Review of research

THE OCCURRENCE OF SUGAR IN FRUITS, VEGETABLES, AND JUICES, AND ITS IMPACT ON THE DIET

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SUMMARY

Carbohydrates are an essential part of a healthy, varied diet. They naturally occur in vegetables and fruits and their products, including juices. Available research highlights the importance of the dietary source of carbohydrates, indicating that sugars derived from vegetables, fruits and juices cannot be treated only as the equivalent of "teaspoons" of sugar, as in case of, for example, sweets.

Available research results confirmed that fruits, vegetables and 100% fruit juices had no significant effect on the increase in fasting blood glucose and insulin. Although the mechanism by which 100% fruit juice does not affect glycemia is not clearly defined, it is believed that the presence of fiber and polyphenols may favorably influence glucose-insulin homeostasis. Notably, the consumption of fruit and 100% fruit juice affects the energy level of the diet. Thus, the amount of their consumption should be properly monitored so as not to lead to an excess of energy supply, which is a significant risk factor for metabolic disorders.

Juices with pulp, due to the presence of bioactive components, such as polyphenols, are characterized by high antioxidant potential. The results of numerous studies confirmed the cardioprotective, chemopreventive and neuroprotective effects of polyphenols present in juices. Regrettably, there is a lack of well-documented scientific data on the health effects of national fruits and their juices.

The use of juices in dietary recommendations for the elderly and/or children should be clarified in the context of the daily dose, in order to balance the benefits of hydration, antioxidant and protective effects on the cardiovascular and nervous systems, and certain risks associated with the risk of weight gain.

THE PHYSIOLOGICAL ROLE OF CARBOHYDRATES

Carbohydrates are macronutrients, which are very diverse in terms of their physiological functions.[1] Nutritionally and physiologically, carbohydrates are divided into two groups:

- **digestible carbohydrates**, i.e., those that are digested in the human gastrointestinal tract, then absorbed and used in cellular metabolism. Examples of such carbohydrates include glucose, fructose, and sucrose.
- **indigestible carbohydrates**, i.e., those that are not digested and absorbed in the human gastrointestinal tract. They may be partially hydrolyzed by intestinal bacteria. Examples of such carbohydrates include pectins.

Digestion and absorption of digestible carbohydrates

The process of digesting carbohydrates, especially starch, begins in the oral cavity. Salivary amylase begins to hydrolyze starch into maltose, maltotriose, and dextrins. In other words, salivary amylase initiates the process of cutting a long chain of interconnected simple sugars into smaller fragments. This does not take long, as carbohydrates, along with a food bite, are carried through the esophagus to the stomach. Due to the acidic environment in the stomach, salivary amylase is inactivated. However, partial digestion of disaccharides (sucrose and maltose) and oligosaccharides (dextrins) occurs to a limited extent due to the low pH.[2,3] Further digestion of carbohydrates takes place in the small intestine, mainly in the duodenum. Pancreatic amylase is secreted into the duodenum, which causes further hydrolysis of carbohydrates. In addition, intestinal juice contains other enzymes: glucoamylase and glycosidases, as well as lactase, sucrase and maltase, which break carbohydrates down into simple sugars.

As a result, carbohydrates are broken down into monosaccharides, i.e., simple sugars (simple carbohydrates), and then absorbed into the bloodstream and transported through the portal vein to the liver. It is believed that about 50% of the glucose is already absorbed in the duodenum and the remainder is absorbed in the jejunum. Moreover, fructose and galactose are partially absorbed in the proximal small intestine and from its central part, i.e., the jejunum.[4]

Metabolism of digestible carbohydrates

The metabolism of simple carbohydrates begins in the liver. There, most hexoses other than glucose are converted to glucose – some of them pass into the bloodstream, another part is oxidized in the liver, and another part is converted into glycogen as energy reserve.

The human body has limited capacity as regards storing digestible carbohydrates. They are mainly stored as glycogen contained in:

- muscles (about 157-350 g, which constitutes about 0.7% of the total human muscle mass). This type of glycogen is used directly for muscular work during physical activity;
- liver (about 60-120 g, which constitutes about 5% of the weight of this organ). This type of glycogen is used to regulate serum glucose, especially between meals.

When discussing carbohydrate metabolism, it is important to pay attention to fructose, which, unlike glucose, cannot be directly used as a source of energy by all cells of the human body.
First, fructose needs to be converted into glucose (e.g., in the liver), lactate or fatty acids. Only such an altered form of fructose may be used by the body. Notably, fructose metabolism leads to the formation of large amounts of 3-phosphoglyceraldehyde, which is considered a precursor of fatty acid synthesis. Therefore, fructose is considered to be a highly lipogenic substance.

A diet high in fructose may increase the risk of lipid disorders (e.g., by increasing triacylglycerols and LDL cholesterol), which are risk factors for heart disease. A study by Bantle et al. (2000)[5] revealed a significant increase in blood triglycerides in men whose diet provided 17% of the energy value from fructose. Schwarz et al. (2015)[6] also showed that a diet high in fructose (20-25% of energy intake in the form of fructose) contributed to a significant increase in hepatic lipogenesis and an increase in the number of atherogenic components of the plasma lipid profile. However, research is still ongoing to determine the optimal amount of fructose consumed. A review of research by Wiebe et al. (2011)[7] indicated that moderate amounts of fructose (<50 g per day) might help maintain normal blood glucose levels.

The literature emphasized the difference in fructose metabolism in the small intestine compared to fructose metabolism in the liver. As regards the small intestine, there is a mechanism that regulates the level of fructose absorption from the gastrointestinal tract depending on the dose, form (e.g., free or bound), and the presence of other nutrients.[8,9]
However, there is no conclusive evidence to confirm the role of fructose in the development of hypertension and weight gain. Therefore, it is necessary to conduct further research on the metabolism and the effects of fructose on human health.

Blood glucose circulates in the human body and is transported to the cells, which use it as fuel. Such cells include:

- brain cells (neurons),
- erythrocytes (red blood cells),
- muscle cells,
- myocardial cells.

Blood plasma glucose levels are maintained relatively constant by hormonal regulation. Two hormones are responsible for this process:

- Insulin, which is produced by the β cells of pancreatic islets. An increase in plasma glucose (e.g., after a meal) stimulates the pancreatic beta cells to produce and release insulin.[10] Increased plasma insulin levels lead to a decrease in glucose levels by:

- increasing the rate of carbohydrate metabolism and glycogen storage (glycogenogenesis) in the muscles and liver,
- increasing protein synthesis,
- increasing the synthesis of fatty acids,
- accelerating the rate of glucose oxidation processes in organs and tissues.

- Glucagon, which is produced by the α cells of pancreatic islets. It is an insulin antagonist and is secreted in response to a drop in plasma glucose levels.[11] Glucagon is released in the following situations:
  - hunger,
  - hypoglycemia,
  - physical exertion.

Glycogen synthesis is inhibited in the liver under the influence of glucagon, the process of glycogenolysis is initiated – the breakdown of glycogen and the release of glucose into the blood.

Both the deficiency and excess of glucose in the blood plasma may lead to serious consequences for the functioning of the human body.

According to the recommendations of the Polish Diabetes Association published in 2022,[12] fasting blood glucose should range from 70 to 99 mg/dl (3.9-5.5 mmol/l) in a healthy person.
Such a level of glucose allows the maintenance of the proper functioning of the central nervous system and red blood cells, which cannot use other sources of energy.

It is assumed that under normal conditions, the adult brain consumes about 140 g of glucose/day (which is about 20% of the basal metabolic rate), and erythrocytes use about 40 g of glucose/day.

Physiological significance of digestible carbohydrates

I. The most important physiological role of digestible carbohydrates is to provide the body with energy

Digestible carbohydrates constitute the basic source of energy for the human body necessary for:

- maintaining normal body temperature,
- internal organ functioning,
- undertaking physical activity.

The metabolic value associated with burning 1 gram of carbohydrates equals about 4 kcal (16 kJ). Carbon dioxide (CO_2) and water (H_2O) are the end products of the combustion of digestible carbohydrates. Carbohydrates provide about 50-60% of energy daily.

The brain has a high metabolic rate, and glucose oxidation is almost the exclusive source of energy for its functioning. Therefore, brain function is entirely dependent on a stable and adequate supply of glucose. While it was initially thought that only glucose deficiency (i.e., hypoglycemic conditions) could affect brain function, it is currently known that slight fluctuations in the availability of this sugar can affect neural function and, consequently, cognitive function. Some authors suggested that although a sharp rise in blood glucose produced a short-term improvement in cognitive function, a more stable blood glucose profile devoid of excessive fluctuations in blood glucose was associated with better cognitive function in a long-term perspective.[13]

II. They are involved in the process of fatty acid oxidation

Carbohydrates are essential for the oxidation process of fatty acids. An insufficient supply of carbohydrates with the diet causes a partial oxidation (combustion) of fatty acids and the formation of ketone bodies. Long-term high levels of ketone bodies in the body (i.e., ketosis) may lead to the development of ketoacidosis, which is dangerous for the body.

III. They are used for the synthesis of glucogenic amino acids

Carbohydrates, after appropriate transformation, may also be used for the synthesis of new amino acids, the so-called glucogenic amino acids, such as alanine, glutamic acid, aspartic acid, and proline.

IV. They participate in building cellular structures

Carbohydrates are found in the human body in combination with proteins and lipids, thus forming glycoproteins or glycolipids. Such molecules are used to build cellular structures.

V. They are components of DNA and RNA

Some carbohydrates (ribose and deoxyribose) are the basic structural elements of DNA and RNA. These acids are carriers of genetic information (e.g., hereditary traits). They also ensure the proper course of all metabolic processes occurring at the cellular level.

VI. Some carbohydrates participate in the process of mineral absorption

A disaccharide called lactose may be an example here. It helps in the absorption of calcium.

Deficiency and excess of digestible carbohydrates

Hypoglycemia occurs in case of glucose deficiency in the blood plasma, e.g., insufficient supply of carbohydrates in the diet. It is a condition in which glucose levels fall below normal. This triggers mechanisms to release glucose stored in the liver (liver glycogen) into the bloodstream and to balance the concentration of this simple carbohydrate in the blood plasma.

If the liver reserves are depleted, and the concentration of glucose in the plasma is low, the mechanism of gluconeogenesis, i.e., the synthesis of glucose from non-sugar sources such as protein, is activated. As a consequence, protein, instead of being used to build new structures, is used for the body's energy needs.

It should be remembered that the consumption of diets including a very low proportion of carbohydrates is not beneficial for the human body. Carbohydrates cannot be entirely excluded from the diet. It may lead to such issues as:

- ketosis, i.e., a condition in which the body produces energy from macronutrients other than carbohydrates, e.g., from fat accumulated in the adipose tissue. It should be noted that long-term ketosis is associated with negative health consequences. The symptoms of chronic ketosis are: fatigue, mood swings, impaired

concentration, loss of consciousness. Abnormalities of blood biochemical parameters are also observed, e.g., an increase in the concentration of triacylglycerols (triglycerides) or homocysteine in the serum. This, in turn, increases the risk of developing heart, liver, biliary tract diseases and osteoporosis.
- nutritional deficiencies (including vitamins A, B, C, and E, zinc, copper, and selenium),
- acidosis (decrease in blood pH below 7.35),
- in extreme cases, to death.

Indigestible carbohydrates

Indigestible carbohydrates include dietary fiber found in plant-based products.[14] It should be noted that dietary fiber is a heterogeneous group of chemical compounds, which includes:

- undigested polysaccharides (cellulose, hemicellulose, pectins, from non-carbohydrate components of lignin),
- plant gums and mucilages,
- enzyme-resistant starch (RS, resistant starch),
- undigested oligosaccharides,
- polydextrose.

In a physiological context, dietary fiber is resistant to the action of digestive enzymes. Therefore, their physiological role is different from that of digestible carbohydrates. Dietary fiber passes through the small intestine to the large intestine in an undigested form.
In the colon, it is exposed to the intestinal flora, which partially hydrolyzes dietary fiber. Increasing evidence indicates that dietary fiber acts as a prebiotic that influences the composition of intestinal microorganisms. Short-chain fatty acids (SCFA) are the product of anaerobic bacterial fermentation of dietary fiber and resistant starch. These acids play an important role in regulating pH, increasing the absorption of calcium, iron and magnesium in the intestine, and have a beneficial effect on glucose and protein metabolism in the liver. SCFAs play a crucial role in maintaining the proper structure, integrity and function of the intestine. By stimulating the growth of saprophytic flora, they inhibit the development of other pathogens, such as *Escherichia coli*, *Campylobacter* or *Salmonella*, competing for the site of colonization. The acceleration of the healing processes and regeneration of the intestinal epithelium is an important function of SCFA in the body confirmed in numerous available clinical studies.[15]

Physiological significance of indigestible carbohydrates

Physiologically, indigestible carbohydrates have four important functions:[16]

- reduction of intestinal transit time and the simultaneous increase in the volume of stool,
- stimulation of fermentation processes in the large intestine,
- reduction of the concentration of total cholesterol and LDL fraction in the blood plasma,
- lowering postprandial plasma glucose and/or insulin levels.

Research results indicated that dietary fiber had a protective effect in relation to obesity. There is an inverse relationship between fiber intake and the occurrence of obesity. This relationship is due to some factors, including the fact that fiber slows down the rate of increase in glucose concentration, thanks to which the increase in insulin concentration in the postprandial period is smaller. Thus, the presence of fiber in the diet reduces the risk of hyperinsulinemia and insulin resistance related to it.[17,18] In addition, fiber prolongs the feeling of satiety by prolonging the time of food consumption resulting from longer chewing of food and slowing down gastric emptying.[19]

CARBOHYDRATE PROFILE IN VEGETABLES, FRUITS AND JUICES

The content of selected carbohydrates, including simple sugars, in domestic vegetables and fruits was described in detail by Kunachowicz, Nadolna, Iwanow & Przygoda (2017).[20] They provided data on the amount of water, fiber, as well as sucrose, glucose and fructose in 100 g of vegetables/fruits. Data concerning these components are summarized below. The Supplement to the report presents tabularized quantitative data.

Carbohydrate profile in domestic vegetables

As regards vegetables available in Poland, the carbohydrate profile including: monosaccharides (glucose and fructose), disaccharides (sucrose) and polysaccharides (fiber), may be characterized as follows:

- vegetables with the highest fiber content: dry white beans (15.7%)* and dry soybeans (15.7%) (Fig. 1),
- vegetables with the highest sucrose content: beet (6.5%) and horseradish (5.9%) (Fig. 2),
- vegetables with the highest glucose and/or fructose content: red pepper (2.1%/2.4%), red and white cabbage (2.1%/1.3% and 2.0%/1.7%) (Fig. 3),
- vegetables with the highest calorie content: dry soybeans (413 kcal/100 g), dry lentils (341/100 g) and dry white beans (315/100 g) (Fig. 4).

Notably, the content of glucose, fructose and sucrose in the vegetable varieties available in Poland is relatively low. The highest glucose or fructose content was recorded in peppers and cabbage, but their share does not exceed the limit of 2.5%. In case of sucrose content in vegetables, the share of which is the highest in beets or horseradish, it does not exceed the level of 7%. It should also be noted that some vegetables available on the domestic market have a high fiber content, which exceeds 15% in case of dry soybeans and white beans.

* The percentage calculated as the weight of a carbohydrate component in grams per 100 g of the product

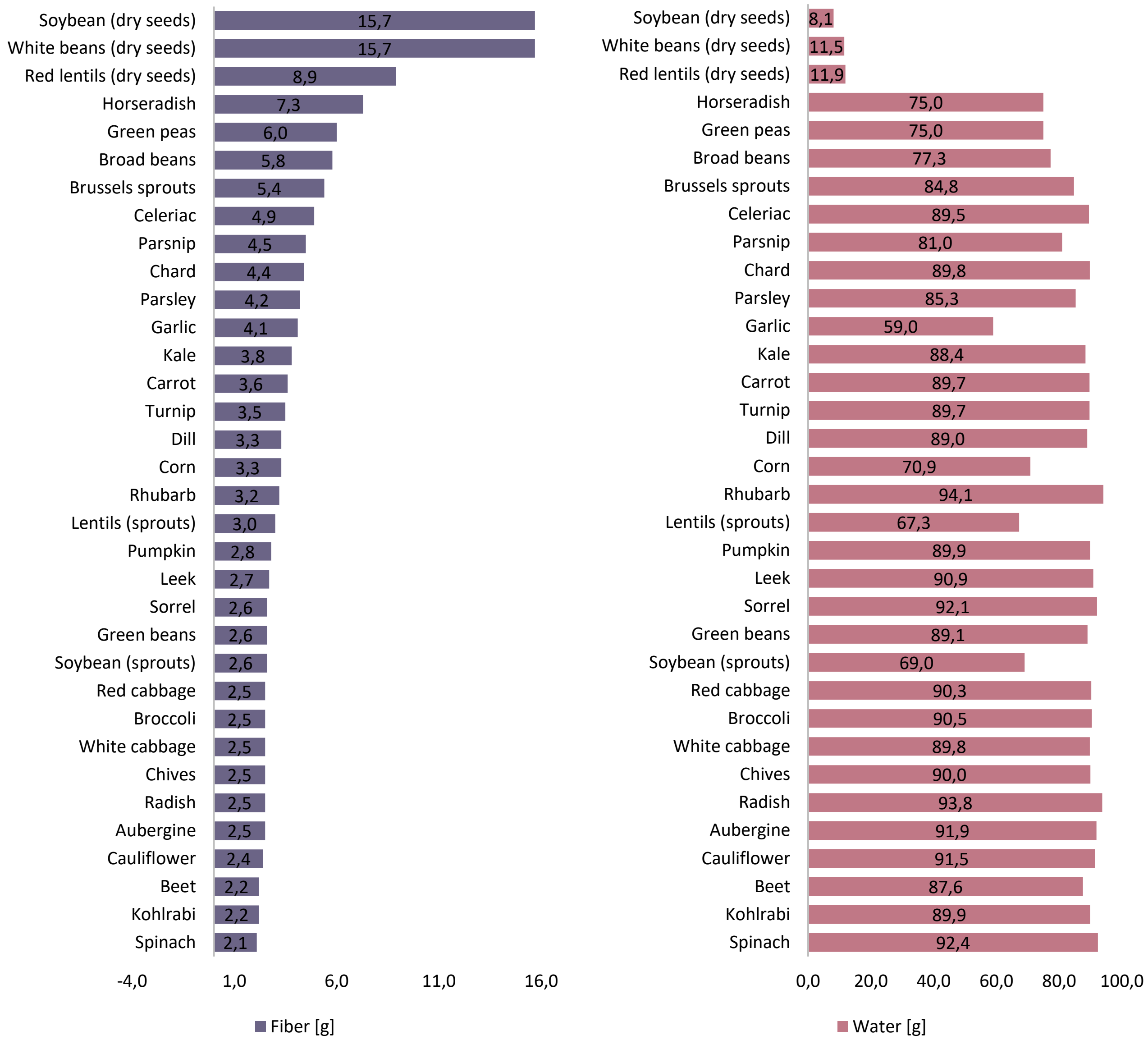

Figure 1. The content of fiber [in g] and water in 100 g of selected domestic vegetables (the figure does not include vegetables with the fiber content below 2 g) [data based on Kunachowicz et al. (2017)].[20]

