Satiety value of groats in healthy women as affected by selected physicochemical parameters

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ABSTRACT

The aim of the study was to investigate the satiety levels following the consumption of groats and to analyze the relationships between selected nutrients found in the groats. A total of 54 women were enrolled in a crossover, single-blind study. The participants tested five types of groats (a 240-kcal portion for 180 min). The highest satiety was determined for oat groats and barley groats. The correlation analysis indicated that the satiety of the examined groats was correlated to the highest extent with the content of dietary fiber and hydration degree. Studies showed that the key role in the regulation of satiety could be played by the presence of soluble dietary fiber (SDF). The results of the study indicated that all studied types of groats are a good source of high satiety food. Due to their high satiety value, groats should be used in the prevention and dietary treatment of people with excess body weight.

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Introduction

Energy balance is regulated by the frequency of meal intake, portion size, method of culinary preparation, and nutritional value, with the simultaneous energy expenditure. A positive energy balance leads to the development of obesity. In the context of overweight prevention and the treatment of obesity, various elimination diets, as well as diets reducing the calorific value of meals (in particular the percentage of simple sugars), are applied. The frequently applied restrictive diets are, in the longer term, ineffective. One of the ways to limit the development of obesity epidemics is to promote meals that provide the proper amount of essential nutrients, with servings of a size sufficient to rapidly induce the feeling of satiety and satiate for a long time, thus extending the period until the next meal and limiting snacking between meals.

Satiety is defined as a feeling of fullness after a meal, which suppresses the sensation of hunger. It is the opposite of appetite and hunger, in both physiological and psychological aspects. Among the many food products with the greatest satiating potential, groats produced from various cereal species should be mentioned. Groats are either whole or crushed cereal grains from which non-digestible components have been eliminated. The technological process of groats production involves pre-treatment and proper processing. After cleaning and sorting by the size of raw material, it is hulled, sorted, rolled, broken up, and polished in order to give an attractive appearance to the groats and to increase their range in the market. At the same time, these operations bring about changes, sometimes significant, to the nutritional value and functional properties of groats in relation to the human body. The consumption of groats is typical of the cuisine of Central and Eastern European countries. Groats prepared from barley, buckwheat, millet, oats, and wheat are...
most commonly used. [11] The nutritional value of groats is very high. They are a rich source of starch, protein, dietary fiber, as well as vitamin B, phosphorus, iron, zinc, and other essential ingredients. They also contain flavonoids which exhibit antioxidant properties. [11–15] Due to the wide range and the possibility for the application of numerous preparation techniques, groats are widely used. For a long time, groats were forgotten, yet recently their percentage in the diet has been steadily increasing, mainly due to their nutritional value. Groats are characterized by a significant percentage of dietary fiber. Water-soluble dietary fiber found in groats exhibits all functional properties of viscous and gel-forming food hydrocolloids. Thanks to these properties, it can increase the filling of the stomach, delay gastric emptying, and reduce the level of intestinal hormones involved in inducing the feeling of appetite and satiety. [15–20]

A significant content of raw fiber reduces the glycemic index of food, which prolongs the duration of feeling satiety and reduces hunger after consumption. Moreover, there are studies which have demonstrated that food with a low glycemic index is characterized by higher energy values, referred to as diet-induced thermogenesis, which is necessary for the absorption and metabolism of food. It is usually reported that it accounts for 10% of the total energy expenditure associated with digestion. [20–23] The main aim of the study was to investigate the hunger and satiety levels after the consumption of the five most popular types of groats and to analyze the relationships between selected nutrients found in the groats and their satiating properties.

**Materials and methods**

**Participants**

The study included 64 women living in northern Poland. The criteria for inclusion in the study were as follows: BMI 18.5–25 kg/m², age of 20–28 years, and female gender. The participants qualified to the study were healthy, in good nutritional condition, without using any medicines, diet supplements, or special diets. All participants voluntarily signed their consent for participation in the study. The study was approved by the Institutional Ethics Committee at the Medical University of Gdańsk (no NKBBN/356/2013). The women participating in the study completed a questionnaire with questions concerning their age, body weight, height, pregnancy status, cigarette smoking, and physical activity. After an additional analysis, four women who smoked more than 10 cigarettes a day and five persons who were not able to complete the study were rejected. In total, 54 women aged between 20 and 28 were enrolled in the study (23.3; SD = 3.5)

**Study products**

In the study, five types of groats produced by the Cenos company were used. The quality of the groats was in accordance with the following standards: pearl barley millet groats, buckwheat groats, grits, and oat groats: industry standard. All groats intended for analyses were cooked according to the instructions on the package and were subjected to testing at a temperature of 65°C.

