclusion of organic acids may delay gastric emptying and may thus be effective in increasing satiety. However, the effect of propionate (Liljeberg and Björck, 1996; Darzi et al., 2012) or acetic acid (Ostman et al., 2005; Hlebowicz et al., 2008) depends on the amount administered, whereas lactic acid has not shown beneficial effects (Liljeberg et al., 1995; Liljeberg and Björck, 1996). The problem is that high amount of acids may affect the hedonic properties of breads that may render them unacceptable (Liljeberg and Björck, 1996). Burton and Lightowler (2006) observed a direct relationship between bread density and satiating effect, although these authors concluded that the very dense texture of bread might possibly influence the higher satiety scores. Alternatively, the rough milling fraction induced a strongest postprandial effect on satiety than breads made with finer milled flour (Isaksson et al., 2011), whereas no differences were found when comparing whole rye kernel with milled kernel (Isaksson et al., 2011) or chickpea bread with extruded chickpea bread (Johnson et al., 2005). Therefore, more RCTs are needed to confirm the positive effect of the incorporation of these types of ingredients into breads and the true effect of the influence of the milling processes on appetite sensation.



As secondary outcomes, the glycemic response data are more consistent because most of the studies support the finding that the inclusion of any type of dietary fiber, as concentrate or as whole-grains or wholemeal, may reduce glycemic response compared with WWB (Skrabanja et al., 2001; Hall et al., 2005; Johnson et al., 2005; Holt et al., 2006; Lee et al., 2006; Keogh et al., 2011; Yuan et al., 2014; Gonzalez-Anton et al., 2015) and that matching for serving size (Yuan et al., 2014) or for available carbohydrates (Gonzalez-Anton et al., 2015) did not influence the positive effect of fiber enrichment on the glycemic response. However, the effect on postprandial insulin secretion appears to be more controversial. Some authors have observed that the insulin response increased when breads were made with lupin (Hall et al., 2005) or chickpea (Johnson et al., 2005) flours. Other studies reported a positive effect with higher amounts of lupin flour (Lee et al., 2006; Keogh et al., 2011), boiled buckwheat (Skrabanja et al., 2001) and with the inclusion of seeds plus wheat, rye, triticale and oat flours (Keogh et al., 2011).



Compared with WWB, postprandial glycemia was significantly lower after the intake of breads containing medium-molecular-weight guar gum and whole-grain corn flour (Ekström et al., 2013), ϐ-glucan-rich bread (Vitaglione et al., 2009; Hartvigsen et al., 2014), rye kernels bread (Hartvigsen et al., 2014) and arabinoxylan-rich bread (Hartvigsen et al., 2014) compared with the WWB. However, the latter study was conducted in volunteers with metabolic syndrome, and therefore, the results may be influenced by the altered metabolism of these subjects. Only one study has reported similar glucose responses after the ingestion of wholegrain wheat bread or WWB consumed with cheese (Kristensen et al., 2010); however, as stated by the authors, in this study, the results may have been influenced by the type of dietary fibers present in wheat, which do not form viscous solutions upon hydration. Therefore, it appears clear that the inclusion of any type of fiber or fiber-rich wholegrain or wholemeal flour in the manufacturing of breads could exert a beneficial effect on postprandial glycemia, and thus on metabolic diseases. On the other hand, the intake of breads containing guar gum and whole-grain corn flour decreased postprandial insulin (Ekström et al., 2013), whereas ϐ-glucan demonstrated no effect (Vitaglione et al., 2009). Moreover, the effects are more controversial when analyzing volunteers diagnosed with metabolic syndrome (Hartvigsen et al., 2014) or diabetic patients (Breen et al., 2013).

