Letters in Food Science & Technology

NARRATIVE REVIEW

FOOD PRESERVATIVES IN THE FOOD INDUSTRY:

Technological functions, regulatory limits (Codex, EU and FSSAI), exposure, health evidence across the life course, and risk management

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ABSTRACT

Background. Food preservatives slow microbial growth, oxidation and enzymatic deterioration. Their public-health value is considerable because spoilage and foodborne disease remain major global burdens [49], yet specific compounds, exposure patterns, susceptible subgroups and reaction products warrant scrutiny.

Approach. This narrative review summarises the principal preservative classes, their mechanisms and applications, the regulatory framework (Codex, EU and the Indian FSSAI system), health-based guidance values, and evidence on adverse effects in children, adults and older adults. It separates hazard identification from risk at realistic exposure, and separates evidence about a specific preservative from evidence about a food category such as processed meat or ultra-processed food.

Findings. The best-established specific concerns are sulfite-triggered reactions in susceptible individuals [15,20,22]; potential formation of N-nitroso compounds in nitrite-cured foods under particular conditions [4,5,23,24]; and small behavioural effects in some children after challenge drinks containing sodium benzoate plus artificial colours [1,8], which do not isolate benzoate as the cause [9]. A worked scenario using Indian maximum permitted levels shows that a child with several heavily preserved items per day could approach the benzoic acid ADI in worst-case assumptions, whereas typical exposure is expected to be lower. Evidence for broad claims that legally used preservatives generally cause chronic disease is inconsistent or insufficient.

Conclusion. Safety depends on authorised use levels, total dietary exposure, processing conditions, labelling and individual susceptibility. A proportionate strategy is to use the minimum effective level, apply validated preservation hurdles, monitor cumulative exposure (including in Indian children), update exposure data, and improve diets with minimally processed foods without compromising microbial safety.

Keywords: Food additives; preservatives; benzoates; sorbates; sulfites; nitrite; nitrate; propionates; natamycin; hurdle technology; FSSAI; acceptable daily intake; children; older adults; food safety; toxicology.

1. Introduction and scope

Preservation is a central food-technology function: It limits spoilage and, when properly designed, suppresses pathogens and toxin formation. It may be achieved through chemical additives, fermentation, heating, chilling, drying, modified-atmosphere packaging, water-activity control, acidification, or combinations of these (the 'hurdle' concept) [45,46]. In regulatory usage, not every ingredient that improves stability is legally a preservative; antioxidants, curing agents, acidity regulators and packaging gases may be governed under different functional classes. This review uses 'preservative' broadly for the main chemical agents that inhibit microbial growth or deterioration, while identifying related classes where relevant.

Foodborne disease provides the benefit side of the benefit-risk balance. WHO-coordinated estimates attribute hundreds of millions of illnesses and several hundred thousand deaths each year to foodborne hazards [49]. Any assessment of preservatives therefore has to ask not only whether an additive carries a hazard, but what would replace its protective function.

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1.1 Literature approach

The review is narrative, not a registered systematic review or meta-analysis. The literature base combines: (i). the seven core references of the original draft, whose DOI records were checked against publisher, PubMed, EFSA, WHO/JECFA or government records, with (ii). landmark human studies, meta-analyses, toxicological and technological reviews, and regulatory opinions added in this revision. Priority was given to randomised or cohort human evidence, official risk assessments (EFSA, JECFA, IARC), Codex and Indian FSSAI documents, and reviews with traceable bibliographic records. Table 1 summarises the approach, and Figure 1 shows the composition of the 60 cited sources.

Table 1. Literature survey design

Element	Description
Question	What are the technological roles, regulatory limits and health-relevant adverse effects of conventional food preservatives, and how strong is the evidence for children, adults and older adults?
Source types	Randomised trials and cohort studies; meta-analyses; EFSA, JECFA and IARC evaluations; Codex General Standard for Food Additives; FSSAI regulations, manuals and compendia; technology and microbiology reviews.
Priority topics	Benzoates, sorbates, sulfites, nitrite/nitrate, propionates, natamycin, BHA/BHT; ADI values; exposure scenarios; susceptible groups.
Weighting rule	Direct human evidence > official risk assessment > mechanistic or animal data > narrative opinion. Food-category evidence (processed meat, ultra-processed food) is reported separately from compound-specific evidence.
Currency	Regulatory values change; all limits and ADIs must be re-checked against the current text before compliance or publication decisions.

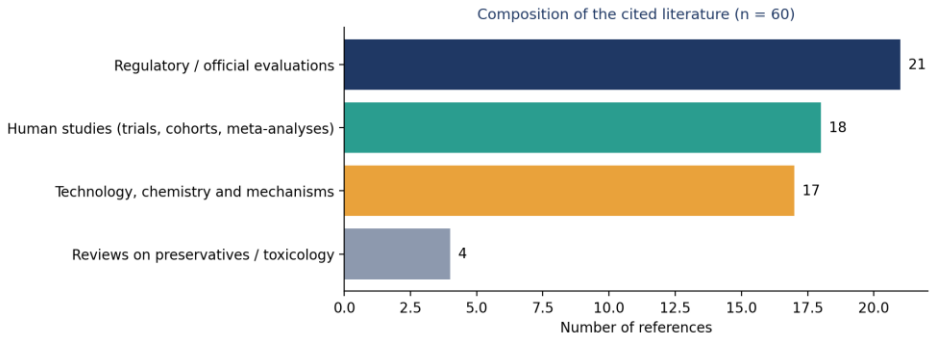


Figure 1. Composition of the cited literature by source type (n = 60). Categories were assigned; some sources span more than one category.

