Supplementary Materials

Moringa oleifera Seed Antimicrobial Peptides: Mechanisms, Matrix Validation, and Barriers to Food Applications

Mingxia Xiao, Jiming Long, Chunpan Zhao, Yanni Liu, Leng Wang, Haiquan Li, Zubing Zhang

This file contains Tables S1–S8, which support the main text. Tables S2–S6 contain the detailed evidence and reference values moved from the main manuscript to improve narrative flow. Table S1 documents the search strategy and screening levels. Table S7 is a reporting-completeness assessment, and Table S8 contains the source data for Figures 2 and 4.

Table S1. Search strings, record counts, and screening levels.

Database / query	Date / window	Records	Screening level
PubMed string A: ("Moringa oleifera") AND ("seed protein" OR "seed peptide" OR "antimicrobial peptide" OR "hydrolysate" OR "coagulant protein" OR "lectin" OR "chitin-binding")	18 Oct 2026; indexed to 1 Oct 2026	116	Title and abstract
PubMed string B: ("Moringa") AND ("food preservation" OR "shelf life" OR "edible coating" OR "film" OR "food packaging" OR "pasteurized milk" OR "goat milk" OR "cheese" OR "meat" OR "sausage" OR "fish" OR "shrimp" OR "egg" OR "fruit" OR "vegetable" OR "postharvest")	18 Oct 2026; indexed to 1 Oct 2026	487	Title and abstract
PubMed strings A + B after duplicate removal	18 Oct 2026	591 unique	Title and abstract
Europe PMC gap-check string C1: ("Moringa") AND (peptide OR hydrolysate OR "seed protein") AND (meat OR pork OR beef OR chicken OR fish OR shrimp OR egg OR sausage)	1 Jan 2024 to 1 Oct 2026	346	Title only
Europe PMC gap-check string C2: ("Moringa") AND (antifungal OR Colletotrichum OR Aspergillus OR Penicillium) AND (coating OR film OR postharvest OR fruit)	1 Jan 2024 to 1 Oct 2026	559	Title only
Europe PMC film/coating query: (Moringa) AND (peptide OR "seed protein") AND (film OR coating OR packaging)	18 Oct 2026	576	Title only

Note: The search was restricted to English and Chinese records. The PubMed counts were obtained on 18 October 2026. Gap-check queries were screened by title only; a null result means that no matching record was retrieved up to the cutoff, not that such work is absent. No formal PRISMA flow, independent duplicate screening, or risk-of-bias appraisal was used.

Table S2. Antimicrobial evidence for seed-derived defense proteins and peptides, with leaf-derived and water-treatment comparator rows.

Molecule/fraction	Target microorganisms	Mechanism (evidence tier)	Measured MIC/MBC	Evidence system	Reference
Mo-CBP3	Plant pathogenic fungi: Fusarium solani, F. oxysporum, Colletotrichum musae, C. gloeosporioides; Candida albicans and other fungi	Chitin binding; disruption of fungal plasma membrane structure and induction of ROS accumulation; inhibits spore germination after 100 °C for 1 h	0.1 mg/mL (fungicidal against F. solani)	In vitro	[19,40,50]
Mo-CBP3 synthetic peptides (e.g., Mo-CBP3-PepII)	Cryptococcus neoformans and other human pathogenic fungi	Multiple mechanisms, membrane permeabilization, and ROS	Not reported	In vitro	[61]
Mo-CBP2	Candida	Increased membrane permeability; ROS production	MIC50 9.45–37.90 μM and MIC90 155.84–260.29 μM [41]	In vitro	[41]
Mo-CBP4	Dermatophytes	Chitin targeting; membrane mechanism	45 μM (50% inhibition of microconidia germination) [39]	In vitro and skin infection model (non-food matrix)	[39]
morintides	Plant pathogenic fungi	Chitin binding; heat and protease resistant	Not reported	In vitro	[42]
<3 kDa peptide fraction in which napin was identified (Moringa and Brassica juncea comparison; leaf-derived)	Multiple pathogens, including Gram-negative bacteria	Bacterial agglutination and growth inhibition; binding sites on LpxC and topoisomerase are docking predictions	MIC 0.5 mg/mL, MBC 1.5 mg/mL (leaf-derived, not seed)	In vitro (leaf-derived purified protein with bacterial suspension)	[38]
WSMoL	Gram-positive and Gram-negative bacteria, Candida, Cryptococcus	Altered membrane permeability, inhibition of protease secretion, antifungal and antibiofilm activity	MIC 15.6 μg/mL and MBC 125 μg/mL (Enterococcus faecalis) [22]; MIC 20 μg/mL and MFC 20–80 μg/mL (Candida) [52]	In vitro	[22,44,52]
MOCP (including synthetic branched peptides)	Pseudomonas aeruginosa, Streptococcus pyogenes (human pathogens); E. coli	Coagulation depends on a glutamine-rich cationic region; killing depends on membrane destabilization by a	Not reported (water treatment doses are usually given in mg/L; no food-basis	Laboratory water system (bacterial suspension, non-food	[45,46,53]

