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The Influence of Thermal Processing of Fruit and Vegetables on Their Glycaemic Index and Glycaemic Load*

Wpływ procesów termicznych owoców i warzyw na ich indeks i ładunek glikemiczny

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A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

Summary

Aim: Diabetes is a metabolic disease caused, among others, by malnutrition. Therefore, more attention is paid to products containing carbohydrates, as they increase the blood glucose concentration. In order to prevent type 2 diabetes and obesity, it is recommended to consume food with a low glycaemic index (GI) and glycaemic load (GL). The GI value of foodstuffs is influenced by their composition, as well as physicochemical and biochemical changes occurring in raw materials during technological processes. The aim of the study was to determine the influence of technological processing on the glycaemic index and glycaemic load values of selected vegetables and fruit.

Material/Methods: The research was conducted on cruciferous vegetables, carrots, potatoes and apples. The raw materials underwent pretreatment, which included washing, peeling, shredding and thermal processing. In order to determine the glycaemic index, clinical trials were conducted on 20 healthy people of both sexes, aged 20–60 years, normal weight (BMI 18–24.5). The content of dietary fibre and its fractions was also measured in the products.

Results: The thermal treatment influenced the GI and GL values of the food products and content of dietary fibre. The highest GI and GL values were measured in the boiled and baked products, whereas the GI and GL values of the steamed foodstuffs were slightly lower.

Conclusions: The results let us conclude that adequate handling of raw materials, i.e. appropriate thermal processing, may limit the development of type 2 diabetes. Diabetic patients are advised to use steaming as the preferable method of thermal processing of foodstuffs.

Keywords: **thermal processing • glycaemic index • glycaemic load • dietary fibre**

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Abbreviations:

ADF – acid detergent fibre; **ADL** – acid detergent lignin; **AUC** – area under the curve; **C** – cellulose; **DM** – dry matter; **GI** – glycaemic index; **GL** – glycaemic load; **H** – hemicelluloses; **IDF** – insoluble dietary fibre; **NDF** – neutral detergent fibre; **SDF** – soluble dietary fibre; **TDF** – total dietary fibre.

INTRODUCTION

Diabetes is an important global problem in the context of public health. It is characterised by hyperglycaemia, which is induced not only by hereditary causes but also by acquired factors such as: obesity, improper diet, and lack of physical activity [8, 23, 25]. According to the data published by the International Diabetes Federation, in 1980 there were 153 million diabetics around the world [5], whereas in 2017 this number increased to 425 million. In Europe there are as many as 60 million people suffering from type 2 diabetes, most of whom are aged over 50 years. It is estimated that the number of diabetics in Europe will have increased to 71 million by 2040 [3].

The consumption of products containing carbohydrates has a diversified influence on the glucose concentration in the blood. The glycaemic index (GI) is indicates the rate of absorption of carbohydrates from various sources. Associations between GI and GL with disease risk have been widely studied [36, 40, 44]. There is a division into low (GI ≤55), medium (GI = 56–69) and high GI products (GI >70), which depends on the change in the glucose concentration after the consumption of a product [2, 4, 12]. Low GI products reduce the risk of occurrence of not only type 2 diabetes but also ischaemic heart disease and obesity. The diabetic diet should also be rich in ingredients which slow down the absorption of glucose into the blood, e.g. dietary fibre [2, 41]. Fujii et al. [15] showed that increasing dietary fiber intake was associated with better glycaemic control in Japanese type 2 diabetic patients. Vegetables, fruits, especially dried ones and cereals are a rich sources of dietary fibre. The consumption of high-fibre products has various benefits. Not only do they limit the absorption of carbohydrates from the gastrointestinal tract, but they also contain polyphenols, which have antioxidative properties. The glycaemic load (GL) not only indicates the quality of carbohydrates but also their quantity [4]. There are low (GL <10), medium (GL = 10–20) and high GL products (GL >20). Hu et al. [18] conducted research on 8.039 oncological patients and found that the consumption of high GL and GI products increased the occurrence of colorectal, pancreatic and prostate cancers [42]. Gnagnarella et al. [16] made a meta-analysis and found a high positive correlation between the consumption of high GL and GI products and the occurrence of colorectal and uterine cancers.

