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Revisión

The effect of oilseed consumption on appetite and on the risk of developing type 2 diabetes mellitus

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Abstract

The prevalence of diabetes mellitus (DM) has rapidly increased worldwide. Excess body fat is an important risk factor for the disease. Strategies have been indicated for the prevention and treatment of DM. Recent studies have associated the consumption of oilseeds resulting in a lower risk of developing obesity and diabetes. It is believed that this effect is associated with low glycemic index and the high fiber content, the unsaturated fatty acids and the magnesium oilseeds. However, the mechanisms involved in appetite and type 2 diabetes control have not been fully elucidated among researchers yet. Thus, the objective of the present article was to critically analyze the articles published on this subject aiming at identifying strategies which may be used in the dietary treatment of diabetes.

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Key words: *Oilseeds. Appetite. Obesity. Diabetes mellitus.*

EL EFECTO DEL CONSUMO DE SEMILLAS OLEAGINOSAS EN EL APETITO Y EN EL RIESGO DE DESARROLLAR DIABETES MELLITUS TIPO 2

Resumen

La prevalencia de diabetes mellitus (DM) ha aumentado rápidamente en todo el mundo. Exceso de grasa corporal es un factor de riesgo importante para la enfermedad. Estrategias se han indicado para la prevención y el tratamiento de la DM. Estudios recientes han asociado el consumo de semillas oleaginosas que resulta en un menor riesgo de desarrollar obesidad y diabetes. Se cree que este efecto está asociado con bajo índice glucémico y el alto contenido de fibra, los ácidos grasos insaturados de las semillas oleaginosas y de magnesio. Sin embargo, los mecanismos implicados en el apetito y el control de la diabetes tipo 2 no han sido completamente aclarada entre los investigadores todavía. Así, el objetivo del presente artículo es analizar críticamente los artículos publicados en este tema con el objetivo de identificar las estrategias que pueden utilizarse en el tratamiento dietético de la diabetes.

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Palabras clave: *Semillas oleaginosas. Apetito. Obesidad. Diabetes mellitus.*

Abbreviations

AGM: Monounsaturated fatty acids.
AGP: Polyunsaturated fatty acids.
AGS: Saturated fatty acids.
ATP: Adenosine triphosphate.
DM: Diabetes mellitus.
HOMA-IR: Homeostasis model assessment.
BMI: Body mass index.
GLP-1: Glucagon 1-like peptide.
GIP: Glucose-dependent insulinotropic polypeptide.
PYY: YY peptide.
PPAR: Receptors activated through peroxisome proliferators.

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Introduction

Diabetes *mellitus* (DM) is a metabolic disorder resulting from a defect in the secretion and/or insulin action.[1] The prevalence of the disease has increased rapidly worldwide. It is estimated that currently more than 246 million people are diabetic patients (approximately 6% of the world population) and that in 2025 there will be 300 million diabetics.[2] It is observed that diabetics have a ten times higher likelihood to develop cardiovascular, peripheral vascular, eye, and kidney diseases, among other chronic diseases, promoting the increased incidence of strokes, heart failure, blindness, limb amputation, childbirth complications and sexual dysfunction.[3]

The manifestation of type 2 diabetes is directly related to the adopted lifestyle. Studies have shown that adopting a healthy lifestyle can prevent or delay the development of the disease in individuals with insulin resistance.[4-6] The consumption of hypercaloric and hyperlipidemic diets with a high glycemic index and which are rich in saturated fatty acids but low in fibers associated with physical inactivity may promote the manifestation and lack of control of diabetes.[7]

Several studies have been conducted aimed at identifying strategies to prevent obesity, thus controlling the expression of chronic diseases like diabetes. Oilseeds have been identified as functional foods able to exert this effect. Although some authors attribute this effect to their nutritional composition, the mechanism responsible for this effect is not yet fully understood.[8]

Obese individuals tend to have higher insulin levels, which in turn leads to peripheral insulin resistance, favoring the manifestation of type 2 diabetes.[9] Hence, the control of obesity becomes important for the prevention of diabetes. The traditional treatment of obesity is based on increasing physical exercises associated with the ingestion of low-calorie diets. However, the long-term adherence to such diets is difficult as it leads to increased hunger and a reduced metabolic basal rate,[10] thus facilitating the recovery of the weight which was initially lost. On the other hand, eating foods with high satiety helps to control the caloric intake, not leading to an increased hunger feeling between the meals.[11] Despite the oilseeds being a high-calorie food, they are also rich in fiber and protein.[12] Therefore, its consumption can be an interesting strategy to be used for the control of satiety[13] being possibly effective for the prevention and control of obesity.