2. How preservatives work

Weak organic acids such as benzoic, sorbic and propionic acids act mainly in their undissociated form, which crosses microbial membranes and acidifies the cytoplasm; efficacy therefore depends on pH, food composition, water activity and microbial species [47]. Because the pKa values are about 4.2 (benzoic), 4.8 (sorbic) and 4.9 (propionic), activity declines steeply above pH 4.5 to 5.0 (Figure 3). This is why benzoate is used in acidic drinks and sauces while propionate, which retains activity at higher pH, is used in bakery products. Sulfur dioxide and sulfites inhibit microorganisms and browning reactions. Nitrite in cured meat helps control *Clostridium botulinum* and contributes to colour, flavour and oxidative stability, but can participate in nitrosation chemistry [23,24]. Natamycin is an antifungal agent used for surface treatment of certain foods [38]. Acetates and lactates contribute antimicrobial hurdles in selected products. Antioxidants such as BHA and BHT delay lipid oxidation and are not always legally preservatives [43].

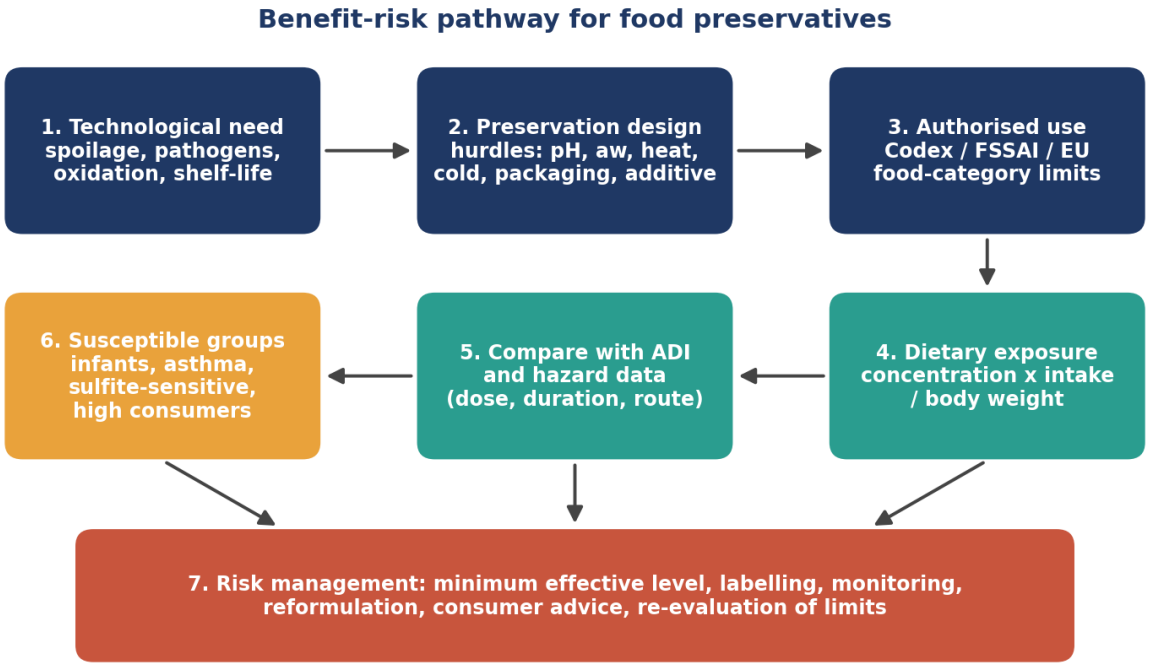


Figure 2. Benefit-risk pathway linking technological need, regulatory authorisation, exposure assessment, susceptibility and risk management.