**Study design**

This was a crossover, single blind study. Each participant tested five breakfasts on five separate days. The order of the test breakfasts was randomized. The study was carried out in the morning, between 8 a.m. and 9 a.m., and the participants were on an empty stomach at the beginning of the study. Each study participant assessed the level of hunger and satiety they felt prior to consuming the product and after consuming it at 1-h intervals for the subsequent 180 min, in intervals of every two days for 10 days. [24]
**Satiety ratings**

An unstructured 100 mm visual analog scale visual analogue scale (VAS) with 0 mm as a “very hungry” end point and 100 mm as a “very satiated” end point was used. Participants consumed the entire sample and the duration of intake was as short as possible and did not exceed 5 min. A serving had a caloric value of 240 kcal. Participants specified the levels on the VAS scale for 180 min in the morning. The first measurement was carried out on an empty stomach and the next measurement after consuming 240 kcal of selected groats. The next measurement was carried out after 60 min, another after 120 min, and the final one after 180 min. Each participant tested each type of groats at 2-day intervals.

**Physicochemical research**

The basic nutrients, protein content P-142 ed. I of 14.05.2012, fat content, and carbohydrate content PN-A-82100:1985 were determined in the analyzed groats. Then, additional parameters likely to affect the feeling of satiety and hunger, i.e. starch content, soluble dietary fiber (SDF) and insoluble dietary fiber (IDF) contents, and water content, were determined. Starch content was assayed using the method PB-265 ed. I of 30.06.2014. The analysis involved hydrolysis of starch with DMSO and HCl solution. The amount of generated NADH was assayed spectrophotometrically. A Starch-Boehringer 10 207 748 035 enzymatic test was applied. The contents of SDF and IDF were assayed using the gravimetric-enzymatic AOAC 991.43:1994 method. The water content of the groats was assayed using the oven-drying method in accordance with standard AOAC 925.10.

**Statistical analysis**

The obtained results were verified statistically with a single factor ANOVA analysis of variance, using STATISTICA 12.0 software. The parameters of multiple regression taking into account the concept of shared variance were estimated using the REGLINP command in the Excel 2010 PL spreadsheet.

In order to determine the levels of satiety and hunger, the area under the curve (AUC) was computed using the trapezoid method. The measurement was carried out every hour for 180 min. The correlation of the tested parameters was then calculated to determine the general trend and the relationships between the tested parameters. The significance level of \( p < 0.05 \) was adopted.

**Results**

Table 1 presents the contents of basic nutrients found in selected cooked groats. A high water content of cooked grits (84.7%) and millet groats (73.9%) determined the significance (compared to other tested types of groats) of the weight of the serving with the caloric value specified in this study (Table 2). The intake of such a large serving during a short period of time was probably responsible for the induction of one of the mechanisms determining the rapid postprandial increase in the level of satiety being experienced, which was associated with the effect of stomach distension. At the same time, the high

### Table 1. Characteristics of the composition of groats after cooking, in 100 g.

| Type of groats    | Protein (%) | Fat (%) | Carbohydrates (%) | Starch (g) | Water content (%) | Total dietary fiber (TDF) (g) | IDF (g) | SDF (g) | Energy kcal |
|-------------------|-------------|---------|-------------------|------------|------------------|-------------------------------|---------|---------|-------------|
| Millet groats     | 2.31        | 0.7     | 22.5              | 17.0       | 73.9             | 0.1                           | 0.05    | 0.05    | 105         |
| Buckwheat groats  | 3.82        | 1.2     | 22.7              | 19.0       | 71.3             | 1.9                           | 1.8     | 0.1     | 112         |
| Pearl barley     | 4.03        | 0.7     | 27.8              | 19.7       | 66.2             | 2.5                           | 1.9     | 0.6     | 128         |
| Oat groats       | 4.40        | 3.2     | 27.3              | 22.3       | 63.4             | 3.4                           | 2.7     | 0.7     | 125         |
| Grits            | 0.78        | 1.0     | 13.0              | 6.1        | 84.7             | 0.2                           | 0.19    | 0.01    | 109         |