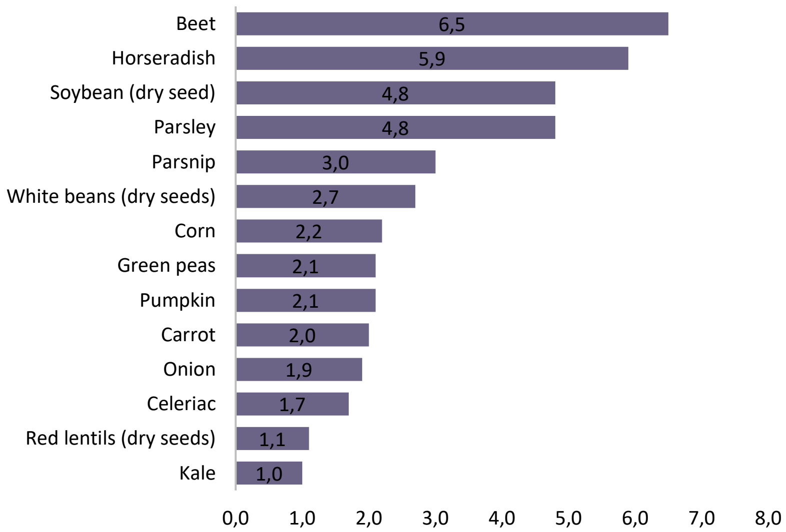

Figure 2. Sucrose content [in g] in 100 g of selected domestic vegetables (the figure does not include vegetables with the content <1 g) [data based on Kunachowicz et al. (2017)].[20]

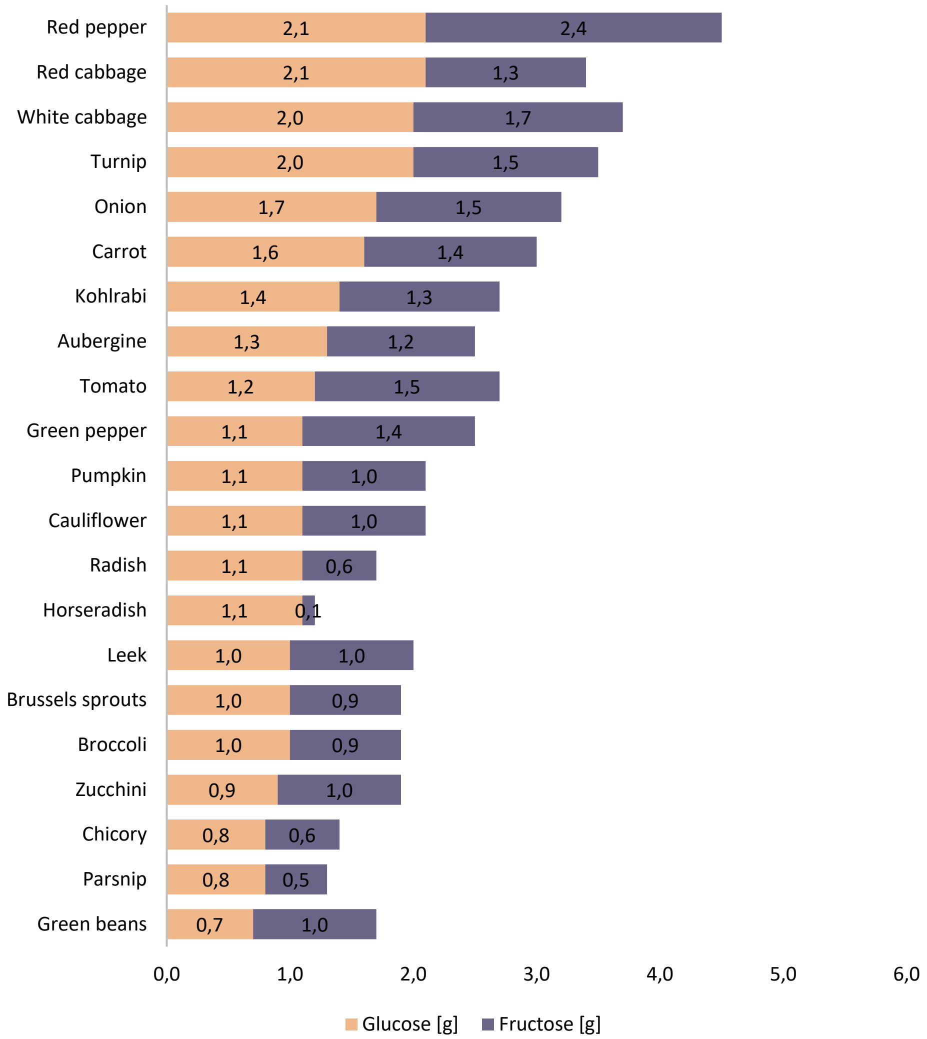

Figure 3. The content of glucose and fructose [in g] in 100 g of selected domestic vegetables (the figure does not include vegetables with the content below 1 g) [data based on Kunachowicz et al. (2017)].[20]

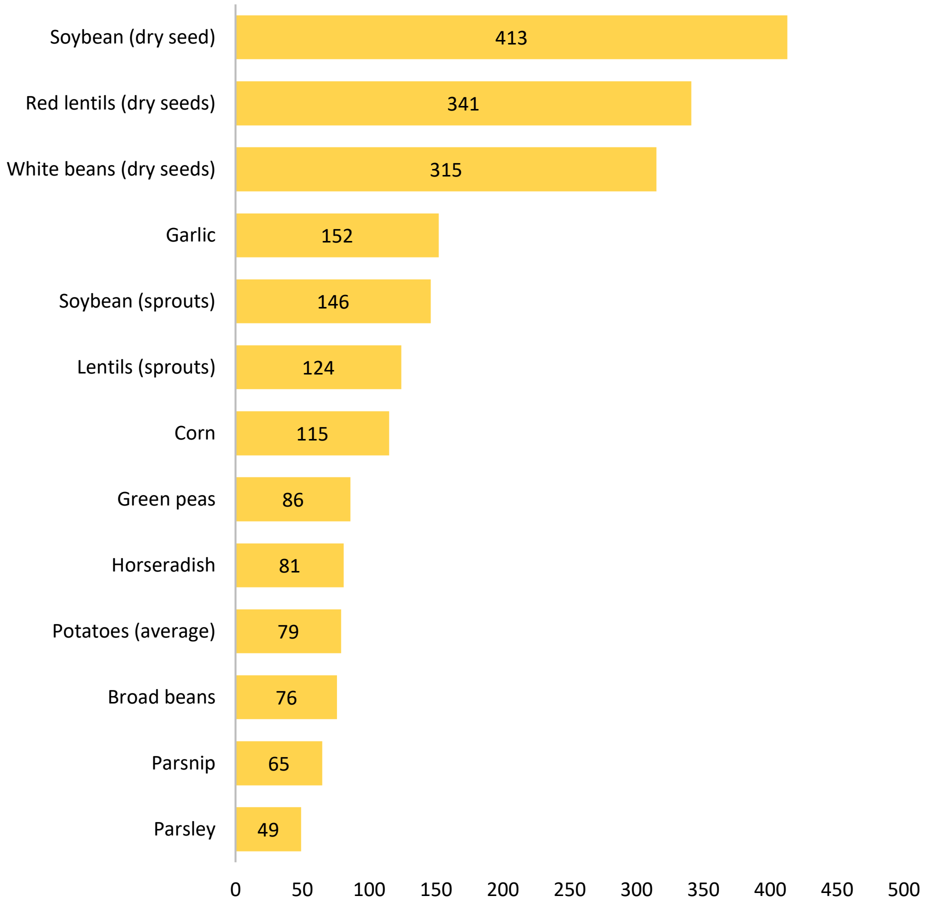

Figure 4. Energy value [kcal] in 100 g of selected domestic vegetables (the figure does not include vegetables with the value <50 kcal) [data based on Kunachowicz et al. (2017)].[20]

Carbohydrate profile in domestic fruits

As regards fruits available in Poland, the carbohydrate profile including: monosaccharides (glucose and fructose), disaccharides (sucrose) and polysaccharides (fiber), may be characterized as follows:

- fruits with the highest fiber content: black and red currant (7.8% and 7.7%, respectively) and raspberry (6.7%) (Fig. 5),
- fruits with the highest sucrose content: nectarine (6.3%), peach (5.2%) and apricot (5.1%) (Fig. 6),
- fruits with the highest glucose content: sweet cherry and sour cherry (6.1% and 4.6%, respectively) (Fig. 7),
- fruits with the highest fructose content: pear (6.2%), sweet cherry (5.4%), apple (5.4%) (Fig. 7),
- fruits with the highest calorie value: sweet cherry (63 kcal/100 g) (Fig. 8).

It is worth noting that the fiber content in the fruit varieties available in Poland is <8%. Sucrose content is similar to that of vegetables, i.e., <6%. Conversely, there is a higher content of monosaccharides (glucose and fructose) compared to vegetables, particularly with regard to fructose content, which low in vegetables. Despite the increased content of monosaccharides, the energy density of the analyzed fruits is lower than 60 kcal/100 g (for comparison, the average energy value of 100 g of potatoes is ~80 kcal).

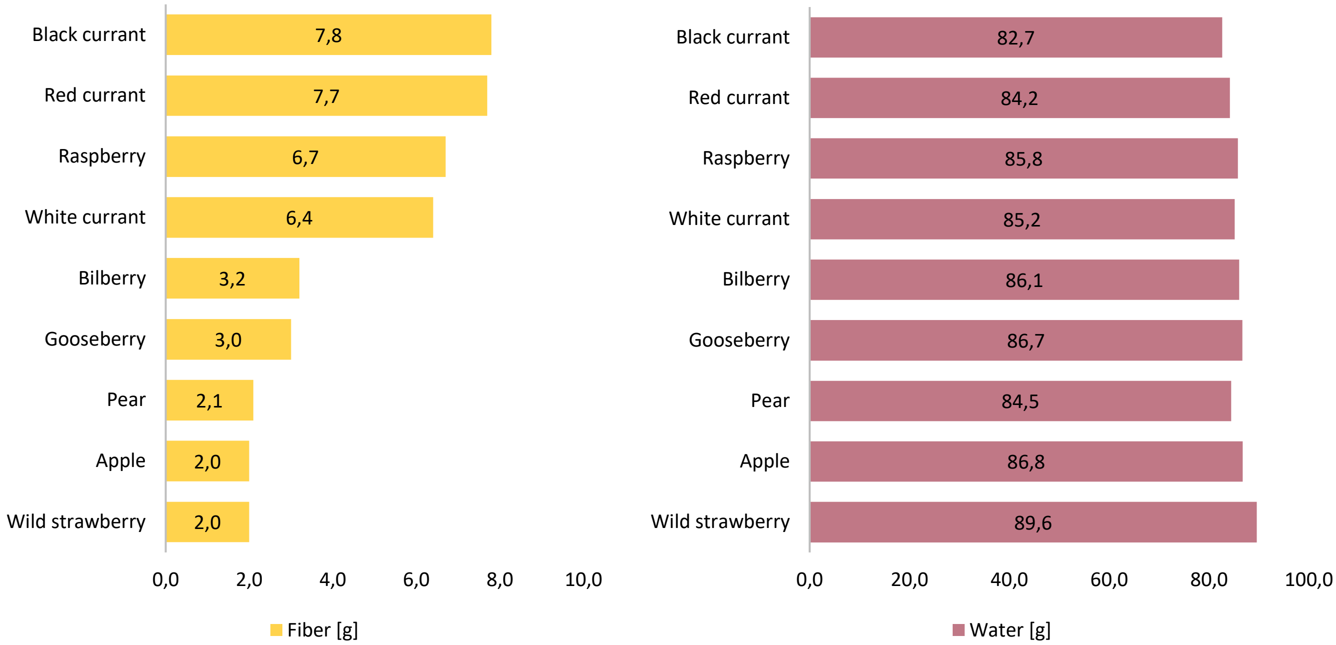

Figure 5. The content of fiber [in g] and water in 100 g of selected domestic fruits (the figure does not include fruits with the fiber content below 2 g) [data based on Kunachowicz et al. (2017)].[20]

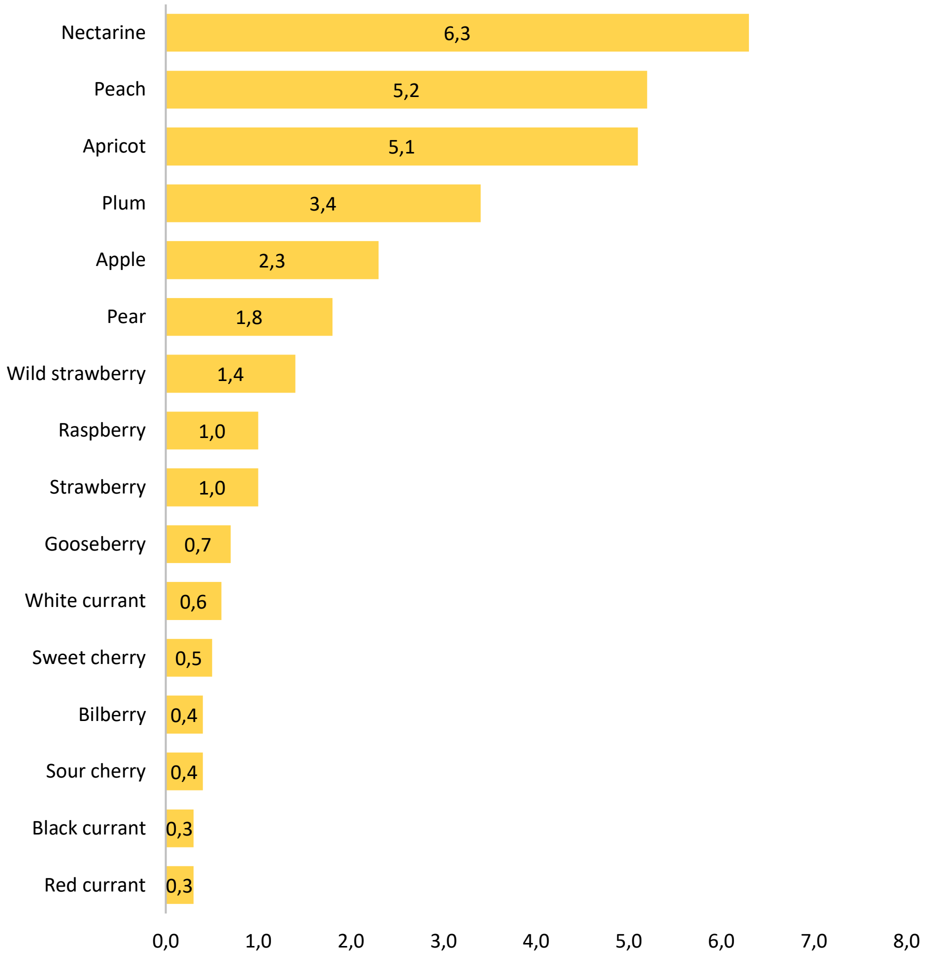

Figure 6. Sucrose content [in g] in 100 g of selected domestic fruits [data based on Kunachowicz et al. (2017)].[20]

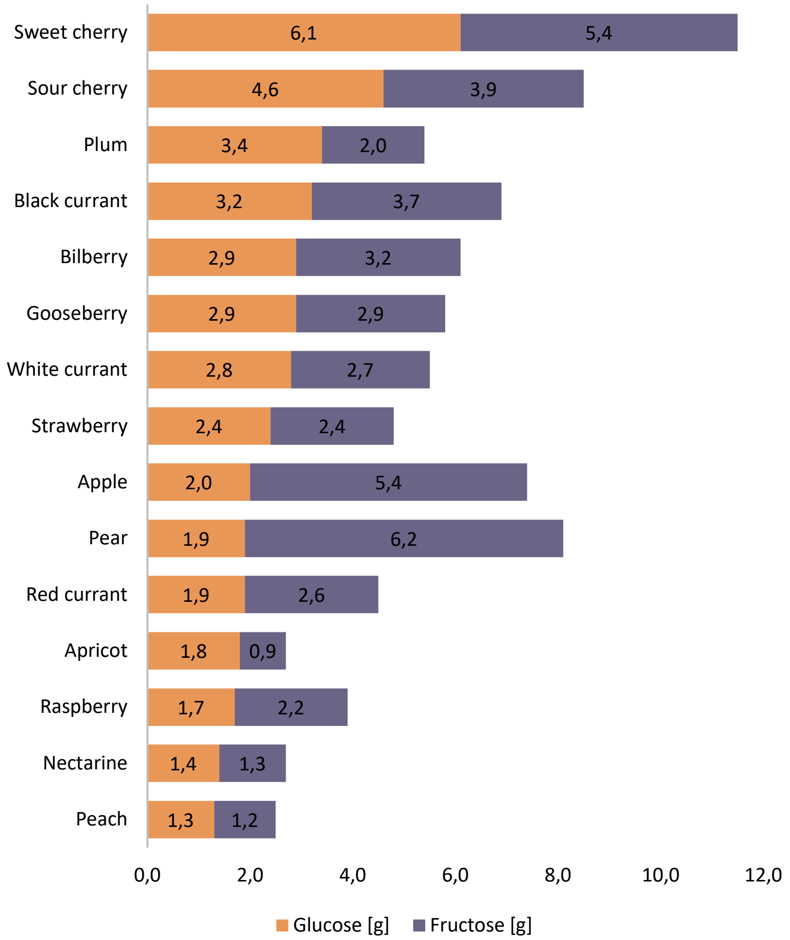

Figure 7. Glucose and fructose content [in g] in 100 g of selected domestic fruits [data based on Kunachowicz et al. (2017)].[20]

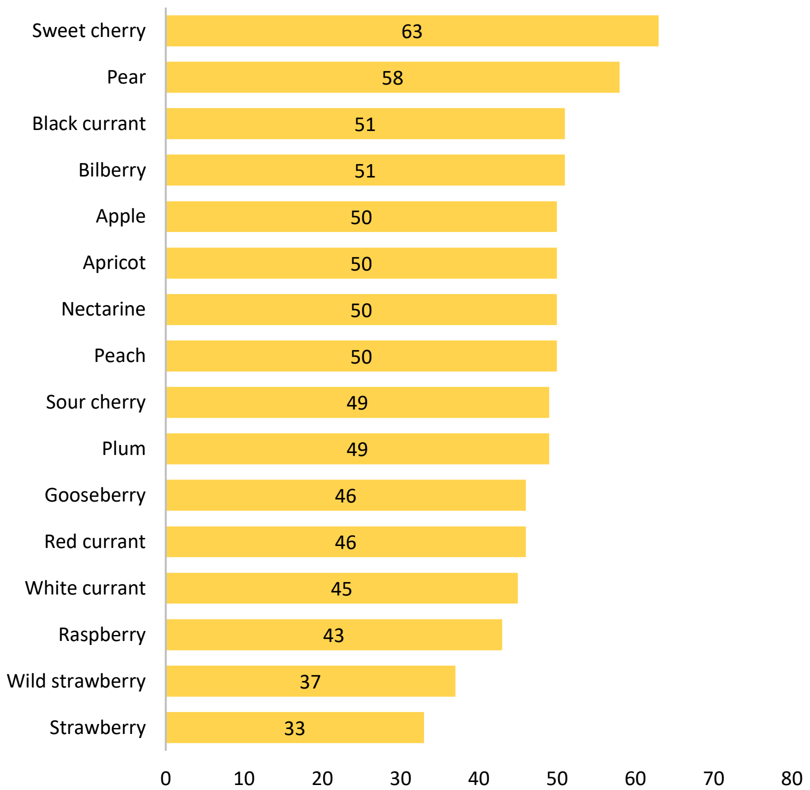

Figure 8. Energy value [kcal] in 100 g of selected domestic fruits [data based on Kunachowicz et al. (2017)].[20]

Carbohydrate profile in juices from domestic fruits and vegetables

As regards the group of fruit and vegetable juices, it is not easy to determine the carbohydrate profile including: monosaccharides (glucose and fructose), disaccharides (sucrose) and polysaccharides (fiber). The tables of content prepared by Kunachowicz et al. (2017)[20] were developed during the period when it was permissible to add sugar to juices (sweetening).