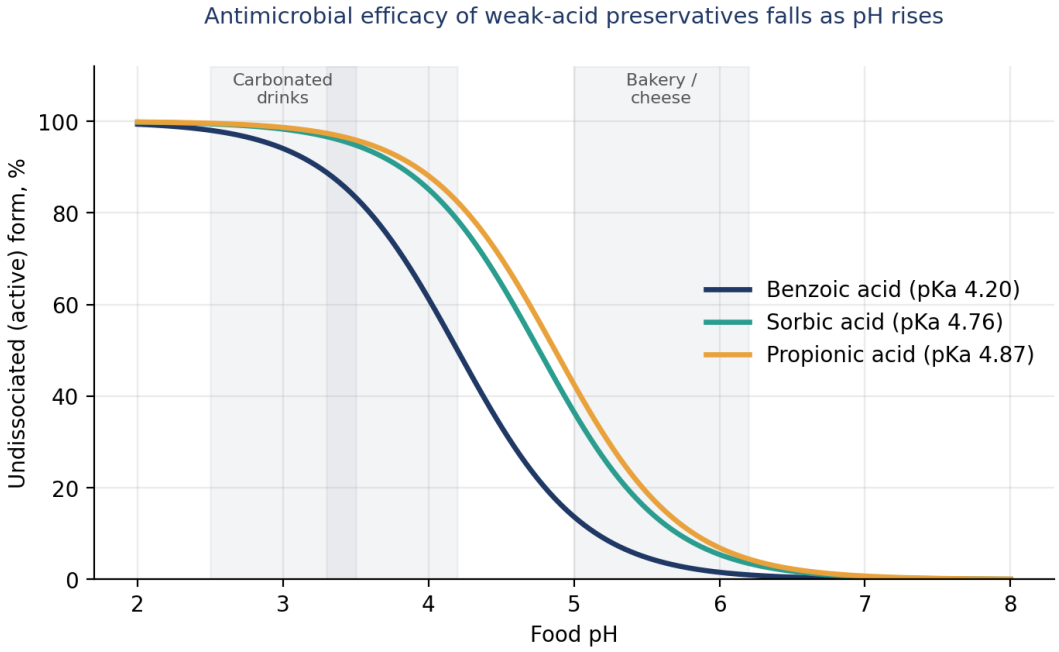


Figure 3. Fraction of weak-acid preservatives in the active, undissociated form as a function of pH, calculated from the Henderson-Hasselbalch relationship (pKa 4.20, 4.76 and 4.87). Shaded bands indicate approximate pH ranges of the food groups named; actual food pH varies.

3. Major preservative classes, applications and limitations

Table 2. Preservative classes, applications, health-based guidance values and key caveats

Class / examples	Main function	Typical applications	ADI (mg/kg bw/day)	Key caveats
Benzoic acid / benzoates (E210-213)	Yeasts and moulds, especially in acidic foods	Soft drinks, sauces, pickles, fruit preparations	5 (as benzoic acid; JECFA and EFSA) [13]	Activity falls as pH rises; hypersensitivity-like reactions in a minority; behavioural trial evidence is confounded by co-administered colours [1,9]; benzene can form from benzoate with ascorbic acid under certain conditions [19].
Sorbic acid / sorbates (E200-203)	Moulds and yeasts	Cheese, bakery, sauces, beverages	25 (JECFA); 3 (EFSA 2015) [14]	Generally well tolerated at authorised levels; rare contact reactions; EFSA lowered its group ADI, narrowing the margin for high consumers.
Sulfur dioxide / sulfites (E220-228)	Microbes; browning and oxidation control	Dried fruit, juices, potato products, wine	0.7 (as SO2; EFSA 2016 [15]); EFSA 2022 follow-up found data insufficient to establish an ADI [2]	Bronchospasm and other reactions in susceptible people, especially some with asthma [20-22]; high consumers may exceed guidance values; labelling matters.
Nitrite / nitrate (E249-252)	Curing; C. botulinum control; colour and flavour	Cured meats; selected other regulated uses	Nitrite 0.07; nitrate 3.7 (as ions) [16,17]	Essential safety function in some cured products; N-nitroso compound formation under particular conditions [4,5]; infant methaemoglobinaemia from excess nitrate/nitrite [27].
Propionic acid / propionates (E280-283)	Mould inhibition	Bread, baked goods, some cheeses	No numerical ADI considered necessary (EFSA) [39]	Usually low concern at authorised use; mechanistic and small acute human findings on glucagon and insulin action [36] should not be over-extrapolated.
Acetic acid / acetates; lactates	Acidification and antimicrobial hurdles	Pickles, sauces, meat and prepared foods	Not specified (normal food constituents)	Sodium contribution may matter for some diets.
Natamycin (E235)	Antifungal, surface treatment	Certain cheeses and sausage casings where permitted	0.3 [38]	Jurisdiction- and product-specific; residue and penetration limits apply.
Antioxidants BHA (E320), BHT (E321)	Delay lipid oxidation	Fats, oils, snacks, formulated foods	BHA 0.5 (JECFA), 1.0 (EFSA) [40]; BHT 0.3 (JECFA), 0.25 (EFSA) [41]	BHA classed IARC Group 2B (possibly carcinogenic, animal evidence) [42]; distinguish animal data from demonstrated human effects.

ADI values are health-based guidance values reported by JECFA and EFSA as cited and should be rechecked against the latest evaluation before use.

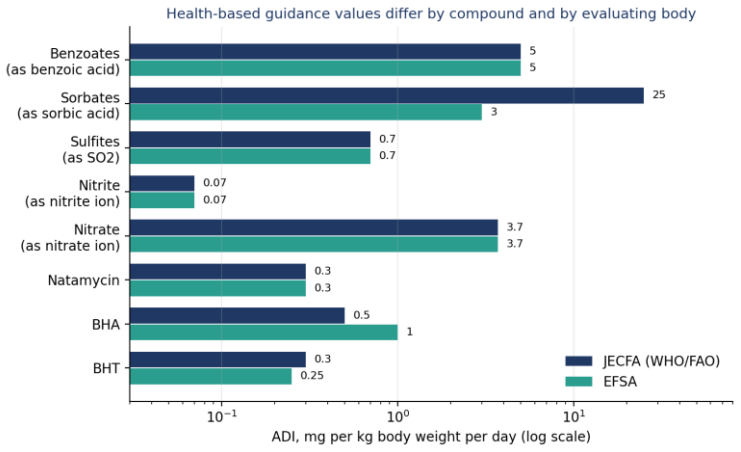


Figure 4. ADI values set by JECFA and EFSA for selected preservatives (log scale). The sulfite value shown is the 2016 EFSA group ADI; the 2022 EFSA follow-up concluded that the data were insufficient to establish an ADI [2,15]. Propionates, acetates and lactates are not shown because no numerical ADI is considered necessary.

