Betaine in Cereal Grains

Subjects: Food Science & Technology
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Betaine is a non-essential nutrient which performs several important physiological functions in organisms. Abundant data exist to suggest that betaine has a potential for prevention of chronic diseases and that its dietary intake may contribute to overall health enhancement.

betaine cereals pseudocereals gluten-free stability cooking baking extrusion

1. Introduction

Betaine (*N*,*N*,*N*-trimethylglycine, glycine betaine) is an organic nitrogenous compound, found for the first time in sugar beet juice (*Beta vulgaris*).

Betaine is a zwitterion of quaternary ammonium which is still named trimethylglycine and glycine betaine (**Figure 1**). It is a methyl derivative of the amino acid glycine ($(CH_3)_3N^+CH_2COO^−$ and molecular weight 117.2). It is characterized as methylamine due to its three free methyl groups [1].

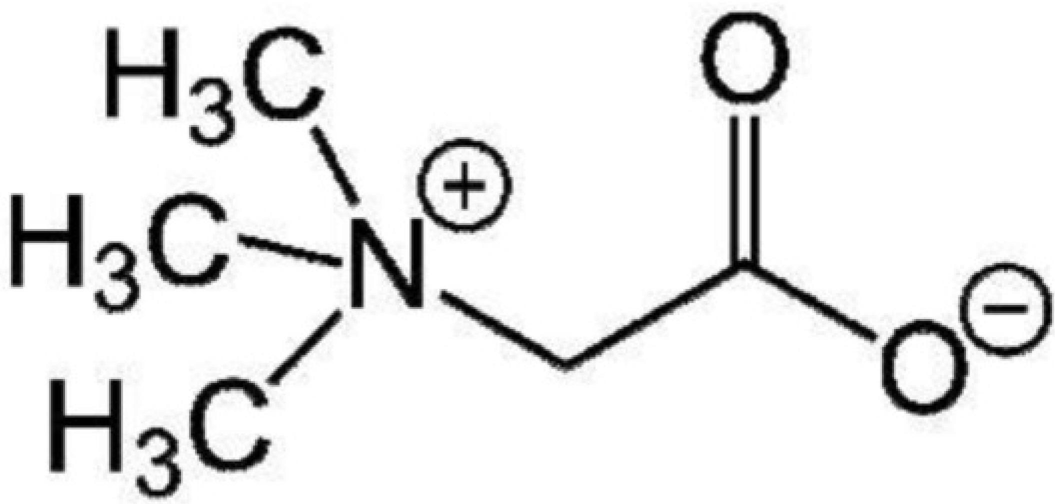

Figure 1. Betaine chemical structure.

Various analogues of glycine betaine exist in plants: proline betaine (stachydrine), trigonelline, arsenobetaine, betonicine, butirobetaine, ergothionine, propionobetaine, and sulfur analogues. The sulfur analogues are several in type: β-alaninebetaine, dimethylsulfonioacetate, and dimethylsulfoniopropionate (DMSP). The food survey study by de Zwart et al. [2] showed that only some betaine analogues were present in food at appreciable levels (>10 µg/g)—glycine betaine, proline betaine, trigonelline, and DMSP. Slow et al. [3] indicated glycine betaine as dominant in grain products, proline betaine in citruses, and trigonelline in coffee. Most recently, some rare forms of betaine were identified in the grains of most common cereals: pipercolic acid betaine in rye flour and valine betaine and glutamine betaine in flours of barley, rye, oat, durum, and winter wheat [4]. The content of betaine analogues was found to be vastly variable in grains; higher betaine levels seem to be induced by plant growth under stress conditions (drought, salt stress, cold, freezing, hypoxia, etc.) [2][3]. Since the potential health effects of betaine analogues, particularly trigonelline and proline, have not yet been fully resolved, currently only glycine betaine has dietary relevance.

Betaine represents a bioactive compound that has significant physiological functions in the human organism as an osmolite and donor of methyl groups for many biochemical processes. As such, it is indispensable to preserve the health of kidneys, liver, and heart [5]. This compound has an important role in preventing and treating many chronic diseases, among which lowering of plasma homocysteine levels has gained the most attention [5][6][7]. High serum homocysteine levels have been associated with increased risk for cardiovascular diseases (stroke, heart attack, atherosclerosis), cancer, peripheral neuropathy, etc. Moreover, betaine has been shown to improve athletic performance by enhancing muscle endurance [7][8].