Therefore, juices available on the market contained not only sugars that naturally occurred in vegetables and fruits, but also additional quantities of sugar added in the production process (this could account for up to 40-50% of the additional amount of sugar compared to natural sugars). Currently, all fruit, tomato and 100% vegetable juices are composed on the basis of natural purees and juices by mixing them in various proportions. However, with the exception of their fiber content, the types of sugars and water are found in juices in the same quantities as in the fruits and vegetables from which they are made. Water or sugars cannot be added to juices. This applies to fruit juices, tomato juices and 100% vegetable juices, juices reconstituted from concentrated juice, NFC juices, fresh juices (to be consumed within 1 day) and freshly squeezed juices. Exceptions are made for certain vegetable juices, whose taste may be improved by adding sugar. However, such information needs to be indicated in the *Ingredients* of the product. It should be noted here that, as regards the process of producing juices reconstituted from concentrated juice, a maximum of water that may be added to the concentrated juice equals the amount previously evaporated. Therefore, it is possible to estimate carbohydrate profiles (Fig. 9-11), water content (Fig. 12) and energy value (Fig. 13) of these juices in relation to the data on fruit and vegetables. Using the data provided by *FoodData Central*,[21] the content of sugars and water was estimated and compared to the data for these ingredients given for fruit and vegetables according to Kunachowicz et al. (2017).[20] It should also be noted that the fiber content depends on whether it will refer to puree juice, naturally cloudy juice or clear juice. Puree juices contain the most fiber. The amounts are similar to the fiber content of the fruit or vegetables from which they are prepared.

In addition, it should be emphasized that the carbohydrate content of fruits and vegetables and the juices obtained from them is variable, because it depends on the variety, region, weather, exposure to sunshine, amount of rainfall, season, degree of ripeness and many other factors to which fruits and vegetables are exposed in the natural environment. Therefore, the available literature data differ to some extent due to the above mentioned conditions.

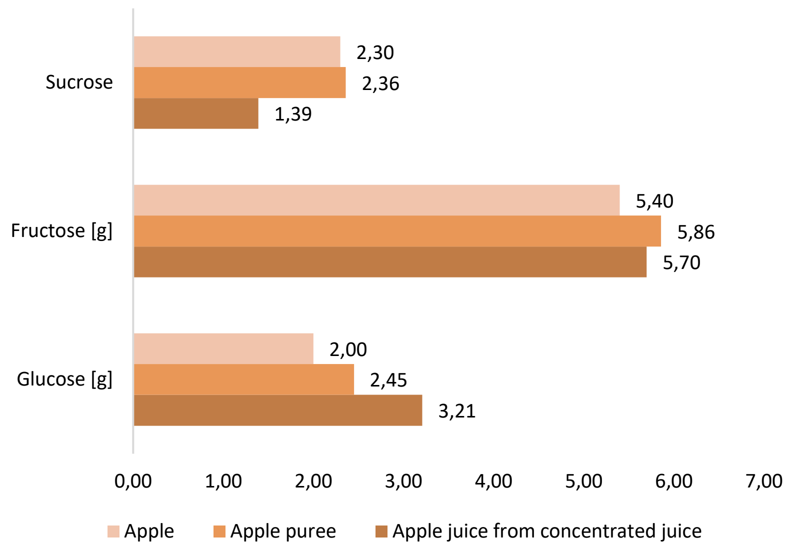

Figure 9. Carbohydrate profile [in g] in 100 g of apples [data according to Kunachowicz et al. (2017)[20]] and in 100 g of their products [data according to *FoodData Central*[21]].

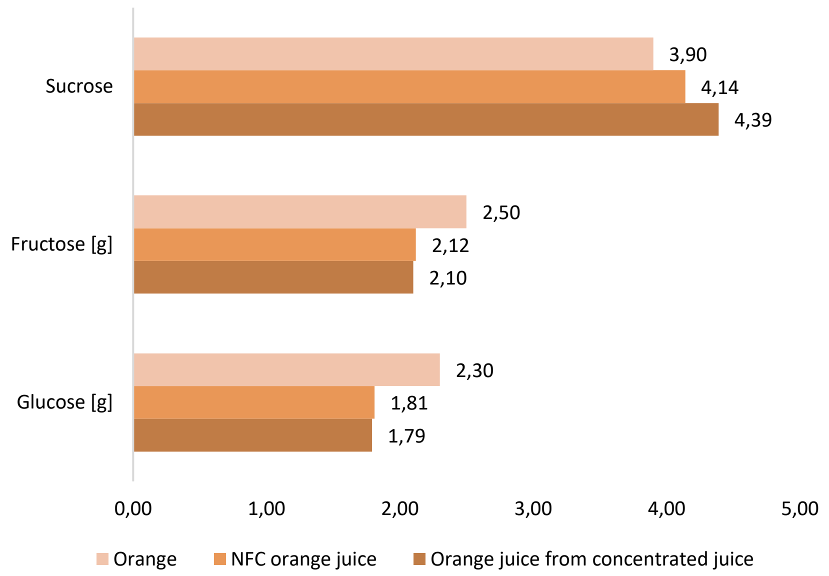

Figure 10. Carbohydrate profile [in g] in 100 g of oranges [data according to Kunachowicz et al. (2017)[20]] and in 100 g of their products [data according to *FoodData Central*[21]].

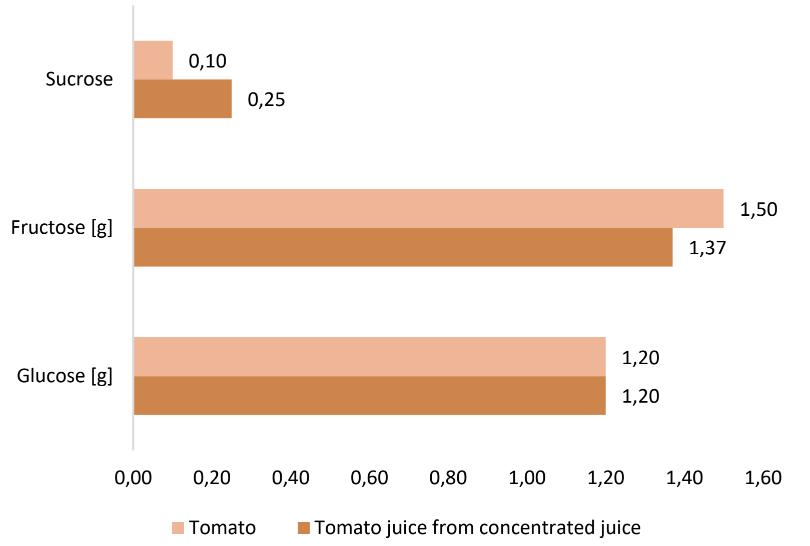

Figure 11. Carbohydrate profile [in g] in 100 g of tomatoes [data according to Kunachowicz et al. (2017)[20]] and in 100 g of their products [data according to *FoodData Central*[21]].

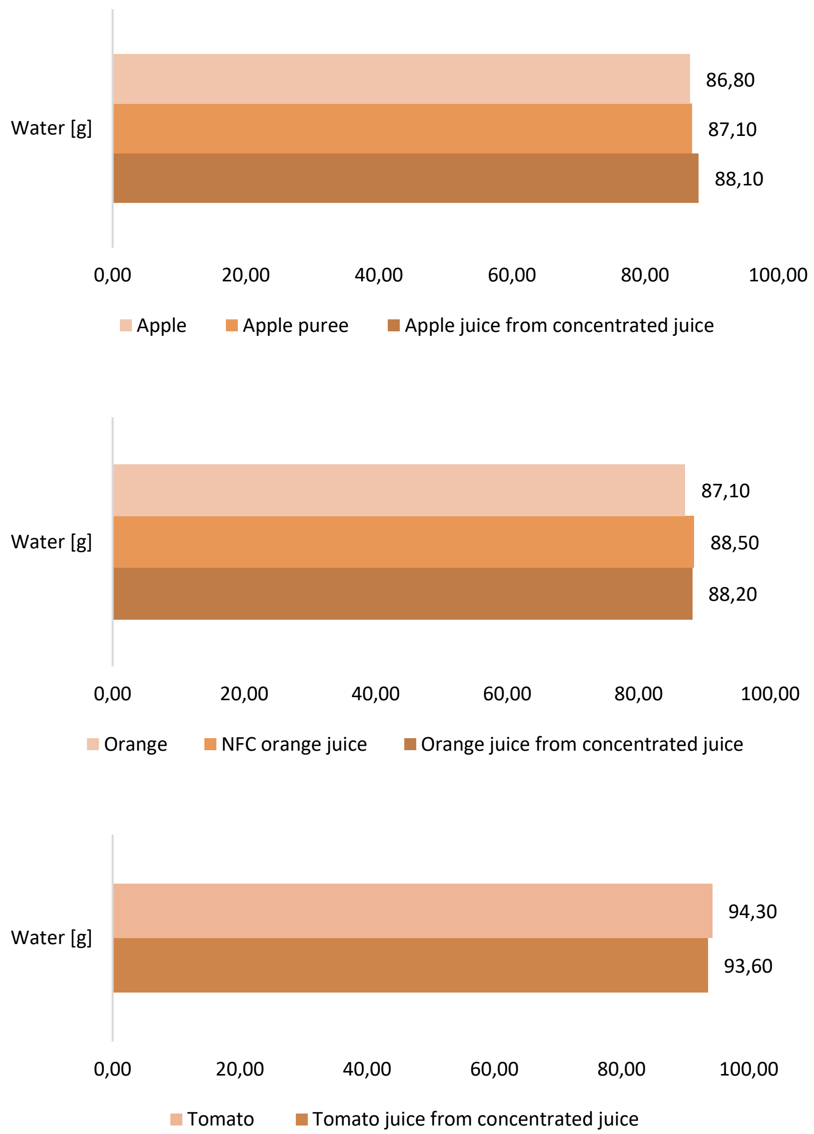

Figure 12. Water content [in g] in 100 g of fruits [data according to Kunachowicz et al. (2017)[20]] and in 100 g of their products [data according to *FoodData Central*[21]].

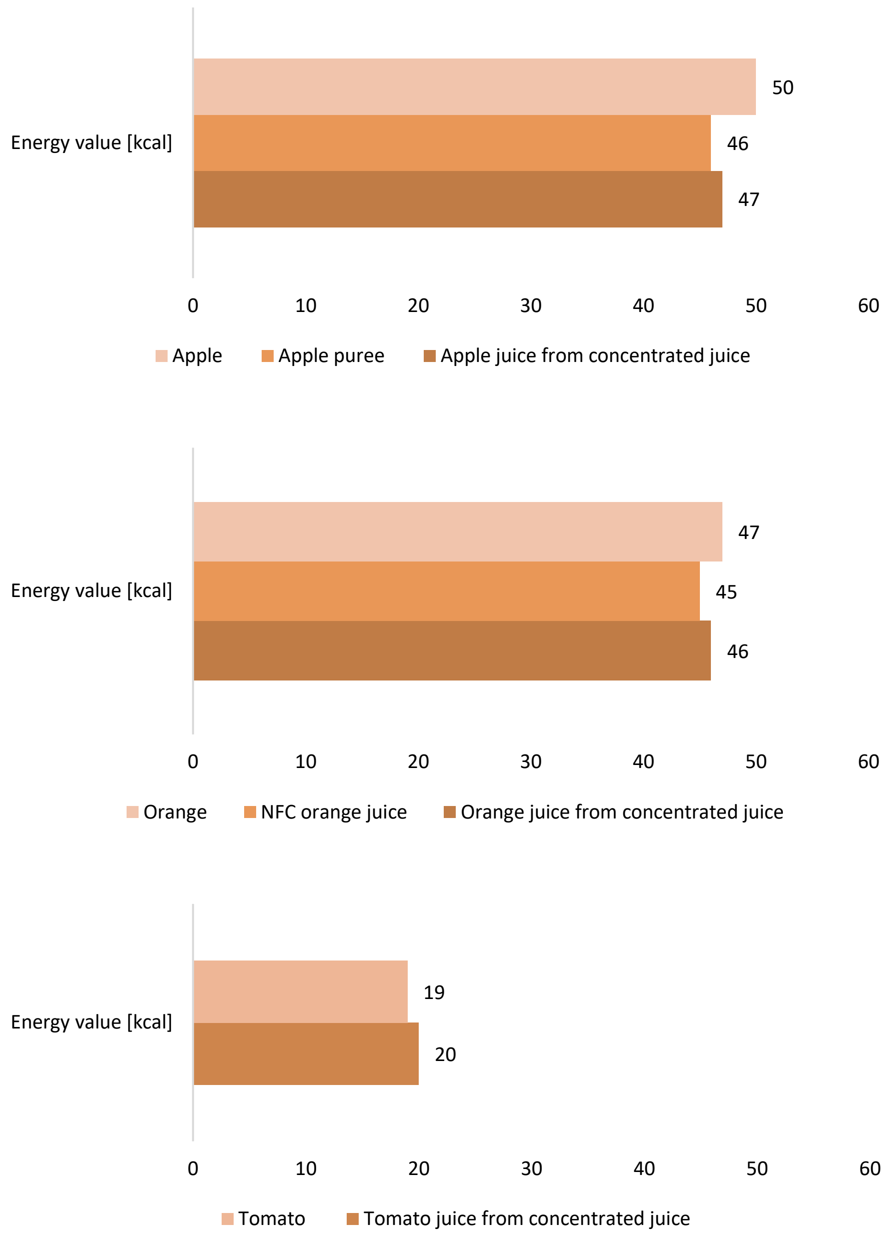

Figure 13. Energy value [in kcal] in 100 g of fruits [data according to Kunachowicz et al. (2017)[20]] and in 100 g of their products [data according to *FoodData Central*[21]].

THE EFFECT OF CARBOHYDRATES FROM VEGETABLES AND FRUITS ON THE BODY

Providing the body with carbohydrates (including mono-, di-, oligo- and polysaccharides) contained in fruits, vegetables and 100% juices, i.e., being part of the so-called matrix made of plant tissues, is not physiologically simultaneous to providing them in products such as beverages and food, where sugars (mainly sucrose) are added during the production process. Available scientific data indicated that the consumption of carbohydrates derived from fruits or vegetables and 100% juices were beneficial for health,[22-24] in contrast to such sources of sugars in the diet as sweetened drinks or sweets.[25]

The most abundant sugars in plants (as discussed above) include monosaccharides, i.e., simple sugars – glucose and fructose, and disaccharides – maltose and sucrose.[26] Galactose (a monosaccharide) and, especially, lactose ("milk sugar", a disaccharide containing galactose and glucose) are more commonly associated with food of animal origin – due to their presence in milk. However, free, oligomeric and polymeric forms of galactose are common in plant tissues.[27] The properties of monosaccharides (fructose, galactose, glucose, maltose and sucrose) are discussed elsewhere in this report (see page 4).

Monosaccharides and disaccharides in the diet

As regards the consumption of foods containing carbohydrates, such as monosaccharides and disaccharides, there are three interesting issues that need to be clarified:

1. **Are such carbohydrates essential in the diet?** The answer is that they are desirable and important as part of a varied and balanced diet.

2. **With regard to a balanced diet, is it simply about controlling the amount of sugars consumed, and not about the fact of what is their source?** The answer is that a balanced diet is, among others, maintaining an equilibrium between the demand and supply of energy. However, this issue includes not only carbohydrates, but also lipids and proteins. Moreover, a varied and balanced diet should ensure that the right amount of micro- and macronutrients is provided with food. Therefore, not only the amount of sugars consumed is important for health, but also what other important components are provided with them in food. Thus, it cannot be considered that the consumption of fruits with a certain amount of monosaccharides (glucose, fructose) is the same as

the consumption of sweetened drinks or sweets containing the same sugar equivalent.

3. **Is it a problem that sugar (such as plant-derived sucrose or glucose-fructose syrup) is used as a purified ingredient added to beverages and confectionery and dominates the diet in this form, or that sugars are consumed at all, e.g., in the form of fruits or vegetables?** The answer to this question is not obvious. While the excess of sugars consumed (regardless of their source) is not beneficial for health as it may lead to obesity or the development of diabetes, their consumption from sources such as fruits and vegetables has important health-promoting properties. Therefore, it should be concluded that focusing on the total energy balance is the essence of a proper diet, so the presence of the right amount of sugars is necessary and desirable.[28] It is also important to note how sugars contained in vegetables and fruits influence the human body, and it is known that they act in a different way than sugars derived from sweets or carbonated and non-carbonated sweetened beverages.

Benefits of consuming fruits and vegetables as a source of carbohydrates

The benefits of consuming fruits and vegetables as a source of carbohydrates in the diet may be presented in the following aspects:

- The content of monosaccharides and disaccharides in fruits is about 10%, where the presence of water and other components in the tissue cause dilution and reduce the amount/volume that can be ingested as a portion. It constitutes a kind of "a brake" in terms of excessive consumption (of sugars) due to the feeling of satiety that is ensured by the consumption of whole fruits/vegetables.