4. Regulatory framework and FSSAI limits

4.1 International context

The Codex General Standard for Food Additives sets maximum use levels by food category and is the main international reference [51]. In the European Union, preservatives are authorised under Regulation (EC) No 1333/2008 [58], and authorised nitrite and nitrate levels were revised downwards by later amending legislation [59]. JECFA and EFSA provide the health-based guidance values used in these frameworks (Figure 4). The two bodies sometimes differ, as with sorbates, which illustrates that ADIs are scientific judgements that are revisited as data accumulate.

4.2 The Indian system under FSSAI

In India, preservatives are governed by the Food Safety and Standards (Food Products Standards and Food Additives) Regulations, 2011, as amended, and the associated compendia [52,54]. Regulation 3.1.4 defines a preservative as a substance that, when added to food, inhibits, retards or arrests fermentation, acidification or other decomposition, and divides preservatives into two classes [53]:

- **Class I** preservatives, such as common salt, sugar, dextrose, glucose syrup, spices, vinegar, honey and edible oils, may be added to any food without numerical restriction.
- **Class II** preservatives are restricted. They may be used only in specified foods, at no more than the specified level, and, as a general rule, only one Class II preservative may be used in a given food. The class covers benzoic acid and its salts; sulphurous acid and its salts; nitrates and nitrites of sodium or potassium (in foods such as ham and pickled meat); sorbic acid and its sodium, potassium and calcium salts; nisin; propionates; lactic acid and its salts; and methyl and propyl p-hydroxybenzoate [53].

FSSAI also prescribes identity and purity specifications for each preservative, and the Labelling and Display Regulations require declaration of the class and name of added preservatives [54,60]. Table 3 gives indicative maximum permitted levels (MPLs) that could be traced in this review. **These values are provided as a working guide.** The consolidated FSSAI Food Additives table is amended frequently, and values below were drawn partly from secondary summaries. They must be confirmed against the current gazette-consolidated text before any compliance decision.

Table 3. Indicative FSSAI-related limits and conditions for selected preservatives (verify against current regulation)

Preservative	Food category	Indicative MPL	Notes and source quality
Class I (salt, sugar, vinegar, spices etc.)	Any food	Not restricted	Stated in FSSAI Manual of Methods of Analysis: Food Additives [53].
Class II preservatives (general rule)	Specified foods only	Per product table	Use is restricted to listed products; more than one Class II preservative in the same food is generally prohibited [53]; confirm exceptions in the current text.
Benzoic acid and salts (as benzoic acid)	Carbonated beverages / soft drinks	120 ppm	Reported in an Indian exposure study citing FSSAI [55]; secondary source.
Benzoic acid and salts	Pickles	250 ppm	As above [55]; secondary source.
Benzoic acid and salts	Sauces (e.g., tomato ketchup)	750 ppm	As above [55]; secondary source.
Sulphur dioxide (sulphites)	Pickles and chutneys	100 ppm	Legacy fruit-product-order values, retained in teaching summaries; confirm current FSSAI value.
Sulphur dioxide	Syrups, sherbets, squashes	350 ppm	As above; confirm current FSSAI value.
Sulphur dioxide	Dehydrated vegetables	2000 ppm	As above; confirm current FSSAI value.
Nitrite / nitrate	Specified meat products (e.g., ham, pickled meat)	Numerical MPL not confirmed here	Class II listing confirmed [53]. Not to be added to infant food, as stated in the FSSAI regulation cited in the original draft.
Sorbates, propionates, nisin, lactates	Specified products	Per product table	Class II listing confirmed [53]; numerical MPLs to be taken from the current compendium.

Two points deserve emphasis for risk interpretation. First, MPLs are ceilings per food category, not typical concentrations; actual levels measured in market surveys are usually lower, although an Indian study of school children reported that sauces and fruit-juice products were within MPLs while younger children (2 to 7 years) reached roughly one-third of the ADI for sodium benzoate [55]. Second, because the one-Class-II-per-food rule limits stacking of preservatives within a single product, cumulative exposure arises mainly across different foods eaten in a day, which is why total-diet assessment matters.

4.3 Worked exposure scenario (benzoic acid)

To show how MPLs, portion size and body weight combine, Figure 5 estimates benzoic acid intake for a 20 kg child and a 60 kg adult under worst-case assumptions: every item contains benzoic acid at its MPL from Table 3 (120 ppm for a 250 mL soft drink, 750 ppm for 30 g of sauce and 250 ppm for 20 g of pickle), with no other dietary sources. Intake is divided by body weight and compared with the ADI of 5 mg/kg bw/day [13].