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Both *A. nodosum* (Hall et al., 2012) and *Salvia hispanica* (Vuksan et al., 2010) showed a positive effect in decreasing postprandial glycemia, although these studies did not measure the insulin response. Incorporating organic acids into breads may aid in improving postprandial carbohydrate metabolism. Propionate improves glycemia and insulinemia in a dose-dependent manner (Liljeberg et al., 1995; Liljeberg and Björck, 1996; Darzi et al., 2012) and was more effective than lactic (Liljeberg et al., 1995; Liljeberg and Björck, 1996) or acetic acid (Ostman et al., 2005; Hlebowicz et al., 2008). Finally, regarding modifying technologies data are limited and only Burton and Lightowler (2006) observed that reducing bread volume led to significant reductions in GI values, whereas a chickpea bread led to lower blood glucose and higher insulin compared with the extruded chickpea bread (Johnson et al., 2005). Therefore, although the data are encouraging, studies are limited and more data are required to ascertain the beneficial effect of these ingredients or different technological methods on carbohydrate metabolism.

Regarding gastrointestinal hormones, the data are limited and the results among different studies are not in agreement (Weickert et al., 2006; Vitaglione et al., 2009; Hartvigsen et al., 2014; Gonzalez-Anton et al., 2015). Therefore, more studies on the effect of different types of bread on postprandial gastrointestinal hormones release are needed to reach definitive conclusions.

## CONCLUSION AND FURTHER DIRECTIONS

It appears that the inclusion of appropriate ingredients such as fiber, proteins, legumes, seaweeds and acids into breads and the use of specific technological methods may result in the development of healthier breads that increase satiety and satiation, which may aid in the control of weight gain and may benefit postprandial glycemia, two important factors in the prevention and treatment of metabolic diseases. However, more well-designed RCTs, with appropriate sample sizes and that include the analysis of gastrointestinal hormones, are required to identify relevant ingredients and to understand how bread may modify appetite and contribute toward maintaining a healthy status.



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**Conflict of interest**

The authors declare no conflict of interest.

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**Table 1. Summary of reviewed randomized control trials regarding the satiating effect of bread**

| **Author** | **CONSORT Score[б]** | **Type of study/ Participants** | **Intervention** | **Satiety evaluation** | **Primary outcomes/conclusions** |
|---|---|---|---|---|---|
| **Breads differing in their flour composition** | | | | | |
| Skrabanja et al., 2001 | L | n=10 healthy subjects (1 male; 9 females) Age 33.3 ± 3.2 years BMI 21.3 ± 0.5 kg/m$^2$ | Postprandial (50 g AV-CHO) -WWB + 50% boiled buckwheat groats* -WWB* | **AS:** Haber et al. scale (1977) | The addition of 50% boiled buckwheat groats to WWB did not affect satiety differently than the WWB. |
| Hal | M | Single- | Postprandial | **AS:** | The inclusion of 10% Australian sweet lupin |

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| | | | | |
|---|---|---|---|---|
| l et al., 2005 | blind, cross-over<br>n=11 healthy subjects (9 males; 2 females)<br>Age 31.6 ± 1.8 years<br>BMI 24.7 ± 2.8 kg/m$^2$ | -WWB with 10% Australian sweet lupin flour*****<br>-WWB***** | Holt et al. scale (1995)<br>**SI**<br>**EI:** food weighed and recorded | flour in WWB did not affect satiety or EI differently compared with the WWB. |
| Lee L et al., 2006 | Cross-over<br>n=16 healthy subjects (8 males; 8 females)<br>Age: 58.6 ± 7.2 years<br>BMI: 31.3 ± | Postprandial<br>**-**WWB with 40% lupin kernel flour + WWB lunch*****<br>-WWB with 40% lupin kernel flour + WWB with | **AS**: VAS<br>**EI:** food weighed and recorded | The inclusion of 40% lupin kernel flour (protein and fiber) in WWB increased satiety and lowered EI compared with the WWB. |

| | | | | | |
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| | | 4.5 kg/$m^2$ | 40% lupin kernel flour***** -WWB+ WWB lunch***** -WWB+ WWB with 40% lupin kernel flour***** | | |
| Holt et al., 2006 | L | Within subject, repeated measures n=10 healthy subjects (3 males; 7 females) Age: 23.5 ± 6.2 years BMI: 22.1 ± 1.3 kg/$m^2$ | Postprandial (238 kcal) -Coarse white bread# -Wholemeal fruit bread# -Low-fat, high-moisture bread# -Protein-fiber-rich bread# -High-fiber bread# | **AS:** Holt et al. scale (1995) **SI** **EI:** food weighed and recor | Maintaining the same amount of energy, the enrichment of WWB with different types and amounts of fiber, and independently of the amount of protein, increased satiety. The subsequent EI was not significantly modified compared with the WWB, but was negatively related to SI and fullness. |