g: gram; kcal: kilocalorie; %: percent; IDF: insoluble dietary fiber; SDF: soluble dietary fiber.
water content of these types of groats determined their low calorific value, which probably contributed to the significantly higher rate of the decrease in the level of satiety being experienced, compared to other types of groats characterized by higher calorific value. It was assumed that the water content of the tested types of groats was primarily determined by the presence of all hydrophilic components capable of binding and retaining water. To this end, the parameters of multiple regression that were used to determine the effects of protein, starch, and dietary fiber contents on water content in cooked groats were estimated. The simultaneous use of many explanatory variables increased the accuracy of forecasting compared to the use of only one variable. The obtained equation took the following form:

\[ y = 2.42x_1 - 1.33x_2 - 2.80x_3 + 91.42, \]

where \( y \) = water content, \( x_1 \) = protein content, \( x_2 \) = starch content, \( x_3 \) = dietary fiber content. The value of the squared coefficient of correlation between the response variable and the best combination of its predictors \( R^2 \) was 0.9819. This means that it expresses the dominant part of the shared variance by this best combination and the response variable. In turn, the standard error of the estimation, which describes the residual dispersion (the residues being the differences between the actual values and forecasted values) was 2.2241. The calculated value of \( F \)-statistics amounted to 18.0596. The obtained results indicate that the degree of hydration of the dry matrix of particles of the tested types of groats, determining the weight of a meal and its calorific value, was a resultant of the predictors taken into account in the regression equation, of which protein content was of the greatest significance. These results only partially explain the varied degree of hydration of particular types of groats. In-depth research should also take into account the differences in geometrical characteristics of particles of the tested types of groats.

Pearl barley (128 kcal/100 g) and oat groats (125 kcal/100 g) were the most calorific. The high calorific value of these types of groats was primarily determined by the high protein content (4.4%), fat content (3.2%), and the very high starch content (22.3%) for oat groats and the high protein content (4.03%) and starch content (19.7%) for pearl barley. The lowest content of starch was found for cornmeal. It was statistically proven that the content of starch significantly differs for different types of groats (\( p = 0.0004 \)). The content of protein in three groats (buckwheat, barley, and oat) was similar and the lowest content of protein was found in cornmeal.

Oat groats also contained a significant amount (3.4 g/100 g) of dietary fiber, which could have affected the results concerning the determination of hunger and satiety levels. The highest content of total dietary fiber (TDF) was found in oat and barley groats. Low amounts of total fiber were found in cornmeal and millet. While analyzing the IDF and SDF separately, it was found that the content of SDF in each examined product was below 1 g per 100 g of boiled groats. For oat and barley groats, the content of SDF was threefold lower than that of IDF. The technical parameters of the cooking process and, consequently, the degree of hydration of groats, can play a decisive role in shaping the satiating properties of the selected groats.

**Hunger and satiety**

The estimated level of satiety being experienced on an empty stomach by participants of the study ranged from 25 to 35 mm (Table 2, Figure 1). Immediately after the intake of isocaloric and isothermal servings of cooked groats, i.e. after a maximum of 8 min from the beginning of the

| Type of groats          | Weight of a serving (g) | On an empty stomach M (SD) | Immediately after ingestion M (SD) | After 1 h M (SD) | After 2 h M (SD) | After 3 h M (SD) | AUC M (SD) | Mean of the variance |
|-------------------------|-------------------------|---------------------------|-----------------------------------|----------------|-----------------|-----------------|-------------|---------------------|
| Millet groats           | 228                     | 31 ± 9                    | 82 ± 7                            | 65 ± 8         | 38 ± 11         | 23 ± 8          | 201 ± 3     | 207.1               |
| Buckwheat groats        | 214                     | 32 ± 9                    | 74 ± 7                            | 68 ± 6         | 47 ± 9          | 35 ± 10         | 212 ± 6     | 223.0               |
| Pearl barley            | 187                     | 32 ± 9                    | 71 ± 6                            | 67 ± 7         | 56 ± 8          | 38 ± 10         | 220 ± 8     | 231.5               |
| Oat groats              | 192                     | 31 ± 9                    | 72 ± 8                            | 71 ± 6         | 62 ± 7          | 50 ± 8          | 221 ± 4     | 254.5               |
| Grits                   | 220                     | 32 ± 8                    | 83 ± 7                            | 64 ± 10        | 29 ± 9          | 16 ± 8          | 190 ± 4     | 192.0               |

\( n = 54 \) women; M: mean; SD: standard deviation; AUC: area under the curve.
study, the experienced satiety level reached the highest value for grits (83 ± 7) and millet groats (82 ± 7). However, after 3 h (the end of the test), the level of satiety being experienced after the intake of these groats fell significantly to reach the lowest noted values (16 ± 8 for grits and 23 ± 8 for millet groats) (Table 2, Figure 1). This means that the intake of grits caused a rapid, yet short-term, increase in the level of satiety being experienced, which was equally rapidly replaced by a growing feeling of hunger (Table 3, Figure 2).

