Reviews

The potential role of selected bioactive compounds from spelt and common wheat in glycemic control

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Abstract

Diet is an important lifestyle factor which influences people's health and the prevention of chronic diseases such as type 2 diabetes. Cereal-based foods constitute the main component of the everyday diet worldwide. Old cereal species like spelt (*Triticum spelta* L.) are becoming more and more popular, especially in Europe. This review focuses on the role of bioactive compounds from spelt and their possible biological mechanisms of action in glycemic control. Spelt grain contains a high amount of dietary fiber, which can modulate postprandial glycemia. Other phytochemicals, such as phytic acid and alkylresorcinols, also contribute to controlling blood glucose levels, insulin sensitivity and hiperinsulinemia. Antioxidant compounds present in spelt grain may act as protection from negative outcomes of chronic hyperglycemia. In this paper the composition and beneficial properties of spelt are also compared with those of widely consumed cereals like common wheat (*Triticum aestivum* L.). The health benefits of whole grain as opposed to refined products are also discussed.

Key words: wheat, glycemic control, spelt

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There are several factors that influence diabetes prevention and management. Some of them – such as age 45 or older, or a family history of diabetes and related diseases – cannot be controlled. But there are several risk factors connected to daily habits and lifestyle which can be easily modified. These include physical activity, weight control, alcohol consumption, smoking status, and intake of red meat, fruit and vegetables. Simple changes in the diet can significantly reduce the risk of diabetes or the prediabetic state.

Spelt (*Triticum spelta* L.) is one of the ancient wheat species, along with emmer wheat (*Triticum dicoccum* Schrank ex Schübl) and einkorn wheat (*Triticum monococcum* L.). It has been known since 7000 or 8000 BC. There are several hypotheses with regard to the origin of spelt in Europe; one theory is that it is a hybrid of emmer and common wheat.[1] Spelt has fewer climate requirements than common wheat and can grow even in high mountains.

In recent decades spelt has become more and more popular owing to its composition and its possible protective influence on human health.

Bioactive compounds

Wheat grain is a rich source of dietary fiber and various phytochemicals, which are unevenly distributed throughout the kernel. Endosperm (80–85% of the grain's weight) consists mostly of starch and some proteins, along with bioactive compounds such as β-glucans, arabinoxylans, carotenoids and flavonoids. Bran constitutes 10–14% of the grain's weight, and the list of its bioactive compounds is long. The most important groups are soluble and insoluble fiber, minerals, vitamins, phytic acid, betaine, choline, phenolic acids, lignans (secoisolariciresinol, matairesinol, syringaresinol, lariciresinol, pinoresinol medioresinol and 7-hydroxymatairesinol), alkylresorcinols and phytosterols. As for the germ (3% of the grain's weight), unsaturated fatty acids and phytosterols constitute its greatest nutritional value. Besides those 2 groups, fiber, minerals, enzymes, sulfur-containing amino acids, glutathione, betaine, choline, myoinositol, tocopherols, lignans, flavonoids and benzoxazinoids (benzoxazolinones, lactams and hydroxamic acids) are present in wheat germ.[2,3] Although spelt and common wheat belong to the same botanical genus (*Triticum* spp.), the content of the grains differ. Details of the composition of both species are presented in Table 1 and Table 2.

Glycemic control is associated with dietary fiber and a few groups of the phytochemicals present in cereal grain. According to the American Association of Cereal Chemists (AACC) "dietary fiber is the edible part of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. Dietary fiber includes polysaccharides, oligosaccharides, lignin and associated plant substances. Dietary fibers promote beneficial physiological effects including laxation and/or blood cholesterol attenuation and/or blood glucose attenuation".[20] Two kinds of dietary fiber can be distinguished: soluble and insoluble, which are further divided into subgroups. Soluble fiber consists of β-glucans, pectins, mucilages, gums and some hemicelluloses; and insoluble consists of celluloses, lignin and

Table 1. Content of macronutrients in spelt (*T. spelta* L.) and common wheat (*T. aestivum* L.) products expressed as g/100 g of DM in grains and g/100 g of sample in food products