	(membrane fusion assays)	hydrophobic loop, with membrane fusion as the dominant mechanism	MIC/MBC reported)	matrix)		
6.7 kDa basic antimicrobial peptide	Salmonella typhimurium, Staphylococcus aureus, Candida albicans	Not reported (the source reports purification and physicochemical characterization: stable at ≤70 °C and pH 5-8; fully inactivated by proteases)	MIC 16, 32, 32 µg/mL (for the three organisms in order); MBC not reported	In vitro		[54]

Note: Note: MIC, minimum inhibitory concentration; MBC, minimum bactericidal concentration; ROS, reactive oxygen species; Mo-CBP, Moringa oleifera chitin-binding protein; MOCP, Moringa oleifera coagulant protein; WSMoL, water-soluble lectin from Moringa oleifera seeds. Not reported means that the source did not report a usable measured value; no value was inferred. In this table, in vitro refers to experiments with bacterial or fungal suspensions and agar systems, whereas laboratory water system refers to drinking-water treatment or model water systems (bacterial suspensions, non-food matrices).

Table S3. Application evidence for Moringa bioactive molecules in food matrices, grouped by matrix.

Food matrix	Active material (source: seed/leaf/oil)	Target microorganism	Dose	Main effect	Evidence type	Reference
Goat milk	moringin isothiocyanate (seed)	Bacillus cereus; Cronobacter sakazakii	MIC 0.14 and 0.25 mg/mL; MBC 0.28 and 0.50 mg/mL; biofilm formation reduced by 77.25% and 75.10% after 72 h at 1× MIC; the concentration applied in goat milk was not stated in the accessible record	Inhibition (mechanism includes membrane damage)	Real food	[81]
Pasteurized milk	MOp3 purified peptide (seed)	Staphylococcus aureus	In vitro MIC 2 mg/mL [57], for order-of-magnitude reference only; the concentration applied in milk was not stated in the accessible record	Inhibition: persists for 7 d of storage at 25 °C and at 4 °C	Real food	[58]
Pasteurized milk	FGMp11 (fermented goat milk origin, not seed-derived)	Staphylococcus aureus	Not stated in the accessible record	Inhibition (used as a concurrent matrix control)	Real food	[59]
Cheese	Moringa seed oil (oil)	Listeria monocytogenes	Surface application at 10 mg/mL; storage at 4 °C for 14 d	Reduced survival and downregulated virulence gene expression; no adverse sensory effect	Real food	[82]
Fermented milk	Leaf plus seed powder (leaf/seed)	NS (no antimicrobial endpoint)	Seed powder 1% (treatment T4, best effect); the leaf powder ratio was not stated in the accessible record	Improved quality and probiotic viability (not an antimicrobial effect; not counted as an activity record)	Real food	[83]