 

| | | | | | |
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| | | | -High-protein bread#<br>-WWB# | ded | |
| Kristensen et al., 2010 | M | Cross-over<br>n=16 healthy subjects (6 males; 10 females)<br>Age: 24.1 ± 3.8 years<br>BMI: 21.7 ± 2.2 kg/m$^2$ | Postprandial (50 g AV-CHO)<br>-Wholegrain wheat bread#<br>**-**WWB# | **AS**: VAS<br>**EI:** food weighed and recorded | Wholegrain wheat bread increased satiety and fullness and reduced hunger and prospective consumption but did not modify EI compared with the WWB. |
| Bodinham et al., 2011 | L | Cross-over, 3-wk intervention<br>n=14 healthy subjects (5 males; 9 females) | Sustained/ Postprandial<br>-Whole-grain wheat bread (48 g)*****<br>**-** WWB***** | **AS:** VAS<br>**EI:** food weighed and recor | The daily consumption of whole-grain wheat bread for 3 weeks had no effect on appetite or EI compared with the WWB. |

| | | | | | |
|---|---|---|---|---|---|
| | | Age: 26 ± 1.4 years BMI: 21.8 ± 0.8 kg/$m^2$ | | ded | |
| Keogh et al., 2011 | L | Cross-over n=20 healthy subjects (10 males; 10 females) Age: 29.4 years (20.1-44.8) BMI: | Postprandial -Wholemeal and seeds (wheat, rye, soy, milk, triticale, oats and barley)* - Lupin bread (40%, with wholegrain rye flour)* -WWB* | **AS:** Holt et al. scale (1995) **EI:** food weighed and recorded | Breads made with 40% lupin and wholegrain rye flours increased fullness and decreased subsequent food intake, but not EI compared with WWB. Breads made with a mixture of cereal wholemeal and seed flours increased fullness and decreased EI compared with the WWB. |

| | | | | | |
|---|---|---|---|---|---|
| | | 21.8 kg/m$^2$ (18.4-24.8) | | | |
| Breen et al., 2013 | M | Cross-over n=10 subjects with T2DM (6 males; 4 females) Age: 53.9 ± 5.5 years BMI: 35.1 ± | Postprandial (50 g AV-CHO)<br>-Wholemeal wheat and buttermilk bread#<br>-Whole-grain wheat bread#<br>**-**Pumpernickel rye bread#<br>-WWB# | **AS:** VAS | No differences in appetite ratings were found among any of the tested breads. |

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| | | 7.5 kg/m$^2$ | | | |
| Forsberg et al., 2014 | M | Cross-over n=21 healthy subjects Age: 39 ± 14 years BMI 23 ± 3 kg/m$^2$ | Postprandial (two portion sizes: large or normal breakfasts) -Whole-grain rye crisp bread* -WWB* | **AS:** VAS **EI:** food weighed and recorded | Hunger and desire to eat were lower, whereas fullness was higher after eating the wholegrain rye crisp bread compared with the WWB. These results were more consistent in the intervention providing the lower EI, and only in that case was EI lower compared with the WWB. |
| Loria-Kohen et | L | n=104 overweight/obese female | Sustained -Diet with WWB -Diet with no WWB | **AS**: VAS | The group that consumed the hypocaloric diet with the WWB reported a greater sensation of satiety after eating. |




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| al., 2011 | | s Age: older 18 years BMI: 25-39.9 kg/m$^2$ | | | |
| **Breads differing in ingredients other than flours** | | | | | |
| Ellis et al., 1981 | M | n=11 healthy subjects (4 males; 7 females) Age: | Postprandial<br>-WWB with guar gum#:<br>• 50 g/kg<br>• 100 g/kg<br>• 150 g/kg<br>-WWB# | **AS**: Haber et al., scale (1977) | Inclusion of 150 guar gum/kg of WWB increased satiety; however, the bread was sensorily unacceptable. |