2. Cereal Grains as a Source of Betaine

Data on the distribution of betaine in various cereals and pseudocereals are scarce and there is definitely a lack of detailed study. Most data come from various studies that were focused on estimation of betaine dietary intake. Nevertheless, available studies report on wide variations in betaine content in cereals. Different types of cereals may have different amounts of betaine [9]. The following ranges were found by de Zwart et al. [2]: 270–1110 µg/g (dry solids) in wheat flour, and 200–1000 µg/g in oats. More detailed overview of betaine levels in various cereals and pseudocereals from different studies is displayed in **Table 1**. The displayed data showed that betaine content spanned in wide ranges within the studied grains. According to Corol et al. [9], betaine content in cereals varies depending on multiple factors including genotype and environmental differences such as geographical and/or year-to-year variations and their interactions with genotype. This study revealed a three-fold difference in glycine betaine content within bread wheat genotypes and a 3.8-fold difference across six environments. The highest glycine betaine levels were found in Hungarian wheat grains whereas the lowest in those grown in the UK [9]. Slow et al. [3] and de Zwart et al. [2] indicated that the level of betaine depends on the level of stress under which the crop grows. This is due to osmoprotectant and cryoprotectant function of betaine. For example, growth under drought can cause higher levels of betaine compared to well-watered crops.

Table 1. Betaine content in different samples of cereals and pseudocereals.

Cereals and Pseudocereals	Betaine (μg/g Dry Weight)	References
Wheat (*Triticum aestivum*)		
raw grain	1150–1320	[10]
	490–574	[11]
bran	5047–5383	[11]
	2717	[12]
	2300–7200	[3]
aleurone	4538–6242	[13]
germ	3414	[13]
wholegrain flour	792	[13]
	730 *	[14]
	604	[15]
	540	[11]
refined flour	718 *	[16]

Cereals and Pseudocereals	Betaine (µg/g Dry Weight)	References
	700 *	[14]
	415–593	[12][11]
	398	[13]
	180 *	[4]
	141.2	[15]
flour (not specified by origin)	270–1110	[2]
Wheat Emmer (*T. dicoccum*)		
raw grain	830–940	[10]
refined flour	195 *	[4]
Wheat Einkorn (*T. monococcum*)		
refined flour	367.3 *	[4]
Durum wheat (*T. durum*)		
semolina	1227	[11]

Cereals and Pseudocereals	Betaine (µg/g Dry Weight)	References
	483	[12]
	683	[13]
refined flour	253–303	[11]
	310	[12]
wholegrain flour	713	[13]
	245 *	[4]
Spelt wheat (*T. aestivum* ssp. spelta)		
raw grain	973–2723	[11]
	565–714	[12]
wholegrain flour	1296–1442	[11]
	1370–1430	[10]
refined flour	978	[13]
	522–593	[11]

Cereals and Pseudocereals	Betaine (μg/g Dry Weight)	References
	410	[12]
Kamut wheat, Khorasan (*T. turgidum* ssp. turanicum)		
raw grains	1100	[14]
Triticale (xTriticosecale)		
raw grain	986–1030	[11]
Rye		
raw grain	2213	[11]
	1530–1760	[10]
	444	[12]
bran	1651	[15]
refined flour	310 *	[4]
wholegrain flour	1500 *	[14]
	1182	[11]

Cereals and Pseudocereals	Betaine (µg/g Dry Weight)	References
	986	[12]
Barley		
raw grain	460	[10]
raw grain from naked var.	980	[10]
wholegrain flour	776–1023	[11]
	779	[12]
refined flour	250 *	[4]
flour from naked var	424	[12]
	574	[11]
pearled grain	274	[12]
Oats		
raw grain	280	[10]
	388	[12]

Cereals and Pseudocereals	Betaine (µg/g Dry Weight)	References
raw grain from naked var.	440	[10]
wholegrain flour	310 *	[14]
flour	404–688	[11]
	53 *	[4]
bran	200 *	[14]
	190	[13]
Maize		
raw grain	107–304	[11]
	175	[12]
wholegrain meal	120 *	[14]
degermed meal	4 *	[14]
semolina	3–22	[13]
refined corn grits	37	[13]

Cereals and Pseudocereals	Betaine (μg/g Dry Weight)	References
flour, enriched	20 *	[14]
refined flour	2.1 *	[4]
bran	184	[12]
	104	[11]
	46 *	[14]
flakes	103–120	[11]
	7–9	[13]
	n.d.	[12]
starch	n.d.	[12]
popped	19	[13]
	n.d.	[12]
Rice		
grain	1–5	[13]

Cereals and Pseudocereals	Betaine (µg/g Dry Weight)	References
	n.d.	[12]
refined flour	8.4 *	[4]
expanded	n.d.	[12]
starch	n.d.	[12]
Amaranth (*Amaranthus cruentus*)		
raw grain	7420	[11]
	680 *	[14]
	646	[13]
expanded grain	669	[11]
	607	[12]
flour	895–1225	[11]
	871	[12]
Proso millet		

supplementation on power performance and fatigue. J. Int. Soc. Sports Nutr. 2009, 6, 7–17.