The value of these indicators is influenced by various factors, such as the degree of grinding of foodstuffs, the method of their processing, the content of nutrients and anti-nutrients, the content of protein, fat and dietary fibre, the ratio between amylose and amylopectin fractions in starch, thermal processing as well as physicochemical and biochemical transformations occurring during technological processes. The high content of amylose in products may reduce the digestion rate because of the formation of amylose-lipid complexes [7].

The aim of the study was to determine the influence of technological treatments applied during the preparation of fruit and vegetable dishes on the glycaemic index and glycaemic load values.

MATERIAL AND METHODS

The research was conducted on commonly consumed fruit and vegetables with high content of fibre, i.e. cruciferous vegetables (*Cilion* white cabbage cultivar, *Lektro* red cabbage cultivar, *Fiona* savoy cabbage cultivar), *Dolanka* carrot cultivar, *Augusta* potato cultivar and *Szampion* apple cultivar.

The fruits and vegetables underwent pretreatment, which included washing, peeling and shredding (cabbage) as well as thermal processing, i.e. boiling, steaming and baking (apples and potatoes). The thermal treatment in water was carried out according to the recommended product-to-water ratio, i.e. 1:1 (v/v) for the potatoes and 2:1 (v/v) for the other materials. The thermal treatment in water started with boiling water at a temperature of 100°C. The steam treatment was conducted in a Rational Combi-Steamer CCC convection oven in a 100°C steam flow at the maximum steam injection frequency (1/s). The baking process was also conducted in a Rational Combi-Steamer CCC convection oven, where hot air heated to a temperature of 200°C was circulating. All the processes were continued until the products were completely soft, according to McGee [28] and device user manual recommended by the oven producer.

In order to determine the GI, the blood glucose level was measured according to ISO [20] in healthy people (n = 20) of both sexes (men = 50%, women = 50%) aged 20–60 years, normal weight (BMI 18–24.5). All experimental procedures were conducted in accordance with ethical research in human subjects (Bioethics Committee consent No. 1013/13). People who declared willingness to participate in the experiment were included in the study. Exclusion criteria were systemic diseases and bad nutritional status. The participants' capillary blood was collected from their fingertips. The patients had their blood glucose levels measured on an empty stomach. On consecutive days, the same group of people were given cruciferous vegetables, carrots, potatoes and apples. The vegetables and fruit were served fresh, boiled, steamed and baked (potatoes and apples) at an amount of 120 g [14, 32]. Next, the glycaemic response curve was determined for each product and for each person separately. Two hours after the consumption of the products, the patients had their blood glucose levels measured at intervals of 15, 30, 45, 60, 90 and 120 minutes. On the following day, the same group of people were given a reference product, i.e. 200 cm^3 of an aqueous glucose solution containing 50 g of pure glucose. The area under the glycaemic curve was calculated from the glycaemic response curves. The ratio between the area under the glycaemic curve after the ingestion of a product (IAUC) and the area under the glycaemic curve after the ingestion of glucose was assumed as the GI value. The result was expressed as a percentage.

The GL value was also calculated by multiplying the GI of the product by the amount of carbohydrates it contained expressed in grams and dividing by 100 according to the following formula:

Product GL= CxGI/100

C – carbohydrate content

The following parameters were also determined: the content of total dietary fibre (TDF), soluble dietary fibre fraction (SDF) and insoluble dietary fibre fraction (IDF) according to the AOAC method [27], the neutral detergent dietary fibre (NDF), the acid detergent fibre (ADF) and the acid detergent lignin (ADL) according to the Van Soest method [39]. The content of hemicelluloses (H) and cellulose (C) was calculated from the difference: H = NDF-ADF, C = ADF-ADL.

STATISTICAL ANALYSIS

The results were analysed using one-way ANOVA with Tukey's test at a statistical significance of p = 0.05. The Pearson test was used to estimate the correlation between values. Statistical analysis was performed using Statistica 10PL software for Windows (Statsoft, Poland).