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| | | 23-54 years Ideal body weight: 94-116% | | | |
| Weickert et al., 2006 | M | Single-blind, cross-over n=14 healthy females | Postprandial<br>-Bread with 10.5 g of wheat fiber#<br>-Bread with 10.5 g of oat fiber#<br>-Low-fiber bread# | **AS**: Holt et al. scale (1995) | Addition of wheat or oat fiber did not induce differences in postprandial hunger compared with the low-fiber bread. |
| Vitaglione et al., 2009 | L | Cross-over n=14 healthy subjects (7 | Postprandial<br>-WWB with 3% ß-glucan*<br>-WWB* | **AS**: VAS<br>**EI:** food weighed and recorded | WWB made with 3% ß-glucan increased satiety and fullness, and reduced hunger and EI compared with the WWB. |




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| | | males; 7 females) Age: 23.9 ± 3 years BMI: 22.9 ± 2.8 $kg/m^2$ | | | |

**Table 1. Continued**

| | | | | | |
|---|---|---|---|---|---|
| Vuksan et al., 2010 | L | Double-blind, cross-over n=11 healthy subjects (6 males; | Postprandial (50 g AV-CHO) -WWB + 7 g of *Salvia hispanica* # -WWB + 15 g of *Salvia hispanica* # -WWB + 24 g of *Salvia hispanica* | **AS:** VAS | Inclusion of *S. hispanica* into WWB induced a dose-dependent effect on appetite ratings at later postprandial times, although the postprandial AUC comparison did not reach significance. |

| | | | | | |
|---|---|---|---|---|---|
| | | 5 females) Age: 30 ± 3.6 years BMI: 22.2 ± 1.3 kg/m$^2$ | # -WWB# | | |
| Hall et al., 2012 | M | Single-blind cross-over n=12 overweight males Age: 40.1± 12.5 | Postprandial -WMB + 4% *Ascophyllum nodosum** -WMB* | **AS:** VAS **EI:** food weighed and recorded | Consumption of WMB with *A. nodosum* did not influence postprandial appetite scores or EI during the 24-h free-living period after the intake of the bread; however, it reduced EI at a test meal 4 h later compared with the WMB. |

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|---|---|---|---|---|---|
| | | years BMI: 30.8 ± 4.4 $kg/m^2$ | | | |
| Ekström et al., 2013 | M | n=12 healthy subjects (7 males; 5 females) Age: 24 ± 1.5 years BMI: 23.3 ± 0.4 $kg/m^2$ | Postprandial<br>-Bread with 24% of whole-grain corn flour#<br>- Bread with 24% of whole-grain corn flour plus:<br>3% medium-molecular-weight guar gum#<br>6% medium-molecular-weight guar gum#<br>9% medium-molecular-weight guar gum#<br>-WWB# | **AS**: VAS | Inclusion of refined wheat flour with whole-grain corn flour alone did not modify appetite compared with the WWB.<br>Inclusion of refined wheat flour with whole-grain corn flour plus guar gum promoted a greater feeling of fullness and less hunger and desire to eat than the WWB. The effect was dose-dependent. |

| | | | | | |
|---|---|---|---|---|---|
| Hartvigsen et al., 2014 | VG | Cross-over n=15 metabolic syndrome subjects (7 males; 8 postmenopausal females) Age: 62.8 ± 4.2 years BMI: | Postprandial (50 g AV-CHO) -WWB with 24% arabinoxylan# -WWB with 13.3% ß-glucan and 1.2% arabinoxylan# -Rye kernel bread (49%)# -WWB# | **AS:** VAS **EI:** food weighed and recorded | WWB enriched in arabinoxylan, ß-glucan and arabinoxylan, and rye bread with kernels (rich in both arabinoxylan and ß-glucans) increased satiety and decreased hunger and prospective consumption compared with the WWB. WWB enriched in arabinoxylan and rye kernel bread (rich in both arabinoxylan and ß-glucans) resulted in greater fullness compared with WWB. There was no effect of the different types of bread on EI. |