9. Corol, D.I.; Ravel, C.; Raksegi, M.; Bedo, Z.; Charmet, G.; Beale, M.H.; Ward, J.L. Effects of genotype and environment on the contents of betaine, choline, and trigonelline in cereal grains. J. Agric. Food Chem. 2012, 60, 5471–5481.

Cereals and Pseudocereals	Betaine (µg/g Dry Weight)	References
sample type not specified	95–112	[13]
dehulled grain	281	[11]
refined flour	1320 *	[4]
Buckwheat		
wholegrain flour	108	[11]
	7–20	[13]
refined flour	n.d.	[12]
groats, roasted	10 *	[4]
	26 *	[14]
Sorghum		
refined flour	425 *	[4]
Quinoa		
grains	6300 *	[14]

Cereals and Pseudocereals	Betaine (μg/g Dry Weight)	References
	3042–4428	[13]
	610.8 *	[4]

n.d. not detected; * result expressed on wet weight.

3. Betaine Content in Cereal-Based Products

The betaine content in cereal products depends on the processing method. Two to four times lower betaine content were found in refined grain products compared to equivalent whole grain products [13]. Betaine content is notably dependent on the loss of bran fraction during processing. The higher the abrasion of aleurone layer, the lower the betaine content in the product. Outstanding betaine levels were determined in wheat bran, up to 7200 μg/g (**Table 1**). Likes et al. [16] analyzed the betaine contents in different milling streams and reported the lowest betaine level in the cleanest milling fractions. In the study of de Zwart et al. [2], a wide range of different foods was analyzed for betaine content and flour was denoted as an item high in betaine (730 μg/g), however it was not specified the type of flour, except that it was available from retail markets. Betaine ranges in bread, pasta, breakfast cereals and snacks are given in **Table 2**. As it can be seen, the variation within each product category is high due to versatility of ingredients in product formulations. In each product category, the highest betaine content was reported for wholegrain products or products containing bran or germ. Among breads, rye, spelt, and wholemeal breads were abundant in betaine. Moderate to high betaine contents were reported for pasta products, but it must be noted that mainly uncooked samples were analyzed (**Table 2**). Breakfast cereals are a mixture of cereal and non-cereal ingredients and the betaine content will depend on the contribution of each ingredient. In the study of Filipčev et al. [11], two samples of commercially available breakfast cereals were analyzed, one of which contained no detectable levels of betaine whereas the other had 471 μg/g (on dry solids). A similar concluded was made by Ross et al. [13] for muesli and muesli bars which were found to contain only low-to-moderate betaine levels. These products were mainly based on oats and contained other low-betaine ingredients such as dried fruits. In contrast to Ross et al. [13], the USDA data [14] report on much wider span of betaine in breakfast cereals, from 7 μg/greaching to as much as 3600 μg/g (on wet weight) betaine.

Table 2. Betaine content in various grain-based products.

Product	Betaine Content (µg/g Dry Weight)	References
Bread		
rye bread	855–1377	[13]
wholegrain spelt	913	[13]
wholemeal	670–790	[3]
wholegrain	499–781	[13]
	560–620	[3]
multigrain	247–678	[13]
white (refined)	360–520	[3]
	174–287	[13]
various (white, sourdough)	310–590 *	[14]
	380 *	[14]
	579	[15]
wheat tortilla	311	[13]

Product	Betaine Content (µg/g Dry Weight)	References
Pasta		
wholegrain wheat pasta	710–1286	[13]
	375	[15]
pasta, not specified	480–1350	[2]
refined wheat pasta	628–706	[13]
refined wheat (*T. aestivum*) pasta, uncooked	253	[12]
durum wheat pasta, uncooked	188	[12]
one–egg spelt pasta	243–516	[13]
barley pasta	211	[13]
noodles with egg, enriched, uncooked	1300 *	[14]
noodles with egg, enriched, cooked	190 *	[14]
refined couscous	691	[13]
bulghur	1311	[13]