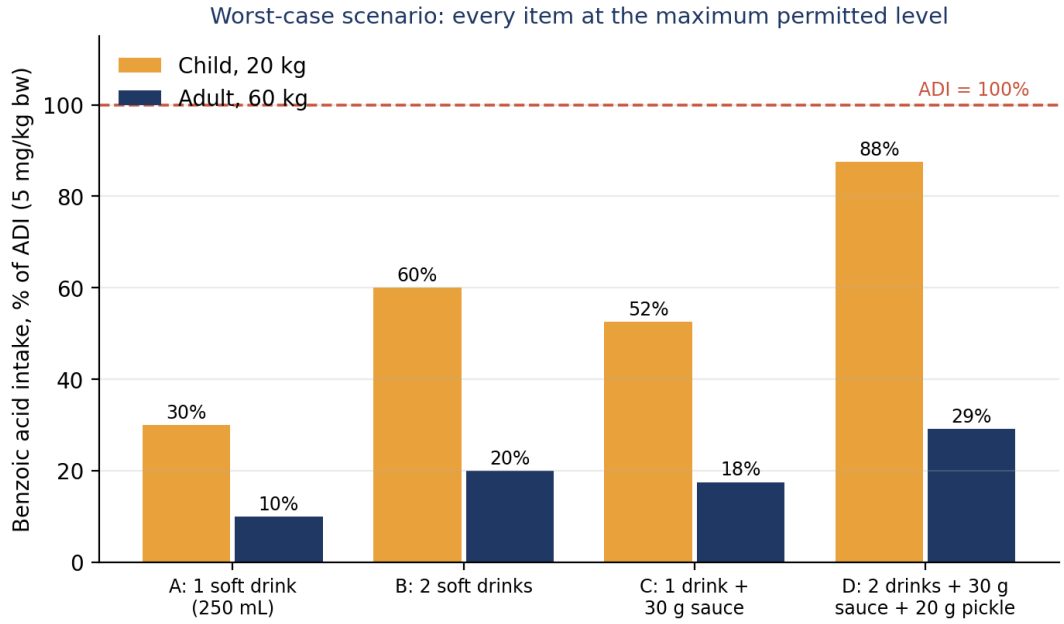


Figure 5. Illustrative worst-case benzoic acid intake as a percentage of the ADI. Calculation: intake (mg) = concentration (mg/kg or mg/L) x portion; % ADI = intake / body weight / 5 mg per kg x 100. Scenarios are hypothetical and are not consumption survey data.

One soft drink supplies about 1.5 mg/kg bw (30% of the ADI) to a 20 kg child but only 0.5 mg/kg bw (10%) to a 60 kg adult. In scenario D, the child reaches about 88% of the ADI whereas the adult remains under 30%. This does not mean harm occurs near the ADI, since ADIs include safety factors, but it shows that children, with higher intake per kilogram, have a narrower margin and that the combination of drinks, sauces and pickles matters more than any single product. It also assumes that the preservative is present in all items at the legal maximum, which is unlikely.

5. Adverse effects and strength of evidence

5.1 Children

Children can receive a higher dose per kilogram of body weight than adults when they consume similar portions, and their diets may include a narrow range of packaged foods (Figure 5). This is an exposure consideration, not proof that children are intrinsically more sensitive to every additive. The most cited human behavioural evidence is the randomised, double-blind, placebo-controlled crossover trial by McCann et al. in 3-year-old and 8/9-year-old children from the general community [1]. Challenge drinks containing mixtures of artificial colours with sodium benzoate (45 mg/day in both mixtures) produced small increases in a composite hyperactivity score in some age groups and analyses. An earlier Isle of Wight study in 3-year-olds had pointed in a similar direction [8]. Because the challenge combined several additives and results differed by mixture and age group, the trial cannot establish sodium benzoate alone as the causal agent; EFSA reviewed the study and concluded that the findings could not be used to change the ADIs of the colours or benzoate [9]. Meta-analytic work indicates that effects of

synthetic colours on ADHD-type symptoms are small, with concerns about publication bias and measurement [10,11]. Genetic variation in histamine-degrading enzymes may modify susceptibility [12].

Nitrite and nitrate exposure deserves particular attention in infants because of the risk of methaemoglobinaemia from excess nitrate or nitrite, first described in infants fed nitrate-contaminated well water [27]. This is not a reason to equate authorised preservative use in ordinary foods with an acute poisoning event. In India, the FSSAI food-additives regulation cited in the original draft states that nitrate or nitrite shall not be added to infant food; the current consolidated regulation should be checked before any compliance decision. Children with asthma may also be among groups at risk from sulfites, and parents should seek clinical advice for reproducible reactions rather than apply broad, unsupervised elimination diets.

5.2 Adults

In adults, the most actionable preservative-specific concern is individual intolerance or hypersensitivity, especially sulfite-associated respiratory symptoms in susceptible people, with prevalence estimates that vary by population and challenge method [20-22]. Benzoates and sorbates have been linked to uncommon skin or intolerance-type reactions, but prevalence and causality are uncertain [18]. The second major concern is nitrite-cured meat. Nitrite has a legitimate antimicrobial role [23,24], while nitrosating conditions, such as high-temperature frying or acidic gastric conditions in the presence of amines, can lead to N-nitroso compounds [4,5]. IARC classified processed meat as carcinogenic to humans (Group 1) on the basis of colorectal cancer evidence, with an average 18% higher relative risk per 50 g daily portion [28,29,30]. This relates to the food category and several mechanisms, including haem iron [31], and should not be read as proving that permitted nitrite alone explains the association. A French cohort reported associations between additive-derived nitrite or nitrate intake and some cancer outcomes, but observational design and residual confounding limit causal inference [32]. Experimental work also suggests that nitrate and nitrite from vegetables and endogenous pathways contribute to physiological nitric oxide signalling, which complicates simple 'nitrite is harmful' messages [25,26,57].