Nutrient	Spelt	Reference	Common wheat	Reference
Carbohydrate (total)	69.7	4	71.2	4
	74.20 F	5	75.94 F	5
	51.94 B	5	53.16 B	5
Starch	66.7	4	68.1	4
	72.07 F	5	71.84 F	5
	50.45 B	5	50.28 B	5
Sugars (glucose, sucrose, maltose)	3	4	3.1	4
	2.13 F	5	4.10 F	5
	1.49 B	5	2.87 B	5
Lipids	2.92	6	2.48	6
	1.43 F	5	1.14 F	5
	1 B	5	0.79 B	5
Saturated fatty acids (%)	20.53	4	18	4
	21.01 F, B	5	20.67 F, B	5
Monounsaturated fatty acids (%)	21.45	4	12.10	4
	14.10 F, B	5	7.9 F, B	5
Polyunsaturated fatty acids (%)	58.02	4	69.90	4
	60.49 F, B	5	67.04 F, B	5
Proteins	12.2	4	13.5	4
	11.83 F	5	10.53 F	5
	8.28 B	5	7.37 B	5
Fiber (total)	2.64	4	2.73	4
	2.65 F	5	2.52 F	5
	1.86 B	5	1.76 B	5

F – flour; B – bread; without annotation – in grain.

Table 2. Content of bioactive compounds in spelt (*T. spelta* L.) and common wheat (*T. aestivum* L.) products expressed as mg/100 g

Nutrient	Spelt	Reference	Common wheat	Reference
Phytic acid	437 B	7	300–1500	2
			218B	7
Myoinositol	nd	–	1.9 7.5	2
Alkylresorcinols	39.5	4	47.5 –55.8	4,9
	4.75–69.39 F	8	365.21 Br	8
			2.92–76.33 F	8
Phytosterols	65.15	10	64.11	10
Lignans	3.25 Br	11	0.34–2.3	12
			9.22 Br	11
Benzoxazinoids	nd	–	0.48	13
Tocochromanols	2.31–3.48	14	3.20–3.29	14
Phenolic acids	38.2–72.6	15	32.6–117.1	15
	42.22–125.74	16	45.6–89.2	16
Policosanol	nd	–	0.3–5.62	2
			3.0 Br	17
			0.017 F	17
Betaine	183–277	18	97–294	18
			1500 Br	19
			226.5 B	19
Choline	20–22	18	18–28	18
Lectins	nd	–	nd	–

nd – no data available; F – flour; B – bread; Br – bran; without annotation – in grain.

some hemicelluloses. Although wheat grain is richer in insoluble than soluble fiber[1,2], it is the latter group that mostly affects glycemic control.[20]

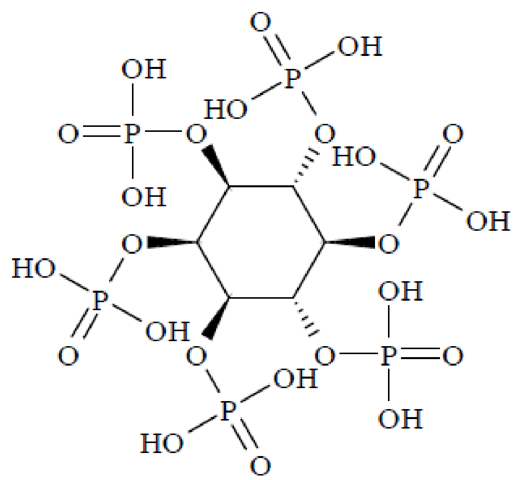
Total arabinoxylans (AX), which consist of water-extractable arabinoxylans (WEAX) and water-unextractable arabinoxylans (WUAX), bind properties of soluble and insoluble fiber.[21] D-xylopyranose residues form the linear backbone of AX. They are connected via β-(1→4) glycosidic linkages with none, 1 or 2 L-arabinofuranose residues in position 2 and/or 3.[21,22] Other compounds which may be tied to the AX structure are short oligomers, uronic acids, acetic acid and hydroxycinnamic acids. The mean content of AX in spelt is 5.74%, including 0.59% WEAX.[22] For spelt flour these values are 1.75% and 0.35% respectively. As for common wheat, the percentage of AX is 1.9%, including 0.50% WAEX.[1] WEAX is capable of creating a gel formation with viscosity proportional to the molecular mass.[21]

β-glucans are another group that has a significant role in controlling blood glucose levels. They are present in smaller amounts than arabinoxylans, with mean percentages of 0.54% (0.23–0.9%) and 0.51% (0.37–0.76%) in spelt and common wheat, respectively.[22] β-glucans are non-branched chains composed of β-D-glucopyranose residues. Usually, 3 or 4 residues linked by β-(1→4) glycosidic bonds create cellulose-like fragments connected to each other via β-(1→3) glycosidic bonds. Sometimes 5–20 residue fragments occur. β-glucans also have gel-forming capacity which depends on the molecular mass, length and ratio of the cellulose-like fragments.[21]

Lectins, also called hemaglutinins, are a large group of proteins with the ability to bind to carbohydrates without changing their structures. They are divided into subgroups based on their highest affinity to the following monosaccharides: mannose, galactose or N-acetylgalactosamine, N-acetylglucosamine, fucose and sialic acid. Among lectins, one specific protein has been distinguished: wheat germ agglutinin (WGA), a small lectin binding to N-acetylgalactosamine. Both adverse and beneficial health outcomes related to this protein have been described. Lectins are not fully degraded during digestion, so they exhibit activity throughout whole gastrointestinal tract.[23] No data is available on lectin content in spelt and wheat.