Study results suggest that the composition of dietary fatty acids intake can modify the composition of fatty acids present in the cell membrane phospholipids of the skeletal muscle, thus affecting the insulin sensitivity. The consumption of a diet rich in unsaturated fatty acids contained in oilseeds, such as peanuts, plays an important role in preventing insulin resistance by increasing the affinity of insulin by its receptor.[14] Moreover, the high magnesium[15,16] and fiber content[17-20] and the low glycemic index[21-23] of oilseeds have been linked to a lower risk of diabetes.

Thus, the purpose of this study was to critically assess studies that evaluated the effect of oilseed consumption on appetite and on the glycemic control.

Methodology

Papers published in national and international journals were reviewed and we consulted the databases Scielo ScienceDirect Periódicos Capes, Bireme, Highwire, using the terms: diabetes *mellitus*, obesity, appetite, intake, oilseeds, glucose control and the corresponding words in English. We selected articles published from 2002 to 2009.

Scientific evidence on the effect of oilseeds on appetite

The prevention and treatment of obesity is a public health priority, since it reduces the risk of occurrences and complications and comorbidities.[24] Although they are highly caloric, the consumption of oilseeds has not been associated with weight gain.[25] It has been proposed that the consumption of oilseeds is capable of promoting greater satiation, encouraging the reduction of the caloric intake.[13]

Although oilseeds are high-calorie foods, their consumption has been inversely related to the body mass index (BMI). Several mechanisms have been proposed to explain the relationship between the consumption of oilseeds and weight loss. The low glycemic index and the high protein and fiber of the oilseeds promote an increased satiety.[26] Its ingestion is associated with increased thermogenesis, an increased ability to oxidize fat and a lower intestinal fat absorption.[27] The results of studies in animals and humans have shown that unsaturated fatty acids increase fat oxidation due to increased thermogenesis induced by the diet, resulting in less accumulation of body fat.[26]

In another study, double-blind, randomized and crossover evaluated the effect of walnut consumption during 4 days in the control of food intake. The study included 20 men and women without an alteration of the blood glucose levels, but with metabolic syndrome.[13] Participants were admitted twice in a clinical center for four days each, when they received the isocaloric diet. In the four days of intervention and after 12 hours of fasting, shakes were consumed at breakfast, containing 48 g of walnuts or without nuts. The satiation, satiety and hunger were assessed by a visual analog scale before breakfast and lunch. Moreover, on the first and fourth days of each intervention, the levels of insulin, glucose, ghrelin, glucagon 1-like peptide (GLP-1), glucose-dependent insulinotropic polypeptide (GIP) and peptide YY (PYY) and adipokines (leptin and adiponectin) were assessed. It was found that the consumption of walnuts increased satiation and satiety, and appetite decreased significantly on the third and fourth days ($p = 0.02$ and $p = 0.03$). It is believed that the high fiber content of walnuts has contributed to this effect. However, there was no significant effect on the hormone levels related to satiety. It is possible that the short duration of this study did not allow any alterations in the hormone levels.

Coelho et al.[24] evaluated the effect of peanut oil on appetite in 24 eutrophic individuals and 24 overweight, who consumed a milk shake containing peanut oil (equivalent to 30% of energy expenditure) for 8 weeks. The overweight subjects presented higher rates of satiation during the 6th and 8th week of the study in response to the consumption of peanut oil. However, the hunger rates remained unchanged during this period. It was found that eutrophic individuals have a reduced food intake, resulting in an increased hunger rate in the 2nd and 6th weeks of the study. However, the satiation rates tended to increase in these individuals. There was a significant increase in body weight (2.4 kg) among overweight individuals due to increased fat mass. However, it is important to emphasize that a control group was not included in the study to compare the effect of oilseeds on appetite.

