

Pulse grain consumption and obesity: effects on energy expenditure, substrate oxidation, body composition, fat deposition and satiety

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Abstract

Pulses have been identified as important components of a healthy diet. Assessment of pulse grains' nutritional composition alongside data from available preclinical and clinical trials suggests that pulses can modulate biological processes that lead to obesity. Components of pulse grains, including pulse-derived fibre and resistant starch, have been shown to alter energy expenditure, substrate trafficking and fat oxidation as well as visceral adipose deposition. Although mechanistic studies are scarce, studies have indicated that fibres found in pulses can have an impact on the expression of genes that modulate metabolism. Arginine and glutamine may produce thermogenic effects as major components of pulse grain proteins. Finally, evidence suggests that pulse-derived fibres, trypsin inhibitors and lectins may reduce food intake by inducing satiety via facilitating and prolonging cholecystokinin secretion. Nonetheless, the aforementioned data remain controversial and associations between dietary pulse grains and energy intake require further study. Given the available evidence, it can be concluded that pulses could be useful as functional foods and food ingredients that combat obesity.

Key words: Pulses: Obesity: Energy expenditure: Substrate oxidation: Satiety

Encompassing lentils, chickpeas, beans and peas, pulses are dry leguminous grains that contain one to twelve edible seeds enclosed in a pod. High in protein, fibre and antioxidants as well as low in fat, they have been established as foods that facilitate health and well-being⁽¹⁾. Research investigating the physiological benefits of pulse grain consumption has focused on the ability for pulses and their components to modulate clinical endpoints such as postprandial and fasting glycaemia, total cholesterol, LDL-cholesterol and TAG levels, as well as blood pressure^(2–6). However, given that obesity and ectopic/visceral fat deposition are risk factors in the development of metabolic abnormalities that contribute to dyslipidaemia and diabetes, it is unfortunate that the physiological impact of pulse grains on processes that may have an impact on obesity and waistline fat deposition has not received the same reception as their effects on other clinical endpoints described above.

Outside a genetic predisposition and the side effects of prescription medications, weight gain and obesity are artifacts of energy imbalance, with individuals consuming more energy than expended via the thermic effect of food, non-exercise thermogenesis and physical activity. Indeed, pharmacological interventions that target energy expenditure are gaining popu-

larity⁽⁷⁾. Nonetheless, preclinical and clinical studies have demonstrated that pulses could prove useful as functional foods that modulate biological processes that facilitate obesity, including thermogenesis, postprandial substrate trafficking/oxidation, visceral adipose deposition and satiety.

The purpose of this review is to discuss the available evidence and possible mechanisms of action by which pulse grain consumption could beneficially influence energy metabolism. Given that, compared with glycaemia and dyslipidaemia, the anti-obesity effects of pulse grains are scarce, the present review will facilitate new hypotheses to be evolved that pursue how pulses and their fractions target satiety and related facets of metabolism that lead to excess weight gain.

Effects of pulse grains on energy expenditure and substrate utilisation

Evidence is emerging to support that pulse grains modulate the gastrointestinal microbiome and facilitate the production of bacteria-derived bioactives which alter energy expenditure, substrate trafficking and substrate oxidation. Pulses are an excellent source of soluble and insoluble fibres. The fermentation of fibre by gastro-microbiota produces SCFA, specifically

Abbreviations: CCK, cholecystokinin; ER, oestrogen receptors; RS, resistant starch; Foxa2, forkhead transcription factor; Pgc-1 β , PPAR γ coactivator β .

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butyric acid, which can be absorbed from the large intestine and alter hepatic and muscle metabolism. For example, one study showed that when rat faeces were inoculated with pea-derived fibre, butyric acid was the most prominent SCFA produced⁽⁸⁾. *In vitro* fermentation of indigestible fractions of pulse grains by human microbiota demonstrated that, compared with chickpeas and a raffinose control, black beans and lentils facilitated the highest production of microbe-derived butyric acid⁽⁹⁾. Similarly, rats fed diets containing 25% adzuki, kintoki or tebou beans significantly increased caecal butyric acid concentrations compared with a control diet rich in ‘cornstarch’⁽¹⁰⁾. In addition, levels of propanoic acid and acetic acid did not differ between the bean and control diets⁽¹⁰⁾. Butyric is a metabolically active SCFA. Mice supplemented with butyric acid demonstrated an increase in hepatic and muscle PPAR γ coactivator α expression alongside enhanced hepatic and muscle energy expenditure, as well as fat oxidation, mitochondrial oxidation and biogenesis⁽¹¹⁾. In

addition, butyric acid has been shown to modulate hepatic trafficking of carbohydrates by increasing glycogen storage and decreasing glycolysis^(12,13) (Fig. 1). Modulation of carbohydrate metabolism could increase hepatic fat oxidation if energy demands of the cell are high and/or less acetyl-CoA is available from carbohydrates.