RESULTS

The research showed that individual products differed in the glycaemic index and glycaemic load values (Table 1). The lowest GI values were noted in the fresh cruciferous vegetables (white cabbage – 19%, red and savoy cabbage – 20%), carrots (31%) and apples (38%), which indicates that they can be classified as low GI products. There was a similar tendency in the GL value. The lowest GL values were noted in the cruciferous vegetables (red cabbage – 1.31, white cabbage – 1.57 and savoy cabbage – 1.76). The GL values of the fresh apples and carrots were higher, i.e. 4.25 and 2.59, respectively. The GI and GL values of the fresh potatoes were not calculated.

Table 1. The GI and GL values vs the method of thermal processing of fruit and vegetables

Raw materials	GI [%]	GL [g]
Raw white cabbage	19^{a}	1.57^{a}
White boiled cabbage	41^{de}	2.77^{cd}
White steamed cabbage	36^{c}	3.13^{d}
Raw red cabbage	21^{a}	1.31^{a}
Red boiled cabbage	43^{e}	2.69^{bcd}
Red steamed cabbage	40^{cde}	2.89^{cd}
Raw savoy cabbage	20^{a}	1.76^{a}
Savoy boiled cabbage	49^{cde}	3.07^{d}
Savoy steamed cabbage	37^{cd}	3.62^{e}
Raw carrot	31^{b}	2.59^{bc}
Boiled carrot	63^{g}	4.17^{f}
Steamed carrot	43^{e}	3.14^{d}
Raw potatoes	nd	nd
Boiled potatoes	91^{i}	13.95^{i}
Steamed potatoes	81^{h}	16.51^{j}
Baked potatoes	91^{i}	28.36^{k}
Raw apples	38^{cd}	4.25^{f}
Boiled apples	20^{a}	2.25^{b}
Steamed apples	42^{e}	4.74^{g}
Baked apples	52^{f}	6.88^{h}

Explanatory notes:
nd – no detected; GI – glycaemic index; GL – glycaemic load; a-k – mean values in the same columns and denoted by different letters for each category vary statistically significantly among themselves at p = 0.05

The type of thermal processing applied to the foodstuffs affected their GI and GL values. The GI value of boiled vegetables was higher than the GI values of steamed vegetables or baked apples. The cruciferous vegetables processed thermally in water and in steam as well as the steamed carrots and baked apples could be classified as low GI products (GI ≤55). As far as the carrots are concerned, the highest GI value was noted in the boiled ones (63%). This value was 100% greater than the GI of the fresh carrots. The GI of the steamed carrots was significantly greater than that of the boiled ones. Among the products the potatoes were characterised by the highest GI, regardless of the thermal processing method (steamed potatoes – 81%, boiled potatoes – 91%). The GI values of the steamed potatoes were significantly lower than those of the boiled or baked ones. The GI value shows that these products belong to the high GI group (GI ≥70).

There was a similar trend observed in the GL, whose value in the cruciferous vegetables ranged from 2.69 (boiled red and white cabbage) to 3.62 (steamed savoy cabbage). There were higher GL values in the carrots as well as boiled, steamed and baked apples. The cruciferous vegetables as well as the carrots and apples were characterised by low GL values, regardless of the thermal processing method applied. The potatoes were characterised by the highest GL value, regardless of the thermal processing method applied. The boiled and steamed potatoes could be included in the medium GL group (13.95 and 16.51, respectively), whereas the baked potatoes could be included in the high GL group (28.36).

Thermal processing destroys the food matrix and changes digestibility, which increases the glycaemic response. In products with a high content of starch, such as potatoes, the starch structure becomes deformed during steaming and baking. In consequence, it is easily available to enzymes, which affects the GI value [26, 35]. The GI and GL values were also affected by the content of dietary fibre and its fractions (Table 2). Among the products analyzed, the highest content of dietary fibre (TDF) was found in the savoy cabbage (42.6% DM), whereas the

Table 2. The content of dietary fibre and its fractions vs the method of thermal processing of fruit and vegetables [g/100 g DM]