Emerging, lower-certainty signals include gut-microbiota perturbation by benzoate, sorbate and other preservatives in a genetically susceptible mouse model [37], and an acute effect of propionate on glucagon and insulin action in mice and a small human experiment [36]. These are hypothesis-generating and do not yet support clinical or regulatory conclusions at authorised intakes.

5.3 Older adults

There are a little direct clinical research isolating preservative effects in older adults. Potentially relevant factors include lower body mass in some individuals, polypharmacy and comorbid asthma or chronic lung disease, kidney or liver impairment that may affect handling of some compounds, and higher consequences from foodborne illness. The most defensible advice is not that older adults must avoid all preservatives, but that they should minimise unnecessary reliance on highly processed foods, read labels when a known sensitivity exists, and prioritise food safety. Preserved foods can be valuable when they improve availability, affordability and microbiological safety.

5.4 General chronic disease claims and ultra-processed foods

Large cohort studies link high ultra-processed food intake with adverse cardiometabolic and cancer outcomes [33,34], and an umbrella review of meta-analyses found consistent associations across many outcomes, mostly of low to moderate certainty [35]. These associations do not establish that preservatives are the causal ingredient: processing level, nutrient profile, energy density, salt, sugar, food matrix and lifestyle confounding may all contribute. Similarly, toxicological effects at high doses in animals are hazard signals that do not directly quantify risk at authorised human exposures. Risk assessment should consider dose, route, duration, metabolism, background exposure and susceptible subgroups.

Table 4. Key studies and evaluations informing the evidence base

Source	Design	Main finding	Main limitation
McCann et al. 2007 [1]	Randomised double-blind crossover; 3-year-old and 8/9-year-old children	Small increase in hyperactivity score after colour + sodium benzoate mixtures in some analyses	Mixtures; benzoate not isolated; behavioural ratings; clinical relevance debated [9]
Bateman et al. 2004 [8]	Placebo-controlled challenge in 3-year-olds	Parent-rated hyperactivity changed with colour + benzoate challenge	Parent ratings; small sample; mixture
Nigg et al. 2012 [10]	Meta-analysis	Small effect of synthetic colours on ADHD-type symptoms	Heterogeneity; publication bias; mostly colours
Vally et al. 2009 [20]	Narrative/clinical review	Sulfite reactions are recognised in susceptible people, notably some with asthma	Prevalence estimates vary; challenge methods differ
EFSA 2022 [2]	Regulatory follow-up	Data insufficient to establish a sulfite ADI; concern for high consumers	Reflects data gaps, not proof of harm
IARC 2018 / Bouvard et al. 2015 [28,29]	Hazard classification	Processed meat: Group 1 (colorectal cancer)	Food category, not nitrite alone
Chazelas et al. 2022 [32]	Prospective cohort	Associations of additive-derived nitrite/nitrate with some cancer outcomes	Observational; exposure misclassification; confounding
EFSA 2017 [16,17]	Re-evaluation	ADIs for nitrite and nitrate; exposure from additives is a minor share of total nitrate	Uncertainty on nitrosamine formation in vivo
Gardner and Lawrence 1993 [19]	Laboratory chemistry	Benzene can form from benzoic acid with ascorbic acid and metal catalysts	Model conditions; mitigated by formulation
Tirosh et al. 2019 [36]	Mouse and small human experiment	Propionate raised glucagon and FABP4; insulin action impaired	Acute, high exposure; small sample

6. Summary matrix: population-specific considerations

Table 5. Exposure, evidence-based concerns and practical interpretation by life stage

Group	Exposure / vulnerability considerations	Evidence-based concerns	Practical interpretation
Children	Higher intake per kg body weight; repeated exposure from drinks, sauces and snacks; developing physiology	Mixed-additive behavioural trial signal [1]; sulfite sensitivity in susceptible children; high nitrate/nitrite exposure in infants is a distinct concern [27]	Do not infer ADHD causation from one mixed-additive trial; favour age-appropriate foods; check labels where sensitivity is diagnosed
Adults	Cumulative intake across many products; occupational or clinical susceptibility	Sulfite reactions [20]; nitrosamine chemistry in some cured meats [4]; rare intolerance reactions	Vary protein sources; limit frequent processed-meat intake [29]; follow clinician advice for reproducible reactions
Older adults	Comorbid asthma/COPD, frailty, medication burden, food-safety vulnerability	Sparse direct age-specific evidence; compound-specific sensitivities may apply	Avoid unnecessary restriction that reduces intake; prioritise safe storage, label awareness and nutritional adequacy

7. Dose, cumulative exposure and interpretation

The acceptable daily intake (ADI) is a health-based estimate of the amount that can be consumed daily over a lifetime without appreciable health risk, derived from a no-observed-adverse-effect level and uncertainty factors. It is not a target intake, a threshold at which poisoning begins, or permission to add the same amount to every food. Legal maximum levels are food-category-specific and may differ between jurisdictions. Total exposure from all foods is more relevant than concentration in a single product; European surveys that compare estimated intake of sulfites, benzoic acid and sorbic acid with ADIs highlight high-consumer scenarios as the point of regulatory interest [50].

Sulfites are the clearest regulatory example. EFSA's 2016 evaluation set a group ADI of 0.7 mg/kg bw/day as SO_2 [15], whereas the 2022 follow-up concluded that the available toxicity data were

insufficient to maintain an ADI and that high consumers could be at concern [2]. This is a statement of uncertainty and a call for better data, not proof that ordinary consumption inevitably causes harm. A later EFSA exposure update (2025) examined alternative maximum levels. Always consult the latest assessment and applicable local law.