In recent study, evaluate the effect of peanut processing on glycemic response, and energy and nutrients intake.[28] Participated thirteen healthy subjects (4 men and 9 women), with a mean age of 28.5 ± 10 years, BMI 22.7 ± 2.5 kg/m², and body fat 23.7 ± 5.7%. After 10-12 h of fasting, one of the following types of test meals were consumed: raw peanuts with skin (RPS), roasted peanuts without skin, ground-roasted peanuts without skin (GRPWS) or control meal. The test meals had the same nutrient composition, and were consumed with 200 ml of water in 15 minutes. Glycemic response was evaluated 2 hours after each meal. Energy and nutrients intake were assessed through diet records reflecting the habitual food intake and food consumption 24 hours after the ingestion of test meal. The area under the glycemic response curve after GRPWS was lower ($p = 0.02$) the one obtained for RPS. There was no treatment effect on energy intake, macronutrients and fiber consumption after the test meal.

Alfenas and Mattes[29] compared the effect of the consumption of muffins containing monounsaturated fatty acids (MFA) (canola oil and peanut oil) or saturated fatty acids (SFA) (butter) or fat-free (control) in the appetite of nine eutrophic men and 11 eutrophic women. After 10 hours of fasting, the participants answered a questionnaire on hunger feelings, eating desire and satiation and consumed one of three muffins (each containing 40 g of each lipid source or control) and 150 mL of water within 15 minutes. The questionnaire on appetite was applied again at 30, 60 and 120 minutes after the ingestion of muffins, and the participants filled in a food record during the next 24 hours. It was observed that the ingestion of muffins containing peanut oil and canola oil resulted in higher rates of satiation and the muffins containing butter, canola and peanut resulted in lower rates of hunger at 30, 60 and 120 minutes after ingestion compared with fat-free muffins. The energy consumption after each session was greater when ingested the fat-free muffins. However, as these muffins did not present fat in their composition, they were less caloric than the muffins with fat, thus contributing to the littlest effect on satiety. The consumption of food with higher caloric density results in a lower sensation of hunger compared to the meals with low calorie density.[30]

In the study of Akuamoah-Boateng et al.[31] the effect of consuming different types of oil on appetite was evaluated. The study was conducted with 63 healthy men and 66 healthy women from three different countries (Brazil, Ghana and USA), who received one of four types of shakes, 3 of which contained oil (peanut or olive or saffron oil) and no additional oil (control) for 8 weeks. At the baseline period and at the 4th and 8th weeks of the study a 3 days food record (2 weekdays and 1 weekend) was conducted. It was observed that the average daily caloric intake increased with the addition of fat in the 3 groups compared to the baseline period. The daily caloric intake during the 4th and 8th weeks of intervention was higher than before the intervention ($p < 0.001$). After 8 weeks, we observed a significant increase in body weight in response to the consumption of the shakes that contained oil compared to the baseline period ($p < 0.05$).

Alper and Mattes[25] evaluated the effect of peanut consumption on appetite. It was a crossover study, including 7 eutrophic women and 8 eutrophic men, which consumed three types of diet: 1) Peanut without dietary counseling for 8 weeks, 2) Addition of peanut to the usual diet for 3 weeks and, 3) Peanut replacing an equal amount of fat for 8 weeks. The participants answered a questionnaire to assess the hunger rates every hour, 24 hours before and after each treatment. There was no significant difference in the hunger rates during the three diets. The mean eating desire, prospective consumption and satiation rates were not affected during the treatment. However, a control group to compare the results was not included in the study.

It is noteworthy that the studies presented above demonstrate methodological differences regarding the way of the oilseed ingestion: liquid (oil) or solid (muffins), added to a food or meal, making it difficult to carry out more detailed comparisons of the results. However, the study results suggest that the amount of oilseeds necessary to result in a reduction of appetite is a serving exceeding 40 g.