Raw materials	IDF	SDF	TDF	NDF	ADF	Hemicelluloses	Cellulose	Lignin
WC[R]	24.1^{gh}	6.4^{cde}	30.5^{fg}	14.2^{d}	10.8^{ef}	3.4^{fgh}	8.9^{e}	20^{de}
WC[W]	36.3^{k}	10.6^{hi}	46.9^{i}	25.6^{i}	19.7^{k}	5.9^{k}	15.9^{i}	3.7^{i}
WC[S]	19.1^{f}	7.7^{efg}	26.8^{e}	14.0^{d}	10.4^{e}	3.6^{gh}	6.0^{d}	4.3^{j}
RC[R]	28.1^{i}	4.6^{bc}	32.7^{fg}	17.3^{fg}	12.5^{ghij}	4.8^{j}	11.3^{gh}	1.2^{ab}
RC[W]	36.4^{k}	18.6^{l}	55.0^{j}	30.6^{j}	24.8^{m}	5.7^{k}	21.3^{j}	3.5^{ghi}
RC[S]	24.5^{gh}	8.7^{fgh}	33.2^{g}	18.0^{g}	13.4^{hij}	4.6^{ij}	11.7^{gh}	1.6^{cd}
SC[R]	33.3^{j}	9.2^{ghi}	42.6^{h}	16.2^{efg}	13.9^{j}	2.3^{de}	12.2^{h}	1.7^{cd}
SC[W]	38.6^{k}	16.3^{k}	54.9^{j}	23.9^{i}	23.2^{l}	0.7^{ab}	20.7^{j}	2.5^{f}
SC[S]	23.3^{gh}	7.6^{efg}	30.9^{fg}	15.7^{def}	12.3^{fghi}	3.4^{fgh}	10.4^{fg}	1.9^{de}
C[R]	25.5^{h}	7.3^{def}	32.7^{fg}	15.5^{def}	11.6^{efg}	3.9^{hi}	9.0^{ef}	2.6^{f}
C[W]	22.3^{g}	11.0^{i}	33.3^{g}	20.4^{h}	18.5^{k}	2.0^{cd}	14.9^{i}	3.6^{hi}
C[S]	16.3^{e}	13.6^{j}	29.8^{ef}	14.4^{de}	13.1^{a}	0.9^{ab}	11.9^{h}	1.6^{cd}
P[R]	5.5^{b}	5.6^{bcd}	11.1^{b}	5.1^{b}	3.1^{b}	2.0^{cd}	1.8^{ab}	1.3^{abc}
P[W]	7.6^{bc}	6.2^{cde}	13.7^{bc}	6.5^{b}	5.5^{bc}	1.0^{ab}	3.1^{bc}	2.4^{f}
P[S]	7.4^{bc}	8.8^{fgh}	16.2^{c}	5.3^{b}	5.1^{b}	0.2^{a}	1.8^{ab}	3.2^{gh}
P[B]	3.1^{a}	1.8^{a}	4.9^{a}	2.1^{a}	1.7^{a}	0.4^{ab}	0.6^{a}	1.1^{a}
A[R]	10.2^{d}	5.9^{cde}	16.1^{c}	8.7^{c}	7.5^{d}	1.3^{bc}	4.4^{c}	3.1^{g}
A[W]	14.3^{e}	5.2^{bc}	19.5^{d}	15.2^{de}	11.8^{efgh}	3.4^{fgh}	10.3^{fgh}	1.5^{bc}
A[S]	9.5^{cd}	3.8^{ab}	13.2^{bc}	9.6^{c}	6.7^{cd}	2.9^{efg}	4.5^{c}	2.3^{ef}
A[B]	9.5^{cd}	6.5^{cde}	16.0^{c}	10.4^{c}	7.9^{d}	2.5^{def}	2.7^{b}	5.2^{k}