In addition to soluble and insoluble fibres, pulse grains also contain substantial levels of resistant starch (RS). RS is characterised as starch polysaccharides that avoid digestion in the small intestine and have been shown to be highly fermentable in the colon^(14,15). In a recent review, Chibbar *et al.*⁽¹⁶⁾ indicate that some beans contain 10–20% RS. *In vivo* fermentation of pulse-derived RS was shown to predominately increase the levels of butyric acid⁽¹⁷⁾. Recently, Higgins *et al.*⁽¹⁸⁾ demonstrated that diets containing RS increased endogenous fat oxidation and suggested that carbohydrate metabolism could have been modulated via the SCFA-based mechanisms described above. Given the products of pulse-derived fibre

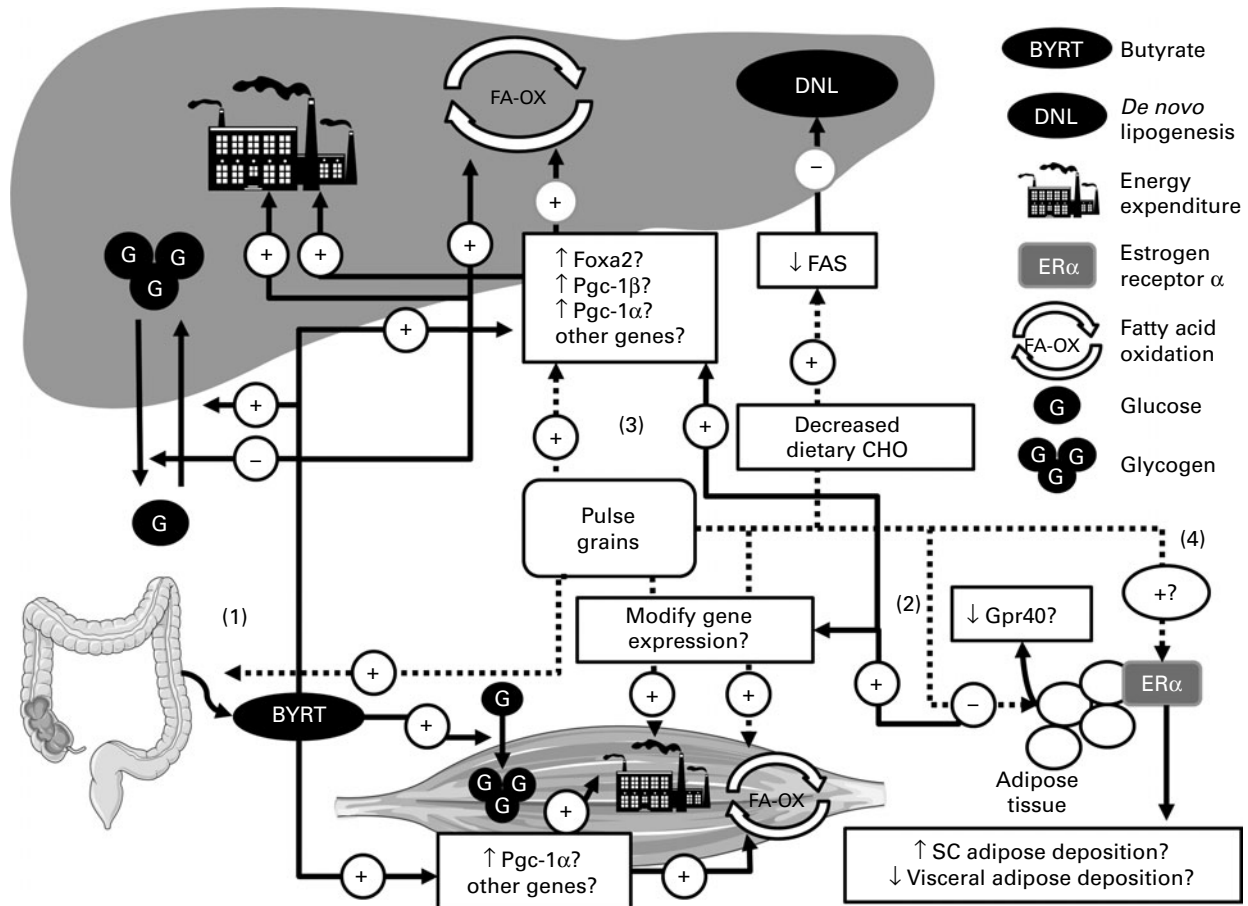


Fig. 1. Pulse grains modulate thermogenesis, substrate trafficking and oxidation, as well as adipose tissue deposition. (1) Fermentation of pulse-derived fibres and resistant starch facilitates the production of SCFA such as butyrate. Butyrate has been shown to alter energy expenditure and fatty acid oxidation by promoting glycogen storage, decreasing glycolysis and increasing the expression of PPAR γ coactivator α (Pgc-1 α). (2) Cellulose and hemicellulose, two insoluble fibres found in pulses, have been shown to mitigate excess adipose deposition and weight gain, causing an increase in hepatic forkhead transcription factor (Foxa2) and PPAR γ coactivator β (Pgc-1 β) expression. Cellulose and hemicelluloses have also been shown to reduce the expression of adipose G-protein-coupled receptor-40 (Gpr40). *De novo* lipogenesis could also be reduced via decreased expression of fatty acid synthase (FAS) secondary to low levels of refined sugars in pulse grains and blunted postprandial glucose responses. (3) Modulation of genes that facilitate increases in energy expenditure could also be secondary to the ability for pulses to induce changes in genes that facilitate energy expenditure and fat oxidation directly. (4) Pulse grains could contribute to the consumption of phyto-oestrogens that interact with oestrogen receptor α (ER α) which facilitate subcutaneous (SC) adipose deposition and reduce visceral adipose deposition. CHO, carbohydrates.

and RS fermentation, evidence suggests that pulse grains could modulate macronutrient metabolism and increase fat oxidation.

