Boron

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Abstract

This page draws on 22 peer-reviewed studies. The complete citation list is at the bottom of the page.

1 | Overview

Boron is a metalloid trace element that occurs naturally as boric acid, borax and other borates 1, and in soil, rocks and water mainly as borates or organoboron compounds 2. It is an essential micronutrient for plants, and excess boron is toxic to plants 34.

Its status in human nutrition is unsettled. A European tea risk assessment states that boron is not an essential nutrient for humans and that no specific biochemical function has been identified, while noting evidence that it may influence calcium metabolism and bone 5. Other cited studies describe it as potentially essential and note that no recommended intake has been set 26.

Boron is easily absorbed from the gut and is excreted mainly in urine 26. Because of this, 24-hour urinary boron rises with intake: intake and excretion were strongly correlated in German vegans and omnivores 6, and one study cites about 90% urinary elimination 7.

2 | Toxicology

The tea risk assessment lists symptoms reported for boron intoxication, including gastrointestinal disturbance, kidney tubule degeneration, exfoliative dermatitis, seizures and circulatory collapse, and identifies developmental toxicity as the most sensitive endpoint 5. The European upper intake level it applies rests on decreased fetal body weight in rats after maternal exposure, with a no-observed-adverse-effect level of 9.6 mg/kg body weight per day divided by an uncertainty factor of 60 5.

A Chinese exposure study summarizes literature reporting gastrointestinal, nervous system, skin, reproductive and circulatory effects of acute excess, developmental effects and testicular accumulation in animals, and mixed findings on sperm quality in boron-exposed workers 7. Borates and boric acid were largely withdrawn as food preservatives after research reported adverse effects of boric acid at more than 0.5 g per day for 50 days 3.

Animal studies

- Broiler chickens fed boric acid at 120 or 240 mg/kg dietary boron for 7 to 14 days accumulated boron in liver and showed raised serum ALT and AST, dose- and time-dependent liver and mitochondrial damage, and gene and protein changes consistent with oxidative stress and ferroptosis 8.
- Ostrich chicks given 640 mg/L of a sodium borate salt in drinking water for 90 days kept an intact thymic structure, but apoptotic cells tended to increase and autophagy and proliferation markers rose; three birds per group were studied 9.

Human observational studies

Two cohorts associate higher boron status with better health markers, but neither can show cause. In 899 German adults, higher plasma boron went with lower BMI, plasma lipids and CRP 2. In 693 kidney transplant recipients, each doubling of 24-hour urinary boron was associated with a hazard ratio for death of 0.51 (95% CI 0.40 to 0.66) 1. In both studies boron tracked plant-rich diets, so confounding by other food constituents is possible. A registered trial of 10 mg/day boron as boron citrate in adults with obesity has published only its protocol 10.

3 | Typical exposure routes

Diet and drinking water are the main routes of human exposure 27.

- **Diet.** On a Chinese island, a three-day duplicate-diet study in 32 families measured 1.562 mg/day from diet and 0.113 mg/day from water, for a total of 1.674 mg/day 7. Young German adults had estimated median intakes of 1515 micrograms per day (omnivores), 1654 (lacto-ovo-vegetarians) and 1913 (vegans), with individual values from 657 to 5836 micrograms per day 6. A German cohort paper cites European intakes of 0.8 to 1.9 mg/day 2.
- **Drinking water.** Reverse osmosis removes boron poorly, so desalinated seawater can carry more boron than reservoir water 7. Near a Turkish boron mine, livestock drinking water within 5 km had a median of 1285 µg/L, against 93 and 74 µg/L farther away 11.
- **Tea.** Modeled exposure of Danish adult tea drinkers reached 4,167 ng/kg body weight per day for rooibos in the high-consumption, high-concentration scenario, the highest of the teas assessed 5.

Measured intake and biomarkers

STUDY / LOCATION	MATERIAL / DESIGN	METAL SPECIES	VALUE (UNITS AND BASIS)	N	INTERPRETATION / LIMITATION
6 Shengsi County, China	Three-day duplicate diet plus water	total B	Total intake 1.674 ± 0.939 mg/d; 0.030 ± 0.012 mg/kg bw/d	32	Small subsample; one person per family

5 Freiburg, Germany	Weighed food diaries, 2 days	total B	Median intake 1515 (omnivores), 1654 (lacto-ovo--vegetarians), 1913 (vegans) µg/d	89	Estimated from mainly US food data
5 Freiburg, Germany	24-hour urine, ICP-MS	total B	Median 1415 µg/24 h (all); 1159 omnivores, 1499 vegetarians, 1849 vegans	89	Young, student-heavy sample
4 Groningen, Netherlands	24-hour urine, ICP-MS	total B	Median 1275 µg/24 h (IQR 925 to 1729)	693	Kidney transplant recipients
3 Kiel, Germany	Plasma, ICP-MS	total B	Median 33.80 µg/L (IQR 25.61 to 44.65); summer 36.9, winter 31.4	899	Older population cohort
6 Shengsi County, China	Morning urine, creatinine--corrected	total B	Median 1.569 (men) and 2.148 (women) mg/g creatinine	199	Spot urine, not 24-hour

4 | Food sources

Cited literature describes boron-rich diets as high in fruits, leafy vegetables, nuts, legumes and plant-derived fermented beverages such as wine, cider and beer, and describes meat, fish and dairy as poor sources 2. Measured biomarkers support this pattern: a dietary pattern high in fruits, nuts and seeds, tea and wine explained about 30% of plasma boron variation 2, and intake of fruit, wine and nuts were key determinants of urinary boron in kidney transplant recipients 1. The cited evidence does not report boron concentrations in fruit, nuts or wine themselves.