Explanatory notes:
WC[R] – raw white cabbage; WC[W] – white boiled cabbage; WC[S] – white steamed cabbage; RC[R] – raw red cabbage; RC[W] – red boiled cabbage; RC[S] – red steamed cabbage; SC[R] – raw savoy cabbage; SC[W] – savoy boiled cabbage; SC[S] savoy steamed cabbage; C[R] – raw carrot; C[W] – boiled carrot; C[S] – steamed carrot; P[R] – raw potatoes; P[W] – boiled potatoes; P[S] – steamed potatoes; P[B] – baked potatoes; A[R] – raw apples; A[W] – boiled apples; A[S] – steamed apples; A[P] – baked apples; GI – glycaemic index; GL – glycaemic load; TDF – total dietary fibre; SDF – soluble dietary fibre; IDF – insoluble dietary fibre; NDF – neutral detergent fibre; ADF – acid detergent fibre; a-k – mean values in the same columns and denoted by different letters for each category vary statistically significantly among themselves at $p < 0.05$

Table 3. The ratio of individual dietary fibre fractions in the fruit and vegetables

Raw materials	IDF/SDF	H/L	C/L	C/H
Raw white cabbage	3.8^{j}	1.7^{de}	4.5^{cd}	2.6^{ab}
White boiled cabbage	3.4^{hij}	1.6^{d}	4.3^{cd}	2.7^{ab}
White steamed cabbage	2.5^{fg}	0.8^{bc}	1.4^{ab}	1.7^{ab}
Raw red cabbage	6.2^{k}	4.1^{g}	9.5^{h}	2.3^{ab}
Red boiled cabbage	2.0^{cdef}	1.7^{d}	6.1^{ef}	3.7^{ab}
Red steamed cabbage	2.8^{gh}	2.8^{f}	7.2^{fg}	2.6^{ab}
Raw savoy cabbage	3.6^{ij}	1.4^{cd}	7.2^{fg}	5.2^{ab}
Savoy boiled cabbage	2.4^{efg}	0.3^{ab}	8.4^{gh}	30.9^{d}
Savoy steamed cabbage	3.1^{ghi}	1.8^{de}	5.4^{de}	3.1^{ab}
Raw carrot	3.5^{hij}	1.5^{d}	3.5^{c}	2.4^{ab}
Boiled carrot	2.0^{def}	0.6^{ab}	4.2^{cd}	7.6^{b}
Steamed carrot	1.2^{ab}	0.6^{ab}	7.4^{fg}	13.9^{c}
Raw potatoes	1.0^{ab}	1.5^{d}	1.3^{ab}	0.9^{a}
Boiled potatoes	1.2^{abc}	0.4^{ad}	1.3^{ab}	3.3^{ab}
Steamed potatoes	0.8^{a}	0.1^{a}	0.6^{a}	7.7^{bc}
Baked potatoes	1.7^{bcde}	0.4^{ab}	0.6^{a}	1.7^{ab}
Raw apples	1.7^{bcde}	0.4^{ab}	1.4^{ab}	3.7^{ab}
Boiled apples	2.9^{gh}	2.3^{ef}	7.0^{f}	3.1^{ab}
Steamed apples	2.5^{fg}	1.3^{cd}	2.0^{b}	1.6^{ab}
Baked apples	1.5^{abcd}	0.5^{ab}	0.5^{a}	1.1^{a}

Explanatory notes:
SDF – soluble dietary fibre; IDF – insoluble dietary fibre; H – hemicelluloses; L – lignin; C – cellulose; a-k – mean values in the same columns and denoted by different letters for each category vary statistically significantly among themselves at $p < 0.05$

Table 4. Correlations between individual variables

Variable	GI	GL	IDF	SDF	TDF	NDF	H	C	L	IDF/SDF	H/L	C/L	C/H
IG	1.00												
LG	0.86	1.00											
IDF	-0.58	-0.65	1.00										
SDF	nc	-0.37	0.66	1.00									
TDF	-0.48	-0.62	0.98	0.81	1.00								
NDF	-0.50	-0.68	0.91	0.76	0.94	1.00							
H	-0.56	-0.57	0.58	nc	0.50	0.65	1.00						
C	-0.45	-0.61	0.91	0.80	0.94	0.96	0.47	1.00					
L	nc	nc	nc	0.28	nc	nc	nc	nc	1.00				
IDF/SDF	-0.69	-0.50	0.57	-0.17	0.40	0.40	0.60	0.36	-0.27	1.00			
H/L	-0.61	-0.47	0.36	-0.16	0.24	0.33	0.73	0.27	-0.44	0.76	1.00		
C/L	-0.62	-0.60	0.72	0.46	0.70	0.68	0.37	0.78	-0.43	0.58	0.60	1.00	
C/H	nc	nc	0.37	0.60	0.46	0.31	-0.42	0.50	nc	nc	-0.35	0.41	1.00