Raw chicken sausage	Defatted seed meal ultrasound extract plus chitosan coating (seed meal)	Escherichia coli; Bacillus cereus	Extract MIC 3.12 mg/g; coating 3% (range 1% to 5%)	Reductions of 1.4 and 1.78 log on days 3 and 6; growth suppression maintained to day 9; antioxidant activity	Real food	[84]
Ground beef	Leaf extract (leaf)	Foodborne pathogens	Leaf aqueous extract 0.5%, 1%, and 2% (w/w); 18 d at 4 °C, including aerobic plate count, Enterobacteriaceae count, and challenge tests with three pathogens	Inhibited pathogens and delayed lipid oxidation	Real food	[85]
Mutton patties	Leaf extract (leaf)	Microbiological indices during refrigerated storage	Moringa leaf extract 1%, 2%, 3%, and 4%	Extended refrigerated shelf life; improved nutritional and quality attributes	Real food	[86]
Chicken burgers	Leaf powder and leaf extract (leaf)	Oxidation indices	Leaf powder 1% and 2%; leaf methanol crude extract 0.02%; 20 d at 4 °C	Antioxidant activity; improved oxidative stability	Real food	[87]
Goat meat nuggets	Moringa flower powder (flower, non-seed)	Microbiological indices during storage	Dried Moringa flower powder 1% (T1) and 2% (T2)	Antioxidant activity; stable quality	Real food	[88]
Beef patties	Leaf ultrasound-assisted extract (leaf)	Oxidation and sensory endpoints	Leaf ultrasound-assisted aqueous extract 0.5%; chilled at 4 ± 1 °C for 0 to 12 d	Antioxidant and inhibitory activity; extended half-life; sensory evaluation included	Real food	[89]
Frozen beef burgers	Leaf extract (leaf)	Microbiological and physicochemical indices during frozen storage	Leaf extract 2% and 4% (oil, ethanol, and water extracts; the ethanol extract performed best); 6 months of frozen storage	Quality retention during frozen storage	Real food	[90]
Vacuum-packed pork patties	Moringa stenopetala leaf ethanol extract (leaf)	Microbiological indices during refrigerated storage	M. stenopetala leaf ethanol extract 0.05% and 0.1% (control: 0.2% potassium sorbate); vacuum-packed at 4 °C	Improved quality attributes and shelf life	Real food	[91]
Minced meat (packaging film)	Leaf extract bio-based film (leaf)	Microbiological indices of minced meat during storage	Leaf extract loading in the film was not stated in the accessible record	Extended shelf life	Real food	[92]
Mango	Leaf extract plus chitosan coating (leaf)	Postharvest quality (no disease endpoint reported)	1.5% chitosan plus 1.5% Moringa leaf extract (best combined treatment); 50 d at 12 ± 1 °C	Stored for the full 50 d; firmness, ascorbic acid, and antioxidant enzyme activity better maintained (disease incidence not stated in the accessible record)	Real food	[94]

