Leafy greens

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Abstract

Cadmium is the metal that most often decides a leafy-green question, and the leaf type matters more than any other single factor in the monitoring data. Across more than 2,200 WHO GEMS/Food spinach results the median was about 41 µg/kg fresh weight, against 19-20 µg/kg for leaf lettuce, 11-12 µg/kg for head lettuce and 2-4 µg/kg for head cabbage. The FDA Total Diet Study found the same order in US market composites from 2018 to 2020: spinach 200, leaf lettuce 57, iceberg lettuce 27 and cabbage 5.1 µg/kg as medians. European monitoring summarised by EFSA gave spinach a mean of 61.5 µg/kg and other leafy vegetables 23.1 µg/kg, with 3.9% of spinach samples above the EU limit.

1 | Leafy greens overview

Lead is usually low in routinely monitored retail leaves.[1,2] Most head lettuce and cabbage results in GEMS/Food were below detection, most FDA lettuce and cabbage composites were below a 4 µg/kg reporting limit, and EFSA's European leafy-vegetable median was 10 µg/kg.[1,2,9] The EU limits are 0.30 mg/kg (300 µg/kg) lead for leaf vegetables and 0.10 mg/kg cadmium, raised to 0.20 mg/kg for spinach and similar leaves and fresh herbs.[8]

Field studies near mining, smelting, coal power plants, wastewater irrigation or heavy traffic report leaves tens to hundreds of times more contaminated than market monitoring.[3,6,7,10] Many of those studies report on a dry-weight basis, which by itself raises concentrations about ten-fold, and several fail checks against their own methods, so the page shows them without comparing them.[11,12,13] For a buyer the supported priorities are the growing site and irrigation water, the leaf type, and lot results for cadmium and lead reported on a fresh-weight basis.[6,8,14]

2 | Leafy greens and their preparations

This page covers edible leaves eaten as vegetables, each kept as its own material: spinach, leaf, head and romaine lettuce, head cabbage, Chinese cabbage, pak choi, kale, chard, amaranth, water spinach, mustard greens, watercress, lamb's lettuce, rocket and leafy herbs such as coriander, parsley, mint and dill.[1,15,16] frozen cooked, canned, fermented and dried leaves are kept apart from raw leaves, because preparation changes water content and can add or remove metals.[1,14]

The basis of a result matters as much as the leaf. Fresh leaves are mostly water, about 92% in the Algerian spinach and salad samples, so a dry-weight result is roughly ten times the fresh-weight value for the same leaf.[11] The page never converts between fresh and dry weight, and results whose basis is not stated stay separate.[17,11] Seaweed sold as sea lettuce, tea and medicinal herb leaves, mixed baby foods that contain spinach, Brussels sprouts, roots and stems are outside this scope.[1,2,18]

3 | How contamination reaches leafy greens

Leaves take metals up from soil and irrigation water, and cadmium moves into leaves more readily than lead.[3,14] In Gazipur, Bangladesh, spinach leaves from a highly polluted industrial area carried 5,970 µg/kg lead and 1,020 µg/kg cadmium dry weight, against 1,160 and 430 µg/kg on a low-pollution research field.[3] In a greenhouse trial, irrigating with water containing 500 µg/L arsenic raised spinach leaf arsenic from 1.05 to 6.57 µg/g dry matter.[14]

Dust and air deposition add a surface load. Near coal-fired power plants in China, water spinach carried 86.7 µg/kg mercury fresh weight at 1 km and 23.9 µg/kg at 10 km, against 0.85 µg/kg in grocery-store leaves, and rinsing removed 19-63% of the mercury.[6] kale grown on urban farms in Baltimore averaged 130 µg/kg lead fresh weight against 10 µg/kg on rural farms nearby.[17] Unwashed coriander from a Johannesburg roadside market carried 191.9 mg/kg cadmium dry weight against 6.6 mg/kg once washed.[7]