8. Evidence appraisal

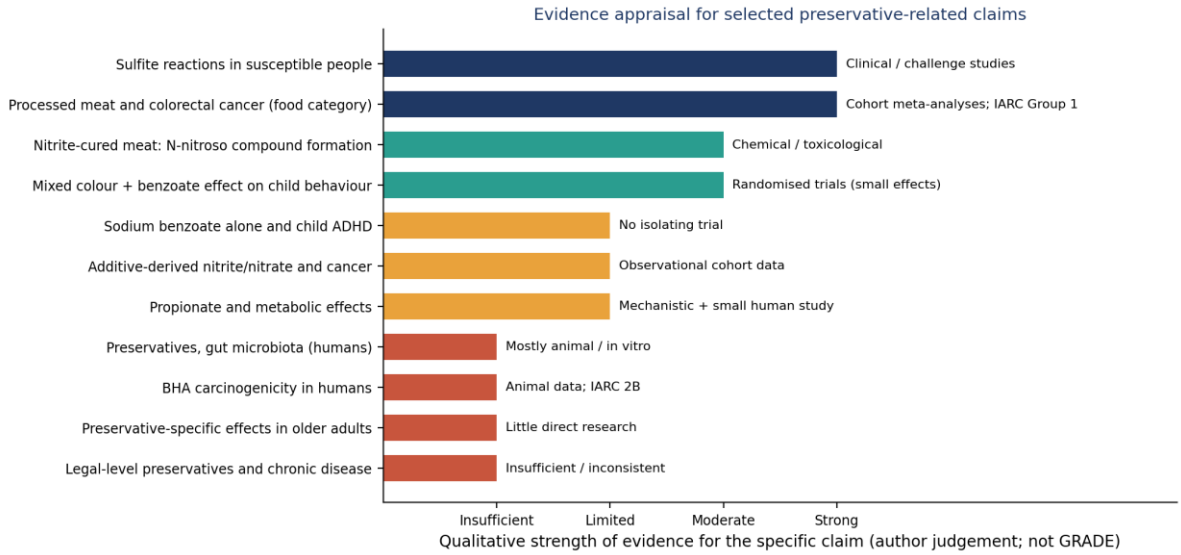


Figure 6. Qualitative evidence appraisal for selected claims. This is the author's interpretation, not a formal GRADE assessment or meta-analysis; categories refer to the specific claim, not to overall preservative safety.

The clearest evidence is compound- and context-specific. Sulfite reactions in susceptible people are clinically recognised, while population-wide chronic effects are less certain. The nitrite and nitrosamine pathway is chemically and toxicologically plausible and supported by research, but risk varies with formulation, processing and diet. The child-behaviour trial is randomised but tests a mixture, limiting causal attribution. Regulatory reassessment can change conclusions as exposure estimates and toxicological data improve.

9. Alternatives and integrated preservation

- Use good manufacturing practice and the minimum effective additive level consistent with validated safety and shelf-life.
- Combine hurdles (temperature control, pH, water activity, hygienic handling, heat treatment, fermentation and suitable packaging) rather than relying on one preservative [45,46].
- Use natural antimicrobials (selected plant extracts, organic acids, bacteriocins such as nisin, or protective cultures) only where efficacy, sensory impact, allergenicity, stability and regulatory status have been established [6,48].
- Validate alternatives against relevant pathogens and spoilage organisms; 'natural' does not automatically mean safer, more effective or more sustainable [44].
- Reduce nitrosamine formation through formulation and process controls, appropriate antioxidant systems where authorised, and compliance with current nitrite limits; do not remove nitrite from high-risk products without validated botulism controls [24,25].
- Improve consumer information, including clear ingredient declarations and, where required, allergen or sensitivity-related statements.

10. Limitations

The conclusions of this review should be read with the following limitations in mind, which concern both the underlying evidence and the review itself.

10.1 Limitations of the underlying evidence

- **Mixture and confounding.** Key child-behaviour evidence tests mixtures of colours and benzoate, so preservative-specific effects cannot be separated [1,9].

- **Food category versus ingredient.** Associations for processed meat and ultra-processed foods reflect whole dietary patterns, nutrients and lifestyle, not individual additives [29,33-35].
- **Dose and extrapolation.** Many toxicological findings come from animals or in vitro systems at doses above realistic human intake; extrapolation relies on uncertainty factors [37,42].
- **Exposure data gaps.** Reliable brand-level occurrence data and individual consumption data are limited, particularly in India, where most evidence derives from small regional surveys [55]; EFSA's sulfite conclusion explicitly reflects such gaps [2].
- **Susceptible groups.** Trials in infants, pregnant women and older adults, and long-term human studies of low-dose preservative exposure, are rare; sulfite prevalence estimates depend on challenge methodology [20,21].
- **Interaction and cumulative effects.** ADIs are set per substance, while real diets contain several additives, and interactions (for example benzoate with ascorbic acid) are poorly characterised [19].
- **Changing assessments.** ADIs and limits evolve (for example sorbates and sulfites), so any snapshot may become outdated [2,14,15].