- **Tea and fruit brews.** Dry black tea from the Polish market averaged 13.5 mg/kg total boron, and fruit brews of dried fruit and hibiscus averaged 17.4 mg/kg 3. Water extracted 8% to 27% of the boron from black teas but 17% to 69% from fruit teas 3. See also tea.
- **Vegetables on high-boron soils.** Broccoli, cabbage and Swiss chard grown on saline, high-boron California soils contained 152 to 239 mg/kg dry matter 12.
- **Oilseeds under boron fertilization.** Foliar borax raised sesame seed boron from 22.48 to 31.00 mg/kg 13 and Indian mustard seed boron from 16.17 to 27.71 mg/kg 14 (see oilseeds).

Measured concentrations in foods and water

STUDY / LOCATION	MATERIAL / DESIGN	METAL SPECIES	VALUE (UNITS AND BASIS)	N	INTERPRETATION / LIMITATION
2 Poland	Black tea, tea bags, acid digestion, ICP-AES	total B	Mean 13.5 mg/kg (8.31 to 18.4); basis not stated	24	Market survey; per-sample values only in a figure
2 Poland	Fruit brews (dried fruit, hibiscus)	total B	Mean 17.4 mg/kg (12.1 to 22.8)	9	No tea leaves in these products
8 California, USA	Broccoli, field-grown on high-boron saline soil	total B	228 (SD 36) mg/kg dry matter	12	One site; not market produce
8 California, USA	Green, red and savoy cabbage	total B	239, 152 and 169 mg/kg dry matter	4, 4, 6	Same site
8 California, USA	Swiss chard	total B	186 (SD 62) mg/kg dry matter	6	Same site
9 Punjab, India	Sesame seed, control vs 40 mg/L foliar boron twice	total B	22.48 vs 31.00 mg/kg, oven-dry	3 replicates	Field trial, two-season means
10 Punjab, India	Indian mustard seed, control vs 1.0% borax plus urea twice	total B	16.17 vs 27.71 mg/kg, oven-dry	3 replicates	Field trial; method stated as AAS
6 Shengsi County, China	Finished drinking water, desalinated seawater	total B	0.68 to 1.46 mg/L	51	Above the 0.5 mg/L national limit then in force
6 Shengsi County, China	Finished drinking water, reservoir	total B	0.30 to 0.39 mg/L	39	Monthly sampling, 2015 to 2016
7 Balıkesir, Turkey	Livestock drinking water, 0 to 5 km from a boron mine	total B	Median 1285 µg/L (47.2 to 6049)	20	Not a human supply

Drinking water measurements above come from one island and one mining district and are not national surveys.

5 | Regulatory limits

The cited evidence reports several reference values, set by different bodies on different bases; they are restated here as the cited papers give them.

STUDY / LOCATION	MATERIAL / DESIGN	METAL SPECIES	VALUE (UNITS AND BASIS)	N	INTERPRETATION / LIMITATION
1 EU	Tolerable upper intake level (EFSA)	boric acid and borates	0.16 mg/kg bw per day	not applicable	From rat developmental NOAEL 9.6 mg/kg bw/day and factor 60
5 EU	Tolerable upper intake level (EFSA), adults	total B	10 mg/day	not applicable	As stated by the study
3 not stated	Upper intake level, adults	total B	20 mg/day	not applicable	Cited from literature; issuing body not named
6 WHO	Tolerable daily intake	total B	0.17 mg/kg bw per day	not applicable	Used as the risk benchmark
6 USA	US EPA IRIS oral reference dose	total B	0.2 mg/kg per day	not applicable	Used for water hazard quotients
6 WHO	Drinking-water guideline value	total B	2.4 mg/L (revised from 0.5 mg/L in 2011)	not applicable	Cited
6 China	GB 5749 drinking-water limit	total B	0.5 mg/L (2006), 1.0 mg/L (revised, 2023)	not applicable	Cited
6 Canada	Maximum acceptable concentration, drinking water	total B	2 mg/L	not applicable	As cited by the study; may not reflect current Canadian value
7 EU	Drinking-water value	total B	1 mg/L	not applicable	Cited secondhand

The WHO drinking-water value is carried in the WHO Guidelines for Drinking-water Quality according to the cited study 7. Against these benchmarks, the tea assessment found that the highest rooibos scenario would use only 2.6% of the upper intake level 5, and island residents' total intake was about 0.03 mg/kg body weight per day, which the authors describe as 17.6% of the tolerable daily intake 7. No German participant exceeded the 10 mg/day value used in that study 6. The cited evidence does not establish any food-specific maximum level for boron.