Mango ('Tommy Atkins')	Moringa seed oil-based coating (oil)	Postharvest quality	Seed oil 0.5%, 1%, and 1.5% (v/v) in a cassava starch-based coating; 15 d at 27 °C	Postharvest preservation	Real food	[93]
Avocado ('Maluma')	Leaf extract with gum arabic 10% or 15%, and carboxymethyl cellulose (CMC) 1% (leaf)	Colletotrichum gloeosporioides	Coating: 21 d at 5.5 °C and 95% RH, then 7 d at 21 °C; the antifungal assay was in vitro	Lower mass loss and retained firmness; in vitro inhibition of radial mycelial growth by 28% to 33%	Real food plus in vitro antifungal assay	[99]
Guava	Pectin, gelatin, and leaf extract coating (leaf)	Postharvest quality	Pectin and gelatin base film with a leaf extract dip coating (exact ratio was not stated in the accessible record)	Improved shelf stability	Real food	[95]
Strawberry	Cassava starch and Moringa coating (leaf)	Postharvest quality	Best treatment (T5): 2% cassava starch, 0.5% CMC, 1% glycerol, and 1.5% Moringa leaf extract; 9 d at 28 °C	Preservation	Real food	[96]
Strawberry	Pectin-based film carrying leaf extract in a natural deep eutectic solvent (NADES) (leaf)	Postharvest quality	Leaf extract in NADES (choline chloride to maltose, 4:1 mol/mol) as the active phase of the pectin film; 11 d at 4 °C; film loading was not stated in the accessible record	Improved quality and shelf life	Real food	[97]
Date palm fruit ('Siwi')	γ-Irradiated poly(vinyl alcohol)/chitosan/Moringa coating (leaf)	Postharvest quality and insect control	Leaf extract 3%, 5%, 10%, and 15% (blended into the poly(vinyl alcohol)/chitosan matrix; 15% performed best; γ-irradiation for crosslinking); 6 months at room temperature; irradiation dose in kGy was not stated in the accessible record	Quality retention and insect control	Real food	[98]
Apple fruit (in vivo inoculation)	Leaf extract (leaf; the strongest activity in the source came from the alga Champia parvula)	Penicillium expansum; P. crustosum; Talaromyces atroroseus	100 mg/mL (at this concentration the strongest activity came from the algal extract)	Reduced pathogen virulence; Moringa extract activity was comparatively weak	Real food (fruit inoculation)	[100]
Tomato (seed coating, in planta)	Seed cake glucomoringin/moringin (seed/seed meal)	Fusarium oxysporum f. sp. lycopersici	1 to 1000 µmol/L (in vitro, dose-dependent); 100 µmol/L for seed coating	Inhibited spore germination and mycelial growth; seedling disease severity reduced by 70%	Real plant (not a food matrix)	[62]
White chocolate	Leaf extract (leaf)	NS (microbiologically safe, that is, not detected)	1% and 3% (w/w)	Improved antioxidant capacity and oxidative stability; the 3% sample showed the highest DPPH inhibition after 15 d	Real food	[101]
Fish and shrimp	NS	NS	NS	No matrix-level evidence retrieved	NS	NS
Egg products	NS	NS	NS	No matrix-level evidence retrieved	NS	NS
Cereals and bakery products	NS	NS	NS	No matrix-level evidence retrieved	NS	NS

Note: Note: Rows are grouped by food matrix. The counting basis is one independent study, and a study that reports both in vitro and matrix-level evidence is counted once at each tier. Evidence type records the endpoint tier: in vitro (inhibition zone, broth dilution, or chemical assay, with no food matrix); real food (microbiological, physicochemical, or sensory endpoints measured in a real food product); real food plus in vitro antifungal assay; or real plant (a whole-plant or seedling trial, not a food matrix). NS means that the source did not state the item; for the final three rows it indicates that no matrix-level evidence was retrieved, which is a negative result rather than a missing value. T1–T5 are treatment codes used in the original reports. The source is given in parentheses after each active material as seed, seed meal, leaf, oil, or flower; leaf- and oil-derived materials do not constitute evidence for seed proteins or their peptides. FGMp11 is of fermented goat milk origin and is not seed-derived; it appears only as a concurrent pasteurized-milk comparator. A behenic acid fraction of the seed methanol extract is a fatty acid rather than a protein and is therefore not listed. Dose is quoted in the units of the original report, and the three bases that occur (extract MIC in mg/g; food addition in % w/w; active concentration in µmol/L or mg/mL) are not mutually convertible (Section 7.2). Values not available in the retrieved sources are marked as not stated in the accessible record; no values were imputed. In vitro MIC and MBC values for seed-derived actives are compiled in Table S5 and are not repeated here, so that no study is counted twice. The search strategies and screening levels are given in Section 1.4 and Table S1. DPPH, 2,2-diphenyl-1-picrylhydrazyl; MBC, minimum bactericidal concentration; MIC, minimum inhibitory concentration.

Table S4. Enzyme-derived bioactive peptides from Moringa oleifera seeds, with non-seed and leaf-derived comparator rows.