In turn, immediately after the intake of the other types of groats tested, the level of satiety being experienced reached similar values (71 ÷ 74) which, after 3 h, decreased and fell within a range from 35 ± 10 (white buckwheat groats) to 50 ± 8 (oat groats) (Table 2, Figure 1). This means that the intake of oat groats and pearl barley resulted in a slower (compared to grits and millet groats), yet relatively longer term, feeling of satiety, which was relatively slowly replaced by a growing feeling of hunger (Table 3, Figure 2).

An analysis of the mean values of the level of satiety subjectively experienced after the intake of the tested groats, which gradually decreased during the test, indicated that the highest level of satiety was associated with the intake of oat groats and the lowest level was associated with the intake of grits (Table 2). At the same time, having analyzed the mean value of the level of hunger experienced after the intake of the tested groats, which gradually decreased during the test, it can be concluded that the lowest level of hunger being experienced was ensured by the intake of oat groats, and the highest level by the intake of grits (Table 3). Based on the obtained results, it can be concluded that the intake of oat groats and pearl barley resulted in the highest satiety level (Figure 1) and the lowest hunger level (Figure 2) expressed using the VAS score.

**Table 3.** Level of hunger mean score (mm) (100 mm VAS) (SD) for an isocaloric serving (240 kcal).

| Type of groats | Weight of a serving (g) | On an empty stomach | Immediately after ingestion | After 1 h | After 2 h | After 3 h | AUC M (SD) | Mean of the variance |
|---------------|-------------------------|---------------------|-----------------------------|----------|----------|----------|------------|---------------------|
| Millet groats | 228                     | 63 ± 10             | 19 ± 6                      | 35 ± 6   | 62 ± 10  | 77 ± 8   | 183 ± 9    | 192.1               |
| Buckwheat groats | 214                   | 64 ± 10             | 25 ± 6                      | 31 ± 6   | 51 ± 8   | 65 ± 9   | 168 ± 4    | 172.4               |
| Pearl barley | 187                     | 63 ± 10             | 28 ± 7                      | 32 ± 7   | 40 ± 8   | 58 ± 9   | 157 ± 8    | 157.7               |
| Oat groats    | 192                     | 63 ± 10             | 26 ± 7                      | 28 ± 6   | 35 ± 6   | 46 ± 9   | 140 ± 11   | 134.2               |
| Grits         | 220                     | 63 ± 10             | 11 ± 5                      | 33 ± 9   | 68 ± 10  | 83 ± 10  | 184 ± 6    | 195.2               |

n = 54 women; M: mean; SD: standard deviation; AUC: area under the curve.
In order to quantify the subjective primary data, the AUC values for satiety were estimated, and compared, which indicated that the lowest level of satiety was observed for the intake of grits and millet groats, as the AUC for these types of groats was the smallest. The largest AUC was determined for oat groats and pearl barley. A statistical analysis demonstrated that the satiety index is determined by the type of groats ($\alpha = 0.05$, $F = 65.22$ of the critical value).

For the determination of hunger level, the aim was to verify a similar assumption concerning the effect of the type of groats on the level of hunger being experienced. As in the case of determining the satiety level, the value $F = 68.35$ determined for the hunger level at the significance level $\alpha = 0.05$ indicated that the hunger level was determined by the type of groats. Based on an analysis of the results, it was concluded that the highest hunger level was observed following the intake of grits and was only slightly lower for millet groats. On the other hand, the lowest level of hunger being experienced was recorded following the intake of oat groats. For grits, hunger appeared the quickest. As early as after 2 h, some participants exhibited severe symptoms of hunger at a VAS level of $68 \pm 10$ mm. For millet groats, the level of hunger after 2 h was high as well (Table 3). The AUC of hunger had the highest values for grits and millet groats. The intake of unroasted buckwheat groats was characterized by moderate levels of hunger and satiety. The AUC amounted to 212 for satiety level and 168.31 for hunger level.