10.2 Limitations of this review

- **Narrative design.** No pre-registered protocol, exhaustive database search, dual screening or formal risk-of-bias assessment was performed, so selection bias is possible; Figure 6 is a qualitative judgement, not GRADE.
- **FSSAI values.** The consolidated FSSAI additive tables are amended frequently, and several limits in Table 3 were obtained from secondary summaries; they are indicative and must be verified against the current gazette text.
- **Scale of exposure scenarios.** The worked scenario assumes concentrations at the maximum permitted level, single servings, and no other sources, and is illustrative rather than a population estimate.
- **Coverage.** The review concentrates on conventional chemical preservatives and does not cover colours, sweeteners, emulsifiers, nanomaterials or processing contaminants beyond nitrosamines.
- **Source verification.** Bibliographic details for items added in this revision should be confirmed against the publisher or PubMed record before submission.

11. Recommendations for consumers, industry and regulators

11.1 Consumers

- Read ingredient lists if a clinician has identified a specific preservative sensitivity, and report suspected severe reactions promptly.
- Prefer dietary variety and minimally processed foods when practical, while maintaining safe handling and refrigeration.
- Limit frequent consumption of processed meats as a broader dietary recommendation; do not attribute all associated risk to nitrite alone.
- For young children, avoid making packaged soft drinks and heavily preserved sauces and pickles daily staples, because per-kilogram exposure is higher (Figure 5).
- Do not use this review to self-diagnose food allergy, ADHD, asthma triggers or chemical intolerance.

11.2 Industry and regulators

- Apply the minimum effective level and validated hurdle design; reformulate where lower levels are shown to be safe microbiologically.
- Strengthen Indian market surveillance and total-diet studies for benzoates, sorbates and sulfites, with age-specific exposure estimates for children.
- Publish current, searchable consolidated MPL tables and revision histories to reduce reliance on secondary summaries.

- Review sulfite and sorbate limits in light of the 2016 to 2025 EFSA assessments, and consider labelling statements for sulfites above threshold concentrations.
- Monitor cumulative exposure, reassess vulnerable groups, verify label compliance and publish transparent exposure data.

12. Conclusions and future research priorities

Preservatives are not a single toxicological category. They range from weak organic acids to sulfites and curing agents, with different mechanisms, exposure patterns, guidance values and safety profiles. Their role in preventing spoilage and dangerous microbial growth is a genuine public-health benefit. Adverse effects are best described narrowly: sulfites can provoke reactions in susceptible individuals; nitrite chemistry can contribute to nitrosamine formation under particular conditions; and one prominent child trial found small behavioural effects from a mixture of colours and sodium benzoate without isolating the causal ingredient. Evidence does not support blanket claims that all permitted preservatives are harmful to children, adults or older people.

Within the Indian regulatory system, the Class I and Class II distinction, the restriction of Class II preservatives to specified foods and levels, and the one-Class-II-per-food principle provide a workable control structure. The remaining risk lies less in any single authorised use than in cumulative intake across foods among children and high consumers, in gaps in exposure data, and in the need for current, easily accessible limits. The appropriate strategy is proportionate risk management: lawful use, realistic exposure assessment, clear labelling, validated preservation hurdles and targeted protection of susceptible consumers.

Priority research questions include: (1) preservative-specific, single-agent challenge trials in children, with long-term follow-up; (2) national total-diet and biomonitoring studies in India for benzoates, sorbates, sulfites and nitrite; (3) prospective cohort studies measuring additive exposure with brand-level data; (4) the human relevance of microbiota and metabolic signals; (5) validation of natural and hurdle-based alternatives for pathogen control; and (6) trials and surveillance for older adults and other vulnerable groups.

Declarations

1. Use of AI-Assisted Tools: AI-assisted tools were used during the preparation of this manuscript for organising scientific information, developing the review structure, improving language and readability, and refining the presentation of technical and regulatory concepts. The author critically reviewed, verified and edited all AI-assisted content and takes full responsibility for the accuracy, scientific integrity, interpretation of the scientific evidence and final content of the manuscript.

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3. Conflict of Interest: The author declares that there is no financial, commercial, institutional, personal, or professional conflicts of interest that could have influenced the preparation, interpretation or presentation of this manuscript.

4. Ethical Approval: Ethical approval was not required for this narrative review because it is based on previously published scientific literature, regulatory documents, food safety guidelines, institutional reports, and publicly available information. No experiments involving human participants or animals were conducted as part of this work.

5. Informed Consent: Not applicable. This manuscript does not involve human participants, clinical investigations, collection of personal information or use of identifiable patient data.

6. Data Availability Statement: No new experimental datasets were generated or analysed during the preparation of this review. The information presented is derived from previously published scientific articles, regulatory databases, food safety publications, risk assessment reports, and publicly accessible documents from organisations such as the Codex Alimentarius Commission, European Food Safety

Authority (EFSA), European Union (EU), and Food Safety and Standards Authority of India (FSSAI). Relevant sources are appropriately cited in the manuscript.

7. Author Contributions: The author contributed to the conceptualisation and development of the review, identification and collection of relevant scientific literature, examination of the technological functions and applications of food preservatives, evaluation of regulatory provisions and permissible limits under Codex, EU, and FSSAI frameworks, assessment of dietary exposure and consumption patterns, critical examination of health-related evidence across different stages of life, evaluation of potential risks and benefits, analysis of risk management strategies, critical revision and approval of the final version.

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