Until now there exist only few studies that evaluated the effect of oilseeds on appetite. In studies, in which this parameter was measured, the appetite was evaluated by subjective methods. The evaluation of the hormonal response after the oilseed consumption is recent among the studies. Studies evaluating the effect of oilseeds on appetite are summarized in table 1.

Table I
Studies that evaluated the effect of oilseeds on appetite

Author (year)	*Objective*	*Sample*	*Experimental design*	*Results*
Brennan et al.[13]	Evaluation of the effect of nuts on satiety.	10 men and 10 women with metabolic syndrome.	Randomized. Double-blind and crossover study. Ingestion of shakes for breakfast, containing 48 g of nuts or a placebo. Duration: 4 days for each intervention.	Increased satiety and satiation before lunch after a breakfast consumption with nuts on the 3rd and 4th day ($p = 0.02$ and $p = 0.03$). No significant change in the hormone levels related to satiety (grhelin, GLP-1, GIP, PYY, leptin and adiponectin).
Coelho et al.[24]	Evaluation of the effect of peanut oil on appetite.	24 euthropic and 24 overweight (12 men and 12 women).	Ingestion of milk shakes containing peanut oil (amount corresponding to 30% of the energy consumption at rest). Duration: 8 weeks.	Increased satiation rates during the 6th and the 8th week and unaltered hunger rates in overweight individuals. The satiation rates tended to increase in addition to a hunger rate increased in the 2nd and 6th week in eutrophic individuals.
Reis et al.[28]	Evaluation the effect of peanut processing on glycemic response and energy and nutrients intake.	4 men and m9 healthy women.	Randomized and crossover study. 3 meals raw peanuts with skin (RPS), roasted peanuts without skin, ground-roasted peanuts without skin (GRPWS) or control meal. Duration: 2 hours.	No significant differences in satiety after the consumption of the 3 analyzed meals.
Alfenas e Mattes[29]	Comparison of the effect on the appetite of two fat sources: AGM with AGS.	9 euthropic men and 11 euthropic women.	Consumption of muffins containing 40 g of butter, peanut, or canola oil or fat free. Duration: 120 min.	The muffins containing peanut oil resulted in higher satiation rates and lower hunger rates compared with the fat-free after 120 min.
Akoamoah-Boateng et al.[31]	Determination of the effect of peanut oil, olive oil and saffron oil consumption on appetite.	63 healthy men and 66 healthy women.	Randomized. Consumption of millshakes with olive, saffron and peanut oil (amount corresponding to 30% of the energy consumption at rest) or without the addition of oil. Duration: 8 weeks.	The average energy intake increased with the milkshake with added fat compared to the fat-free milkshake.
Alper e Mattes[25]	Evaluation of the effect of peanut consumption on appetite, energy intake, body weight, energy consumption and diet-induced thermogenesis.	7 euthropic women and 8 euthropic men.	Crossover. 3 intervention types: 1) Peanut consumption without dietary counseling for 8 weeks; 2) Addition of peanuts to the usual diet for 3 weeks, and 3) Peanut consumption replacing the equal amount of dietary fat. 89 = 21 g of peanuts.	No significant difference in the hunger rates during the three diets. The mean eating desire, the prospective consumption and the satiation rates did not show a significant difference during the treatments.

Possible mechanisms responsible for controlling appetite in response to the consumption of oilseeds

Oilseeds in general are rich in protein[32] and fiber,[33] favoring the food intake control[25]. Protein increases satiety by promoting the concentration of amino acids in the bloodstream after meals, stimulating the release of anorexigenic hormones and insulin.[34] Dietary fiber helps to control body weight by increasing satiation (reducing the caloric intake in the meal) and satiety (increase of the interval between meals) or by influencing the energy metabolism (increased fat oxidation, thus reducing the body fat level). Soluble fiber may reduce the rate of carbohydrate absorption, postprandial blood glucose and consequently the insulin secretion, preventing the occurrence of hypoglycemia during the post-absorptive period, promoting greater satiety and fat oxidation.[35]