6 | Testing

- **ICP-MS** is used for plasma, urine and food in the human studies 2167 and, in triple-quadrupole form, for tea 5. One urine method reports a detection limit of 0.21 µg/L with commercial urine quality-control material at two levels 6; a Chinese food method reports 0.20 mg/kg 7. See ICP-MS.

- **ICP-OES or ICP-AES** is used for tea, vegetables, livestock samples and poultry liver 312118. The tea study recovered 102.5% of the certified boron in apple-leaf reference material after acid digestion, but only about 56% with water extraction 3. It also notes that atomic absorption is prone to interference, memory effects and boron loss without a suitable modifier 3. See ICP-OES.
- **Azomethine-H spectrophotometry** is used for drinking water and plant tissue 713. One oilseed study states that boron was measured by atomic absorption without describing quality control 14 (see atomic absorption spectrometry).
- **Reporting pitfalls.** A livestock study reported feed boron per liter of digest with negative minima, and its serum values all fall below its stated serum detection limit 11.

Boron also appears in analytical chemistry as a material rather than an analyte: boron-doped diamond electrodes, boron-doped carbon dots and boron nitride or boron carbon nitride composites are used in sensors for pesticides, drugs, bisphenol A, mycotoxins and amino acids 1516171819. These papers do not measure boron and do not bear on exposure (see electrochemical detection methods and fluorescence sensors).

7 | Microbiome effects

The cited evidence does not establish any effect of boron on the gut or other host microbiomes. The only microbial finding is that gelatin packaging films containing boric acid or borate salts inhibited Staphylococcus aureus, Pseudomonas aeruginosa, Aspergillus niger and Candida albicans on agar 20. That is an antimicrobial material property and says nothing about dietary boron and gut microbes.

8 | Vulnerable populations

- **Pregnancy.** The European upper intake level is based on fetal effects in rats, which makes pregnancy the life stage the limit is built to protect 5. The cited evidence includes no human pregnancy data.
- **Reduced kidney function.** In German adults, plasma boron rose as kidney function fell below an eGFR of about 97 mL/min/1.73 m2, which the authors attribute to reduced renal clearance 2.
- **Users of desalinated water.** Residents supplied with reverse-osmosis seawater receive water above the former Chinese limit of 0.5 mg/L unless it is blended 7.
- **Livestock near boron mines.** Livestock water within 5 km of one Turkish mine had a median of 1285 µg/L, against 73.75 µg/L at 15 to 30 km 11.
- **Plant-based diets.** Vegans had the highest estimated intake and urinary excretion among young German adults, though all stayed under the 10 mg/day value used 6.
- **Sex differences.** Creatinine-corrected urinary boron was higher in women than men on the Chinese island 7.

The cited evidence does not establish boron exposure or effects in infants or children.

9 | Mitigation

- **Water blending.** Mixing desalinated seawater with reservoir water lowered boron and hazard quotients, and tap water was lower than finished water from the same source 7. Additional boron removal after desalination raises cost 7.
- **Brewing.** Only a fraction of tea boron reaches the infusion, and the share is much larger for fruit brews than for black tea 3. Brewing longer than the 3 minutes used in the tea transfer study may raise extraction 5.

- **Crop side.** Plant studies address boron tolerance in crops through breeding markers and protective treatments, not reduction of boron in food 214. Agronomic studies instead use boron sprays to raise crop boron 1322.

The cited evidence does not establish processing methods that remove boron from foods.

10 | Open questions

- Boron concentrations in fruit, nuts, legumes, wine, coffee and dairy, which cited papers name as main dietary sources, are not measured in the cited evidence.
- No market survey of boron in drinking water beyond one island and one mining district.
- No data on infants, children or pregnant people.
- No maximum levels for boron in specific foods are reported.
- No evidence on gut microbiome effects of dietary boron.
- No processing or cooking studies on boron removal from food.
- Whether the inverse associations of boron with mortality and cardio-metabolic markers are causal is untested; the only trial is a protocol.
- Different upper intake values (10 mg/day, 20 mg/day, 0.16 mg/kg body weight per day) are cited without reconciliation.
- Boron in meat, milk or eggs from animals exposed near mines or on high-boron feed is not measured.

11 | What remains uncertain

The human evidence here is a handful of observational studies in Germany, the Netherlands and China, plus one tea risk assessment. Intake estimates rely on duplicate diets in 32 families or on food-composition tables drawn mostly from US data, so they may not transfer to other diets. Urinary and plasma boron track intake but also kidney function, which complicates their use as exposure markers in clinical groups.

Food concentration data are thin and skewed toward special conditions: tea bags from one market, vegetables from one saline high-boron field, and oilseeds under deliberate boron fertilization. Several papers have reporting problems, including per-cup tea values that do not match bag masses and livestock serum values below the stated detection limit, so those figures are reported but not relied on.

Reference values differ across bodies and are mostly restated secondhand in the cited papers. The developmental toxicity basis of the European upper level comes from rat data summarized in a short report, not from the original opinion.

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