- A varied diet including natural and low-processed foods is very important. Food production in the technological process sometimes leads to the removal of important nutrients, and sometimes it contributes to concentration, such as in the production of sucrose from beets and sugar cane, which is done at the expense of other nutrients. The pure sugar (sucrose) obtained in this way, although it is of vegetable origin, does not contain important ingredients that are present in vegetables, fruits or 100% fruit, tomato and vegetable juices.

- Sugars in an aqueous solution are very easily absorbed from the human small intestine. Therefore, sweetened drinks provide the body with large amounts of easily digestible monosaccharides. This has such consequences as a sudden increase in glycemia after ingestion and an increased load on pancreatic beta cells due to the high demand for insulin. This process is particularly rapid if it is not accompanied by monosaccharides, e.g., fiber or other bioactive components, such as polyphenols, which slow down the absorption process. Even if complex carbohydrates, such as polysaccharides, are broken down (depolymerized) into simple sugars, they require a much longer time to be released in the process of enzymatic degradation. In addition, the molecules of simple sugars formed in the digestion process are absorbed more slowly, which translates into a smaller increase in glycemia after consumption. The kinetics of absorption is not so dynamic in this case, and the peak of glycemia is not as acute.

- Complex and resistant forms of starch, a glucose polymer, are slowly (if at all) digested by humans, especially if they are obtained from food that has not been heat-treated, which is the case with the consumption of raw vegetables.[29] Maceration and cooking are expected to accelerate the process of digesting starch and releasing glucose molecules from this natural polymer, which accelerates the absorption and an increase in glycemia.[30] Interestingly, this assumption is true for boiled potatoes (about 17% starch content), but not for boiled carrots (about 0.3% starch content).[31]

- Nutrient intake should be in harmony with the body's use of nutrients. For comparison, does a can of sweetened beverage (not to be confused with juice) containing 11% of sucrose provide the same balance of nutrients as, for example, eating an apple or a pear? The fruit provides a slower consumption process (the need to chew), a wider range of nutrients, a longer feeling of satiety, access to glucose and nutrients limited by the dynamics of digestion and intestinal transit processes. Sugar contained in a sweetened beverage is quickly absorbed and isolated from other nutrients. It is also easier to provide sugar in excess, for example in a sweetened drink, than as a result of eating fruit or vegetables. It is also worth mentioning here that Murphy et al. (2017)[32] indicated that fruit juice had a neutral effect on glycemic control and was not associated with an increased risk of diabetes.

- The human intestine sometimes has difficulty coping with an excess of simple sugars in the form of solutions in a short time, which may lead to osmotic diarrhea.[33] Therefore, it is more natural to consume sugars “trapped” in the plant matrix, where they are located in cellular structures and the matrix of fruits or vegetables.

- Dried fruits typically contain between 40% and 80% of sugar.[34] There are many unknowns concerning the process of dried fruit digestion, although they are considered healthy even with their high sugar content, and not only because of their broad nutrient profile. They are rich in antioxidants/polyphenols.[35]

- Dried fruits may lower the glycemic index of white bread.[36,37] This is partly due to the fact that the glycemic index of sucrose in dried fruit is lower than the glycemic index of glucose produced via the hydrolysis of amorphous starch in white bread. Sugar-free ingredients in dried fruits are also used to dilute starch and, thus, reduce the overall glycemic index. Similar results for rice and dried fruit were reported by Zhu et al. (2018).[38] Broader conclusions regarding the role of dried fruits in the diet were formulated by Hernández-Alonso et al. (2017),[34] who discussed how the composition of nuts and dried fruits made them useful in counteracting metabolic diseases such as type 2 diabetes.

- Sadler et al. (2019)[35] highlighted a number of health benefits associated with the consumption of dried fruits: the nutrients in dried fruits are equivalent to fresh fruits, although they are more concentrated; there is no evidence that the consumption of dried fruits promotes tooth decay; dried fruits can provide appetite control; dried fruits are rich in dietary fiber and polyphenols – some of them are rich in sorbitol, which has laxative properties and increases stool mass.

- Processes related to the production of juices, such as pasteurization, may also be important for the bioavailability of certain bioactive components. Aschoff et al. (2015)[39] analyzed the bioavailability of β-

> cryptoxanthin (provitamin A) contained in freshly squeezed orange juice and pasteurized juice. They noted that pasteurization contributed to an increase in bioavailability. Moreover, both types of juices were characterized by a much higher bioavailability of the total of carotenoids compared to fresh orange fruits. Similar observations were made as regards an increase in the bioavailability of β-carotene from thermally pasteurized carrot juice[40] and the bioavailability of lycopene from pasteurized tomato juice.[41]

Providing carbohydrates and, most of all, monosaccharides is more beneficial for health if their sources are fruits, vegetables and 100% juices, rather than sugar extracted, for example, from beets (like sucrose).[25] These ingredients, as part of the natural matrix of plant tissue, are consumed in smaller amounts (restriction of intake), at the same time providing access to a wide range of other important nutrients included in fruits and vegetables. Issues related to the rate of absorption are much more difficult to define, although there are also scientific indications of benefits related to eating fruits and vegetables in this respect.

VEGETABLES, FRUITS AND JUICES VS TYPE 2 DIABETES

The effect of carbohydrate intake on the incidence of type 2 diabetes depends on the type of carbohydrate consumed. If fructose is consumed in small amounts, it is slowly absorbed and converted into glucose and lactate in the intestines, which prevents a surge in glycemia.[42] However, when consumed in large quantities, it reaches the microflora colonizing the colon and is delivered to the liver, where it promotes *de novo* lipogenesis and fatty liver (see page 5).[43] Compared to animal studies,[44] human studies provided little direct evidence concerning an association between the consumption of sugars (such as fructose and sucrose) and the development of type 2 diabetes.[45] However, it is known that beverages containing high-fructose corn syrup may pose a risk of developing metabolic syndrome and nonalcoholic fatty liver disease.[46] A meta-analysis showed that high fiber intake reduced the risk of developing type 2 diabetes by 20-30%.[47] Therefore, the type and amount of carbohydrates consumed may modify the risk of developing type 2 diabetes.

Bondonno et al. (2021)[48] evaluated the association between fruit and fruit juice consumption and the risk of type 2 diabetes in the Australian Diabetes, Obesity and Lifestyle Study (AusDiab). The participants were divided into four groups according to their median total fruit intake at baseline which was found to be inversely correlated with insulin secretion and positively correlated with insulin sensitivity. In addition, postprandial blood glucose levels were significantly lower and insulin sensitivity was significantly higher in the highest intake group compared to the lowest intake group. The authors also investigated the association between high fruit intake and the prevention of type 2 diabetes. Total fruit intake showed a non-linear, inverse association with the onset of the symptoms of type 2 diabetes. The group consuming moderate amounts of fruit (230 g per day) showed a 36% lower incidence of type 2 diabetes after 5 years of follow-up than the group consuming the lowest amounts. The incidence of type 2 diabetes was lower in those who consumed moderate to high amounts of fruit. In particular, apple intake was inversely correlated with serum insulin levels, pancreatic beta cell activity, and tissue insulin sensitivity.[48]

In response to the results of the AusDiab study, it may be hypothesized that dietary fiber reduces glycemic load and is associated with beneficial intestinal microflora, which promotes satiety through a greater production of short-chain fatty acids and GLP-1 secretion.[49] Flavonoids are known to improve tissue sensitivity to insulin, causing beta cell proliferation and reducing muscle inflammation. Moreover, small amounts of fructose do not increase plasma glucose levels, despite its high sweetness. Fructose also induces the secretion of two hormones that influence appetite: GLP-1 in the intestine and fibroblast growth factor 21 (FGF-21) in the liver. GLP-1 induces a feeling of satiety by influencing the areas of the brain involved in the regulation of feeding. Both fructose and sucrose stimulate the secretion of FGF-21 protein, which reduces the intake of monosaccharides, and since fruits are rich in fructose, their consumption may be associated with fructose-induced secretion of GLP-1 and FGF-21. Finally, it is known that chewing food suppresses appetite,[50] and, given that the consumption of fruit juices is not associated with the development of type 2 diabetes, chewing whole fruits may additionally protect against type 2 diabetes. Thus, fruit consumption may reduce the risk of type 2 diabetes in several ways.[49]

Further research is needed to elucidate why 100% fruit juices do not affect the risk of type 2 diabetes and to assess whether fruit consumption is useful in maintaining good glycemic control in patients with type 2 diabetes.

Polyphenols and glycemia

It has been observed that polyphenols contained in vegetables, fruits and juices have a great potential to reduce the risk of diabetes and its treatment, because they show several beneficial physiological effects related to carbohydrate management and glycemic control. Their mechanism of action includes the reduction of oxidative stress, inhibition of DPP-IV (dipeptidyl peptidase 4) and enzymes responsible for carbohydrate metabolism and the reduction of insulin resistance.

Flavonoids (including the subclasses of flavones, flavonols, flavanones, flavanols, anthocyanidins, isoflavones) were found to support pancreatic β-cell survival and function through molecular mechanisms that include reducing oxidative stress, increasing the expression of anti-apoptotic genes (e.g., Bcl-2 protein), and decreasing the expression of proapoptotic genes (e.g., caspase-3 and caspase-8) and DNA damage, protecting them from autophagy, apoptosis, necrosis, and cell damage under hyperglycemic conditions.[51] Scientific evidence also suggested that phenolic metabolites and phenolic acids might reduce oxidative stress, inflammation and protein glycation, inhibit key enzymes associated with carbohydrate metabolism, increase the expression of glucose transporter 4 (GLUT-4) and glucose uptake. All these effects improve glycemic control along with the activation of pathways responsible for signaling and insulin secretion.[52,53]

Recently, it has been found that some phenolic compounds might inhibit the activity of digestive enzymes, and reduce the hydrolysis of carbohydrates and fats.[54] Possible mechanisms by which anthocyanins inhibit the activity of digestive enzymes include competitive interactions between these compounds and enzyme substrates, and even through interactions with the active site of enzymes, consequently reducing their catalytic activity.[55]

Incretins are essential for glycemic homeostasis because they are involved in insulin secretion, transcription, and biosynthesis. They lower glucose levels by engaging G protein-coupled receptors, act as regulators of glucagon release, reduce appetite and food intake, and delay gastric emptying and effects on fat metabolism. Therefore, the use of agents that may inhibit DPP-IV can be considered a promising approach to glycemic control and the course of diabetes. In this context, Fan et al. (2013)[56] demonstrated that polyphenols commonly present in fruits and vegetables had a good inhibitory effect on DPP-IV, i.e., resveratrol, luteolin, apigenin and flavone.

Recommendations related to the consumption of fruits and vegetables due to the presence of bioactive compounds, such as polyphenols, are related to their ability to inactivate reactive oxygen species. It helps maintain the oxidative-reductive balance, increases the resistance of cells to oxidative stress, which may help prevent the development of diabetes and its complications.[57] Consuming the daily required portion of vegetables and fruits allows you to meet the body's needs in terms of its resistance to oxidative stress and reducing inflammatory reactions.

In conclusion, bioactive compounds contained in vegetables, fruits and juices have numerous positive health effects, also in relation to the regulation of carbohydrate metabolism and glycemic control. It may also be argued that despite the relatively high dose of simple sugars, particularly in fruits and 100% fruit juices, the health benefits associated with their consumption significantly exceed the negative aspects that may be associated with the excess of these sugars in the diet. The restriction of sugars in the diet should be sought in limiting the consumption of other foods, particularly sweets and artificial carbonated beverages. This hypothesis seems to be accurate in case of the diet of people with diabetes and also of healthy individuals.

Whole fruits vs 100% fruit juices

Whole fruits and 100% fruit juices constitute a rich source of bioactive polyphenols, and their consumption is associated with a reduced risk of certain chronic and degenerative diseases.[58,59] Recently, they have also been linked to beneficial health effects, including the ability to improve cognitive function/memory.[60] Compared to coffee, tea and cocoa, fewer authors have focused on polyphenols derived from whole fruits and 100% fruit juice so far.

Partly due to their fiber content, there is a tendency to favor eating whole fruits instead of 100% fruit juice. However, differences between these two sources of polyphenols may not be as large as initially thought. Whole fruits contain more fiber, but the role of 100% fruit juice in disease prevention has not been sufficiently recognized, although its consumption is within the dietary recommendations for the daily portion of fruit and is a very good source of biologically active polyphenols. Despite comparable nutrient and phytochemical profiles, there are still mixed opinions about the benefits of consuming 100% fruit juice. Some authors confirmed that 100% fruit juice could successfully be a part of a balanced and varied diet.[61] A review of 48 studies on cardiovascular disease and cancer conducted by Ruxton et al. (2006)[62] revealed that 100% fruit juices were not “nutritionally inferior” to whole fruits in reducing the risk of those diseases. The consumption of 100% fruit juice was shown to help meet daily recommendations for fruit consumption and reduce costs compared to the consumption of whole fruit.[63] From an economic point of view, 100% fruit juices ensure that the recommended consumption of the fruits specified in the nutritional guidelines is achieved, as the whole fruit is a greater financial burden related to diet than other products obtained from fruit.[64]

From the point of view of the composition, the main difference between whole fruits and 100% fruit juice is linked to fiber, as it is partially lost when juice is obtained. Puree juices are an exception here. Fiber is a beneficial component of the diet. However, the health benefits of eating fruit were suggested not to depend on the occurrence of fiber, which is absent (or found in lower amounts) in 100% fruit juices.[62] It is commonly overlooked that the matrix of tissues that make up the whole fruit may limit the bioavailability of polyphenols that are important for health, probably due to their “entrapment” in fiber or inside intact cells. Furthermore, competition was observed as regards the process of absorption with other components of the matrix or as a result of increased viscosity due to the presence of fiber.[65]

Currently available literature lacks scientific data directly comparing the bioavailability of polyphenols from whole fruits compared to 100% fruit juice. However, an *in vitro* study revealed that flavonoid bioavailability was higher in case of orange juice (fresh and pasteurized) compared to orange fruit.[39] Differences in bioavailability may result from different macronutrient profiles. Whole fruits require mechanical and enzymatic digestion in order to release and transfer polyphenols to the aqueous environment of the intestinal fluid before the absorption process begins. Thus, a polyphenol-rich beverage, such as 100% fruit juice, may be more bioavailable due to the liquid matrix, which may allow for higher intestinal absorption of polyphenols compared to fiber-rich solid matrix, e.g., when whole fruits are consumed.[66] Polyphenol complexes (e.g., cell wall or biopolymer interactions) may form during the digestion of whole fruits,[67] potentially limiting the bioavailability of polyphenols in the intestine. Renard et al. (2017)[68] reviewed interactions between polyphenols and polysaccharides, with particular attention paid to the effect of food processing and digestion on the extraction and bioavailability of polyphenols. Although not fully understood, the resulting polyphenol-biopolymer structures may have a significant impact on the bioavailability of polyphenols in the upper gastrointestinal tract and/or colon, potentially modifying absorption. Further research should be conducted to compare and clinically evaluate the effects in relation to other fruits and juices produced from them.

Given the complex nutritional and phytochemical profile of fruit, it is also difficult to predict how processing, e.g., heat treatment or juice squeezing (and a subsequent change in the polyphenol profile), influences functionality and bioactivity.

A SYSTEMATIC REVIEW OF JUICES

The review was prepared according to strict rules described in detail in the 2020 PRISMA Guidelines (*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*).[69]

The preparation of the review included the following stages:

1. Formulation of the main search area,
2. Development of search strategies,
3. Data collection and the development of a reference database,
4. Selection of research found for compatibility with the subject matter,
5. Critical assessment of the quality of the research,
6. Preparation of a thematic summary.

1. FORMULATION OF THE SEARCH AREA

The main search area has been defined based on the subject of the review. It was decided to include three reference bibliographic and abstract databases that collect information on published scientific papers on such subjects as health, health sciences and medicine. The so-called gray literature was not taken into account in the preparation of the review.

Bibliographic and abstract databases covered by the search:

- The PubMed/Medline database – developed by the *National Library of Medicine* in the USA. It includes medicine, pharmacy, nursing, dentistry, veterinary sciences, healthcare systems and preclinical sciences. It contains over 34 million bibliographic records from more than 5,000 journals published in 30 languages since 1950. About 52% of the records come from magazines published in the USA. Medline is the most important component of the PubMed database.

- The Scopus database – developed by specialists from Elsevier publishing house. It indexes literature in the field of natural sciences, engineering, medical and social sciences. A collection of abstracts available in the database, supplemented with appendix bibliographies and references cited in the articles.

- The Web of Science Core Collection is a set of databases from Clarivate Analytics (formerly Thomson Reuters). The databases index journals included in the *Master Journal List* (the so-called *Impact factor* list), which has included over 12,000 titles of scientific journals since 2010.