The results of some studies show the occurrence of increased levels of cholecystokinin after the ingestion of meals rich in fiber for low-fiber meals. Cholecystokinin is secreted by cells in the small intestine and acts on the satiety center, inhibiting food intake.[35] The fibers also act by stimulating the secretion of GLP-1, which has an effect on the vagal afferent nerve, inhibiting appetite in order to reduce the rate of gastric emptying, signaling the brain to reduce food intake.[36]

The largest component of the peanut is the lipid fraction (49%) with predominantly unsaturated fat (40%). The oilseeds are excellent sources of AGM and AGP.[8] The results from studies in animals and humans have suggested that these unsaturated fatty acids are more easily oxidized than SFA, resulting in increased satiety.[37] The results of studies in rats suggest that the fat that is oxidized leads to satiety, while the stored fat is not. The MFA, such as oleic acid, are absorbed and oxidized more quickly than the SFA as stearic acid. The results of studies in rats have shown that the MFA have the greatest effect on satiety compared to SFA.[24]

The impact of oilseeds on the glycemic control

The occurrence of postprandial hyperglycemia has been considered a risk factor for cardiovascular diseases[38] and DM complications.[39] In epidemiological studies, 2-hour postprandial glucose has been recognized as an independent risk factor for cardiovascular problems.[38] Various components of oilseeds have been associated with a reduced risk of the development of diabetes and its complications.[40]

Epidemiological studies, such as the Nurses' Health Study,[41] the Shanghai Women's Health Study[42] and the Physicians' Health Study I,[43] sought to clarify the relationship of oilseeds with DM. The Nurses' Health Study performed a follow-up of 83 818 women from 11 states for 16 years (1980-1996). The women aged 34-59 years had no history of diabetes, cardiovascular disease or cancer. A semi-quantitative food frequency questionnaire was applied in 1980, 1984, 1986, 1990 and 1994 to evaluate the consumption of oilseeds and peanut butter.

Women who consumed such foods ≥ 5 times/week presented a 30% reduction and those who consumed these foods 1-4 times/week a 20% reduction in risk for developing type 2 diabetes compared to those who almost never consumed these foods. The inverse association persisted even after adjusting for risk factors for the development of diabetes such as age, obesity, physical activity, smoking, family history of diabetes and other dietary factors.[41] A cohort study[42] conducted in China with a duration of 4.6 years involving nearly 64,000 women, showed a similar result as the one of Jiang et al.[41]. A significant 20% reduction of the risk of developing diabetes after the adjustment of the dietary and non-dietary variables was observed. However, in the recent Physicians' Health Study I, there was no association between the consumption of oilseeds and the risk of developing type 2 diabetes in eutrophic, overweight or obese women. The study included 20,224 women who were assessed during 19.2 years.[43]

However, in the studies cited above, food intake was assessed after analysis of data obtained from the food frequency questionnaire, through which the oilseed ingestion was detected. The participants in these studies were questioned about their consumption of oilseeds during the previous year, thus requiring a good memory for the provision of accurate information. According to some authors, the food frequency questionnaires do not always present the intake faithfully.[44]

However, the results of Brennan et al.[13] did not confirm the beneficial effect of walnuts on blood glucose and insulin. It was a randomized, crossover and double-blind study, involving a total of 20 men and women without an alteration of the blood glucose levels, but with metabolic syndrome. The participants were admitted twice in a clinical center for four days each time, while receiving an isocaloric diet. The blood glucose and the insulin were assessed after 12 hours of fasting, on the first and fourth day of intervention in response to the consumption of shakes for breakfast containing 48 g of walnuts or a placebo.

In another study[45] lasting 14 days, 20 women with type 2 diabetes aged 40-60 consumed 10g of almonds per day at breakfast. The fasting blood glucose and the 2 postprandial hours were assessed on day 0, 7 and 14 before and after the beginning of intervention. At the end of the study, it was found that the consumption of almonds reduced ($p < 0.01$) the fasting and the postprandial blood glucose. The results of this study suggest that the consumption of oilseeds needs to be done for at least 14 days to be able to detect significant changes in the blood glucose level.