Phytic acid (Fig. 1), or phytate (the salt form), is a phosphorus storage compound located in the aleurone layer.[6] It is composed of myoinositol hexaphosphate (IP6). Unfortunately, the quantitative phytic acid content in spelt grain has not been evaluated, but bread baked from spelt flour type 1400 contained more phytic acid than bread made from common wheat flour type 1400 (437 mg/100 g and 218 mg/100 g, respectively).[7] For a long time phytic acid was regarded

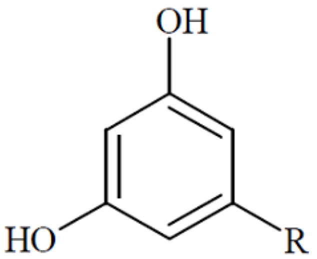
Fig. 1. Phytic acid



as an antinutrient; nowadays, it is described as having health benefits, including glycemic control.[2]

Alkylresorcinols (AR) are phenolic lipids (Fig. 2) restricted strictly to the outer parts of grain. They are 1,3-dihydroxybenzenes with an odd-numbered alkyl chain attached to C5, which can be saturated, mono- or diunsaturated. The length of the side chain is 13–27 carbon atoms.[24] The C17:0/C21:0 homolog ratio is specific for each species. It is 0.1 for both common wheat and spelt, and 1 for rye.[25] AR are absorbed in the small intestine and can be detected as intact homologs in plasma, and as small amounts of intact homologs and their metabolites in urine.[26] The AR content in whole spelt grain is 39.5 mg/100 g; in common wheat it is 47.5–55.8 mg/100 g.[4,9] Refined products contain trace amounts of alkylresorcinols due to a lack of bran.

Fig 2. The basic structure of alkylresorcinols

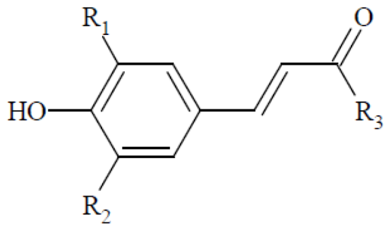


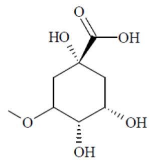
Name		R
5-*n*-Tridecylresorcinol	(C13:0)	$C_{13}H_{27}$
5- *n* -Pentadecylresorcinol	(C15:0)	$C_{15}H_{31}$
5- *n* -Heptadecylresorcinol	(C17:0)	$C_{17}H_{35}$
5- *n* -Nonadecylresorcinol	(C19:0)	$C_{19}H_{39}$
5- *n* -Heneicosylresorcinol	(C21:0)	$C_{21}H_{43}$
5- *n* -Tricosylresorcinol	(C23:0)	$C_{23}H_{47}$
5- *n* -Pentacosylresorcinol	(C25:0)	$C_{25}H_{51}$
5- *n* -Heptacosylresorcinol	(C27:0)	$C_{27}H_{55}$

Phytosterols, also called plant sterols, are a group of secondary metabolites present in particularly high amounts in the germ. They can be found in free or esterified form, rather than as glycosides or acylated glycosides.[3] Quantitative estimates show no significant differences in the phytosterol profiles of common wheat and spelt. However, a higher content of the main compound of this group – β-sitosterol glycoside – has been observed in spelt.[10]

Phenolic acids and tocochromanols (vitamin E forms) create a heterogeneous group. Phenolic acids can be divided into derivatives of hydroxycinnamic acid (Fig. 3)

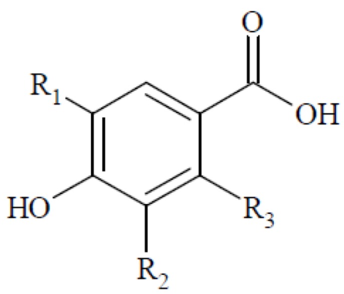
Fig. 3. Derivatives of hydroxycinnamic acid