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| | | 31.1 ± 3.2 kg/m$^2$ | | | |
| Yuan et al., 2014 | M | Double-blind cross-over n=83 healthy subjects Age: 21±2.8 years BMI: 22.5±2.7 kg/m2 | Postprandial -WWB with 216 g of fruit fiber# -WWB with 216 g of FibreMaxÊ # -WWB# | **AS**: VAS **EI**: food weighed and recorded | Addition of fruit fiber or FibreMaxÊ did not induce differences in postprandial hunger, satisfaction, fullness prospective consumption or EI compared with the WWB. |
| Gonzalez-Anto | VG | n=30 healthy subject | Postprandial **-**Bread made with wheat, oat, | **AS**: VAS **EI**: food weighed and recorded | Bread enriched in fiber and proteins increased satiety compared with WWB, but |

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|---|---|---|---|---|---|
| n et al., 2015 | | s (17 men; 13 women) Age: 25 ± 1 years BMI: 23.3 ± 0.5 kg/$m^2$ | and spelt flours, dried fruits and enriched with fiber (10.1%) and wheat proteins (10%)# -WWB* | | did not modify EI. |
| **Breads with added organic acids** | | | | | |
| Liljeberg et al., 1995 | L | n=11 healthy subjects (5 males; 6 | Postprandial 80% barley WMB + 20% white wheat flour -with sourdough (lactic acid 0.18 mol/kg)* | **AS**: Haber et al. scale (1977) | Inclusion of lactic acid did not modify appetite compared with the reference bread. Only the inclusion of a high dose of sodium propionate increased postprandial satiety AUC compared with the |

 

| | | | | | |
|---|---|---|---|---|---|
| | | females)<br>Age: 26-48 years<br>BMI: normal | -with lactic acid (0.18 mol/kg)*<br>-with Ca-lactate (0.19 mol/kg)*<br>-with Na-propionate (0.21 mol/kg)*<br>-with Na-propionate (0.61 mol/kg)*<br>-80% barley WMB + 20% white wheat flour * | | reference; however, that bread was sensorily unacceptable. |
| Liljeberg and Björck, 1996 | L | n=12 healthy subjects (4 males; 8 | Postprandial<br>80% barley WMB + 20% white wheat flour<br>-with lactic acid (0.17 mol/kg)*<br>-with Na- | **AS:** Haber et al. scale (1977) | Inclusion of lactic acid did not modify appetite compared with the reference bread.<br>Inclusion of sodium propionate increased postprandial satiety. |

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| | | females) Age: 24-56 years BMI: 21.7 ± 1.9 kg/$m^2$ | propionate (0.56 mol/kg)* **-**80% barley WMB + 20% white wheat flour * | | |
| Ostman et al., 2005 | L | n=12 healthy subjects (2 males; 10 females) Age: 22.9 ± 0.5 years | Postprandial (50 g AV-CHO) -WWB + 18 mmole acetic acid* -WWB + 23 mmolemmolee acetic acid* -WWB + 28 mmole acetic acid* -WWB* | **AS:** Haber et al. scale (1977) | Inclusion of acetic acid into WWB produced a linear dose-response with decreased satiety rating, although satiety was only significantly higher after consuming the bread with the higher amount of acetic acid. |

| | | | | | |
|---|---|---|---|---|---|
| | | BMI: 21.4 ± 0.7 kg/m$^2$ | | | |
| Hlebowicz et al., 2008. | M | Single-blinded, cross-over n=13 healthy subjects (9 males; 7 females) Age: 25 ± 4 years BMI: 22.8 ± | Postprandial (50 g AV-CHO)<br>-Whole-kernel wheat bread + 23 mmole acetic acid#<br>-WMB + 23 mmole acetic acid#<br>-WWB + 23 mmole acetic acid#<br>-WWB# | **AS:** Haber et al. scale (1977) | The addition of vinegar (acetic acid) to WWB or WMB did not influence satiety.<br>The addition of vinegar (acetic acid) to the whole-kernel wheat bread increased feelings of satiety compared with the other breads. |