In a prospective study of 24 weeks, the effect of consuming low-calorie diets enriched with 84 g of almonds per day (diet 1, n = 32) or rich in complex carbohydrates + 2 tablespoons saffron oil (diet 2, n = 33) was assessed in the blood glucose level, the insulin level and in the HOMA-IR index (Homeostasis Model Assessment). There were observed 37 overweight women and 28 overweight men with a median age of 55 years and a BMI range between 27 and 55 kg/m^2, which were stratified according to their gender and the presence or absence of diabetes. Diet 1 consisted of 39% fat (25% MFA, 3% SFA and 11% PFA) and 32% carbohydrates. Diet 2 contained 18% fat (5% MFA, 3% SFA and 10% PFA) and 53% carbohydrates. In addition to promoting a significant reduction of the HOMA-IR, the ingestion of diet 1 promoted a 54% reduction in fasting insulin, compared to a reduction of 32% of diet 2. It is also important to emphasize that the use of medications for the glycemic control was lower among type 1 diabetics after the intake of a diet 1 compared to the other diet (96 and 50%, respectively).[46]

However, it should be noted that diet 2 contained a higher amount of available carbohydrate in relation to diet 1. The available carbohydrate quantity and the quality (glycemic index) of the consumed carbohydrate may alter the glucose and insulin responses. The intake of foods rich in carbohydrates increases the plasma concentrations of insulin and postprandial glucose[47]. Therefore, the results of this study may not reflect the effect caused only by the intake of almonds.

In randomized and crossover study, participated 15 hyperlipidemic men and 12 hyperlipidemic women whit a mean BMI of 25.7 ± 3 kg/m^2 and age 64 ± 9 years.[8] The study consisted of three steps, in which the following foods were consumed: muffins (control-147 ± 6 g/day) or 73 ± 3 g of almonds per day or ½ serving of almonds (37 ± 2 g/day) + ½ serving of muffins (75 ± 3 g/day). Each phase lasted four weeks, being separated in 2 weeks each. Blood samples were collected after fasting of 12-14 hours during week 0, 2 and 4. There were no statistical differences in blood glucose, insulin and insulin resistance between the treatments. The lowest daily almond intake for a shorter period of time than that observed in the study of Wien et al.[46] may inhibited the observation of significant effects on the glucose metabolism in this study.[8]

In another study, which was conducted to evaluate the effect of almonds on the insulin sensitivity, 10 healthy men and 10 healthy women aged 20-50 with a BMI between 18-30 kg/m^2 consumed 100 g of almonds (the almonds in a whole or ground and mixed in cake or cookie dough) for 4 weeks. It was found that the addition of almond consumption does not cause a significant change in the blood glucose level and the insulin sensitivity. However, there was a significant increase in body weight after 4 weeks.[48] In the study of Yücesan et al.,[49] there also was not found a significant difference in the glucose levels after 4 weeks of diet enriched with chestnuts (1 g/kg of body weight/day) in 21 healthy subjects.

The results of the studies of Wien et al.[46], Choudhary et al.[45] (table II), Tapsell et al.[50] and Brehm et al.[51] suggest that the oilseed consumption has a beneficial effect on the glycemic control in people who present a degree of hyperglycemia. It is possible that the inclusion of oilseeds in the dietary treatment prescribed for diabetic patients is beneficial. However, the results of the epidemiological studies are not conclusive about the effect of oilseeds in the prevention of type 2 diabetes. Despite conducting these studies in order to indicate the possible existence of an association between the two variables, they do not prove causality. The studies which evaluated the effect of oilseeds on the blood glucose levels are summarized in table II.