Peptide/fraction	Preparation route	Activity and mechanistic evidence tier	Measured MIC/MBC	Food matrix validation	Reference
MOp2 (octapeptide HVLDTPLL)	Seed protein hydrolysis, isolation, and identification	Anti-S. aureus: membrane damage (permeability plus electron microscopy, experimentally confirmed); intracellular targets (dihydrofolate reductase, DNA gyrase) are docking predictions (unvalidated); TMT proteomics and transcriptomics support multi-target perturbation	MIC 2.204 mM (≈2 mg/mL; octapeptide Mr ≈ 0.91 kDa); >90% activity in 5% salt and about 78% after 115 °C for 30 min; negligible hemolysis at 2.0 × MIC	No (in vitro and omics)	[49,55,56]
MOp3	Seed protein hydrolysis (affinity	Anti-S. aureus; metabolomics indicates metabolic reprogramming	MIC 2 mg/mL (S. aureus) [57]; MBC and the concentration in	Yes: pasteurized milk (single	[57,58]

Peptide/fraction	Preparation route	Activity and mechanistic evidence tier	Measured MIC/MBC	Food matrix validation	Reference
	adsorption isolation)		milk were not reported [58]	strain, single matrix)	
FGMp11 (TPVVVPPFLQP; non-seed, fermented goat milk)	Identification and screening from fermented goat milk	Hydrophobic peptide damaging S. aureus membrane integrity; Mur enzyme targets are docking predictions	Not reported	Yes: pasteurized milk	[59]
<3 kDa peptide fraction in which napin was identified (leaf-derived)	Purified protein fractionation below 3 kDa (Moringa and Brassica juncea comparison)	Bacterial agglutination and growth inhibition; target conclusions are docking predictions	MIC 0.5 mg/mL, MBC 1.5 mg/mL (leaf-derived, not seed; not counted as seed peptide evidence)	No	[38]
Antioxidant and selenium-enriched peptides	Enzymatic hydrolysis plus selenium enrichment	Radical scavenging; antioxidant mechanism resolved	Not reported (non-antimicrobial target)	No (in vitro chemical models)	[26,68,69]
<3 kDa globulin peptide fraction (alcalase hydrolysate)	Enzymatic hydrolysis plus ultrafiltration	Most active antioxidant fraction; relatively low in vitro antihyperglycemic activity (no carbohydrase inhibition detected in this fraction)	Not reported (non-antimicrobial target)	No (in vitro chemical models)	[66]
ACE and renin inhibitory peptides	Enzymatic hydrolysis	Antihypertensive (ACE and renin inhibition)	ACE IC_{50} 0.29 and 0.31 mM for LGF and GLFF [71] (note: [71] is a leaf-derived peptide used for comparison); [70] did not report IC_{50}, only a 31.85% gain in ACE inhibition for the 5-10 kDa fraction relative to the hydrolysate	No	[70,71]
Antihyperglycemic peptides	Enzymatic hydrolysis	α-Amylase and α-glucosidase inhibition; antiglycation; structural and stability characterization	α-Amylase IC_{50} 0.17-1.31 mg/mL and α-glucosidase IC_{50} 0.46-0.70 mg/mL [73]; pepsin hydrolysate Ki 0.029 and 0.333 mg/mL [75]; MoHpP-2 α-glucosidase IC_{50} 109.65 μM [76]	No	[73,75,76]

Note: Note: MIC, minimum inhibitory concentration; MBC, minimum bactericidal concentration; TMT, tandem mass tag; ACE, angiotensin-converting enzyme; IC_{50}, half-maximal inhibitory concentration; Ki, inhibition constant; Mr, relative molecular mass. Food-matrix validation means an effect demonstrated in a real food system. Not reported means that the source did not report a usable value.

Table S5. Summary of measured minimum inhibitory and bactericidal concentrations for seed-derived actives and comparators.