Explanatory notes:
GI – glycaemic index; GL – glycaemic load; IDF – insoluble dietary fibre; SDF – soluble dietary fibre; TDF – total dietary fibre; NDF – neutral detergent fibre; H – hemicelluloses; L – lignin; C – cellulose; nc – no correlated; estimated correlation factors are significant at $p < 0.05$

lowest content was found in the potatoes (11.1% DM). Among the fresh fruit and vegetables, the highest NDF content (Table 2) was found in the red cabbage (17.3 g/100 g DM), whereas the lowest content was measured in the potatoes (5.1 g/100 g DM). The cellulose fraction predominated in the products – its content ranged from 1.8 g/100 g DM (potatoes) to 12.2 g/100 g DM (savoy cabbage). The highest content of the hemicellulose fraction was found in the red cabbage (4.8 g/100 g DM), whereas the highest content of the lignin fraction was measured in the apples (3.1 g/100 g DM). Likewise, the content of NDF and its fractions was also influenced by the type of product and thermal processing method. There were different ratios of individual fractions (H/L, C/L and C/H) in the products (Table 3), which may have affected the GI values of the vegetables and apples. The tested products differed in IDF and SDF fractions content. The IDF fraction dominated in all raw materials, except the potatoes, where the IDF/SDF ratio was 1:1 (Table 3). Among the fresh vegetables, the highest IDF/SDF ratio was found in the red cabbage (6.2), whereas the lowest ratio was found in the potatoes (1.2) and apples (1.7). After the thermal processing, the IDF/SDF ratio dropped in the vegetables, except the boiled and baked potatoes as well as boiled and steamed apples. Our results showed that the GI was negatively correlated with the content of IDF ($r = -0.58$) and hemicellulose fractions ($r = -0.56$). It was shown that proportion H/L and C/L were also negatively correlated, respectively ($r = -0.61$ and $r = -0.62$) – Table 4. In the case of GL, a negative correlation was found for TDF ($r = -0.62$) and NDF ($r = -0.68$), as well as IDF ($r = -0.65$) and C/L ratio ($r = -0.60$). High-fibre meals containing H and C fraction have a preventive effect against diabetes.