	R_1	R_2	R_3
p-Coumaric acid	-H	-H	-OH
Ferulic acid	$-OCH_3$	-H	-OH
Sinapic acid	$-OCH_3$	$-OCH_3$	-OH
Chlorogenic acid	-OH	-H	

or hydroxybenzoic acid (Fig. 4); tocochromanols can be divided into tocopherols (Fig. 5a) or tocotrienols (Fig. 5b). Examples of hydroxycinnamic derivatives are p-coumaric, ferulic, sinapic and chlorogenic acids. Hydroxybenzoic derivatives include p-hydroxybenzoic, protocatechuic, vannilic and syringic acids.[3,15] All phenolic acids have an aromatic ring in their structure, with at least 1 hydroxyl group. They may appear as free, conjugated or insoluble bound forms (e.g. lignins). The content and composition of phenolic acids differ according to the type of cereal, environmental conditions, time of harvest and morphological fraction, with the biggest portion in bran.[3]

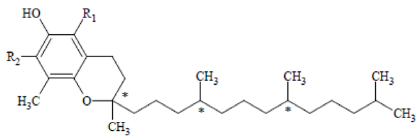
Fig. 4. Derivatives of hydroxybenzoic acid



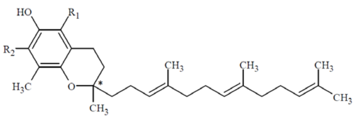
	R_1	R_2	R_3
p-Hydroxybenzoic acid	-H	-H	-OH
Protocatechic acid	-H	-OH	-H
Vannilic acid	$-OCH_3$	-H	-H
Syringic acid	$-OCH_3$	$-OCH_3$	-H

Fig. 5

a) Structure od tocopherols



b) Structure of tocotrienols



	α	β	γ	Δ
R_1	$-CH_3$	$-CH_3$	-H	-H
R_2	$-CH_3$	-H	$-CH_3$	-H

Spelt contains 38.2–125.74 mg/100 g and common wheat 32.6–117.1 mg/100 g.[15,16] Ferulic acid is the most abundant and p-coumaric acid takes the second place.[3]

Tocochromanols are lipid-soluble compounds with vitamin E activity. Their basic structure is a 6-chromanol ring with a 16-carbon hydrophobic side chain attached to C2. Tocotrienol side chains have 3 double bonds, while tocopherol side chains are saturated. Another difference between tocotrientols and tocopherols is the number of asymmetric carbons. Tocotrienols have 1 (at C2 of the chromanol ring), while tocopherols contain 3 (at C2 of chromanol ring, and C4' and C8' of the side chain). The content of tocochromanols in spelt is in the range of 2.31–3.48 mg/100 g, while common wheat contains an average of 3.25 mg/100 g, ranging from 3.20 to 3.29 mg/100 g.[14]

Possible mechanisms of action

Glycemic control is not a simple act; it is a complex process dependent on various factors such as the structure, composition and degree of food processing as well as digestive enzyme activity. Wholegrain products, despite their high carbohydrate content, do not cause such a high and rapid rise in blood glucose level as refined products do. This can be explain by the discrepancy in the content of dietary fiber and bioactive compounds, and different rates of digestion. Glycemia can be controlled on different levels: during food production, by choosing wholegrain and wholemeal raw materials instead of refined ones, and in the body after ingestion. It is difficult to pinpoint specific groups of phytochemicals and corresponding mechanisms of glycemic control. Various groups of compounds act together to produce a synergistic effect. Sometimes the mechanisms of action of different groups mesh together and sometimes they complement each other to achieve the effect.[2]

The macronutrient composition of grain plays a major role in the glycemic response. The content of spelt and common wheat grains differ. The higher protein and fat content of spelt grain favors better glycemic control. Despite that, in a study comparing the glycemic response to spelt bread and common wheat white bread, no difference in the glycemic index (GI) was observed; both breads had a high GI. This might be because refined flour, not wholemeal flour, was used to bake both breads[5]

Lower blood glucose level might be achieved by prolonging the time of digestion. Soluble fiber, arabinoxylans, short-chain fatty acids (SCFA, e.g. propionic acid), which are products of fiber fermentation in the gut, and phytic acid have an ability to delay gastric emptying.[2,27] Phytic acid (or phytate) also hinders digestion by binding with starch and starch-associated protein. The inhibition of enzymes modulates the rate of glucose release from starch. Alkylresorcinols, lectins and phytic acid are able to bind to α-amylase (an enzyme involved in starch digestion), limiting its activity. Phytic acid also influences this enzyme by chelating calcium, which is a cofactor for α-amylase.[2] Another enzyme involved in carbohydrate digestion is α–glucosidase, which can be inhibited by phenolic acids and alkylresorcinols.[28,29] Increased viscosity due to the presence of soluble fiber and arabinoxylans limits access to enzymes and impedes absorption of glucose in the small intestine.[2,27] Thus, changes in glucose level are smoother.[20] Absorption of glucose from the intestines to the bloodstream goes through sodium-dependent glucose transporter SGLT1 localized in the intestinal brush border membrane. Ferulic and chlorogenic acids exhibit an ability to block this transporter, limiting the rate of absorption.[28] All these mechanisms lengthen the time of digestion and prevent rapid changes and high peaks in blood glucose.