Possible mechanisms responsible for the glycemic control in response to the consumption of oilseeds

The high content of monounsaturated and polyunsaturated fatty acids from oilseeds (table III) seems to favor the reduction of insulin resistance and consequently the risk of developing type 2 diabetes. However, the mechanisms by which these fatty acids affect the insulin sensitivity are not yet fully understood.[52]

It is believed, however, that fatty acids which are present in the phospholipids of the cell membrane's muscle are affected by the fatty acid intake type, thus affecting the insulin sensitivity. The unsaturated fatty acids existent in the cell membrane influence the action of insulin, through affecting the binding/affinity of insulin to its receptor.[26] There is the hypothesis that a higher unsaturation of fatty acids in the cell membrane facilitates the movement of the glucose receptor to the cell surface, thus increasing the insulin sensitivity.[53]

In addition, monounsaturated fatty acids act through the stimulation of glucagon 1-like peptide (GLP-1) secretion, thus improving the efficiency of beta cells. This peptide acts in the clearance regulation of postprandial glucose and insulin sensitivity.[54] Recent studies suggest another mechanism that involves the participation of fatty acids by determining the gene expression and the enzyme activity. The SFA and the MFA act in the lipogenic gene expression, while the PFA inhibit the expression of these genes, in part through the binding and activation of nuclear receptors, such as the receptors activated by peroxisome proliferators (PPAR).[55] It is suggested that the activation of PPAR exerts a therapeutic role for the treatment of type 2 diabetes, because it induces the fatty acid clearance by the adipose tissue, decreasing its plasma levels and thus increasing the insulin sensitivity in the muscle.[56]

The high magnesium content of the oilseed fibers has been related to the same beneficial effect on the

Table II
Studies that evaluated the effect of oilseeds on the glucose level

Author (year)	*Objective*	*Sample*	*Experimental design*	*Results*
Jiang et al.[41]	Examination of the relation between oilseed consumption and the risk of type 2 diabetes.	83,818 women.	Prospective color study. Duration: 6 years. Use of a semi quantitative Food Frequency Questionnaire.	30% reduction of the DM2 risk with a consumption of ≥ 5 week. 20% reduction of the DM2 risk with a consumption of 1-4x week.
Brennan et al.[13]	Investigation of the effect of nuts on the insulin resistance.	20 men and women with a metabolic syndrome.	Use of isocaloric diet with shakes for breakfast containing 48 g of nuts or a placebo. Duration: 4 days.	No significant difference in the insulin and glucose levels.
Choudhary et al.[45]	Evaluation of the glycemic response of fasting and of the 2-hour postprandial glucose after the consumption of almonds.	20 women with type 2 diabetes.	Free consumption. Additon of 10 g of almonds day for the first meal. Duration: 1-4 days.	The almond consumption reduced (p: 0.01) the fasting and postprandial glucose.
Wien et al.[46]	Evaluation of the effect of a low-calorie diet rich in AGM or in carbohydrate complexes in the metabolic parameters.	37 overweight or obese women and 28 overweight or obese men.	Diet 1 - 84 g of almonds per day (n = 32). Diet 2 - consumption of carbohydrate complexes + 2 tablespoous of saffron oil per day (n = 33). Duration: 24 weeks.	Fasting insulin - Diet 1 - 54% reduction. Diet 2 - 32% reduction. HOMA Index - Diet 1 - 66% reduction. Diet 2 - 35% reduction. The type 1 diabetes subjects decreased the use of medication after diet 1.
Loveloy et al.[48]	Evaluation of the effect of almonds on the insulin sensitivity.	10 healthy men and 10 healthy women.	100 g of almonds per day. Duration: 4 weeks.	No significant difference in the insulin and the glucose sensititivy after the consumption of almonds.
Jenkins et al.[8]	Evaluation of the effect of almonds on glucose, insulinemy and the HOMA index.	15 hyperlipidemic men and 12 hyperlipidemic women.	Randomized study, crossover, 3 stages: - muffins control - 147 ± 6 g/day). - 73 g ± 3 g of almonds per day. - 1/2 serving of almonds (37 ± 2 g/day) + 1/2 serving of muffins (75 ± 3 g/day). 4 weeks per stage, separated for 2 weeks.	No statistical difference in glucose, insulinemy or insulin resistance between the treatments.