Inputs and land use also shape levels. Phosphate fertilizers raised lettuce cadmium by up to 91% in a Chinese greenhouse field trial, while farmyard manure lowered cadmium in cabbage and lettuce compared with mineral fertilizer in a long-term English trial.[19,20] Manures raised spinach lead from 0.11 to 0.50-0.75 mg/kg in a Turkish field trial.[21] Mining areas raised mercury in Houttuynia leaves to 260 µg/kg dry weight against 40 µg/kg elsewhere, and lead in chard from Spanish mining-town gardens to 698 µg/kg against 118 µg/kg from a city market.[10,22]

4 | Lower measured levels by source and type

For cadmium the leaf type gives the most consistent lower-contamination choice.[1,2,15] Head cabbage was among the lowest in every large dataset: GEMS/Food median 2-4 µg/kg fresh weight (only lamb's lettuce lower), the l owest of the five FDA foods at 5.1 µg/kg, 6 µg/kg against 25 µg/kg for lettuce in the UK total diet study, and 4.6-5.4 µ g/kg in an English field trial.[1,2,19,18] Head and iceberg lettuce were lower than leaf and romaine lettuce (GEMS/Food 11-12 against 19-20 µg/kg; FDA 27 against 57 µg/kg; Gran Canaria iceberg 4.0 against romaine 11.9 µg/kg), and spinach was highest in all of them.[1,2,15] Lamb's lettuce and watercress were among the lowest-cadmium leaves w here they were measured (GEMS/Food lamb's lettuce median 0-2 µg/kg; Gran Canaria 1.1 and 1.9 µg/kg).[1,15] Because the order repeats across independent European, US and Spanish datasets, this is a supported pattern for cadmium, not a single-study observation.

Lead and arsenic do not follow the cadmium order, so the lowest-cadmium leaf is not automatically lowest in everything.[1,15] Lamb's lettuce had the highest total-arsenic median among the leaves in GEMS/Food (22-23 µ g/kg) and in Gran Canaria (18.9 µg/kg), and a higher lead median (23-25 µg/kg) than lettuce or cabbage.[1,15] iceberg lettuce was lowest for lead (2.0 µg/kg), arsenic (0.5 µg/kg) and aluminum (1,581 µg/kg) in Gran Canaria,

and FDA detected lead in none of 27 iceberg or cabbage composites.[2,15] In Hong Kong, water spinach carried 74 µg/kg inorganic arsenic as eaten, against non-detects for European cabbage and lettuce, and watercress had the highest lead (96 µg/kg).[5,16]

Origin comparisons are weaker, because GEMS/Food records the reporting region rather than where leaves were grown and the regions cover different years.[1] Lead was higher in Western Pacific submissions from 2001-2009 (median about 107 µg/kg for leafy vegetables, 47-50 µg/kg for pak choi) than in European ones (4-21 and 0-10 µg/kg), while cadmium in spinach and leaf lettuce was higher in the Americas (125 and 40 µg/kg) than in Europe (40 and 18-19 µg/kg).[1] These are tentative regional differences, not a supported country ranking; within single studies, the clearest lower-contamination origin is simply a site away from industry, mining, roads and contaminated water.[6,10,17,23]

In Gran Canaria supermarkets, iceberg (0.5 µg/kg) and romaine lettuce (1.6 µg/kg) had the lowest total arsenic and lamb's lettuce the highest (18.9 µg/kg).[15] In Hong Kong, inorganic arsenic was not detected in European cabbage or lettuce, while water spinach averaged 74 µg/kg.[5] Near contaminated irrigation in Gazipur, the aquatic leaf helencha carried 1.85-2.02 mg/kg arsenic dry weight.[24]

In Gran Canaria, watercress (33 µg/kg) and romaine lettuce (39 µg/kg) had the lowest nickel and spinach the highest (86 µg/kg), while aluminum ranged from 1,581 µg/kg in iceberg lettuce to 41,947 µg/kg in spinach.[15] In Hong Kong, Chinese cabbage (200 µg/kg) and European cabbage and lettuce (320 µg/kg) were lowest in aluminum and Chinese spinach highest (35,000 µg/kg).[16]

5 | Washing, preparation and derivatives

Washing removes surface deposits but not metal taken up into the leaf.[6,7,25] Washing halves of the same Johannesburg roadside purchases lowered the group mean cadmium from 51.5 to 6.8 mg/kg and nickel from 199 to 8 mg/kg dry weight, yet the washed leaves stayed above supermarket leaves for cadmium.[7] A 10% vinegar soak lowered lead in market lettuce from 155 to 95 µg/kg fresh weight but left farm lettuce unchanged (73.3 against 73.1 µg/kg), consistent with removal of surface lead only.[25]