Within vegetarian populations, pulses exist as a major source of dietary protein. The high protein content of pulse grains suggests that pulses could increase energy expenditure directly because, compared with carbohydrate diets, protein produces the highest thermic effect of food secondary to the energetic costs associated with dietary peptide catabolism, protein synthesis and gluconeogenesis^(19–21). Abete *et al.*⁽²²⁾ showed that human subjects consuming legume-rich diets for 8 weeks demonstrated increased mitochondrial oxidation, contributing to greater weight loss compared with controls. In addition, enhancements in mitochondrial oxidation were similar to individuals consuming diets high in animal-based protein⁽²²⁾. Furthermore, high-legume diets induced the greatest reductions in LDL-cholesterol levels, suggesting that a protein-rich diet that modulates metabolism does not need to incorporate protein sources that are high in saturated fats and cholesterol which promote hypercholesterolaemia. Nonetheless, it should be noted that the Abete *et al.* study does not specify the proportion of legumes in the diet comprised of pulses. Unpublished indirect calorimetry data from our laboratory have demonstrated that hamsters fed diets containing 10% whole pea flour at the expense of 'cornstarch' consumed higher levels of oxygen compared with controls. However, given that diets were fairly isonitrogenous, we postulated that the amino acid composition could have facilitated an increase in energy expenditure. Published amino acid profiles of yellow peas⁽²³⁾ suggest that the whole pea diets fed to hamsters contained approximately 24% higher arginine levels compared with the control diet. Arginine has been shown to possess thermogenic properties which enhance carbohydrate and fat oxidation via increased mitochondrial biogenesis and the modulation of genes that regulate energy expenditure⁽²⁴⁾. In addition, analysis of protein meal, protein concentrate and protein isolates of peas, faba beans and lentils has demonstrated that arginine is a major amino acid constituent of pulse-derived protein at 9.7–11.1, 10.5–12.0 and 11.3–11.0 g/16 g N, respectively⁽²⁵⁾. In addition to arginine, peas, faba beans and lentils also contain substantial amounts of glutamine at approximately 15.0 g/16 g N⁽²⁵⁾, which has been shown to increase postprandial energy expenditure by 49% in human subjects⁽²⁶⁾. Iwashita *et al.*⁽²⁶⁾ demonstrated that glutamine initially enhanced postprandial carbohydrate oxidation up to 180 min after a test meal while fat oxidation was enhanced after 210 min. It has been suggested that glutamine can improve insulin-mediated glucose disposal during the early postprandial period. Thus, reduced levels of carbohydrate would be available during the latter postprandial period and force cells to rely on fat as a source of energy⁽²⁶⁾. Modern-day food processing techniques such as fractionation allow for isolation and concentration of pulse-derived proteins for future use in studies examining the direct effects of pulse grain peptides on thermogenesis.