Table III
Fatty acid composition of oilseeds

Oilseeds	*SFA (g/100 g)*	*MFA (g/100 g)*	*PFA (g/100 g)*
Almonds	3.73	30.89	12.07
Cashew nuts	7.78	23.80	7.84
Hazelnuts	4.46	45.65	7.92
Peanuts	6.83	24.43	15.56
Oilseeds in general	0.42	0.78	0.89
Walnuts	6.13	8.93	47.17
Brazil nuts	15.14	24.55	20.58
Macadamia nuts	12.06	58.88	1.50
Pecan nuts	6.18	40.80	21.61
Pine	9.38	22.94	25.67
Pistachio	5.44	23.32	13.45

Source: Adapted from López-Uriarte et al., 2009. SFA: Saturated fatty acids; MFA: Monounsaturated fatty acids; PFA: Polyunsaturated fatty acids.

glycemic control The hypomagnesemia has been implicated as a cause of insulin resistance.[40] In periods of acute hyperglycemia, the kidneys lose the ability to retain magnesium, which is then eliminated in the urine, resulting in the mineral's low blood levels. It has been shown that the correction of that depletion improves the response and the insulin action. The magnesium deficit interferes with the reactions that use or produce adenosine triphosphate (ATP), thus altering the enzyme cascade involved in the carbohydrate metabolism, favoring the development of DM.[58]

Oilseeds in general are good fiber sources (4-12 g/100 g): cellulose, followed by hemicellulose, pectin and lignin.[33] Diets rich in complex carbohydrates and fiber are associated with the increased insulin sensitivity and the reduced plasma insulin level, promoting better glycemic control in diabetic patients.[59] Soluble fiber may increase the intraluminal viscosity, slowing down the gastric emptying. These fibers also act as a physical barrier against the enzyme action of carbohydrate digestion in the small intestine. As a consequence, the carbohydrate absorption velocity and the concentration of postprandial glucose tend to be lower after the ingestion of fiber-rich foods compared to foods or meals poor in fibers.[35] Animal experiments have shown that several types of dietary fiber improve the glucose homeostasis by means incretins.[60] The incretins, the GLP-1 and the GIP stimulate the insulin secretion by beta cells and promote the proliferation of these cells, favoring the maintenance of normal blood glucose levels.[61]

The fibers are resistant to enzymatic digestion in the small intestine and thus susceptible to fermentation by bacteria in the colon. The products of this fermentation are short chain fatty acids: acetate, propionate and butyrate, which act in order to reduce the hepatic glucose production and to stimulate the secretion of GLP-1.[35]

It is noteworthy that oilseeds are relatively low in carbohydrates, representing approximately 15% of the total energy.[62] Oilseeds have low glycemic index and therefore cause less elevation of the blood glucose level, requiring less insulin secretion, thus favoring the control of DM.[63]

Conclusions

The mechanisms responsible for the effect of oilseeds in reducing appetite and in the glycemic control are not entirely clear. However, some mechanisms are proposed. It is possible that these foods have an effect on satiety as they are rich in protein, fiber and unsaturated fatty acids. The study results suggest that a daily serving of more than 40g of oilseeds could have the effect of reducing appetite. However, in these studies, the evaluation of the appetite was subjective. Therefore, further studies are needed to assess this parameter more objectively, evaluating, for instance, the hormonal response after chronic consumption of oilseeds.

There is evidence that the components of oilseeds, such as fiber, magnesium, unsaturated fatty acids, and carbohydrates conducive to reducing the risk of developing type 2 diabetes. Epidemiological studies indicate the possible existence of an association between the consumption of oilseeds and the risk of developing diabetes, but they are not yet conclusive.

The consumption of oilseeds for a longer period of time was only able to have an important effect on the blood glucose level when ingested by individuals with hyperglycemia. This effect appears to be enhanced when the consumption was associated with the ingestion of a low-calorie diet. These results show the benefits of oilseeds as an adjunct in the treatment of type 2 diabetes. However, long-term studies are needed to evaluate their effects on pre-diabetic individuals with insulin resistance, preventing the manifestation of type 2 diabetes.

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