Active compound (source)	Target	Measured MIC	Measured MBC or other threshold	Evidence system	Reference
MOp2 (seed; enzyme-derived octapeptide HVLDTPLL)	Staphylococcus aureus	2.204 mM, i.e., ≈2.0 mg/mL (converted using Mr ≈ 0.91 kDa)	Not reported	In vitro culture medium	[49]
<3 kDa peptide fraction in which napin was identified (leaf-derived, not seed; comparator row)	Bacterial panel (13 strains in the source; per-strain MIC not reported)	0.5 mg/mL	1.5 mg/mL	In vitro culture medium	[38]
Mo-CBP3 (seed; chitin-binding protein)	Plant pathogenic fungi (Fusarium, Colletotrichum)	Fungicidal from about 0.1 mg/mL	Not reported	In vitro culture medium	[40]
6.7 kDa cationic peptide (seed)	S. typhimurium / S. aureus / Candida albicans	16 / 32 / 32 μg/mL	Not reported	In vitro culture medium	[54]
Moringin (RBITC; seed-derived isothiocyanate, non-peptide comparator)	Bacillus cereus / Cronobacter sakazakii	0.14 / 0.25 mg/mL	Not reported	In vitro and goat milk	[81]
WSMoL (seed lectin)	Enterococcus faecalis; Candida	MIC 15.6 μg/mL (E. faecalis); 20 μg/mL (Candida)	MBC 125 μg/mL (E. faecalis); MFC 20–80 μg/mL (Candida)	In vitro culture medium	[22,52]
Mo-CBP2 (seed; chitin-binding protein)	Candida	MIC50 9.45–37.90 μM; MIC90 155.84–260.29 μM	Not reported	In vitro culture medium	[41]
Mo-CBP4 (seed; chitin-binding protein)	Dermatophytes	45 μM (50% inhibition of microconidia germination)	Not reported	In vitro culture medium and skin infection model	[39]

Note: Note: Mr, relative molecular mass; MIC50 and MIC90, concentrations inhibiting 50% and 90% of growth; MBC, minimum bactericidal concentration; MFC, minimum fungicidal concentration; RBITC, 4-(α-L-rhamnosyloxy)benzyl isothiocyanate (moringin), a seed-derived isothiocyanate. The MIC of MOp2 was reported as a molar concentration, and the value ≈2.0 mg/mL is a conversion using Mr ≈ 0.91 kDa. All values are as measured in the original reports and were not weighted by evidence strength. The isothiocyanate (non-peptide), leaf-derived <3 kDa, and Mo-CBP2/Mo-CBP4 rows are comparators or additional seed proteins and are not included in the seed-derived dose range of Section 10.1 unless stated.

Table S6. Order-of-magnitude comparison between food addition levels required for seed-derived actives and regulatory reference values, with 100 g food equivalents for orientation.

Reference compound	Metric basis	Value	Equivalent in 100 g food	Source
Seed-derived actives (estimate of this review)	Food addition required to reach 1× MIC or threshold	16–2,000 mg/kg	1.6–200 mg	Table S5; Section 10.1

Reference compound	Metric basis	Value	Equivalent in 100 g food	Source
Nisin (E 234)	EU maximum permitted level, Annex II (category-specific; 10 mg/kg in mascarpone)	≈10–12.5 mg/kg	≈1.0–1.25 mg	[121]
Nisin (E 234)	JECFA ADI (reaffirmed 2024; applies to nisin A only)	0–2 mg/kg bw/day	≤140 mg/day (70 kg adult)	[117]
Nisin (E 234)	Upper bound of the JECFA dietary exposure estimate	0.07 mg/kg bw/day	≈4.9 mg/day (70 kg adult)	[117]
Nitrite (E 249/250)	Maximum permitted level in meat products (added amount, expressed as nitrite; category-specific)	150 mg/kg	15 mg	[121]
Sorbates (E 200–203)	Maximum permitted level, Annex II	200–2,000 mg/kg	20–200 mg	[121]
Benzoates (E 210–213)	Maximum permitted level, Annex II (soft drinks 150 mg/L)	150–2,000 mg/kg	15–200 mg	[121]

Note: Note: ADI, acceptable daily intake; bw, body weight; JECFA, Joint FAO/WHO Expert Committee on Food Additives; EFSA, European Food Safety Authority. The table compares orders of magnitude and does not imply toxicological equivalence. Seed-derived peptides have no ADI or no-observed-adverse-effect level (NOAEL), and the nisin ADI serves only as an order-of-magnitude reference. An ADI is expressed per kilogram body weight (different basis from mg/kg food); the equivalent for a 70 kg adult is given. The EFSA group ADIs for sorbates (11 mg/kg bw/day) and benzoates (5 mg/kg bw/day) are EFSA values and are not part of Regulation (EC) No 1333/2008 [121]; the EU maximum permitted levels are category-specific. For nitrite, the value is the maximum permitted level for meat products, expressed on the basis specified in Annex II. The 100 g equivalents are simple arithmetic conversions and are not regulatory exposure assessments.