| | | | | | |
|---|---|---|---|---|---|
| | | 3.0 kg/m$^2$ | | | |
| Darzi et al., 2012 | M | Single-blind, cross-over n=20 healthy subjects (9 males; 11 females) Age: 25.1 ± 4.6 years BMI: 23.1 ± 2.4 | Postprandial WWB propionate-rich sour* (3% Domani starter culture) -WWB* | **AS**: VAS **EI:** food weighed and recorded | The addition of propionate to WWB did not influence appetite ratings. |

 

| | | | | | |
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| | | kg/m$^2$ | | | |
| **Breads made using different baking technological methods** | | | | | |
| Johnson et al., 2005 | M | **Extruded bread** Single-blind, cross-over n=11 healthy subjects (9 males, 2 females) Age: | Postprandial -Chickpea bread* -Extruded chickpea bread* -WWB* | **AS:** Holt et al. scale (1995) **EI:** food weighed and recorded | Both chickpea breads did not exert any differences in satiety compared with the WWB. |



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| | | 32.2 ± 2 years BMI: 24.7 ± 0.8 kg/m$^2$ | | | |

**Table 1. Continued**

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| Burton and Lightowler, 2006 | L | **Different volumes** Repeated-measures n=10 healthy subjects (4 males; | Postprandial -WWB with different volumes: - 1100 ml# - 1700 ml# - 2400 ml# - 3000 ml# | **AS:** Holt et al. scale (1995) **SI** | Decreasing the loaf volume increased the satiety response. |

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|---|---|---|---|---|---|
| | | 6 females) Age: 50.4 ± 9.1 years BMI: 23.9 ± 2.0 kg/$m^2$ | | | |
| Isaksson et al., 2009 | M | **Milling fraction study** Within-subjects n=16 healthy subjects | Postprandial<br>-Rye bran bread (20% of the total grain)*****<br>-Intermediate rye fraction bread*****<br>-Sifted rye flour bread (80% of the total grain)*****<br>-WWB***** | **AS**: VAS<br>**EI:** food weighed and recorded | Each of the three rye bread breakfasts resulted in increased satiety, decreased hunger and decreased desire to eat compared to the WWB breakfast. The rye bran bread breakfast induced the strongest effect on satiety before lunch but no differences were found in the afternoon among the breads. |

| | | |
|---|---|---|
| (2 males; 14 females) Age: 35 ± 10 years BMI: 22 ± 2.8 kg/m$^2$ | | |
| **Dose-response study of the milling fraction** Within-subject | Postprandial<br>- Rye bran bread (8 g fiber)*****<br>- Rye bran bread (5 g fiber)*****<br>- Intermediate rye fraction bread (8 g fiber)*****<br>- Intermediate rye fraction bread | The inclusion of rye bran fiber or intermediate rye fraction fiber increased satiety similarly compared with the WWB and independently of the amount included. |

| | | | | | |
|---|---|---|---|---|---|
| | | n=16 healthy subjects (3 males; 13 females) Age: 38 ± 12 years BMI: 23 ± 2 kg/$m^2$ | (5 g fiber)* **-**WWB* | | |
| Isaksson et al., 2011 | M | **Milling process** Cross-over n=24 healthy | Postprandial -Whole rye kernels bread* -Milled rye kernels bread* -WWB* | **AS:** VAS | Both rye breads resulted in similar increased postprandial satiety and reduced desire to eat compared with the WWB. |

subject

s

(2

males;

22

females

)

Age:

25 ± 8

years

BMI:

22.7 ±

2.6

kg/m$^2$

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* Indicates that the bread was provided as part of a complete breakfast; # indicates that the bread was provided only with water. [ϐ]CONSORT score (Moher et al., 2010): L: low; M: moderate: G: good; VG: very good. Abbreviations: AS: appetite ratings; BMI: body mass index; EI: energy intake; SI: satiety index; T2 DM: Type 2 diabetes mellitus; VAS: visual analogue scale; WMB: wholemeal bread; WWB: white wheat bread.