**The dependence of hunger and satiety on selected physicochemical parameters**

Based on the values of Pearson’s correlation coefficient, it was determined that the highest level of correlation occurs between hunger and satiety levels and protein and dietary fiber contents. Based on an analysis of linear regression describing the relationship between nutrient contents and the feeling of satiety, it was concluded that satiety was determined, to the greatest extent, by the dietary fiber content of the tested types of groats. An increase in the percentage of dietary fiber by one percentage point may lead to an increase in the satiety level by 10.6 points according to the VAS score, with other features remaining unchanged (Table 4). In turn, an increase in the percentage of protein by one percentage point results in an increase in the satiety level by 5.5 points according to the VAS score, with the same assumption (Table 4). On the other hand, an analysis of linear regression describing the relationship between the level of hunger being experienced and dietary fiber content demonstrated that an increase in dietary fiber content by one percentage point may result in a
decrease in the feeling of hunger by 18.4 points on the VAS scale, with the remaining feature being constant. The effect of protein content on the growing feeling of hunger is decidedly smaller (Table 4). The analysis of the IDF and SDF fractions showed that although none of the variables was found to be significant due to a low number of observations, a strong correlation of these variables indicates that such a correlation exists. A considerably greater effect on the satiety of groats was recorded for the content of soluble fiber compared to the effect of insoluble fiber.

Moreover, while adopting the approach taken previously (assuming that the simultaneous use of many explanatory variables would help to increase the accuracy of forecasting), the parameters of the equation describing the effect of water, starch, and dietary fiber contents in the tested types of groats on the level of satiety being experienced after their intake, expressed in the AUC values of satiety and parameters of the equation describing the effect of the same variables on the level of hunger being experienced (expressed in the AUC values for hunger) were estimated.

The obtained multiple equation of satiety took the following form: $y = -0.78x_1 + 0.36x_2 + 3.39x_3 + 253.66$, where $y = \text{water content}$, $x_1 = \text{water content}$, $x_2 = \text{starch content}$, $x_3 = \text{dietary fiber content}$. The value of the squared correlation coefficient $R^2$ took a value of 0.9807, which means that it expresses the dominant part of the shared variance. In turn, the standard error of estimation, describing the residual dispersion, took a value of 3.6509. The value of $F$-statistics amounted to 16.9004. The obtained results indicate that the level of satiety being experienced following the intake of groats was a resultant of the predictors taken into account in the regression equation, of which dietary fiber content was of the greatest significance for inducing the feeling of satiety. In the long term, the presence of water contributed to the decrease in the satiating potential of groats, most probably because it only serves the function of a mechanical filler of the stomach, which is independently not capable of staying within it.

The multiple equation of hunger took the following form: $y = 1.68x_1 + 1.55x_2 - 9.46x_3 + 35.12$, where $y = \text{AUC M of hunger}$, $x_1 = \text{water content}$, $x_2 = \text{starch content}$, $x_3 = \text{dietary fiber content}$. The value of the squared correlation coefficient $R^2$ was 0.9720, expressing the dominant part of the shared variance. In turn, the standard error of estimation was 6.2340 and the value of $F$-statistics amounted to 11.5860. The collected results indicate that the level of hunger being experienced following the intake of groats was a resultant of the predictors taken into account in the regression equation, of which dietary fiber content was of the greatest significance for suppressing the feeling of hunger, which is proven by the negative value of this parameter (counteracting the tested phenomenon). On the other hand, water and starch contents determined, to a similar extent, the emergence of the feeling of hunger. Both water and starch had positive values in the determined equation, which suggests that their presence was conducive to promoting the feeling of hunger (cooperation with the tested phenomenon). Water, as a component lacking the ability to provide energy, does not counteract the feeling of hunger. On the other hand, starch, as a result of its pasting, was easily digested, triggering an increase in glycaemia, which was conducive to another episode of hunger.

| Table 4. Parameters of correlation between satiety and protein and dietary fiber contents. |
|--------------------------------------|----------------|--------|--------|--------|
|                                      | Coefficients  | Standard error | t-stat | p-value |
| Satiety                              |               |                 |        |         |
| Protein                             | 5.48          | 2.256           | 0.876  | 0.473   |
| TDF                                 | 10.62         | 6.522           | 0.876  | 0.473   |
| IDF                                 | 2.84          | 16.361          | 0.170  | 0.891   |
| IDF                                 | 18.84         | 26.632          | 0.710  | 0.617   |
| Hunger                               |               |                 |        |         |
| Protein                             | 1.31          | 5.414           | 0.242  | 0.830   |
| TDF                                 | -18.37        | 5.646           | -3.256 | 0.083   |
| IDF                                 | -7.17         | 13.402          | -0.540 | 0.690   |
| SDF                                 | -29.58        | 21.834          | -1.361 | 0.401   |
Considering the regression result for the combined effect of water, starch, and fiber on the level of satiety and hunger, it was found that fiber induced the feeling of satiety to the highest degree. At the same time, fiber counteracted the feeling of hunger to the highest degree. A multiple regression analysis was carried out taking account of different types of fiber.