Pulse grains and fat deposition

Excess waistline adipose deposition is primarily visceral/ectopic fat and is an independent risk factor for CVD, diabetes and the metabolic syndrome^(27,28). Thus, by shifting fat deposition away from visceral fat depots and into subcutaneous adipose tissue, risk factors related to excess weight could decline before weight loss. Although human clinical trial data are still forthcoming in examining the effects of pulse consumption on regional fat deposition, animal studies have suggested a beneficial effect. Rats consuming a high-fat diet with added chickpeas demonstrated similar energy intake compared with high fat-fed rats and increased energy consumption compared with rats on normal-fat diets⁽²⁹⁾. Nonetheless, chickpeas significantly reduced epididymal fat deposition, a measure of visceral adipose tissue, compared with high fat-fed controls. Moreover, rats receiving chickpeas demonstrated similar levels of epididymal fat mass *v.* normal fat-fed rats. A reduction in epididymal fat deposition in rats receiving chickpeas was also reflected in decreased leptin mRNA expression. In addition, compared with the high-fat diet, chickpeas decreased muscle and hepatic TAG levels by 39 and 23%, respectively⁽²⁹⁾. Chickpea-enriched diets also normalised the activities of lipoprotein lipase and hepatic TAG lipase, as well as decreased lipoprotein lipase mRNA expression and postprandial glycaemic responses to levels that were similar to animals consuming normal levels of dietary fat⁽²⁹⁾. In another study, despite identical energy intakes, rats fed diets containing mung beans demonstrated a 48% reduction in retroperitoneal adipose tissue mass, a visceral fat depot, compared with control diets⁽³⁰⁾. Moreover, mung beans were shown to induce a 40% reduction in circulating leptin levels and a 62% reduction in hepatic fatty acid synthase expression⁽³⁰⁾. Researchers⁽³⁰⁾ suggest that reduced levels of refined sugars and blunted postprandial glucose responses with mung bean diets could have blunted fatty acid synthase expression. SCFA from the fermentation of pulse-derived fibres could also modulate adipose deposition. In the study described above by Gao *et al.*⁽¹¹⁾, butyric acid-induced enhancements in energy expenditure and fat oxidation prevented obesity in high fat-fed mice. Finally, a human clinical trial using whole pea flour as a dietary intervention, alongside an energy-controlled paradigm that prevented fluctuations in weight, demonstrated a significant reduction in android:gynoid fat ratios in women, indicating that fat deposition was directed away from the waistline area⁽³¹⁾.

The bioactive components of pulse grains that induce shifts in adipose tissue deposition are unknown. As described above, insoluble fibre is the primary fibre type found in pulses⁽³²⁾. Fibre compositional analysis of pulses is scarce; however, yellow pea hulls consist primarily of cellulose (69%), hemicellulose (7.5%) and lignin (1.4%)⁽³³⁾. A recent study investigating the metabolic effects of insoluble fibres containing primarily cellulose and hemicellulose showed an increase in the expression of forkhead transcription factor (*Foxa2*) and PPAR γ coactivator β (*Pgc-1 β*), two genes that facilitate hepatic fat oxidation⁽³⁴⁾. In addition, compared with soluble fibre, mice consuming insoluble fibre demonstrated reduced adiposity despite no differences in dietary energy intake, digested



energy or faecal energy output⁽³⁴⁾. Although researchers hypothesise that modulation of *Foxa2* and *Pgc-1 β* could be secondary to reduced weight gain and insulin resistance among insoluble fibre-fed mice, they do not discard the possibility of insoluble fibre having a direct effect on gene expression⁽³⁴⁾. Finally, insoluble fibre attenuated the expression of G-protein-coupled receptor-40⁽³⁴⁾, a G-coupled protein that is associated with obesity-induced hyperinsulinaemia, impaired glucose tolerance and hepatic glucose output⁽³⁵⁾. Data suggest that pulse grain-derived insoluble fibres could either directly or indirectly, via the production of microbe-derived bioactives, modulate visceral adiposity (Fig. 1).