 

**Figure 1**

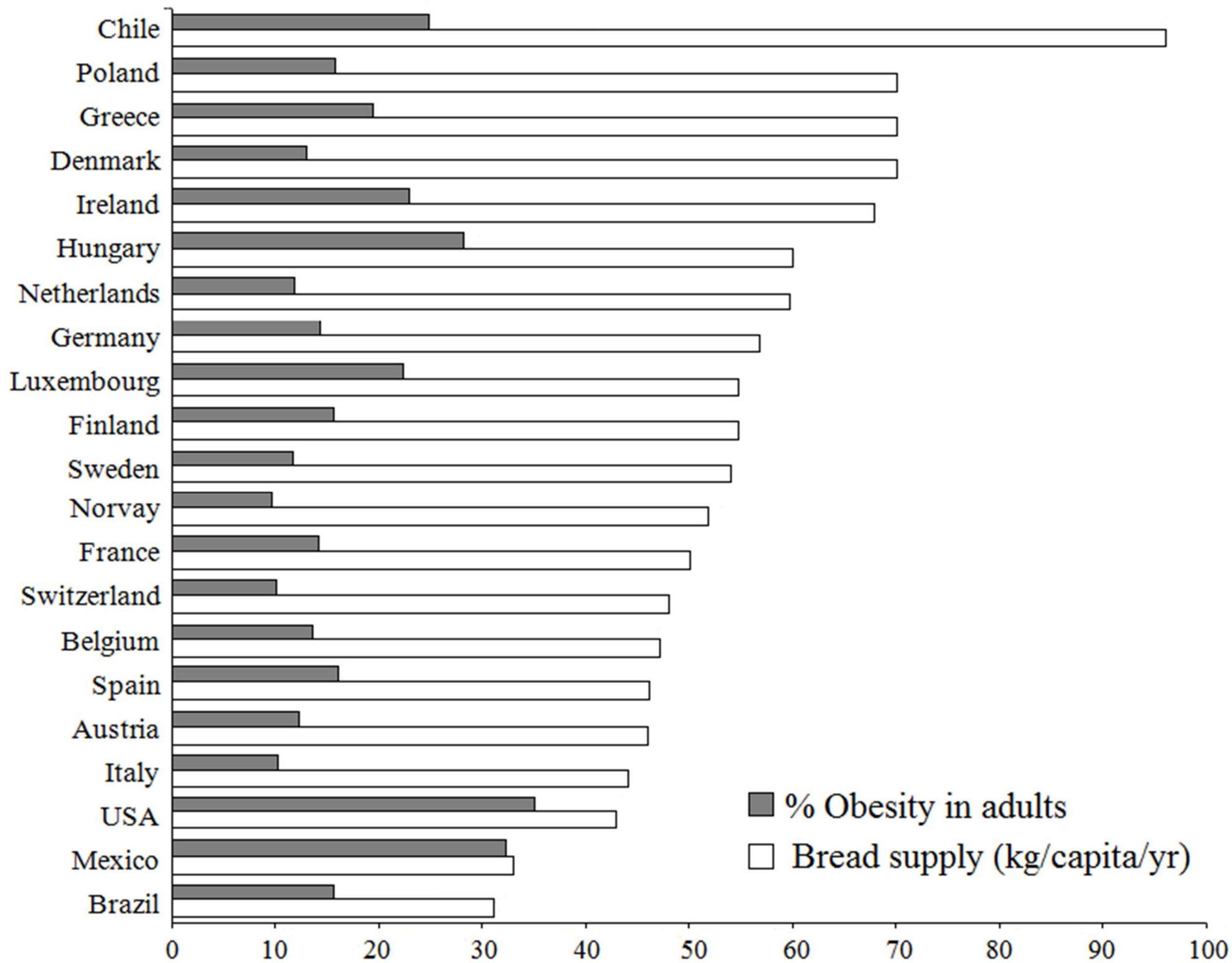


**Figure 1.** Bread supply quantity *versus* obesity prevalence in adults of selected American and European countries. The *x*-axis represents both the prevalence of obesity in percentages (OECD, 2014) and the bread supply quantity in kg/capita/yr (UIB, 2006).