Table S7. Reporting-completeness assessment of the food-matrix studies in Table S3.

Reference	Food matrix	Target organism named	Dose with unit reported	Endpoint tier
[81]	Goat milk	Yes	Yes (MIC/MBC); applied concentration not stated	Real food
[58]	Pasteurized milk	Yes	Partial (in vitro MIC)	Real food
[59]	Pasteurized milk	Yes	No	Real food
[82]	Cheese	Yes	Yes	Real food
[83]	Fermented milk	No (quality endpoint)	Partial	Real food
[84]	Raw chicken sausage	Yes	Yes	Real food
[85]	Ground beef	Pathogen group	Yes	Real food
[86]	Mutton patties	Microbiological indices	Yes	Real food
[87]	Chicken burgers	Oxidation indices	Yes	Real food
[88]	Goat meat nuggets	Microbiological indices	Yes	Real food
[89]	Beef patties	Oxidation/sensory	Yes	Real food
[90]	Frozen beef burgers	Microbiological indices	Yes	Real food
[91]	Pork patties	Microbiological indices	Yes	Real food
[92]	Minced meat film	Microbiological indices	Partial	Real food
[94]	Mango	Postharvest quality	Yes	Real food
[93]	Mango	Postharvest quality	Yes	Real food
[99]	Avocado	Yes	Yes	Real food + in vitro
[95]	Guava	Postharvest quality	Partial	Real food
[96]	Strawberry	Postharvest quality	Yes	Real food
[97]	Strawberry	Postharvest quality	Partial	Real food
[98]	Date palm	Postharvest quality	Yes	Real food
[100]	Apple	Yes	Yes	Real food
[62]	Tomato (seed coating)	Yes	Yes	Real plant (not food)
[101]	White chocolate	No (quality)	Yes	Real food

Note: This assessment records whether the target organism and a dose with a unit are stated in the extracted record; it is not a risk-of-bias score. Randomization, blinding, and replication were not systematically reported and are not scored.

Table S8. Source data for Figures 2 and 4.

(a) Figure 2: food-matrix entries by matrix and endpoint.

Food matrix	Entries	Endpoint total
Dairy	5	13 antimicrobial
Meat and meat products	9	10 quality/oxidative
Aquatic and egg products	0	23 total
Fruits and vegetables	8	
Fats and fatty foods	1	
Cereals and baking	0	
Total	23	

(b) Figure 4: measured potency and converted food-addition levels.

Analyte	Measured potency	Converted level	Reference
6.7 kDa peptide	16–32 μg/mL	16–32 mg/kg	[54]
WSMoL	15.6–20 μg/mL	15.6–20 mg/kg	[22,52]
Mo-CBP3	100 μg/mL	100 mg/kg	[40]
Moringin (RBITC)	140–250 μg/mL	140–250 mg/kg	[81]
<3 kDa fraction (leaf)	500–1,500 μg/mL (MIC–MBC)	500–1,500 mg/kg	[38]
MOp2	2,000 μg/mL (2.204 mM)	2,000 mg/kg	[49]
Nisin (E 234), EU limit	—	≈10–12.5 mg/kg	[121]
Nisin (E 234), ADI	—	0–2 mg/kg bw/day; ≤140 mg/day (70 kg)	[117]
Nitrite (E 249/250), EU limit	—	150 mg/kg	[121]
Sorbates (E 200–203), EU limit	—	200–2,000 mg/kg	[121]

Note: Conversions assume 1 kg food, 1× MIC, and a partition coefficient of 1 (Section 10.1). They are lower-bound order-of-magnitude estimates, not formulation doses.