2. DEVELOPMENT OF SEARCH STRATEGIES

The search strategy was based on the use of keywords, synonyms and MeSH terms (*Medical Subject Headings*) from a thesaurus, i.e., a dictionary of medical terms. The following elements making up the phrase constituting a query to the bibliographic and abstract database were distinguished:

#1	Fruit and vegetable juices	*"Fruit and Vegetable Juices"[Mesh]* *Vegetable Juices* *Juice, Vegetable* *Juices, Vegetable* *Vegetable Juice* *Fruit Juices* *Fruit Juice* *Juice, Fruit* *Juices, Fruit*
#2	Glycemia	*"Hyperglycemia"[Mesh]* *Hyperglycemias* *Hyperglycemia, Postprandial* *Hyperglycemias, Postprandial* *Postprandial Hyperglycemias* *Postprandial Hyperglycemia* *"Blood Glucose"[Mesh]* *Blood Sugar* *Sugar, Blood* *Glucose, Blood*
#3	Carbohydrates	*"Carbohydrates"[Mesh]* *Carbohydrate* *"Dietary Carbohydrates"[Mesh]* *Carbohydrates, Dietary* *Carbohydrate, Dietary* *Dietary Carbohydrate* *"Dietary Sugars"[Mesh]* *Sugars, Dietary* *Dietary Sugar* *Sugar, Dietary*
#4	Bioactive compounds	*"Polyphenols"[Mesh]* *Polyphenol* *Provinols* *"Antioxidants"[Mesh]* *Anti-Oxidants* *Anti Oxidants* *Antioxidant* *Anti-Oxidant* *Anti Oxidant* *Endogenous Antioxidants* *Antioxidants, Endogenous* *Endogenous Antioxidant* *Antioxidant, Endogenous* *Antioxidant Activity* *Activity, Antioxidant* *Antioxidant Effect* *Anti-Oxidant Effect* *Anti Oxidant Effect* *Anti-Oxidant Effects* *Anti Oxidant Effects* *Antioxidant Effects*

#5	Anti-inflammatory effect	*Inflamm** *"Anti-Inflammatory Agents"[Mesh]* *Anti Inflammatory Agents* *Antiinflammatory Agent* *Agent, Antiinflammatory* *Antiinflammatory Agents* *Agents, Antiinflammatory* *Anti-Inflammatories* *Anti Inflammatories* *Antiinflammatories* *Anti-Inflammatory Agent* *Agent, Anti-Inflammatory* *Anti Inflammatory Agent* *Agents, Anti-Inflammatory* *Agents, Anti Inflammatory*
#6	Effect on the nervous system	*Neuro** *"Neuroprotective Agents"[Mesh]* *Agents, Neuroprotective* *Neuroprotectant* *Neuroprotective Drugs* *Drugs, Neuroprotective* *Neuroprotectants* *Neuroprotective Agent* *Agent, Neuroprotective* *Neuroprotective Drug* *Drug, Neuroprotective* *Neuroprotective Effect* *Effect, Neuroprotective* *Neuroprotective Effects* *Effects, Neuroprotective* *Cognit** *"Nootropic Agents"[Mesh]* *Agents, Nootropic* *Nootropics* *Nootropic* *Anti-Dementia Agents* *Agents, Anti-Dementia* *Anti Dementia Agents* *Procognitive Agents* *Agents, Procognitive* *Nootropic Agent* *Agent, Nootropic* *Nootropic Drugs* *Drugs, Nootropic* *Antidementia Agent* *Agent, Antidementia* *Cognitive Enhancer* *Enhancer, Cognitive* *Nootropic Drug* *Drug, Nootropic* *Procognitive Agent* *Agent, Procognitive* *Antidementia Agents* *Agents, Antidementia* *Cognitive Enhancers* *Enhancers, Cognitive* *Anti-Dementia Agent* *Agent, Anti-Dementia* *Anti Dementia Agent*
#7	The cardiovascular system	*"Cardiovascular Diseases"[Mesh]* *Cardiovascular Disease* *Disease, Cardiovascular*

		Major Adverse Cardiac Events *Cardiac Events* *Cardiac Event* *Event, Cardiac* *Adverse Cardiac Event* *Adverse Cardiac Events* *Cardiac Event, Adverse* *Cardiac Events, Adverse* *"Cardiotonic Agents"[Mesh]* *Cardiotonic* *Myocardial Stimulant* *Stimulant, Myocardial* *Cardioprotective Agent* *Agent, Cardioprotective* *Cardiotonic Agent* *Agent, Cardiotonic* *Cardiac Stimulant* *Stimulant, Cardiac* *Cardiac Stimulants* *Cardioprotective Agents* *Cardiotonic Drugs* *Cardiotonics* *Inotropic Agents, Positive Cardiac* *Cardiotonic Drug* *Drug, Cardiotonic* *Myocardial Stimulants* *"Blood Vessels"[Mesh]* *Blood Vessel* *Vessel, Blood* *Vessels, Blood*
#8	Neoplastic diseases and carcinogenesis	*"Neoplasms"[Mesh]* *Tumor* *Neoplasm* *Tumors* *Neoplasia* *Neoplasias* *Cancer* *Cancers* *Malignant Neoplasm* *Malignancy* *Malignancies* *Malignant Neoplasms* *Neoplasm, Malignant* *Neoplasms, Malignant* *Benign Neoplasms* *Benign Neoplasm* *Neoplasms, Benign* *Neoplasm, Benign* *"Carcinogenesis"[Mesh]* *Carcinogeneses* *Tumorigenesis* *Tumorigeneses* *Oncogenesis* *Oncogeneses*

The syntax was adapted to the format of a given bibliographic and abstract database.

During the search of bibliographic and abstract databases, a faceted search was used with the following inclusion criteria:

- Time frame: from January 1, 2000,
- Type of research: human studies,
- Type of publication: primary clinical studies (experimental and observational), secondary studies (non-systematic and systematic reviews, meta-analyses),
- Language of publication: English or Polish,
- Type of source: peer-reviewed scientific journals.

The primary search was supplemented by the so-called secondary search, i.e., the inclusion of research found on the reference lists of publications eligible for review.

3. DATA COLLECTION AND THE DEVELOPMENT OF A REFERENCE DATABASE

The search results generated in bibliographic and abstract databases were exported to a reference manager (EndNote™ ver. 20) in the *.RIS file format (*Research Information Systems*). The following source data were comprised:

- List of authors of the publication,
- Title of the publication,
- Summary of the publication,
- Key words,
- Bibliographic data (journal name, volume, issue and page range),
- Date of publication,
- DOI ID (*Digital Object Identifier*).

4. SELECTION OF RESEARCH FOUND FOR COMPATIBILITY WITH THE SUBJECT MATTER

Complete data collected using the reference manager were exported to the *Rayyan Intelligent Systematic Review* software allowing independent work of experts preparing the review.[70] The first step involved reviewing the search results for the presence of duplicates. The final database for expert work was developed from the original list of searched records.

Two independent experts (M.M./M.H. and M.P.) simultaneously assessed individual publications for compliance with the subject matter. At this stage, the title of the publication and the content of the abstracts were evaluated. In the event of disagreement in expert opinions, the dispute was settled as a result of discussion and consensus.

5. CRITICAL ASSESSMENT OF THE QUALITY OF THE RESEARCH

The last stage of building the bibliographic database involved a detailed assessment of the publications selected at the previous stage. During this phase of work, two independent experts (M.M./M.H. and M.P.) again made a simultaneous independent assessment of the searched records in terms of the quality of research based on the analysis of the full texts of the publications. In the event of disagreement in expert opinions, the dispute was settled as a result of discussion and consensus.

CASP checklists (*Critical Appraisal Skills Programme*) were used to critically evaluate the research.[71] The level of evidence was determined in accordance with the scale proposed by Guyatt & Sackett (1995).[72]

Table 1. Levels of scientific evidence according to Guyatt & Sackett (1995).[72]

Level	Description
I	Evidence from a systematic review or a meta-analysis of RCTs (randomized clinical trial) or evidence-based clinical practice guidelines based on systematic reviews of RCTs or 3 or more good quality RCTs that produce similar results.
II	Evidence from at least one well-designed RCT (e.g., a large multicenter RCT).
III	Evidence from well-designed non-randomized clinical trials (i.e., quasi-experimental).
IV	Evidence from well-designed observational studies: case-control or cohort ones.
V	Evidence obtained from systematic reviews of descriptive and qualitative studies (the so-called metasynthesis).
VI	Evidence from one descriptive or qualitative study.
VII	Evidence obtained on the basis of an expert opinion or expert committee reports.
VIII	Evidence obtained from preclinical studies (laboratory tests and tests on animal models).

6. PREPARATION OF A THEMATIC SUMMARY

70 studies included in the final analysis were characterized by heterogeneity based on the presented results, methodology type and the scope of the discussed subject. A collective narrative synthesis of the included studies was made.

A matrix was created which contained the following data:

- Bibliographic data,
- Main topic (keywords),
- Type of publication (primary or secondary),
- Type of clinical trial (experimental, observational),
- Population studied,
- Sample size,
- The aim of the study,
- Primary endpoint,
- The main results (including the measures of effect: RR, OR, HR, etc.),
- The main conclusion with regard to the purpose of the study.

A NARRATIVE SYNTHESIS CONCERNING JUICES

A "narrative" synthesis refers to an attempt to summarize the results of numerous studies constituting a systematic review.[73] It is mainly based on the classification of words, phrases and terms contained in the texts of the publications included in the review. It provides a summary leading to an explanation of the results of the synthesis and allows generalized conclusions to be drawn.

As part of the narrative synthesis, two thematic groups were distinguished:

Group I includes scientific papers tackling the issue of the physiological impact of carbohydrates contained in fruit, vegetable, fruit and vegetable juices or vegetable and fruit juices on the human body;

Group II includes scientific papers tackling the issue of the physiological impact of bioactive compounds contained in fruit, vegetable, fruit and vegetable juices or vegetable and fruit juices on the human body.

CARBOHYDRATES IN JUICES

1. COMPOSITION OF FRUIT AND VEGETABLE JUICES

Carbohydrates, including disaccharides (sucrose) and monosaccharides (glucose and fructose) are the main macronutrients of all fruits and vegetables. Thus, fruit, tomato and 100% vegetable juices, which by law cannot contain added sugar, contain sugars of natural origin in their composition.[74] Additionally, they are a source of bioactive substances (including quercetin, catechins, carotenoids, flavonoids, anthocyanins), with confirmed beneficial effects on health.[75] Also, the diversity of juices contributes to a large variety of types and amounts of bioactive substances contained in them, which has an impact on the human body. The content of the above mentioned elements depends on the composition of the juice depending on the type of fruits and/or vegetables used in its production, the proportions between the individual ingredients, as well as the preparation process itself. These are determinants influencing the course of digestion and the predicted rate of increase in glucose concentration in the postprandial period.

The amount of product consumed is an important factor which has a direct impact on the energy value and carbohydrate content, including easily absorbable sugars. Although fruit juices contain only sugars derived from the fruit they were produced from, there are doubts whether their content may have a similarly harmful effect as sugars added to beverages.[76] Added sugars consumed in excess contribute to an increase in the energy value of the diet, which leads to a positive energy balance, increased fluctuation in blood glucose concentration and the overproduction of insulin in the postprandial period. It is associated with an increased risk of developing metabolic disorders including obesity and type 2 diabetes.[22]

2. DIGESTION AND ABSORPTION OF CARBOHYDRATES FROM THE GASTROINTESTINAL TRACT

In the process of digestion, complex carbohydrates and disaccharides require a number of reactions leading to the production of monosaccharides, which are absorbed in the small intestine. The concentration of glucose in the blood depends on its absorption in the intestines, consumption and production in the liver and its use by peripheral tissues. Correct regulation of blood glucose concentration mainly depends on insulin secretion by the β cells of Langerhans islets and on the effect of insulin on target cells.

As mentioned at the beginning of this report, carbohydrate digestion begins in the oral cavity by activating salivary amylase released during mastication. The role of salivary amylase is to break down starch into oligosaccharides (dextrins) and maltose. Amylase is sensitive to changes in pH and its effect is inhibited by the acidic environment in the stomach. However, the digestion of disaccharides (sucrose and maltose) and oligosaccharides, such as dextrins, is limited in the stomach.[3] The continuation of the digestive process occurs under the influence of the secretion of pancreatic amylase, which is released into the small intestine along with other digestive enzymes under the influence of secretin and cholecystokinin. Oligosaccharides and disaccharides are digested by specific enzymes in the intestinal microvilli, while monosaccharides do not require an additional enzymatic digestion process. Therefore, the rate of carbohydrate absorption is largely dependent on the availability of easily absorbable sugars, which are then transported to the portal circulation. Carbohydrates that have not been digested in the small intestine pass into the large intestine, where they are digested by bacteria colonizing the colon. This results in the release of short-chain fatty acids (propionate, butyrate and acetate) along with methane, which do not affect the glycemic effect in the postprandial period.

Glucose is actively transported from the lumen of the small intestine by a sodium glucose transporter (sodium-glucose co-transporter-1, SGLT-1) located on the brush border membrane of the small intestine, primarily in the duodenum and jejunum. The absorption of fructose occurs through diffusion facilitated by the GLUT-5 transporter (glucose transporter 5), which is located in the enterocytes of intestinal villi. The GLUT-5 transporter is not the only factor regulating fructose absorption. It was found that its absorption was stimulated by the presence of glucose. This effect was dependent on the amount of individual sugars and was the strongest when the concentrations of glucose and fructose were equal.[77]

The intestine is both a barrier limiting glucose absorption and a regulatory mechanism maintaining adequate blood glucose levels. Postprandial glycemia may be affected by individual stages of the digestive process. One of the known mechanisms involves slowing gastric emptying and intestinal transit. It slows intestinal glucose absorption and modulates the secretion of gastric hormones involved in such processes as the regulation of hunger and satiety. Dietary fiber is the main ingredient influencing this process. It is found in puree and naturally cloudy vegetable, fruit, vegetable and fruit and fruit and vegetable juices.

3. THE INFLUENCE OF SELECTED FACTORS ON GLUCOSE FLUCTUATIONS

An increase in blood glucose after a meal is a fully physiological process. The dynamics of fluctuations in blood glucose concentration depend on the amount and type of carbohydrates consumed, the presence of other macronutrients such as proteins and fats, but also on individual factors of the consumer.

Available studies whose aim was to analyze the impact of 100% juice consumption on metabolic parameters, are characterized by a large discrepancy in the assumed methodology. Thus, different types and amounts of juices consumed (<250-600 ml) were assessed, which directly affected the content of easily digestible sugars (22-97 g). Elements including the duration of the intervention, the selection of the study and control group, the occurrence of concomitant diseases as well as the age and baseline body weight of patients were also important factors. It should be emphasized that available research results on the impact of 100% juice consumption on glycemic and insulinemic values were not unambiguous in assessing the mechanisms affecting the analyzed parameters of carbohydrate metabolism.[78] In addition to the factors related to the characteristics of the product itself, individual consumer parameters should be taken into account, such as the age, baseline body weight, fasting glucose concentration as well as the degree of insulin resistance. They are important determinants affecting glucose fluctuation, which vary between patients with normal and impaired glucose tolerance.[79]

Glycemic index and load, fiber content and the presence of polyphenols are the most frequently discussed elements having a potential impact on these processes. Therefore, it is advisable to conduct further research in order to systematize knowledge in this area.

Glycemic index and load

In order to determine the value of the glycemic index of juices, laboratory tests are necessary, which will allow a qualitative analysis of a given product. The glycemic index of juices is primarily influenced by elements such as the type and amount of carbohydrates contained in fruits or vegetables, and the production methods, which directly affect the fiber content of juices.[80] Notably, the seasonality and country of origin of the selected fruits and vegetables may additionally influence the qualitative differences in the final product.

In general, products rich in fiber and poorer in fructose, such as vegetable juices (tomato juice IG=38, carrot juice IG=40) are characterized by a low glycemic index (IG). Fruit juices are defined as products with a low (apple juice IG=41) or medium glycemic index (orange juice IG=55).[81] It is worth noting differences in IG reference values between specific products that are prepared from the same type of raw material. For this reason, it is necessary to consider the IG value as an estimate that allows for the application of an overall, qualitative assessment of the product.

Glycemic load is an index that allows a more precise analysis. Its value depends on the amount of product consumed. Therefore, a juice with a low IG consumed at a large amount causes a more dynamic increase in glycemia than a small portion of juice with a high IG. Such an effect is not only expressed by the fluctuation of glycemia, but also by the overall energy value provided with the juice consumed.

Fiber Dietary fiber does not undergo digestion due to the lack of the production of digestive enzymes capable of hydrolysis in the gastrointestinal tract. Thus, undigested fiber undergoes a fermentation process in the large intestine under the influence of the intestinal microbiota. Dietary fiber is classified according to its solubility in water into insoluble fiber, which improves intestinal peristalsis, and soluble fiber, which may reduce the glycemic effect in the postprandial period. Water-soluble fiber has adhesive properties, thanks to which it slows down the absorption of carbohydrates and delays the transit of chyme from the stomach to the small intestine. As a result, it suppresses the increase in postprandial glucose concentration.[19]

The amount of dietary fiber in the product is an important element influencing the values of glycemic index and load. Fruits and vegetables are a valuable source of fiber. However, products obtained from them may have a lower content of this valuable ingredient. The differences may result from the juice extraction process, during which certain amounts of fiber are removed.[82] However, recently, more and more puree and mixed juices have appeared on the market, which are characterized by the fiber content comparable to fruits/vegetables. It is worth noting that a product characterized by a low fiber content undergoes the process of digestion and absorption in the gastrointestinal tract much faster. Therefore, the expected effect of the increase in blood glucose concentration may be more dynamic. Additionally, the rapid rate of gastric emptying and transit of chyme may limit the feeling of satiety. It is a factor that may potentially contribute to the occurrence of excess energy in the diet and, in the longer term perspective, may cause metabolic disorders. For this reason, it is recommended to choose 100% juices, mousses and purees that contain more fiber than clear juices.[83] Thus, it is worth emphasizing that the available research results revealed that the presence of fiber in juices might contribute to slowing the occurrence of hyperglycemia in the postprandial period.[84]

Polyphenols Some *in vitro* studies and ones conducted on animal models indicated a beneficial effect of polyphenols contained in 100% juices that might influence glucose and insulin homeostasis.[85-88] These processes may result from the effect of insulin secretion by the pancreas, inhibition of glucose absorption from the small intestine, activation of insulin receptors as well as through cellular glucose uptake. Moreover, researchers noted the potential protective effect of compounds that prevented glycation and reduced oxidative stress. [89,90]

Glycation is spontaneous and its intensity depends on the content of monosaccharides in the body, including glucose. The resulting glycation products become substrates for further reactions that may contribute to the development of oxidation-reduction imbalance.[91] The abundance of scientific evidence showed the negative impact of glycation leading to cell and tissue damage and, thus, the development of insulin resistance and the progression of diabetes complications.[92] Based on conducted *in vitro* studies, it was observed that drinking fruit juice had an inhibitory effect on the albumin glycation process under the influence of fructose. However, the differences depended on the type of juice drunk. Pomegranate juice was found to have the greatest protective effect, and orange, grape and cranberry juice inhibited glycation by 20%.[90]

4. JUICE PREPARATION PROCESS

Processing and preparation of juices is another important element to pay attention to.[82,93] It is a factor that significantly influences the nutritional value of the juice. Juice extraction from fruit containing seeds may lead to a reduced glycemic response.[82,94] It is believed that grinding seeds may increase the proportion of fiber, polyphenols including piceatannol, healthy fats and protein in juices. As a consequence, it may slow down gastric emptying and the rate of glucose absorption.[86] The preparation of puree juices also ensures a sufficiently high content of fiber, which is valuable in the diet.

According to the EU and national regulations, manufacturers are not allowed to add fiber to fruit juices or grind seeds, because such a product would have to be called a drink. Fiber in juices can only come from the quantity and type of fruit and/or vegetables from which the juice is made. The potential benefits of adding fiber remain unknown due to the lack of sufficient scientific data in this aspect. Pomace, i.e., a by-product in the production of orange juice, is a rich source of soluble and insoluble fiber (40:60). It is rich in pectins, that have specific gelling properties, which can also potentially influence glucose metabolism and lower glycemic response in the postprandial period.[83]

The available results of studies involving healthy people did not reveal significant differences in the overall two-hour glycemic profile between juice with an additional portion of fiber and traditional fruit juice. However, it should be emphasized that in case of the consumption of juice with an additional portion of fiber, the moment of obtaining the maximum value of glucose and insulin concentration occurred later and was characterized by lower values than after the consumption of fruit juice without the addition of fiber.[83] Decreasing postprandial glucose and insulinemia is particularly important in both diabetic and insulin-resistant patients.[95]

5. THE EFFECT OF 100% FRUIT JUICE ON FASTING BLOOD GLUCOSE AND INSULIN

Based on the available results of meta-analyses evaluating fasting blood glucose concentration, it was observed that the consumption of 100% fruit juice had no significant effect on fasting glycemia compared to the control group which was not consuming juices. In addition, similar results were obtained with respect to the analysis of fasting insulin concentration. Based on the available values of fasting glucose and insulin concentration, it was also possible to assess the insulin resistance index using HOMA-IR (*Homeostatic Model Assessment For Insulin Resistance*). The results revealed no significant differences in HOMA-IR values after the consumption of 100% fruit juices.[78,96] Slight differences in glycemic control and insulin sensitivity were observed, which mainly depended on the characteristics of the studied population.