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**Figure 2**

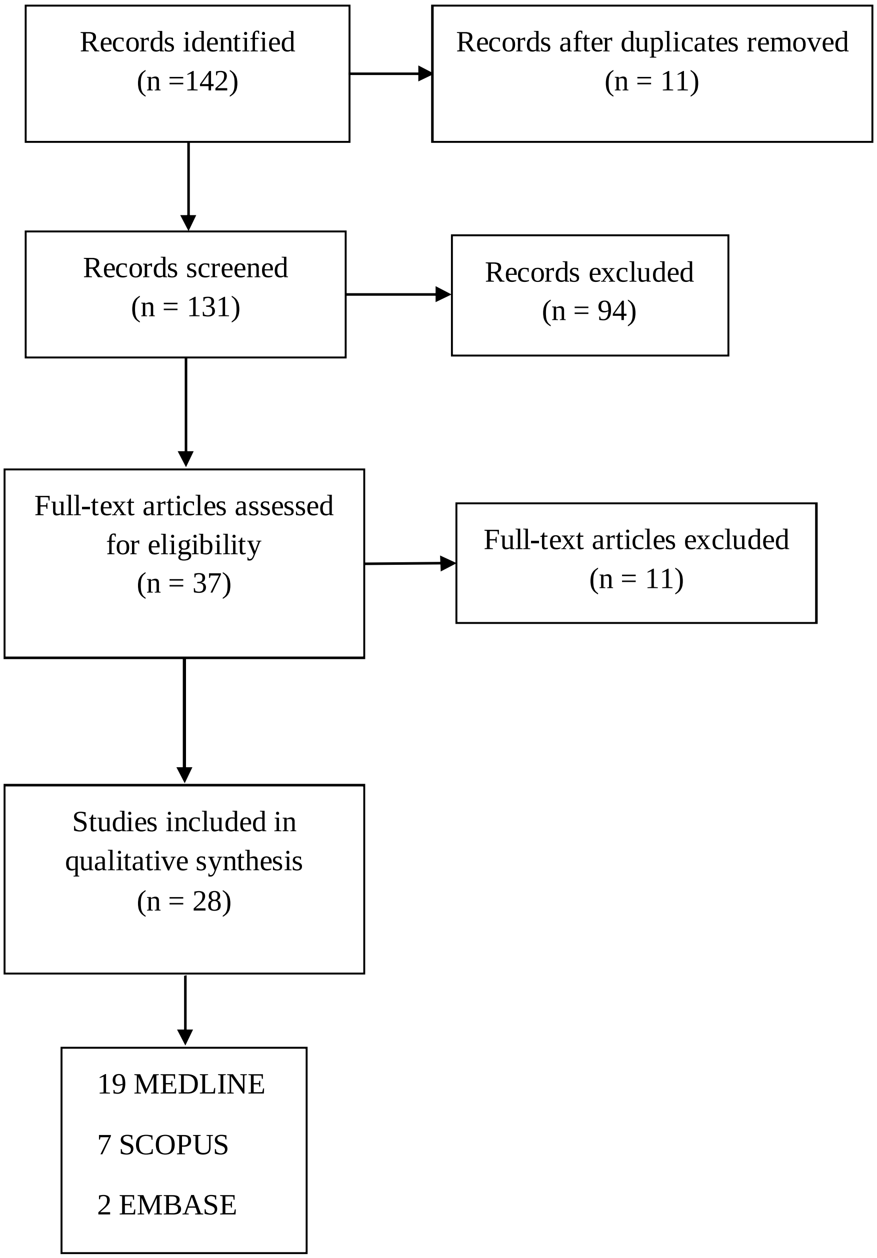


**Figure 2.** PRISMA flow diagram of the systematic review of randomized controlled trials on bread consumption and appetite (based on Liberati et al., 2009).


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