A multiple equation for the correlation between the feeling of satiety and the presence of both fiber fractions in the water with which they interact was constructed:

\[ y = -1.20 x_1 - 6.91 x_2 + 4.29 x_3 + 290.25, \]

where \( y = \text{AUC M of satiety}, \) \( x_1 = \text{water content}, \) \( x_2 = \text{content of water soluble fiber fraction (SDF)}, \) \( x_3 = \text{content of water insoluble fiber fraction (IDF)}. \)

The value of the square of the correlation coefficient \( R^2 \) equalled 0.9978, which indicates the dominant part of shared variance. The standard error of estimation reached the value of 1.2431, while the value of statistic \( F \) was 148.33. On the other hand, a multiple equation describing the correlation between the feeling of hunger and the presence of both fiber fractions in water (which determines the manifestation of fiber fraction functional properties) was constructed:

\[ y = 0.46 x_1 - 20.2 x_2 - 8.95 x_3 + 148.43, \]

where \( y = \text{AUC M of hunger}, \) \( x_1 = \text{water content}, \) \( x_2 = \text{content of water soluble fiber fraction (SDF)}, \) \( x_3 = \text{content of water insoluble fiber fraction (IDF)}. \)

The value of the square of the correlation coefficient 0.9740, standard error of estimation reached the value of 6.0142, while the value of statistic \( F \) was 12.47.

Based on a comparative analysis of parameters of both regression equations, it can be concluded that these results may be treated as confirmation of the diverse role of a soluble dietary fiber fraction (SDF) compared to the insoluble dietary fiber fraction (IDF) in affecting the capacity of food to induce the feeling of satiety and counteract the feeling of hunger. Both IDF and SDF had negative values in the constructed equation, which suggests that their presence limited the feeling of hunger. However, based on our studies it is difficult to conclusively determine the effect of the particular fractions on satiety because it is not a model study and the present study covers a variety of variables with an effect on satiety. Nevertheless, all of the examined groats were characterized by a high degree of satiety.

**Discussion**

The current study concerns the novel issue of satiety and is the first study to investigate the satiating properties of groats. The results of the study demonstrate that groats can be considered as a product with high-satiating properties. The satiating potential of buckwheat groats, oat groats, and pearl barley is particularly noteworthy. The satiating properties of groats are probably a resultant of many factors. The basic determinant shaping the satiety value of groats is their chemical composition, which determines the nutritional value. The chemical composition differs depending on the species of cereal used to produce groats and on the type of groats – which is determined by the adopted method of technological processing.\(^{[26,27]}\) In addition, the duration and method of cooking may increase the degree of water absorption and affect the size of a portion. The effect of the intake of groats on the regulation of hunger and satiety is relatively poorly known. The literature remains ambiguous as to which macronutrients trigger the most satisfactory effect of satiety. It is suggested that protein satiates hunger most effectively compared to fats and carbohydrates. Protein-rich diets were the subject of numerous studies which have demonstrated that the protein contained in foods may effectively contribute to a favorable energy balance and help to control body weight.\(^{[28,29]}\) Groats, however, are not a rich source of protein. The protein content of grits is negligible and amounts to 0.78 g/100 g, while in other types of groats, the protein content amounts to a maximum of 4.5 g/100 g. Therefore, this is not a value which could determine the satiating properties of groats. Neither protein nor fats are components to which the satiating properties of groats could be attributed.