The analyzed study involved a long-term intervention (4-7 weeks), thanks to which it provided reliable basis for assessing the long-term consumption of 100% fruit juices. The authors used control products that had the same content of carbohydrates or easily absorbable sugars as well as beverages containing sweeteners. Thanks to such selection, it was possible to assess the impact of bioactive substances present in 100% juices. Additionally, the choice of water as a control fluid made it possible to assess the physiological changes following the consumption of juices.[97]

The available results of clinical trials revealed no negative effect of the consumption of 100% fruit juices on the occurrence of obesity and metabolic disorders. However, the effect depended on the overall energy value of the diet. It should be emphasized that the risk of the above mentioned diseases increased significantly with a positive energy balance.[98-100]

6. JUICE AND GLUCOSE SOLUTION

Research conducted in young volunteers with normal body weight (BMI 19.2-24.7 kg/m^2) revealed differences in glucose and insulin concentration after the consumption of different types of juices with a low and medium glycemic index compared to the intake of glucose solution. The glucose solution caused a faster initial increase and a higher peak at 30 minutes of venous plasma glucose measurement compared to the juices tested. The plasma glucose concentration at 45, 60, 90 and 120 minutes was significantly higher after the ingestion of the glucose solution compared to the values obtained after the consumption of juices. After the participants drank the juice, the glucose concentration at 120 minutes of the study was lower than the initial fasting concentrations, while no such trend was observed after the ingestion of the glucose solution. A similar trend was observed for insulin concentration, with the peak at 30 min and a gradual decline over 120 min.[80]

BIOACTIVE COMPOUNDS IN JUICES

1. BIOACTIVE INGREDIENTS – CHARACTERISTICS

Bioactive ingredients are sunstances whose consumption produces a specific biological effect.[101] A typical diet can provide 25,000 types of bioactive ingredients in addition to dietary fiber, basic antioxidants, i.e., vitamins A, C and E, as well as polyphenols. More than 8,000 polyphenolic compounds have been identified so far. Polyphenols are secondary metabolites of plants, conditioning their growth, color, and structure. They also protect against ultraviolet radiation.[102] Structurally, they have one or more aromatic rings and from one to several hydroxyl groups of an acidic nature. Based on their structure, they were divided into the following groups: phenolic acids, coumarins, simple phenols, xanthones, stilbenes, lignans, anthraquinones and flavonoids.[103]

Flavonoids are the most numerous group. They are divided into six classes: flavonols, flavones, isoflavones, flavanones, anthocyanidins, and flavanols.[104] The main sources of individual flavonoid groups are presented in Table 2.

Table 2. The occurrence of flavonoids in food.[105,106]

Flavonoid class	Sources in food
Flavonols (quercetin, kaempferol, myrecytin, fisetin, morin)	apple, broccoli, cherry tomato, leek, onion, dark grape, cabbage
Flavones (luteolin, apigenin)	celery, parsley leaves, red pepper, thyme, spinach, artichoke, oregano, mint leaves, dill leaves
Flavanones (naringenin, naringin, hesperetin, hesperidin)	grapefruit, orange
Flavan-3-ols (epicatechin, catechin, epigallocatechin, theaflavin, thearubigin)	tea, cocoa, banana, apple, green peas, soy, pecan nuts, nectarine, pear, strawberry, sour cherry, blueberry, blackberry, red wine
Anthocyanidins (cyanidin, malvidin, pelargonidin, peonidin, delphinidin)	black currant, dark grape, sour cherry, blackberry, bilberry, blueberry, strawberry, lingonberry, elderberry
Isoflavones (genistein, daidzein)	soy and soy products, various species of beans, lentils, green beans, broad beans, wheat and its sprouts, rice, hops

The content of polyphenols in plants depends on the species, environmental factors, the degree of fruit maturity, the method of storage, the production process or the culinary treatment used. Due to the fact that sunlight intensifies the biosynthesis of polyphenols, most of these compounds are found in the leaves or under the skin of the fruit. The content of phenolic acid decreases with the degree of fruit maturity, while anthocyanin increases.[104] A Polish study included the analysis of several juices in terms of their antioxidant potential. Chokeberry juice had 2 to 4 times higher antioxidant capacity compared to blackcurrant nectar and 4 to 6 times higher capacity compared to sour cherry juice. Chokeberry juice was immediately followed by sea buckthorn juice (Georgia), pomegranate juice (Georgia) and blackcurrant nectars (Poland) which had slightly lower antioxidant activity.[107] Analyses indicated that the phytochemical profile of fruit juices was similar to that of fruits. Moreover, numerous analyses emphasized a higher content of polyphenols in juices compared to consuming fruit (often without the peel and seeds), because these parts contain bioactive ingredients which pass into juice during the production process. Obviously, juice clarification process contributes to adverse changes in the content of polyphenols.[108]

Furthermore, despite disagreement over the status of juices in dietary recommendations, some authors suggested that juices had no less cardioprotective or anti-cancer effect compared to whole fruits.[62]

As regards beverages, the highest content of polyphenols is found in double esspresso or green tea, followed by apple, pomegranate, grapefruit, cranberry, grape or orange juices (Table 3).[109]

Table 3. Antioxidant content in selected beverages.[109]

Product	Antioxidant content mmol/100g*	N	Min.	Max.
Espresso	14.20	2	12.64	15.83
Filter coffee	2.50	31	1.24	4.20
Cocoa with milk	0.37	4	0.26	0.45
Black tea, brewed	1.00	5	0.75	1.21
Green tea, brewed	1.50	17	0.57	2.62
Apple juice	0.27	11	0.12	0.60
Cranberry juice	0.92	5	0.75	1.01
Grape juice	1.20	6	0.69	1.74
Orange juice	0.64	16	0.47	0.81
Pomegranate juice	2.10	2	1.59	2.57
Plum juice	1.00	3	0.83	1.13
Tomato juice	0.48	14	0.19	1.06

* valid when N>1

Notably, each of the antioxidants is characterized by different bioavailability, absorption and metabolism. Hence, the consumption of products with the highest concentration of antioxidants does not translate into a higher concentration of active metabolites. The concentrations of polyphenol metabolites reach plasma values from 0 to 4 µmol/L.[110-112] Wan et al. (2021)[113] noted that only 5% of the daily polyphenol supply was absorbed in the duodenum, while the remaining amount underwent fermentation in the intestine due to the presence of the microbiota. First, polyphenols are hydrolyzed by intestinal enzymes or the intestinal microflora. As a consequence of these processes, various metabolites with unknown biological activity are obtained.[113,114] Isoflavones are characterized by the highest bioavailability. They are followed by flavanols (catechins) and flavanones (citrus fruits). Anthocyanins and proanthocyanidins are characterized by the lowest degree of absorption.[114]

Flavonoids are the most popular among researchers. *In vivo* and *in vitro* studies confirmed their antioxidant, anti-inflammatory, anti-aggregant and antihypertensive effects, which is why they can be used in the prevention and support of the treatment of inflammatory diseases.

The antioxidant capacity or antioxidant activity is expressed by the ability to eliminate reactive oxygen species, scavenging free radicals, chelating metal ions, most often iron and copper, and inhibiting enzymes from the group of oxidases. The content of individual polyphenols in the product does not determine its antioxidant activity, due to the redox reactions or synergism between individual polyphenolic compounds.[115] No universal method for assessing the antioxidant activity of polyphenols is available. However, the following 3 methods are commonly used:[115]

- FRAP (*Ferric Reducting Antioxidant Power*) consisting in the reduction of the Fe III/TPTZ complex (2,4,6 tripyridyl-S-triazine) under the influence of antioxidants to the Fe II/TPTZ complex; overall, this method determines the ability of the product to reduce iron ions;

- TEAC (*Trolox Equivalent Antioxidant Capacity*) measuring free radical quenching capacity;

- TRAP (*Total Radical-trapping Antioxidant Parameter*) method consists in measuring the fluorescence decrease of the R-phycoerythrin protein caused by the action of peroxide radicals.

Pellegrini et al. conducted a study using the above mentioned methods to assess the antioxidant activity of 104 products commonly consumed in Italy. Depending on the method used, different results were obtained. Therefore, in order to facilitate the interpretation, specific ranks were attributed to the results (Tables 7 and 8).
As regards vegetables, spinach was characterized by the greatest antioxidant potential due to the high content of glucuronic and p-coumaric acids, as well as lutein and chlorophyll. Spinach was followed by chili pepper and red pepper, as well as beets. It may indicate the possibility of using juices from these vegetables in juice compositions mixed with fruit. Fruits, particularly blackberry, red currant, raspberry and black olives, had a higher antioxidant potential than vegetables. Nevertheless, similar research should be conducted for vegetable and fruit varieties and their processed products available in Poland.

Table 4. Antioxidant potential of selected vegetables from Italy.[115]

Product	The FRAP method		The TRAP method		The TEAC method	
	value	rank	value	rank	value	rank
	mmol Fe2+/kg FW		mmol Trolox/kg FW			
Avocado	4.90	21	1.87	21	2.22	15
Red beet	15.31	6	7.67	2	2.94	13
Onion	5.28	18	2.43	17	1.82	18
Zucchini	3.33	26	ND	32	2.86	14
Pumpkin	4.00	23	ND	33	3.71	8
Green beans	2.35	28	0.65	30	1.27	23
Mushrooms	16.39	5	6.26	7	4.93	6
Cauliflower	4.27	22	1.61	23	1.10	25
Cabbage	8.17	14	2.35	18	2.08	16
Artichoke	11.09	12	6.85	3	1.55	20
Dill	2.33	29	0.78	28	0.43	30
Carrot	1.06	32	0.70	29	0.44	29
Chili pepper	23.54	2	6.42	5	7.62	3
Red pepper	20.98	3	5.47	9	8.40	2
Tomato	5.12	19	1.31	24	1.65	19
Leek	2.15	30	1.02	25	0.72	27
Radish	3.77	24	3.62	11	2.22	15
Lettuce	4.94	20	2.31	19	1.33	22
Celery	1.16	31	0.47	31	0.49	28
Asparagus	10.60	13	9.71	1	3.92	7
Spinach	26.94	1	5.79	8	8.49	1

Table 5. Antioxidant potential of selected fruits from Italy.[115]

Product	The FRAP method		The TRAP method		The TEAC method	
	value	rank	value	rank	value	rank
	mmol Fe2+/kg FW		mmol Trolox/kg FW			
Pineapple	15.73	10	5.92	10	9.91	8
Watermelon	1.13	30	0.46	29	0.69	28
Banana	2.28	28	1.05	27	0.64	30
Blueberry	18.61	9	9.30	7	7.43	10
Peach	6.57	19	1.49	25	1.67	21
Fig	5.82	20	2.06	21	2.47	18
Yellow grapefruit	10.20	13	4.04	13	3.05	15
Pear	5.00	22	3.87	14	2.19	20
Apple (Red Delicious)	3.84	24	2.23	20	1.59	22
Apple (Golden green)	3.23	26	1.54	24	1.31	25
Blackberry	51.53	1	21.01	1	20.24	1
Kiwi	7.41	17	2.30	18	2.28	19
Raspberry	43.03	3	10.48	5	16.79	2
Mandarin	8.88	15	2.74	16	3.10	14
Melon (Cantaloupe)	5.73	21	0.95	28	1.20	26
Apricot	4.02	23	2.29	19	1.44	24
Black olives	39.99	4	18.08	2	14.73	3
Green olives	24.59	6	14.64	3	10.43	7
Orange	20.50	8	5.65	11	8.74	9

Red currant	44.86	2	12.14	4	14.05	4
Plum	12.79	11	8.09	9	5.11	11
Strawberry	28.00	5	10.34	6	11.34	5
Dark grape	11.09	12	2.50	17	3.85	13
White grape	3.25	25	1.59	23	2.48	17
Sour cherry	8.10	16	4.17	12	2.69	16

When analyzing the protective mechanisms of polyphenols on the cardiovascular system, it is worth describing the pathogenesis of such diseases. Atherosclerosis is a chronic disease occurring with an inflammatory and proliferative reaction of the vessel walls to destructive factors. Endothelial dysfunction related to homeostasis disorders is particularly important in the pathogenesis of this disease. It may result from disorders of carbohydrate and lipid metabolism, increased concentration of homocysteine or the action of environmental factors. Endothelial dysfunction is associated with the adhesion of monocytes and lymphocytes to vessel walls. After the transformation of monocytes into macrophages, oxidized LDL cholesterol molecules (oxLDL) are captured and foam cells are formed. An increased expression of adhesive molecules induces the inflammation and prothrombotic activity of the endothelium. Endothelial dysfunction is associated with an increased pro-inflammatory and pro-aggregatory activity. It contributes to an increase in blood pressure. Additionally, free radicals, by activating platelets, influence their adhesion to the endothelial cells leading to the initiation of thromboembolic processes.[116] In the light of both preclinical and clinical studies, polyphenols have a protective effect on the endothelium, reduce the intensity of inflammatory processes, and reduce blood pressure.

The cardioprotective mechanisms of polyphenols are manifested via:[117]

- limiting the adhesion and aggregation of platelets and reducing the release of platelet factors,
- reduction of oxygen free radicals,
- counteracting the oxidation of LDL lipoproteins,
- chelating metal ions (iron and copper) – the catalysts for lipid oxidation reactions,
- increasing the production of nitric oxide (NO) and prostacyclin (PGI2),
- reducing the expression and release of vascular endothelial growth factor (VEGF).

A meta-analysis indicated that the consumption of ≥500 ml/day of orange juice was associated with a reduction in total cholesterol and LDL-cholesterol.[118] Another meta-analysis revealed an inverse association between orange juice consumption and the occurrence of stroke when consuming up to 200 ml of orange juice, and all cardiovascular events when consuming up to 170 ml/day. It was probably due to the effect of bioactive components on the reduction of blood pressure – systolic by 3.14 mm Hg and diastolic by 1.68 mm Hg.[119] Decreased diastolic blood pressure was also observed in case of the consumption of pomegranate juice in quantities up to 240 ml (this amount was considered a limit). The effect of systolic pressure reduction was greater when using the intervention for up to 12 weeks compared to longer observations (<12 weeks: the weighted mean difference was -5.83 mm Hg, 95% CI: -10.05 to -1.61, P=0.007 and >12 weeks: the weighted mean difference was -4.36 mmHg, 95% CI: -7.89 to -0.82, P=0.016). The authors of the meta-analysis suggested the inclusion of pomegranate juice in the diet used in the prevention of cardiovascular diseases.[120] Although the significant effect of pomegranate juice on the reduction of the concentration of ICAM, Vcam and e-selectin adhesion proteins on the surface of the endothelium was not confirmed, a significant reduction in the concentration of pro-inflammatory interleukin-6 was confirmed. According to the analysis, doses from 50 to 250 ml/day were used with interventions lasting from 2 to 48 weeks. The authors paid attention to the necessity of conducting further randomized research with a longer time frame.[121]

Another meta-analysis provided similar conclusions regarding the consumption of cranberry and sour cherry juice.[122] The consumption of the average of 432 ml of cranberry juice per day led to a reduction in both systolic and diastolic pressure, while the consumption of up to 330 ml of sour cherry juice contributed to the systolic pressure reduction (systolic pressure -1.52 mm Hg [95% CI -2.97 to -0.07; P=0.05], diastolic -1.78 mm Hg [95% CI -3.43 to -0.12, P=0.04 for cranberry juice and systolic -3.11 mm Hg for sour cherry juice [95% CI -4.06 to -2.15; P=0.02], respectively). However, the authors emphasized that small groups of respondents, the lack of the analysis of the composition and quality of juices used in the interventions, as well as the application of juices in amounts not consumed in usual portions make it difficult to formulate binding conclusions. It only allowed the indication of the direction of further research.[122]

Beet juice is a natural source of nitric oxide (NO), which exhibits vasodilating properties. Interesting conclusions were provided by the authors of a meta-analysis on the effect of beet juice on blood pressure values.[123] Overall, systolic pressure was 3.55 mm Hg lower, while diastolic pressure was 1.32 mm Hg lower compared to the control group (-3.55 mm Hg; 95% CI: -4.55, -2.54 mm Hg and -1.32 mm Hg; 95% CI: -1.97, -0.68 mm Hg, respectively). The mean difference was greater in the group using beet juice for more than 14 days compared to the group subjected to a shorter observation (-5.11 vs -2.67 mm Hg). The effect was also demonstrated to be dose-dependent, with a greater blood pressure-lowering effect reported when consuming 500 ml of juice per day compared to the group consuming 70 or 140 ml/day. The authors emphasized that, apart from NO, polyphenols also had an effect on lowering blood pressure, as confirmed by the results of numerous studies on beet juice that did not contain NO, but had comparable vasodilatory properties (dilating blood vessels). However, in order to introduce beet juice into the treatment of hypertension, further testing with a product standardized in terms of nitric oxide and polyphenol content is required. The study should also be carried out over a longer period.[123]

As regards the impact of juices on the risk of cardiovascular diseases, researchers also assessed juices or extracts of chokeberry fruit with a very similar composition of polyphenols. It was shown that the dose of 300 mg/day of chokeberry polyphenols consumed for up to 10 weeks, had a clinically significant effect on lowering LDL cholesterol and increasing HDL cholesterol. Further research is needed, especially with randomization, to be conducted on more homogeneous study groups to indicate an effective dose in the treatment of hyperlipidemia.[124]

A randomized study was carried out to evaluate the effect of cranberry juice at a dose of 500 ml/day on blood pressure values when consumed for 8 weeks by a group of overweight and obese people. A positive effect was noted, but only on the diastolic pressure values and the lipid profile. The initial inflammatory status determined using CRP might influence the results, so further research is necessary.[125]