Cooking acts differently on different metals and leaves. Boiling in clean water removed 55-69% of the arsenic from amaranth but only 3-31% from spinach, while boiling market spinach in water containing 1,000 µg/L arsenic raised it from 0.01 to 0.75 µg/g fresh mass.[14] Cooking with coconut milk or oil generally lowered the in-vitro bioaccessible fraction of nickel, cadmium, chromium and lead in Sri Lankan leaves, but not in every case, and bioaccessibility is not the total concentration.[26] canned frozen and fermented leaves are reported separately in GEMS/Food; sauerkraut, for example, had a lead median of 13-14 µg/kg, which is not a measure of what fermentation does to a given cabbage.[1]

6 | Controls for leafy greens

Controls for leafy greens act mainly where the leaf grows: choosing the site, the irrigation water and the soil inputs.[6,14,20] Covering contaminated greenhouse soil with 15 cm of clean soil cut lettuce cadmium by 62% (2.57 to 0.98 mg/kg dry weight), and a biochar-alginate amendment cut it by 63% in pots and 77% in the field.[20,27] Arsenic-free irrigation water is the control that the irrigation trials support for arsenic.[14,28]

After harvest, washing and testing are the levers. Washing lowers surface lead, mercury and cadmium, and testing finds high lots without removing anything; the EU limits apply to the edible part after washing.[6,7,8] Most

amendment evidence comes from pot or greenhouse experiments with spiked soils, so effect sizes do not transfer directly to commercial fields.[29,30,31]

7 | Trade-offs and failure modes

Soil amendments can raise the metal they are meant to lower.[20,32] In the same greenhouse field trial that found clean-soil covering effective, corn-straw biochar raised lettuce cadmium at most application rates (by up to 44%) and attapulgite clay raised it by 24-56%.[20] Wollastonite raised pak choi cadmium in three of four soils, in one case from 7.63 to 16.62 mg/kg.[32]

Organic or manure-based growing is not uniformly cleaner. Manures that lowered arsenic, chromium and nickel in Turkish spinach raised its lead four- to seven-fold, while farmyard manure lowered cadmium in English cabbage and lettuce without changing lead.[19,21] Organic crop protection changed only cabbage nickel in the English trial, and organic certification was associated with lower cadmium and nickel in New Zealand market-garden vegetables but not consistently across leaves.[19,33]

Choosing a leaf for low cadmium can trade off against other metals. Lamb's lettuce is low in cadmium but higher i n arsenic and lead than lettuce, and watercress was low in cadmium in Gran Canaria but highest in lead in Hong K ong.[1,15,16]

8 | Sampling and testing leafy greens

Results are only comparable when the basis is stated.[17,11] Many surveys report dry weight and then compare their values with fresh-weight limits, which overstates exceedance about ten-fold for leaves that are around 90% water.[11,12] A useful report gives the leaf, fresh-weight basis, the edible part analyzed, whether it was washed, and the quantification limit for each metal.[2,8]

Detection limits must sit well below the limits being checked.[1,2] FDA reported lead down to 4 µg/kg, but several surveys report values below their own stated detection limits, and those rows are held.[2,12,13] Total arsenic is not inorganic arsenic, and inorganic mercury submitted to GEMS/Food is not total mercury; the page keeps each species separate.[1,5]

Some extreme values do not survive a check against their own papers. In a Dhaka study every detected lead value was below the method's own detection limit, and in a Yuyao study every mustard mean was below the c rop detection limits printed in the same paper.[12,13] Other high values are real but site-specific, such as unwashed roadside coriander in Johannesburg.[7]