It appears that the most important factor affecting the satiating potential of groats is the content and type of carbohydrates. Their role is manifold, depending on their type and structure. The effects of carbohydrates on metabolism are associated with the occurrence of hormonal effects, the properties of particular carbohydrates contained in food products, and the ability of certain carbohydrates...
to ferment in the large intestine. \cite{30-32} Properly composed meals based on complex carbohydrates can help control the body weight due to their satiating properties. In the current study, carbohydrate contents in groats varied from 22.7 to 27.8 g/100 g, with the exception of grits (13 g/100 g). They are the dominant component determining the energy value of cooked groats. The greatest share is that of starch. Starch properties depend mainly on the amylose-to-amylopectin proportion, which can vary to a large extent even within one cereal species. Regarding the types of groats under study, the amylose-to-amylopectin ratio was as follows: millet grains, 1:3; buckwheat groats, 1:4.8; pearl barley, 2.1:1; oat groats, 1:2.3; grits, 1.85:1. \cite{33}

Starch content is linked to the GI. A higher amylose content in relation to amylopectin ensures lower postprandial glycaemia and insulinemia, as amylose contained in starch is less sensitive to the action of enzymes. \cite{34} The properties of dietary fiber also contribute to the feeling of satiety. Its presence mainly contributes to the occurrence of the effect of stomach distention and an increase in the viscosity of stomach contents, which also delays stomach emptying. In turn, the presence of dietary fiber in the intestine results in the slowdown of the rate of digestion of carbohydrates and lipids. \cite{24,35,36}

Based on studies, apart from starch, the most important component of grain products is dietary fiber. In the recent years, there has been an interest in the possibilities of using dietary fiber in the regulation of satiety. In the present study, the total fiber content in a variety of groats ranged from 0.1 g to 3.4 g. The highest TDF content and the highest satiety degree were characteristic of oat groats and pearl barley. On the other hand, Hęś et al. reported that following hydrothermal treatment, the content of TDF was considerably higher for buckwheat groats (16.45 g/100 g) compared to barley groats (7.99 g/100 g), which was not confirmed by the current study. \cite{37} Moreover, Górecka et al. \cite{38} found a higher TDF content in boiled barley groats than in buckwheat groats. Presumably, these differences in TDF content resulted from the technological treatment methods applied, grain variety, and species. Nevertheless, oat groats was characterized by the highest content of dietary fiber. Gelieter et al. studied the effect of oat and corn flakes on the feeling of satiety. The satiety was higher and the consumption of the tested meal \textit{ad libitum} was lower following the consumption of ots than following consumption of corn flakes, which was confirmed in the present study. \cite{39} Schroeder et al. conducted studies of the effect of fiber on satiety and reported that the consumption of full-grain barley with a high fiber content (12 g of fiber/56 g barley portion) induced an increase in the feeling of satiety before a meal \textit{ad libitum} at dinner time when compared to full-grain wheat (5 g of fiber/56 g portion) and refined rice (1 g of fiber/56 g portion). This confirms that oat products are characterized by a very high satiety value. \cite{40}

On the other hand, Korczak et al. do not confirm that correlation. They studied the effect of oat and barley bran on satiety (10 g of oat bran, 10 g of barley bran, and low content of fiber), and did not find any differences between bran type and satiety.\cite{40} A comparison of the study results concerning satiety properties is very difficult due to the differences in the type of used fiber (SDF versus IDF) and doses used in preliminary load. An extensive account of model studies using different fiber types can be found in the literature. Authors reported that an addition of dietary fiber to food considerably increased the feeling of satiety. \cite{41,42} Bajerska et al. examined the effect of an addition of cherry pomace (CP), a by-product from fruit processing, to muffin production, as a substitute of wheat flour, in a variety of concentrations. They found that an substitution of wheat flour with cherry pomace at both levels of 20% CP and 30% CP improved satiety and resulted in a lower energy consumption after 3 h (level 40%CP addition, altough tested as well, was not acceptable for consumer due to sensory properties). \cite{43} Lyl\text{y} et al. found some benefits when measuring satiety after providing the study participants with beverages enriched with a variety of fibers in comparison to a fiber-free beverage. It was found that not all the fiber added produced a desirable effect. Only the beverage enriched with guar gum ensured a statistically significant increase in the feeling of satiety compared to a fiber-free beverage. \cite{44} For many years, researchers have been studying the effect of enrichment of bread with fiber to increase its satiety. Touyarou et al. studied satiety response to two types of bread enriched with fiber compared to white bread. Although the soluble:insoluble fiber ratio was similar in the fortified breads, one of them resembled a multi-grain bread while the other
resembled a traditional sandwich bread. The researchers found that a weaker feeling of hunger was achieved following the consumption of both breakfasts compared to the consumption of the control breakfast, while the appearance and taste did not affect a subconscious decision of the consumers. [45]

In the current study, since all of the participants also liked groats and did not reveal an aversion to any of them, consumer preferences did not have a significant effect. Other studies [46–50] found that food enrichment with psyllium, lupin, or flax may considerably regulate the consumption of a meal and reduce the energy of a daily diet, while the predominance of fiber insensitive to digestion does not produce a desirable effect. Recently, increasingly frequently researchers have been analyzing the effect of fiber content on satiety, depending on their fraction and proportion.