Pulse grain-derived phyto-oestrogens could also contribute to the modulation of adipose deposition via their interaction with oestrogen receptors (ER). Phyto-oestrogens are plant-derived compounds that mimic the actions of human oestrogen, but with less potency⁽³⁶⁾. Regional fat deposition is, in part, regulated by sex hormones and their affinity for appropriate receptors dispersed throughout visceral and subcutaneous adipose⁽³⁷⁾. In fact, stimulation of ER α and ER β decreases and increases subcutaneous adipose lipolysis, respectively⁽³⁷⁾. Thus, stimulation of specific ER with phyto-oestrogens could give rise to a healthier regional adipose profile. The most well-known phyto-oestrogens are genistein and daidzein, which are primarily soya-derived and not found in significant concentrations in pulse grains. Compared with ER α , the soya-derived phyto-oestrogen genistein has been shown to have a higher affinity for ER β ⁽³⁸⁾. In one study by Sites *et al.*⁽³⁹⁾, it has been hypothesised that the significant reduction in subcutaneous adipose tissue in postmenopausal women could have been secondary to the stimulatory effects of soya-derived phyto-oestrogens on ER β . The lignan secoisolariciresinol is a phyto-oestrogen that is found in some pulses. Metabolism of secoisolariciresinol involves its conversion to enterolactone by gastrointestinal microflora. Contrary to genistein, enterolactone preferentially binds to ER α ⁽⁴⁰⁾. Furthermore, compared with men, females express higher levels of ER α in subcutaneous adipose^(41,42) and ER α favours subcutaneous adipose deposition^(41,43). Recently, Morisset *et al.*⁽⁴⁴⁾ showed that, despite no difference in subcutaneous adiposity, postmenopausal women with the highest concentrations of circulating enterolactone have reduced visceral adiposity and waist circumferences compared with women with low levels of circulating enterolactone. Reduced visceral adipose deposition was accompanied by a decrease in hyperinsulinaemia and impaired glucose tolerance, as well as increased glucose disposal⁽⁴⁴⁾. Published analysis of secoisolariciresinol levels in legumes/pulses indicates that kidney beans and black gram sprouts contain the highest levels of secoisolariciresinol at 153 and 468 $\mu\text{g}/100\text{ g}$, respectively⁽⁴⁵⁾. Comparatively, levels of secoisolariciresinol in pulses are far below those of flax seeds (approximately 369 900 $\mu\text{g}/100\text{ g}$)⁽⁴⁵⁾. However, it is unlikely that individuals, especially in North America, will consume upwards of 100 g/d flax. Thus, specific pulse grains could contribute to secoisolariciresinol intake and promote a healthier adipose phenotype among women.

Effects of pulse grains on satiety

A reduction in overall energy intake and a reduction in overall energy balance are ultimately the most effective means of reducing adiposity. Studies have demonstrated that pulse grains modulate satiety (Fig. 2). While controlling the subject's background diet, one study has revealed that chickpea flour increased satiety with volunteers feeling fewer cravings for sweet and fatty foods⁽⁴⁶⁾. Recently, subjects consuming at least 1200 g/week canned chickpeas for 12 weeks reported a significant increase in satiety compared with when they consumed their habitual diet⁽⁴⁷⁾. However, despite an increase in dietary fibre intake, no differences in total energy intake were observed⁽⁴⁷⁾. Similar results were described by Wong *et al.*⁽⁴⁸⁾ where, although various preparations of navy beans reduced appetite, compared with controls, there was no difference in cumulative food intake 120 min following a pizza meal. The fact that appetite was reduced, but overall energy intake was not deterred with pulse grain consumption emphasises the psychological component of eating, whereby satiety signals are not always effective when unlimited food is available. Moreover, Johnson *et al.*⁽⁴⁹⁾ showed that regular and extruded chickpea flours had no effect on satiety. The authors suggest that the dose of chickpea flours could have been insufficient to mitigate volunteers' desire to eat. Assuming that sufficient quantities are consumed, available evidence is in support of pulse grains' ability to induce satiety.