DISCUSSION

After thermal processing, there were different GI values in the products, which depended on the type of product, thermal processing method and product composition (the content of dietary fibre). According to Brand-Miller et al. [1], the GI values of carrots, baked potatoes and steamed potatoes were 49%, 94%, and 65%, respectively, whereas in this study these values were 31%, 91%, and 81%, respectively. Jenkins et al. [22] found that the GI of apples was 39%, which was almost identical with the value noted in this study (38%). In other studies, Tahvonen et al. [38] observed that the GI of boiled potatoes amounted to 101%, which was 8% greater than the GI value noted in this study. Potatoes generally have one of the highest GI values of any food, although some varieties appear to be lower than others. According to Foster-Powell et al. [13] and Henry et al. [17], young potatoes have a lower GI than more mature potatoes, which may be attributed to differences in starch structure. Ek et al. [9] observed that the GI of boiled potatoes ranged from 53% to 101%, depending on the potato cultivar, cooking time and fragmentation. These authors also found that the thermal processing of potatoes increased their GI, especially when they were baked or boiled, and to a lesser extent, when they were steamed. The research conducted by Soh & Brand-Miller [37] showed that the GI of young potatoes was lower than that of mature ones. Henry et al. [17] conducted research using various potato cultivars and observed a positive correlation between the GI value and the texture rating. Starches potatoes with low water and sugar content and high starch content were classified as high GI products, whereas compact consistency potatoes were classified as medium GI products. The research showed that the highest GI and GL values were noted in the boiled products (except the apples) and baked one. The GI and GL values were slightly smaller in the steamed products. The lowest values were measured in the fresh products. Other authors [2, 22] also observed that most fresh fruit and vegetables were characterised by low GI values, whereas the GI of potatoes was high. These observations were in agreement with our research findings. Jenkins et al. [21] proved that potatoes and other long-boiled as well as shredded vegetables were characterised by high glycaemic indexes. Shredding damages the cell walls of products, reduces the size of starch molecules, which becomes more available and susceptible to enzymes. Thermal processing in water causes the gelation of starch, which becomes more susceptible to amylolytic enzymes. In consequence, the glycaemic index increases [17, 37]. Morris and Zemel [29] proved that the decrease in the GI and GL values depended on the content of dietary fibre, especially the soluble fraction. Other authors [15, 43] also proved that a diet with high content of dietary fibre significantly limited the development of type 2 diabetes. Englyst et al. [11] observed that the GI of spaghetti was 52% immediately after cooking, but after cooling it decreased to 42%, which may have been caused by the formation of resistant starch, classified as dietary fibre. Many studies showed significantly lower glucose response to pasta meals than to bread meals and/or potato meals [19]. Tests on potatoes showed that, like wheat bread, they could be classified as high GI products. The GI of freshly boiled potatoes was 98%, but after cooling, it dropped to 87%. The alternating cycles of high and low temperature (cooking and cooling) reduced the absorbability of starch contained in the starchy products and thus significantly reduced their glycaemic response. The significance of dietary fibre for the maintenance of the normal blood glucose level was also noted by Brouwer-Brolsma et al. [2]. The authors proved that the GI was negatively correlated with the content of TDF ($r = -0.95$; $p = 0.00$) and its fractions (SDF, $r = -0.73$; $p = 0.07$ and IDF, $r = -0.87$; $p = 0.01$). A high-fibre diet seems to have preventive effect with respect to the GI and GL of products and dishes.

The research showed that the thermal processing of fruits and vegetables caused qualitative and quantitative changes in individual dietary fibre fractions of the products (Table 2), which led to changes in GI and GL values. The thermal processing of vegetables and legumes changes their texture due to changes in pectins and alpha-galacto-oligosaccharide, which are classified as soluble fibre. They become leached during cooking, which affects the content of fibre in the cooked product [30, 31]. Apart from that, the leaching of soluble components into the solution changed the percentage of these components in the products under study and resulted in an apparent increase in the content of dietary fibre. The research conducted by Komolka et al. [24] also confirmed that technological processes increased the content of the insoluble dietary fibre fraction. These observations were in agreement with our research findings. The results of our research showed considerable diversification in the content of individual dietary fibre fractions in the fresh and thermally processed products. Other authors also made similar observations [6, 10, 34]. Punna and Rao Paruchuri [33] indicated no significant changes in TDF, IDF and SDF contents of all investigated green vegetables (agathi, alternanthera, amaranth, basella, cabbage, colocasia, coriander, curry leaves, drumstick, fenugreek, hibiscus, mint, portulaca, rumex, spinach) during cooking.

The results let us conclude that the adequate handling of raw materials, i.e. appropriate thermal processing, may limit the development of type 2 diabetes. Diabetic patients are advised to use steaming as a preferable method of thermal processing of foodstuffs.

CONCLUSIONS

1. The values of the glycaemic index and glycaemic load in the thermally processed fruit and vegetables were significantly higher than in the fresh products. The highest increase in these indicators was found after thermal processing in water. The smallest increase was observed after steaming the products, except the apples.
2. The technological processes had a different effect on the content of dietary fibre and its fractions. It depended on the thermal processing method and the type of product. Thermal processing in water significantly changed the content of dietary fibre and the share of individual fractions.
3. Diabetics are recommended to use steaming as the preferable method of thermal processing of fruits and vegetables. Boiling and baking are not recommended.
4. The hemicellulose and cellulose fractions of dietary fibre have a beneficial effect on glycaemic index and load.

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