Physiologically, the glucose level is under hormonal control. Insulin released by pancreatic β-cells decreases postprandial glycemia. Cell resistance to insulin may be the first step in the development of type 2 diabetes. A study conducted on mice showed that supplementation with arabinoxylans improved insulin resistance.[27] Betaine is another compound with the potential ability to overcome insulin resistance.[2] Various studies have shown that insulin response and postprandial glucose levels were lower in healthy, obese and diabetic subjects when arabinoxylans were added to their diets.[27] β-glucans improve insulin sensitivity as well.[21] In an in vitro study, ferulic acid promoted insulin secretion in cell cultures.[28] Spelt grain is also a rich source of magnesium. A sufficient supply of this mineral is needed to sustain insulin sensitivity. In case of hyperglycemia, pancreatic β-cells are potentially protected from the toxic activity of glucose by tocochromanols.[2]

The blood glucose level is also dependent on the function of the liver. Propionate, one of the SCFAs, reduces hepatic gluconeogenesis and stimulates glycolysis, which modulates glycemia. Glycolysis is performed by metalloenzymes, most of which contain magnesium in their structure. Thus, an adequate supply of magnesium is necessary.[2]

The last mechanism of glycemic control is modulation of glucose uptake form the bloodstream to muscle cells. This activity is performed by ferulic and chlorogenic acids.[28]

A 9-week intervention study was carried out in animal model with Zucker diabetic fatty (ZDF) rats to investigate the physiological effects of 5 different diets (emmer, einkorn, spelt, rye and refined wheat) on the development and progression of type 2 diabetes. The ancient wheat diets downregulated key regulatory genes expression (hepatic genes PPAR-α, GLUT2, SREBP-1c) engaged in glucose and fat metabolism. Spelt and rye induced a lower acute glycemic response compared to refined wheat. These results provide strong evidence that spelt, in contrast to wheat, plays a role in the prevention or delay of diabetes development.[30]

Hartvigsen et al.[31] checked the impact of arabinoxylans on glycemic control as indicated by postprandial glucose and hormone responses, fermentation and appetite in human beings in an acute randomized cross-over study with 15 subjects with metabolic syndrome, which may be associated with type 2 diabetes. A meal of concentrated arabinoxylan combined with rye kernels reduced the acute glucose and insulin responses and the feeling of hunger to a greater extent than the control meal of semolina porridge. Concentrated arabinoxylan and concentrated arabinoxylan combined with rye kernels also stimulated SCFA production, i.e. butyrate and acetate. However, no significant differences were observed for the second meal responses of glucose, insulin, free fatty acids (FFA), glucagon-like peptide-1 (GLP-1) and ghrelin.[31]

Phenolic acids and other polyphenols, such as lignans and flavonoids, are known for their antioxidant properties. Tocochromanols, tocotrienols and phytic acid also contribute to the antioxidant mechanism of action of spelt and wheat because of their chelating properties. Alkylresorcinols possess these properties as well, although they are rather weak.[32] These compounds might be useful in protection against glyco-oxidation, which takes part in diabetic complications and results in the formation of advanced glycation end products (AGEs) and advanced oxidation protein products (AOPPs). In a study with 52 diabetic patients (18 with type 1 and 34 with type 2), AGEs in serum were elevated only in patients with type 2 diabetes, while AOPPs were elevated in both types of diabetes, with higher levels in type 2.[33] Antioxidants may prevent glucose oxidation and AGE formation, which are increased in hyperglycemia and under the influence of oxidative stress.[34] AOPP formation can also be inhibited by antioxidants, e.g. vitamin E.[35]

Summary

Cereals may play a beneficial role in the prevention of type 2 diabetes. Certain differences between the nutritional and bioactive compound content of spelt and common wheat can endow spelt with a significant protective role.

Phytochemicals such as polyphenols may affect and modify lipid and glucose homeostasis and therefore play an important role in the prevention of type 2 diabetes and related diseases. However, the mechanisms of the protective role of their compounds against diabetes needs to be clarified and requires further study.

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