Physiological signals that stimulate satiety are not completely understood⁽⁵⁰⁾. However, given the nutritional composition of pulse grains, hypotheses surrounding the mechanisms by which these dietary ingredients induce satiety can be formulated. In addition to dietary protein and fat,

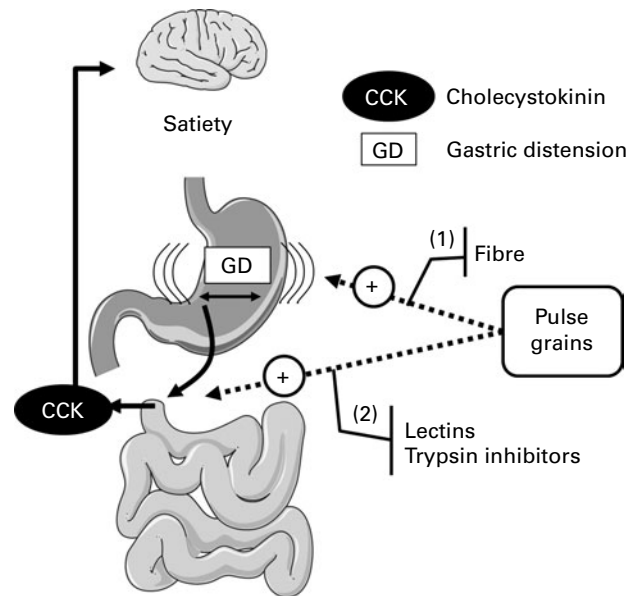


Fig. 2. Mechanisms by which pulse grains could induce secretion of cholecystokinin. (1) Pulse grain fibres increase and prolong cholecystokinin (CCK) secretion by inducing gastric distension (GD) and decreasing the rate of gastric emptying, respectively. Decreasing the rate of gastric emptying can also prolong CCK secretion. (2) Pulse grain-derived lectins and trypsin inhibitors increase CCK secretion directly.

gastric distention induces the secretion cholecystokinin (CCK), a duodenum-derived hormone that delays gastric emptying and modulates satiety by interacting with receptors on the vagus nerve^(51,52). High-fibre foods are believed to stimulate and prolong CCK secretion by facilitating gastric distention and slowing the rate of gastric emptying⁽⁵³⁾, respectively. Therefore, it is reasonable to hypothesise that appropriate dosages of pulse grain fibres can stimulate CCK release⁽⁵⁰⁾. When added to a mixed meal, high-fibre bean flakes have been shown to increase satiety⁽⁵⁴⁾ and CCK levels⁽⁵⁵⁾ compared with potato purée and rice with skimmed milk, respectively. Researchers suggest that trypsin inhibitors found in the bean flakes may also stimulate CCK release directly⁽⁵⁵⁾. Stimulation of CCK secretion by trypsin inhibitors has been demonstrated in the literature using soya^(56,57). In addition, consumption of bean-derived lectins, another class of anti-nutritional compounds found in pulses⁽⁵⁸⁾, has been shown to increase CCK secretion, compared with controls fed lactalbumin⁽⁵⁹⁾. Similar results have been demonstrated when rats were fed kidney beans or had kidney bean-derived lectins infused into their duodenum⁽⁵⁷⁾. Overall, the fibre and anti-nutritional bioactive content of pulse grains could work in concert to facilitate CCK secretion and induce satiety. Nonetheless, future studies are needed to investigate the effects of whole pulse grains or their components on satiety and the secretion of satiety-modulating hormones such as ghrelin, glucagon-like peptide 1 and peptide YY.

Conclusions

The present review discusses existing evidence concerning the use of pulse grains as functional foods that modulate weight gain and obesity. Available data suggest that pulse grains possess bioactives that modulate the physiological responses that facilitate obesity, such as energy expenditure, substrate trafficking and oxidation, lipid deposition and satiety. However, given that the satiating effects of pulse grains do not necessarily facilitate a reduction in food/energy intake, further research investigating associations between satiety, pulse grains and obesity is required. It is our hope that the present review will foster the development of new hypotheses and initiate the development of future studies that investigate pulse grains' efficacy and their mechanisms of action as to how these functional food ingredients aid in the dietary management of obesity.

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