It is assumed that the effect of the insoluble fraction on the promotion of satiety is mainly determined by the reduction of an energy value of a diet. Other studies [51] have indicated that the presence of hemicelluloses may contribute to a decrease in hunger. Many studies however underline the role of soluble fiber which, even in small amounts, may play a key role in satiety regulation. The presence of soluble fiber promotes satiety through slowing down glucose absorption. In the small intestine’s environment, with the required amount of water, fiber swells and forms viscous gels. IDF to SDF ratios in grain products are similar; however, it is underlined that the highest share of water-soluble fiber can be found in oat products [15,52,53], due to the content of β-glucans and other soluble components. In the current study, the highest satiety was obtained following the consumption of oat groats (with the highest SDF content).

Other researchers have underlined the role of arabinoxylans and β-glucans in satiety regulation. FOSCHIA et al. found that, among the cereals, the highest content of β-glucans was reported for barley (2–20 g per 100 g dry matter) and (3–8 g) for oats. [54] Other cereals also contain these compounds although in considerably lower amounts. On the other hand, reports [55,56] suggest that cereal grain processing and the use of hulless grain to a material degree impoverish a product in these components. The amount of these compounds in boiled groats is insufficient to ensure a significant reduction of the feeling of hunger. It was observed that, although the content of glucans is presumably the highest in barley and oat groats compared to other cereal products, this would not produce a desired satiety effect. However, this could reduce energy consumption from the next meal. [57] Water-soluble and water-insoluble fibers reveal different physicochemical properties and it may be expected that they have a varied effect on satiety signals after a meal. The results of multiple studies show that different types of fiber modulate the appetite control time and may cause changes in consumption motivation and patterns, not necessarily affecting total energy consumption. [58–61]

Dietary fiber and starch contents affect the glycemic index and satiety level. An increase in short-term satiety with the intake of low-glycemic products has been proven in many studies [62], while the effect of the application of a low-glycemic diet on the feeling of satiety and body weight in the long term still remains controversial. [63–65] Regarding the groats in the current study, the determined satiety levels correlate with the typical GI values. The types of groats which exhibited high satiating potential in the current study are assigned low GI values in the literature (oat groats GI = 47, pearl barley GI = 45, millet groats GI = 70). All of the examined groats were characterized by high satiety compared to other food products. [66–68] Further research to verify this relationship is required.

Given the capacity of groats for inducing and maintaining the feeling of satiety, it is also necessary in further research to take into account (in addition to the mentioned dietary fiber protein and starch) water content (the degree of hydration) which determines the degree of starch pasting and viscosity of food. The results of the current study indicate that the water present in groats affects the feeling of satiety within a short time after consuming them. Depending on the method of technological processing and the degree of overcooking, groats differ not only in water content but also in the GI and satiating properties. The water content of cooked groats is determined by the geometrical features of the groats’ granules and the degree of their hydration. Grits and millet groats were characterized by the highest water content. They were also characterized by the smallest granules, which could, as a result, determine the satiety value of groats. Groats with large, hard granules after
cooking (pearl barley, oat groats, buckwheat groats) were characterized by relatively high satiating potential, which was confirmed by numerous studies. This suggests that not only the chemical properties of groats, but also their physical features, mainly those associated with the structure of groats’ granules and rheological properties of the stomach contents after their intake, may have an effect on the occurrence of the feeling of satiety. Therefore, while determining the satiating potential of food products, it is necessary to take into account not only the nutrients but also the physical features of the product. An assessment of the satiating properties of groats should be extended in the future with additional tests focused on the physical parameters of foods, which may have an effect on the duration of the feeling of satiety and on the time of the appearance of another episode of hunger, with constant chemical parameters of foods and hormonal parameters of the body.

Conclusion

The satiety potential of groats is mostly determined by the dietary fiber content and the degree of hydration of the groats after cooking. Oat groats and pearl barley were the groats, which satiated most efficiently, at relatively the highest level of protein. A study of the correlation between satiety and IDF and SDF fractions did not produce clear conclusions. In the course of the study it was found that all the examined groats were characterized by high satiative properties. The consumption of groats should be the basis for each rational diet, not only for people caring for health and controlling body weight but also for obese people and patients with diabetes type 2 as they are characterized by a relatively low GI.

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