9 | Sourcing and supplier evidence

Limits differ by market and by leaf.[8,34,35] The EU sets 0.30 mg/kg lead for leaf vegetables (fresh herbs excluded) and 0.10 mg/kg cadmium, or 0.20 mg/kg for spinach, similar leaves and fresh herbs, and from July 1, 2025 0.50 mg/kg nickel for leafy vegetables and 1.2 mg/kg for fresh herbs.[8,36] Codex sets 0.3 mg/kg lead (the edition held in the library excludes spinach from that entry) and 0.2 mg/kg cadmium for leafy vegetables, China 0.3 mg/kg lead and 0.2 mg/kg cadmium, Korea the same values for spinach and Chinese cabbage, and Hong Kong 0.2 mg/kg cadmium.[34,35,37,38]

Spinach is the leaf most likely to approach a cadmium limit.[1,4] In GEMS/Food, 105 of 2,262 spinach results were definitely above 0.20 mg/kg cadmium and 193 of 3,456 leaf lettuce results above 0.10 mg/kg, against 11 of 3,523

head cabbage results.[1] Ask for lot results by leaf with the growing site and irrigation source, because most datasets identify only the market and the clearest high-contamination cases are site-specific.[1,3,6]

10 | Finished products and dietary exposure

Leafy greens are a modest but real share of dietary cadmium and lead.[39,40] In Europe leafy vegetables supplied 3.9% of cadmium exposure overall and 4.8-5.9% for adults and the elderly; JECFA cites national estimates of 11% in China and 20% in the USA.[39,40] In Guangzhou, leafy vegetables supplied 20% of dietary lead, and in Chongqing 4.9-8.9% of arsenic exposure.[41,42]

Exposure depends on how much is eaten as much as on concentration. A Southern California food-frequency survey found a mean intake of 33.6 g of leafy greens a day, and JECFA estimated that leafy vegetables gave less than 5% of the tolerable cadmium intake in every GEMS/Food region it assessed in 2006.[43,44] No source in the ledger measured metals in finished leafy products together with the leaves that went into them.

11 | Evidence review and remaining questions

This assessment covers every source record in the library tagged to leafy greens or naming a leafy vegetable, and every leafy-vegetable row in WHO GEMS/Food, the FDA Total Diet Study and the other indexed datasets; each item has a recorded decision based on its content.[1,2] Values from more than 30 sources that could not be reconciled with their own methods or figures are shown and held.[7,12,13]

Seyfferth (2024) reviewed cadmium and lead occurrence in U.S. Spinach using paired 1980s USDA-FDA-EPA survey data and FDA Total Diet Study results. Cadmium in U.S. Spinach ranged approximately 0.01 to 1.1 mg/kg fresh weight, with newer TDS data higher than 1980s samples, likely reflecting geographic shift toward the Salinas Valley growing region. Lead in U.S. Spinach has declined substantially over time, consistent with the phase-out of leaded gasoline, though approximately 15 to 30% of recent TDS samples exceeded the FDA draft guidance limit for vegetables in baby and young-child foods. The review proposes that reducing chloride in irrigation may limit cadmium bioavailability. These findings were measured in spinach; their applicability to other leafy greens depends on the species and growing conditions.[46]

Remaining gaps are specific. The Peruvian mining-region dataset with chard, spinach and lettuce results is held in an external repository not in the library, several papers print leaf values only as charts, and the Korean Food Code was recovered from the library volume rather than the declared file.[37,45]

References identify the sources used in these answers. The Sources index preserves additional discovery links; inclusion there does not mean a source has been reviewed for this assessment. Corrections, completed searches, new direct evidence and changes in requirements should reopen the relevant answer.

12 | Leafy greens FAQs

Cadmium and lead are measured most often, and cadmium is the one most often found at levels that matter, especially in spinach.[1,2] Studies also report total and inorganic arsenic, mercury, nickel, chromium, aluminum, tin and uranium; most mercury and arsenic results in monitored retail leaves are near or below detection.[1,2,15]

Through roots from soil and irrigation water, and on the leaf surface from dust and air deposition.[3,6,14] Near coal power plants, water spinach mercury fell from 86.7 µg/kg at 1 km to 23.9 µg/kg at 10 km.[6]

Yes, through dust, handling and cooking water.[7,14] Leaves sold at a Johannesburg roadside carried far more cadmium unwashed than washed, and boiling spinach in arsenic-contaminated water raised its arsenic from 0.01 to 0.75 µg/g.[7,14]