A lot of attention was paid to the influence of Concord grape juice dose on the risk factors for cardiovascular diseases. The analysis of the results of clinical trials used regression analysis to indicate the potential impact of usually consumed portions of 118 ml (half a glass) and 237 ml (a glass) on blood pressure values, radial artery expansion, and platelet functions. It was demonstrated that the daily consumption of 118 or 237 ml of this variety of grape juice could lead to a reduction in systolic pressure (by 2.16 and 3.07 mm Hg, respectively) and diastolic pressure (by 0.86 to 1.49 mm Hg, respectively). A significant improvement from 0.24 to 0.46 could also be expected in terms of radial artery expansion depending on the amount of grape juice drunk per day. In the long term, these measures could translate into a lower risk of acute coronary syndrome, ischemic stroke and vascular interventions.[126] Overall, it was noted that the consumption of 100% fruit juice contributed to a reduction in the risk of stroke by 18%, and stroke-related death by 33%. In addition, the authors of the review, based on the results of the meta-analysis, concluded that fruits and fruit juices reduced the risk of cardiovascular events as much as vegetables. They suggested that juices should be reconsidered in the context of their participation in the implementation of the recommendations on daily fruit consumption.[127]

Fruit juices are also studied in the field of sports dietetics. It was indicated that the consumption of polyphenol-rich juices after exercise reduced the severity of delayed-onset muscle soreness, and accelerated muscle regeneration, with a maximum effect reached 48 to 72 hours after exertion. Although the quality of the evidence is moderate to low, this is a new area of research.[128] Similar conclusions were provided by another systematic review devoted to polyphenols derived from pomegranate juice. The antioxidant and anti-inflammatory effects were confirmed both during and after physical exertion, by improving cardiac parameters, greater endurance, as well as post-exercise regeneration.[129]

2. INFLUENCE ON INFLAMMATORY MARKERS, ANTINEOPLASTIC ACTIVITY OF BIOACTIVE COMPONENTS PRESENT IN JUICES

Regrettably, few studies are devoted to the impact of juices on the functioning of the immune system. Available publications mostly tackled the issue of citrus fruit juices. Citrus juices contain not only vitamin C and folates necessary to reduce the effects of oxidative stress but, above all, bioactive ingredients such as hesperidin and narirutin. According to some authors, the content of polyphenols was comparable in juices freshly squeezed at home to those produced commercially (62.9±5.94 mg/100 ml and 63.3±5.85 mg/100 ml of juice, respectively). Polyphenols support the functioning of the immune system by controlling the degree of inflammation, and supporting the innate and acquired cellular response. The anti-inflammatory effect is expressed by inhibiting the synthesis of the NF-kappa B transcription factor, which plays a role in the transcription of genes encoding proteins in the inflammatory state.[130]

Interesting observations were provided by Ghanima et al. (2010),[131] who demonstrated that the consumption of orange juice after a high-fat and high-carbohydrate meal reduced the intensity of inflammation. Available research indicated a possibly counterbalancing effect of fruit juices with high antioxidant potential on mitigating the effects of metabolic stress resulting from the consumption of meals rich in fats and simple carbohydrates, especially in relation to cranberry juice [Burton-Freeman et al. 2010; Morabito et al. 2015].[132,133]

A meta-analysis revealed that orange juice lowered the inflammatory index of CRP compared to the control group (CRP weighted mean difference: -0.467 mg/l, 95% CI: -0.815, -0.120, P=0.008.[118] Car et al. (2022)[89] confirmed that the daily consumption of 237 to 1000 ml of orange juice caused a significant reduction in the concentration of interleukin-6 (pooled difference: -1.51 pg/mL; 95% CI: -2.31, -0.70), an insignificant reduction in high-sensitivity CRP and malondialdehyde (a marker of oxidative stress, mainly of lipid peroxidation). The results suggested an effect of 100% orange juice on the reduction of inflammation. However, the results should be interpreted with caution due to the low strength of the evidence, moderate risk of error and the low number of subjects included in the interventions. A similar effect was noted for dark grape products, including juice with the effect being more marked in the group consuming >500 mg of polyphenols per day for over 12 weeks.[134]

Pomegranate juice also has antioxidant and anti-inflammatory effects. Regrettably, the majority of studies focusing on the effect of pomegranate juice on inflammatory markers were conducted on animal models and, despite promising results in supporting the treatment of prostate cancer, diabetes, irritable bowel syndrome or hyperlipidemia, these results may not be translated into the human population.[135] Eghbal et al. (2021)[136] analyzed the results of clinical trials focusing on the effect of pomegranate juice or extract on inflammatory or tumor markers. Despite divergent results of research on the effects on CRP, interleukin-6 or the PSA index (in case of prostate cancer), the authors highlighted the need to continue well-designed research on the undeniable antioxidant effect of numerous bioactive components present in pomegranate juice (flavonols, flavones, i.e., catechin, epicatechin, gallocatechin, kaempferol, quercetin or apigenin).[136] Also, Wong et al. (2021)[137] conducted a literature review and demonstrated a positive effect of both pomegranate juice and extracts on antineoplastic mechanisms in both cell lines and animal models. The results of clinical trials in patients with breast, prostate and colorectal cancer were also presented. The results indicated antiproliferative and anti-inflammatory effects of polyphenols contained in pomegranate. However, the majority of authors used concentrated extracts instead of juices in the amounts usually drunk. The authors pointed to the need for long-term research and the need to develop tumor-sensitive and tumor-specific markers.[137]

Similarly, the majority of *in vitro* studies on apple juice provided evidence to confirm the effect of oligomeric procyanidins present in apple extracts, including juices, on antimutagenic activity, modulation of carcinogen metabolism, antioxidant, antiproliferative, and apoptosis-inducing activity. Epidemiological studies indicated that consuming at least 1 apple per day might reduce the risk of colorectal and lung cancer.[138] Antioxidant and anti-inflammatory effects were also demonstrated in case of citrus juices and, although the results were mostly obtained from preclinical studies, the authors indicated the further direction of research aimed at the chemopreventive activity of bioactive components both in the prevention and support of cancer treatment.[139] Further clinical trials including homogeneous patient groups are required to develop effective and safe recommendations. Particular emphasis should be placed on studies that establish a clear dose-response relationship.

3. EFFECTS OF BIOACTIVE INGREDIENTS PRESENT IN JUICES ON COGNITIVE FUNCTION

A review of epidemiological and randomized studies by Rastani et al. (2021)[140] revealed that the consumption of 200-500 ml of dark grape juice per day improved cognitive functions (memory, learning, reaction time, orientation), especially in people with mild form of disorders. The main role is attributed to resveratrol, the bioactive compound present in these fruits.[140]

A recent randomized controlled trial showed a positive effect of polyphenol-rich tropical fruit juice on cognitive function in middle-aged women. The authors mainly observed improvements in memory, learning ability, information processing speed, and visual-motor function. The subjects received, 1500 ml of juice, 3 days a week for 10 weeks (9135 gallic acid as an equivalent to phenolic compounds and 194.1 mg of cyanidin-3-glucoside as an equivalent to anthocyanin monomers).[141] Lamport et al. (2016)[142] also reported an improvement in spatial memory and driving ability in women aged 40-50 who drank 355 ml of Concord grape juice (777 mg of polyphenols) every day for 4 months.

General cognitive function improved in the elderly after an 8-week intervention consisting in the inclusion of 500 ml of orange juice/day (305 mg of flavanones) into the diet. No effect was observed on lowering blood pressure and improving mood.[143] An interesting study was conducted by Krikorian et al. (2012).[144] In the study, Concord grape juice was consumed by elderly people with mild cognitive impairment. The dose was 6.7-7.8 ml/kg body weight 3 times a day. After 16 weeks of the intervention, the researchers noted a significant improvement in cognitive function, as well as the activation of the anterior and posterior regions of the right hemisphere of the brain, which would confirm the effect of Concord dark grape juice on neurocognitive functions.[144] A similar effect was demonstrated in case of pomegranate juice in people reporting mild memory impairment. The subjects consumed 237 ml daily for 4 weeks. The study showed an increase in fMRI activity during verbal and visual tasks compared to the placebo group. The results of the verbal memory test (according to the Buschke Selective Reminding Test) also improved.[145]

RECOMMENDATIONS

The main findings:

Dietary guidelines promote the consumption of fruit as part of a balanced and healthy diet. However, they recommend a moderate consumption of fruit in the form of juice, so that it is a supplement to, and not a substitute for, fruit consumption. In addition, it should be remembered that, like fruits, the consumption of juice should be included in the energy balance of the daily diet.

Despite concerns about the adverse metabolic effects following juice consumption, fruit juices have been shown not to have a significant negative effect on glycemic control in individuals without impaired pancreatic secretory function. It is believed that naturally occurring carbohydrates in the presence of fiber and polyphenols do not adversely influence fasting glucose and insulin homeostasis and in the postprandial period. The mechanism by which fruit juice may have a beneficial impact on glycemic control is unclear, so further research is needed to understand this effect.

The phytochemical composition of pulp-containing juices is similar, or even richer for some fruits, compared to whole fruits. Antioxidant activity seems to be similar to raw fruits and vegetables due to the high content of bioactive ingredients. Hence, it might be justified to consider nutritional recommendations in the context of including selected juices with high antioxidant potential, replacing a portion of fruit.

Research results indicated that juices, especially from pomegranates, cranberries, dark Concord grapes, sour cherries or citrus fruits, were characterized by a wide range of bioactive ingredients with cardioprotective and chemopreventive uses. Recently, it has also been shown that they may be neuroprotective. Despite the promising results of numerous clinical trials, there is still a lack of data on the effective daily supply of juices from individual fruits.

Limitations of available research:

- It should be emphasized that the number of participants in some of the presented studies was relatively low, which makes it difficult to draw clear conclusions, and the conclusions obtained should be interpreted with caution.
- The variability of some parameters of the interventions, populations and the overall study design is also an important factor hindering the synthesis of results collected from individual studies.

Directions for future research:

- Further studies on different population groups are recommended to clarify the effect of fruit juice on indicators of glucose and insulin homeostasis. In addition, research should take account of commonly consumed types of juices in moderate portions, reflecting dietary recommendations.
- It would be valuable to develop a list of juices from specific fruits in quantitative terms (consumption per day) in order to create a table of fruit equivalents. Recommendations for the consumption of juices should be precisely defined with an indication of the daily amount, time of use, group of consumers, as well as possible contraindications.
- The planned research should precisely determine the effective dose of juice, the time of use to achieve lasting therapeutic effects, the way of feeding the subject, as well as clear and reliable markers indicating changes in the course of individual diseases or disorders. In order to standardize research and the possibility of comparing the results, it is suggested to standardize juices used in interventional studies.
- It is also important to plan larger-scale research on the properties of fruit juices from temperate zones (apple, chokeberry, black currant, sour cherry, strawberry, plum and gooseberry juice) and juices from domestic vegetables (carrots, pumpkin, beet). Obtaining reliable scientific data from this type of research is necessary to consolidate the position of these products as important components of a varied diet.
- Further long term clinical studies conducted in homogeneous groups are required, with a clearly defined dose of juice that can be consumed in the daily ration, taking account of the supply of carbohydrates and energy.

CRITICAL EVALUATION OF SELECTED SCIENTIFIC EVIDENCE CONCERNING JUICES

First author (year)	Type of study/ level of evidence*	Population	Sample / group size	Type of juice
Visuthranukul et al. (2022)[80]	Pre-post clinical trial (level III)	Thailand	12 healthy, non-obese volunteers.	100% Florida orange juice with pulp /100% Tangerine orange juice/ 100% mixed blackcurrant juice with strawberries and red grapes / Veggie V9 – orange carrot, 40% mixed fruit juice, 60% mixed vegetable juice concentrate.
The aim of the study	The main objective of the study was to quantify the GI (glycemic index) and GL (glycemic load) values of fruit juices available on the market in Thailand. The second objective was to assess postprandial insulin secretion, as well as its correlation with the fructose to glucose ratio and fiber content in various fruit juices.			
Results	Plasma glucose and insulin levels peaked 30 minutes after consuming the beverage. Then, it began to decrease after 120 minutes. Tangerine juice had the lowest GI (34.1±18.7) and GL (8.1 g). Veggie V9 had the highest IG (69.6±43.3), but it was in the third GL range (12.4 g). Insulin response was well correlated with GI. The fructose to glucose ratio was inversely proportional to GI and insulin for all fruit juices tested. The fiber content of the tested juices was not correlated with glycemic and insulin indices.			
Final conclusion	Glycemic indices of fruit juices varied, but they consistently showed a positive correlation with insulin indices. Low-GI fruit juices are a healthier choice for people with diabetes, as well as people who are prone to glucose disorders because they cause more subtle postprandial reactions to glucose and insulin secretion.			
Total reliability score**	5/11 (45.5%)			
Alkutbe et al. (2020)[82]	Quasi-experimental crossover study (level III)	United Kingdom	36 participants: 24 healthy non-obese (BMI <25.0) and 12 obese (BMI >30.0) ones.	Study arm 1: raspberry juice (with seeds) and mango. Study arm 2: passionfruit juice (with seeds) and mango.
The aim of the study	Effect of nutrient extraction on postprandial glycemic response in individuals with obesity and normal body weight. It was hypothesized that eating fruits with seeds would lower the glycemic response because fiber (and fats/proteins) would be released from the seeds. This may be compared to eating a whole fruit, where most of the seeds are intact. Therefore, the effect of fruit seeds (raspberries and passionfruit) in combination with mangoes on the effect of nutrient extraction was investigated.			
Results	Nutrient extraction was shown to significantly lower the glycemic index compared to eating whole fruits in people with obesity (raspberry/mango: 25.43±18.20 vs 44.85±20.18, P=0.034 and passionfruit/mango (26.30±25.72 vs 42.56±20.64, P=0.044). Similar results were obtained in people with normal body weight.			
Final conclusion	The study indicated that the extraction of nutrients from raspberries and passionfruit mixed with mangoes lowered the glycemic index not only in people with normal body weight, but also in people with obesity. The data prompt future studies on the potential for nutrient extraction to enable increased fruit intake without causing a high glycemic response, particularly in people with obesity, insulin resistance, and other disorders of glycemia.			
Total reliability score**	6/11 (54.5%)			
Guzman et al. (2021)[83]	RCT crossover study (level II)	United States	Study 1: 17 adults [65% of women aged 39.3±3.1 years and BMI 24.6±0.7]; Study 2: 45 adults (47% of women aged 25.1±4.3 years and BMI 22.5±1.6).	100% sugar-matched orange juice (OJ); 100% orange juice (OP) with the addition of orange pomace (OP) as a source of 5 g of fiber; whole orange fruit (WOF).
The aim of the study	Two separate studies were conducted to determine the effect of the addition of OP (orange pomace) to 100% orange juice on the postprandial glycemic response compared to pure sugar-matched orange juice (OJ) or whole orange fruit (WOF). The concentrations of glucose (glucose incremental area under the curve – iAUC) and insulin were measured on an empty stomach and at multiple time points within 2 hours after the ingestion of the test product (study 1: serum; study 2: plasma).			
Results	In Study 1, glucose iAUC was not significantly lower for 100% OP-added orange juice compared to OJ or WOF (825±132 vs 920±132 and 760±132 mg · min · dL^{-1}, P=0.570, respectively). In Study 2, glucose iAUC was significantly lower in WOF compared to 100% OP-added orange juice and OJ (689±70.7 compared to 892±70.7			

	and 974±70.7 mg · min · dL^{-1}, P=0.020 and 0.001, respectively). Data from both studies indicated that 100% OP-added orange juice reduced Cmax compared to OJ and that the reductions were similar to WOF (Study 1: OP, 115±4.06 compared to OJ, 124±4.06 and WOF, 114±4.06 mg · dL^{-1}, P=0.002 and 0.750, Study 2: OP, 128±1.92 compared to OJ, 136±1.92 and WOF, 125±1.92 mg · dL^{-1}, P=0.001 and 0.280, respectively).
Final conclusion	Data from both studies showed no significant effect of OP on postprandial iAUC compared to OJ. However, the addition of OP to OJ attenuated postprandial glucose Cmax, and the responses were comparable to WOF in healthy adults.
Total reliability score**	8/11 (72.7%)

* 8 levels of scientific evidence according to Guyatt & Sackett (1995)[72]

** critical evaluation of the study according to the CASP checklist (*Critical Appraisal Skills Programme*)[71]

First author (year)	Secondary study type/ level of evidence*	Type of juice
Wang et al. (2014)[96]	Systematic review with meta-analysis (level I)	Various fruit juices
The aim of the study	Analysis of scientific evidence from RCTs evaluating the effect of fruit juice on glycemic control and insulin sensitivity.	
Results	The meta-analysis included 12 studies including a total of 412 patients. The number of studies reporting fasting glucose, fasting insulin, HbA1c, and HOMA-IR, were 12, 5, 3, and 3, respectively. The consumption of fruit juices was not found to exert a significant effect on fasting glucose and insulin levels. The net change was 0.79 mg/dL (95% CI: -1.44; 3.02 mg/dL; P=0.49) for fasting glucose concentrations and -0.74 µIU/mL (95% CI: -2.62; 1.14 µIU/mL; P=0.44) for fasting insulin concentrations in the fixed-effect model. Subgroup analyses also suggested that the effect of fruit juice on fasting glucose concentration was not influenced by the population region, baseline glucose concentration, duration, type of fruit juice, glycemic index of fruit juice, nutritional composition of fruit juice, or the total dose of polyphenols.	
Final conclusion	The meta-analysis showed that fruit juices might not have an overall effect on fasting glucose and insulin concentrations.	
Total reliability score**	6/8 (75.0%)	
Murphy et al. (2017)[78]	Systematic review with meta-analysis (level I)	Various 100% fruit juices
The aim of the study	A systematic review and quantitative summary of the results of randomized trials (RCTs) evaluating the effect of 100% fruit juice on glucose and insulin homeostasis.	
Results	Using data from eighteen RCTs, the meta-analyses evaluated the mean difference in fasting blood glucose (16 studies), fasting insulin (eleven studies), homeostatic model assessment – insulin resistance (HOMA-IR; 7 studies), and glycated hemoglobin (HbA1c; 3 studies) between intervention groups of 100% fruit juices and control groups using a random-effects model. Compared to the control group, 100% fruit juice had no significant effect on fasting blood glucose (-0.13 (95% CI -0.28, 0.01) mmol/L; P=0.070), fasting insulin (-0.24 (95% CI -3.54, 3.05) pmol/L; P=0.890), HOMA-IR (-0.22 (95% CI -0.50, 0.06); P=0.130), or HbA1c (-0.001 (95% CI -0.38, 0.38); P=0.28). The results of stratified and univariate metaregression analyses also mostly showed a lack of significant associations between 100% fruit juice and control glucose measurements.	
Final conclusion	The results of this RCT meta-analysis suggested a neutral effect of 100% fruit juice on glycemic control. These results are consistent with some observational studies suggesting that consuming 100% fruit juice was not associated with an increased risk of diabetes.	
Total reliability score**	6/8 (75.0%)	
Cirmi et al. (2017)[139]	Systematic review from preclinical studies (level V)	Various citrus fruit juices
The aim of the study	Summary of scientific evidence from clinical and preclinical studies on the potential of citrus fruit juices and their extracts as antineoplastic agents.	
Results	22 studies met the inclusion criteria and were eligible for inclusion in the final review. Due to the type of research, the selected studies were divided into preclinical (n=20) and observational (n=2) studies. A total of 12 publications from preclinical studies assessed the impact of citrus fruit juices *in vitro* on experimental models, and 8 on *in vivo* models. Only 2 observational clinical trials met the criteria for systematic review. A prospective cohort study aimed to assess the impact of fruit and vegetable intake and the risk of preneoplastic oral lesions in the USA. The authors observed significant inverse relationships with the consumption of citrus fruits and their juices (mainly orange) demonstrating a 30-40% lower risk with higher consumption (e.g., citrus fruit juice RR=0.65, IC 95%: 0.42, 0.99).	
Final conclusion	The research discussed in this review strongly confirmed the role of citrus fruit juices and their preserves as potential antineoplastic agents.	
Total reliability score**	7/8 (87.5%)	
Sarkhosh-Khorasani et al. (2021)[134]	Systematic review with a meta-analysis (level I)	Grape products containing polyphenols
The aim of the study	A meta-analysis of RCTs was conducted to determine the effect of grape products containing polyphenols on CRP levels.	
Results	A meta-analysis was conducted on 17 eligible RCTs involving a total of 668 participants. Based on the results, it was found that grape products containing polyphenols significantly reduced the level of CRP (SMD=-0.229; 95% CI -0.41, -0.05; P=0.013). According to the subgroup analysis, higher doses of grape polyphenols (>500 mg/d) and longer intervention periods (≥12 weeks) had a significant effect on CRP levels. Similarly, grape seed extract and other grape products such as grape extract, juice, and raisins significantly lowered CRP levels. According to the results of metaregression, the level of CRP depended on the dose and duration of grape polyphenol supplementation.	
Final conclusion	Based on the findings, it was found that grape products containing polyphenols had a significant impact on the level of CRP. Further well-designed and long-term clinical trials are strongly recommended for more comprehensive and accurate results.	
Total reliability score**	6/8 (75.0%)	