Product	Betaine Content (µg/g Dry Weight)	References
cooked bulghur	830 *	[14]
Breakfast cereals		
ready-to-eat wheat germ, toasted, plain	4100 *	[14]
ready-to-eat wheat bran, toasted	3200 *	[14]
wholegrain rye flakes	1640	[13]
wholegrain wheat-based cereals	732–915	[13]
wholegrain oat and wheat-based muesli	310	[13]
wholegrain oat-based muesli	117–226	[13]
breakfast cereals, not specified	180–300	[12]
muesli bar	171	[13]
wholegrain porridge oats	128–167	[13]
extruded whole grain oat cereals	73–91	[13]
cereal bar	74–75	[13]

Product	Betaine Content (µg/g Dry Weight)	References
various ready-to-eat cereals	7–3600 *	[14]
Snacks, cookies, crackers, crispbread, cakes, pastry		
wholegrain rye crispbread	1428–1527	[13]
frozen, read-to-eat pancakes	690–720 *	[14]
wholegrain wheat crackers	293–649	[13]
crackers, classic, saltines, cheese	340–580 *	[14]
wholegrain wheat rusks	556–564	[13]
wholegrain wheat muffin	437–501	[13]
various commercial cakes	190–480 *	[14]
wholegrain wheat biscuit	425	[12]
Graham cookies	390 *	[14]
doughnuts	270–380 *	[14]
English muffins	220–360 *	[14]

Product	Betaine Content (µg/g Dry Weight)	References
extruded spelt	308	[12]
refined wheat crackers	258–332	[13]
digestive biscuit	271–309	[13]
apple pie, commercial	160 *	[14]
biscuit	4–144	[13]
Danish pastry, fruit enriched	140 *	[14]
plain Danish pastry	81 *	[14]

* Result expressed on wet weight.

4. Betaine Content in Gluten-Free Cereal Products

Gluten-free products have been generally recognized to be low in betaine content [13][15]. In the majority of commercially available gluten-free products, a very low level of betaine (<50 µg/g) was observed [13]. **Table 3** lists the betaine levels reported for commercial gluten-free products from several studies. In the bread and biscuits category, betaine levels ranged from non-detectable to 107 µg/g. Similar findings were reported by Kojić et al. [12], who also found that gluten-free samples (starch, corn extrudates, pasta, cornflakes, and rice) contained no detectable levels of betaine. Gluten-free cereals contained much lower amounts of betaine in comparison to glutenous cereals: corn had 107–304 µg/g betaine [11]; teff and millet between 50–150 µg/g [13], proso millet 280 µg/g [11]. Buckwheat is a frequent ingredient in gluten-free products. According to Ross et al. [13], buckwheat was among those ingredients low in betaine (<20 µg/g) although as high as 390 µg/g betaine was found in buckwheat uncooked pasta (**Table 3**).

Table 3. Betaine content in gluten-free products.

Product	Betaine Content (µg/g Dry Weight)	References
Bread and biscuits		
gluten-free crispbread	9–107	[13]
savory biscuits	n.d.–104	[11]
wholegrain gluten-free bread	12–68	[13]
oatmeal biscuits	3	[13]
gluten-free flour enriched with fibers	1	[13]
sweet biscuits	n.d.	[12]
flour mixture for gluten-free bread	n.d.	[12]
gluten-free cookies with almonds, crackers, salty sticks	n.d.	[12]
expanded maize	n.d.	[12]
Pasta		
buckwheat pasta, uncooked	390	[11]
	382	[13]

Product	Betaine Content (μg/g Dry Weight)	References
	175	[12]
maize-based pasta	2–20	[13]
maize and rice-based pasta, uncooked	n.d.	[12]
rice-based pasta, uncooked	n.d.	[12]
Breakfast cereals and related products		
soy bran	182	[12]
unseasoned popcorn	19	[13]
cornflakes	14	[13]
buckwheat flakes	10	[13]
rice-based breakfast cereals	4–5	[13]
expanded rice	n.d.	[12]

n.d. not detected.

5. Stability of Betaine in Grain-Based Products

Betaine is known to be a thermostable compound that survives the severe treatment during sugar beet processing (extracting with water, treatment with $CaOH_2$ and CO_2, concentration, crystallization) and almost quantitatively accumulates in molasses [17]. Pure anhydrous betaine decomposes at > 245 °C. Since food processing practices do not employ such high temperatures, betaine losses caused by food thermal treatments were initially not expected [18]. However, some data suggest that certain cooking and baking losses of betaine may exist in spite of its thermostability in the pure form. Being a water-soluble compound with a small molecule, it is not unlikely that some betaine losses will occur, depending on the type of food processing and cooking. Available data suggest that losses are very high if processing involves water removal after cooking or boiling due to its solubility in water. Very high losses were observed during the baking of betaine-enriched bread, implying that fermentation by baker's yeast may be one of the causes but future research is needed to understand the possible mechanisms.