Not consistently. In a long-term English trial, organic crop protection changed only cabbage nickel, while farmyard manure lowered cadmium; in New Zealand, organic market-garden vegetables were lower in cadmium and nickel overall but not consistently by leaf.[19,33] Manures raised lead in Turkish spinach, so an organic label alone does not establish lower metals.[21]

Head cabbage, followed by head and iceberg lettuce; lamb's lettuce and watercress were also low where m easured.[1,2,15] spinach was highest in every large dataset, with a GEMS/Food median of about 41 µg/kg against 2-4 µg/kg for cabbage.[1]

Iceberg lettuce and cabbage in monitored markets: FDA detected lead in none of 27 composites of either, and iceberg had the lowest lead median (2.0 µg/kg) in Gran Canaria.[2,15] kale, spinach and lamb's lettuce had higher l ead medians (13-25 µg/kg) in GEMS/Food.[1]

Iceberg lettuce (1,581 µg/kg) in Gran Canaria and Chinese cabbage (200 µg/kg) in Hong Kong; spinach and Chinese spinach were highest.[15,16] Aluminum varies more than twenty-fold between leaves in the same survey, so leaf type matters more than origin.[15]

No country ranking is supported. GEMS/Food reports reporting regions rather than growing countries: lead was higher in Western Pacific submissions from 2001-2009 and cadmium in spinach higher in the Americas than in Europe, but these regions cover different years.[1] The clearest lower-contamination origin is a growing site away from mining, industry, roads and contaminated water.[6,10,17]

No. They describe concentrations; risk depends on how much you eat, your other diet and your health.[39,43] In Europe leafy vegetables supplied about 4-6% of adult cadmium exposure.[39]

No. Washing removed most surface cadmium, nickel and mercury in roadside and power-plant studies, but a vinegar soak left lead in farm lettuce unchanged, because metal taken up into the leaf stays.[6,7,25]

No. Inorganic arsenic is the more toxic part; Hong Kong measured it directly and found 74 µg/kg in water spinach but none detected in European cabbage or lettuce.[5] Most surveys report total arsenic only.[1,15]

No study in the library tested an overnight water soak. A 5-10 minute vinegar soak lowered surface lead in market lettuce, and boiling in clean water removed part of the arsenic from amaranth.[14,25]

Only when the detection limits are low enough.[1,2] A result below a 4 µg/kg limit says more than one below 200 µg/kg, and non-detects with different limits cannot be ranked against each other.[1,2]

No, though supermarket leaves were lower than roadside leaves in Johannesburg.[7] Supermarket monitoring datasets still include spinach and lettuce results above EU cadmium limits.[1,4]

Because fresh leaves are about 90% water.[11] Removing the water concentrates the metal, so a dry-weight result is roughly ten times the fresh-weight value; limits are set on fresh weight.[8,11]

Sometimes, and it depends on the metal and leaf.[14,26] Boiling removed 55-69% of arsenic from amaranth but only 3-31% from spinach, and cooking with coconut milk or oil generally lowered the bioaccessible fraction of several metals.[14,26]

Yes: the EU sets 0.30 mg/kg lead and 0.10 mg/kg cadmium (0.20 mg/kg for spinach and fresh herbs), Codex 0.3 mg/kg lead and 0.2 mg/kg cadmium, and China 0.3 and 0.2 mg/kg.[8,34,35] The EU also sets 0.50 mg/kg nickel for leafy vegetables from July 1, 2025.[36]

Yes, in the field studies that compared it.[3,14] Leaves near industrial effluent in Bangladesh carried several times the lead and cadmium of leaves from a low-pollution field, and arsenic in irrigation water raised leaf arsenic in proportion.[3,14]

The leaf, the edible part analyzed, whether it was washed, the fresh-weight basis, the quantification limit for each metal and the growing site.[2,8] For arsenic and mercury it should say whether totals or species were measured.[1,5]

A modest one.[39,40] In Europe they supplied 3.9% of cadmium exposure overall; national estimates cited by JECFA are 11% in China and 20% in the USA.[39,40]

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DATA AVAILABILITY

Every source behind this ingredient profile is listed with its own source record at https://heavymetalindex.com/ingredients/leafy-greens#sources.

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