Ammar et al. (2018)[129]	Systematic review without a meta-analysis (level I)	Pomegranate products (POM)
The aim of the study	This systematic review aimed to (i) evaluate the available literature assessing the effects of POM supplementation on exercise performance and recovery; exercise-induced muscle damage, oxidative stress, inflammation; and cardiovascular outcomes in healthy adults, and (ii) present experimental conditions in which POM supplementation was more or less favorable in terms of exercise and/or recovery outcomes.	
Results	Available evidence suggested that POM supplementation had the potential to contribute to antioxidant and anti-inflammatory effects during and after exercise, improve cardiovascular responses during exercise, and increase endurance and strength performance and post-exercise recovery. However, beneficial effects of POM supplementation were found to be less likely when (i) unilateral eccentric exercises were performed, (ii) POM consumed by the subjects was not rich in polyphenols (<1.69 g/L), and (iii) the time between POM intake and physiological response/performance assessment was insufficient (≤1 hour).	
Final conclusion	The review indicated that POM might improve exercise performance and accelerate recovery after intense exercise. The findings and recommendations included in the review might help optimize the practice of POM supplementation in athletes and trainers to potentially improve exercise performance and post-workout recovery.	
Total reliability score**	6/8 (75.0%)	
Miles et al. (2021)[130]	Narrative review (level V)	Citrus fruit juices
The aim of the study	Review of studies on the effect of citrus fruit juices and their bioactive components on inflammation and immunity.	
Results	Citrus fruit juices are a particularly good source of vitamin C and folic acid, which play a role in maintaining the integrity of immune barriers and supporting the function of numerous types of immune cells, including phagocytes, NK cells, T cells, and B cells. Vitamin C is an antioxidant and it reduces the aspects of the inflammatory response. Important bioactive polyphenols in citrus fruit juices include hesperidin, narirutin, and naringin. Hesperidin is a hesperetin glycoside, while narirutin and naringin are naringenin glycosides. It was found that hesperidin, hesperetin, naringenin, naringin and narirutin had anti-inflammatory effects in model systems, and human trials of hesperidin revealed a reduction in inflammatory markers. In humans, orange juice was found to reduce postprandial inflammation caused by a high-fat and high-carbohydrate meal. Daily consumption of orange juice for several weeks was reported to reduce the markers of inflammation, including C-reactive protein.	
Final conclusion	Micronutrients and other bioactive substances present in citrus fruit juices played an important role in controlling oxidative stress and inflammation and in supporting innate and acquired immune responses. Human trials revealed that orange juice reduced inflammation; its effect on innate and acquired immunity requires further research in well-designed studies in relevant population subgroups, such as the elderly.	
Total reliability score**	6/8 (75.0%)	
Zurbau et al. (2020)[127]	Systematic review with a meta-analysis (level I)	100% fruit juice
The aim of the study	Evaluation of the relationship between different sources of fruit and vegetables and the condition of the cardiovascular system based on a systematic review and meta-analysis of prospective cohort studies.	
Results	A total of 81 cohorts including 4,031,896 subjects and 125,112 cardiovascular events were analyzed. Total fruits and vegetables, fruits, and vegetables were associated with a reduction in the frequency of cardiovascular disease (risk ratio, 0.93 [95% CI, 0.89-0.96]; 0.91 [0.88-0.95] and 0.94 [0.90-0.97], respectively), coronary heart disease (0.88 [0.83-0.92]; 0.88 [0.84-0.92]; and 0.92 [0.87-0.96]) and stroke (0.82 [0.77-0.88], 0.82 [0.79-0.85] and 0.88 [0.83-0.93], respectively). Total fruits and vegetables, fruits, and vegetables were associated with a reduction in the number of cardiovascular diseases (0.89 [0.85-0.93], 0.88 [0.86-0.91] and 0.87 [0.85-0.90], respectively), coronary heart disease (0.81 [0.72-0.92], 0.86 [0.82-0.90] and 0.86 [0.83-0.89]) and stroke (0.73 [0.65-0.81], 0.87 [0.84-0.91] and 0.94 [0.90-0.99], respectively). As regards fruit sources, greater benefits were observed for citrus fruits, 100% fruit juice and pome fruits, and as regards vegetables: allium vegetables, carrots, cruciferous plants and green leaves. No sources demonstrated an unfavorable relationship.	
Final conclusion	The level of evidence was "very low" to "moderate", with the highest score for the sum of fruits and/or vegetables, pome fruits, and leafy greens. There is a paucity of good cohort observational studies on the effect of fruit, vegetable and fruit and vegetable juice consumption on the condition of the cardiovascular system.	
Total reliability score**	6/8 (75.0%)	
Bahadoran et al. (2017)[123]	Systematic review with a meta-analysis (level I)	Beet juice
The aim of the study	Review and meta-analysis of RCTs to elucidate several aspects of beet juice supplementation for systolic blood pressure (SBP) and diastolic blood pressure (DBP).	
Results	A total of 22 RCTs conducted between 2009 and 2017 were included. They encompassed 47 intervention groups (n=650) and 43 control groups (n=598). Overall, SBP (-3.55 mm Hg; 95% CI: -4.55; -2.54 mm Hg) and DBP (-1.32 mm Hg; 95% CI: -1.97; -0.68 mm Hg) were significantly lower in the beet juice supplementation groups than in the control groups. The mean difference in SBP was greater between the beet juice group and the control group in the longer versus shorter (≥14 vs <14 d) duration of the study (-5.11 vs -2.67 mm Hg) and the highest versus the lowest (500 vs 70 and 140 ml/d) doses of	

	beet juice (-4.78 vs -2.37 mm Hg). A positive correlation was observed between beet juice doses and mean differences in blood pressure values. In contrast, a smaller blood pressure effect was observed after supplementation with a higher NO_3^- (milligrams per 100 ml of beet juice). A weak magnitude of effect was observed in a meta-analysis of studies in which nitrate-depleted beet juice was used as placebo compared to other interventions (-3.09 compared to -4.51 mm Hg for SBP and -0.81 compared to -2.01 mm Hg for DBP).	
Final conclusion	The results showed the blood pressure lowering effect of beet juice and highlighted its potential effect independent of the content of NO_3^-.	
Total reliability score**	7/8 (87.5%)	
D'Elia et al. (2021)[119]	Systematic review with a meta-analysis (level I)	100% fruit juice
The aim of the study	A meta-analysis of prospective studies and randomized controlled trials (RCTs) that examined the association between 100% fruit juice intake and cardiovascular risk profile and the risk of cardiovascular events.	
Results	A total of 21 prospective studies and 35 RCTs met the inclusion criteria. The dose-response analysis showed a significant inverse relationship between low and moderate intake of 100% fruit juices and the risk of stroke (up to 200 ml/day) or the total number of cardiovascular events (up to 170 ml/day) compared to no intake. No significant association between coronary heart disease and diabetes risk was found. RCTs revealed beneficial and significant effects of 100% fruit juice consumption on blood pressure (systolic, MD: -3.14 mm Hg) and endothelial function (flow-dependent extension, 2.10%). Neutral effects were observed as regards body weight, blood lipids and glucose metabolism.	
Final conclusion	The results of these analyses indicated that the consumption of 100% fruit juice was not associated with a higher cardiovascular risk. A non-linear inverse dose-response relationship occurred between 100% juice consumption and cardiovascular disease, particularly in case of stroke risk, possibly mediated by a decrease in blood pressure.	
Total reliability score**	6/8 (75.0%)	
Sahebkar et al. (2017)[120]	Systematic review with a meta-analysis (level I)	Pomegranate juice
The aim of the study	A systematic review and meta-analysis of evidence obtained from RCTs evaluating the effect of pomegranate juice intake on blood pressure (BP).	
Results	Quantitative data synthesis from 8 RCTs showed significant reductions in both systolic pressure [weighted mean difference (WMD): -4.96 mm Hg, 95% CI: -7.67 to -2.25, P<0.001) and diastolic pressure (WMD: -2.01 mm Hg, 95% CI: -3.71 to -0.31, P=0.021) after the consumption of pomegranate juice. The impact on SBP remained stable in sensitivity analyses. Pomegranate juice reduced SBP regardless of duration (>12 weeks: WMD=-4.36 mm Hg, 95% CI: -7.89 to -0.82, P=0.016 and <12 weeks: WMD=-5.83 mm Hg, 95% CI: -10.05 to -1.61, P=0.007) and the dose consumed (>240 cm^3: WMD= -3.62 mm Hg, 95% CI: -6.62 to -0.63, P=0.018) and <240 cm^3: WMD=-11.01 mm Hg, 95% CI: -17.38 to -4.65, P=0.001, pomegranate juice per day). Doses >240 cm^3 provided an effect at the limit of statistical significance as regards DBP reduction.	
Final conclusion	A meta-analysis suggested consistent benefits of consuming pomegranate juice on BP. Evidence suggested that it may be sensible to include this fruit juice in a cardioprotective diet.	
Total reliability score**	7/8 (87.5%)	

* 8 levels of scientific evidence according to Guyatt & Sackett (1995)[72]

** critical evaluation of the study according to the CASP checklist (*Critical Appraisal Skills Programme*)[71]

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SUPPLEMENTARY DATA

Table 1S. Energy value and content of carbohydrates and water in domestic vegetables (values for 100 g of product)[†]

Name	Energy value [kcal]	Water [g]	Glucose [g]	Fructose [g]	Sucrose [g]	Fiber [g]
Aubergine *Solanum melongena*	26	91.9	1.3	1.2	0.1	2.5
Chard *Beta vulgaris var. cicla*	26	89.8	ND	ND	0.2	4.4
Broad bean *Vicia faba*	76	77.3	ND	ND	0.9	5.8
Broccoli *Brassica oleracea var. botrytis var. cymosa*	31	90.5	1.0	0.9	0.4	2.5
Brussels sprouts *Brassica oleracea var. gemmifera*	47	84.8	1.0	0.9	0.8	5.4
Beet *Beta vulgaris*	42	87.6	0.2	0.2	6.5	2.2
Onion *Allium cepa*	33	90.8	1.7	1.5	1.9	1.7
Horseradish *Armoracia rusticana*	81	75.0	1.1	0.1	5.9	7.3
Zucchini *Cucurbita pepo var. giromontina*	17	95.0	0.9	1.0	0.6	1.0
Chicory *Cichorium intybus*	23	93.1	0.8	0.6	0.5	1.0
Garlic *Allium sativum*	152	59.0	0.4	0.6	0.6	4.1
Pumpkin *Cucurbita pepo, Cucurbita maxima*	33	89.9	1.1	1.0	2.1	2.8
White beans (dry seeds) *Phaseolus vulgaris*	315	11.5	ND	ND	2.7	15.7
Green beans Phaseolus vulgaris	37	89.1	0.7	1.0	0.5	2.6
Green peas *Pisum sativum*	86	75.0	0.1	0.1	2.1	6.0
Kale *Brassica oleracea var. acephala*	36	88.4	0.6	0.9	1.0	3.8
Cauliflower *Brassica oleracea var. botrylis*	27	91.5	1.1	1.0	0.2	2.4
Kohlrabi *Brassica oleracea var. gongylodes*	33	89.9	1.4	1.3	0.8	2.2
White cabbage *Brassica oleracea var. capitata alba*	33	89.8	2.0	1.7	0.4	2.5

[†] based on Kunachowicz H, Nadolna I, Iwanow K, Przygoda B. Wartość odżywcza produktów spożywczych i typowych potraw. (Nutritional value of selected food products and typical dishes.) Wydawnictwo Lekarskie PZWL; 2017.

Red cabbage *Brassica oleracea var. capitata rubra*	31	90.3	2.1	1.3	0.5	2.5
Dill *Anethum graveolens*	33	89.0	0.3	0.2	0.1	3.3
Corn *Zea mays*	115	70.9	0.6	0.2	2.2	3.3
Carrot *Daucus carota*	33	89.7	1.6	1.4	2.0	3.6
Cucumber *Cucumis sativus*	14	95.8	0.7	0.7	0.1	0.5
Red pepper *Capsicum annuum*	32	91.0	2.1	2.4	0.1	2.0
Green pepper *Capsicum annuum*	22	93.5	1.1	1.4	0.1	2.0
Parsnip *Pastinaca sativa*	65	81.0	0.8	0.5	3.0	4.5
Parsley *Petroselinum sativum*	49	85.3	0.4	0.5	4.8	4.2
Tomato *Lycopersicum esculentum / Solanum lycopersicum*	19	94.3	1.2	1.5	0.1	1.2
Leek *Allium porrum*	29	90.9	1.0	1.0	0.8	2.7
Rhubarb *Rheum rhaponticum*	15	94.1	0.4	0.4	0.3	3.2
Turnip *Brassica rapa*	33	89.7	2.0	1.5	0.5	3.5
Radish *Raphanus sativus*	18	93.8	1.1	0.6	0.1	2.5
Lettuce *Lactuca sativa*	16	94.5	0.4	0.5	0.1	1.4
Celeriac *Apium graveolens var. rapaceum*	30	89.5	0.5	0.3	1.7	4.9
Red lentils (dry seeds) *Lens esculenta*	341	11.9	ND	ND	1.1	8.9
Lentils (sprouts) *Lens esculenta*	124	67.3	ND	ND	0.8	3.0
Soybean (dry seed) *Glycine max*	413	8.1	ND	ND	4.8	15.7
Soybean (sprouts) *Glycine max*	146	69.0	ND	ND	0.4	2.6
Sorrel *Rumex acetosa*	26	92.1	0.2	0.3	0.5	2.6
Chives *Allium schoenoprasum*	35	90.0	0.7	0.8	0.2	2.5
Asparagus *Asparagus officinalis*	21	93.7	0.6	0.9	0.1	1.5
Spinach *Spinacia oleracea*	22	92.4	0.3	0.3	0.2	2.1
Potatoes (average) *Solanum tuberosum*	79	78.8	0.2	0.2	0.5	1.5

Table 2S. Energy value and content of carbohydrates and water in domestic fruits (values for 100 g of product)[‡]

Name	Energy value [kcal]	Water [g]	Glucose [g]	Fructose [g]	Sucrose [g]	Fiber [g]
Gooseberry *Ribes grossularia*	46	86.7	2.9	2.9	0.7	3.0
Peach *Prunus persica*	50	86.3	1.3	1.2	5.2	1.9
Bilberry *Vaccinum myrtillus*	51	86.1	2.9	3.2	0.4	3.2
Sweet cherry *Prunus avium*	63	83.6	6.1	5.4	0.5	1.3
Pear *Pirus communis*	58	84.5	1.9	6.2	1.8	2.1
Apple *Malus domestica*	50	86.8	2.0	5.4	2.3	2.0
Raspberry *Rubus idaeus*	43	85.8	1.7	2.2	1.0	6.7
Apricot *Prunus armeniaca*	50	86.4	1.8	0.9	5.1	1.7
Nectarine *Prunus persica var. nectarina*	50	86.6	1.4	1.3	6.3	1.2
White currant *Ribes album (Ribes petraeum)*	45	85.2	2.8	2.7	0.6	6.4
Black currant *Ribes nigrum*	51	82.7	3.2	3.7	0.3	7.8
Red currant *Ribes rubrum*	46	84.2	1.9	2.6	0.3	7.7
Wild strawberry *Fragaria vesca*	37	89.6	ND	ND	1.4	2.0
Plum *Prunus domestica*	49	87.0	3.4	2.0	3.4	1.6
Strawberry *Fragaria sp.*	33	90.5	2.4	2.4	1.0	1.8
Sour cherry *Prunus cerasus (Cerasus vulgaris)*	49	87.3	4.6	3.9	0.4	1.0

Table 3S. Energy values and carbohydrate and water content in selected juices and purees (values for 100 g of product)[§]

Name	Energy value [kcal]	Water [g]	Glucose [g]	Fructose [g]	Sucrose [g]
Apple juice from concentrated juice	47	88.1	3.21	5.70	1.39
Apple puree	46	87.1	2.45	5.86	2.36
Orange juice from concentrated juice	46	88.2	1.79	2.10	4.39
NFC orange juice	45	88.5	1.81	2.12	4.14
Tomato juice from concentrated juice	20	93.6	1.20	1.37	<0.25

[‡] based on Kunachowicz H, Nadolna I, Iwanow K, Przygoda B. Wartość odżywcza produktów spożywczych i typowych potraw. (Nutritional value of selected food products and typical dishes.) Wydawnictwo Lekarskie PZWL; 2017.

[§] based on: U.S. Department of Agriculture. FoodData Central. Accessed 01-03-2023, https://fdc.nal.usda.gov/fdc-app.html#/?query=juice


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