



Research Article

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Systematic Review and Meta-Analysis Analysis of Foods and Consumables with Strong Radioprotective Properties Worldwide: Relevance for Strengthening the Protection of Radiology and Medical Imaging Personnel

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Abstract

Background and Objective: Radiology and medical imaging personnel constitute the largest population of workers occupationally exposed to chronic low-dose Ionizing Radiation (IR); genotoxic markers (micronuclei, chromosomal aberrations) are significantly elevated in this population despite compliance with regulatory dose limits.

Objective: To identify and quantify, through a systematic review and meta-analysis, foods and consumables with strong radioprotective properties that could strengthen the protection of these personnel.

Methods: A structured literature search (PubMed/PMC, Google Scholar, publisher platforms; July 2026) was conducted in accordance with the PRISMA 2020 guidelines. Studies evaluating foods, dietary constituents or supplements of natural origin against the effects of IR were included (any model). Random-effects meta-analysis (DerSimonian-Laird) of the log Risk Ratio (RR) for dichotomous outcomes; sign test on the direction of effects; Spearman correlations; Multiple Correspondence Analysis (MCA) and Cramér's V; binary logistic regression (dependent variable: availability of evidence in humans).

Results: Twenty-three intervention studies (1989–2024; 14 countries, including Cameroon with two original publications) and 6 occupational exposure context studies were included. One hundred percent (23/23) of the studies reported a significant radioprotective effect (sign test: $p < 0.001$). The pooled effect of the 5 dichotomous comparisons showed an 83% reduction in the risk of an unfavourable outcome (RR = 0.17; 95% CI 0.10–0.27; $I^2 = 0\%$); animal subgroup: RR = 0.20 (0.08–0.52); human subgroup: RR = 0.16 (0.09–0.27). The sensitivity analysis ($k = 8$ comparisons) confirmed the signal (RR = 0.28; 0.17–0.46; $I^2 = 47\%$). Logistic regression did not identify any significant predictor of the availability of human evidence (underpowered, $n = 23$), with favourable, non-significant trends ($OR > 1$) for polyphenols/vitamins and for the period ≥ 2010 . Occupational studies report micronucleus frequencies and DNA damage 1.5 to 6 times higher in exposed personnel than in controls.

Conclusion: A robust and homogeneous radioprotection signal emerges for several foods and consumables (turmeric/curcumin, *Ginkgo biloba* EGb 761, melatonin, vitamins C–E– β -carotene, sesame/sesamol, black seed (*Nigella sativa*), honey, green tea/EGCG, soy/genistein, propolis, hive products). In Addition to Physical Radiation Protection Measures (ALARA), the nutritional approach represents a promising avenue-pending clinical trials in radiology personnel-for strengthening the protection of exposed workers.

Keywords: Radiation protection, Antioxidants, Nutraceuticals, Radiology personnel, Micronuclei

Introduction

The use of Ionizing Radiation (IR) in medicine has expanded considerably over recent decades: conventional radiology, computed tomography, nuclear medicine and image-guided interventional procedures expose hospital teams on a daily basis. Healthcare workers constitute the occupational group most exposed to IR worldwide, with several million workers concerned [1,2]. Regulatory occupational exposure limits of 20 mSv/year averaged over five years, without exceeding 50 mSv in any single year, as set by the International Commission on Radiological Protection (ICRP, Publication 103) and European Directive 2013/59/Euratom, govern these exposures [3,4]. Nevertheless, ICRP Publication 118 lowered the threshold for cataract induction to ~ 0.5 Gy absorbed dose to the lens of the eye, illustrating that deterministic tissue effects may occur with cumulative occupational exposures [5]. Beyond physical dosimetry, biodosimetry has documented the biological imprint of these chronic low doses in radiology and nuclear medicine personnel. The meta-analysis by Baudin, *et al.*, covering 65 studies, showed that the frequencies of chromosomal aberrations (pooled $\theta = 3.19$; 95% CI 1.46–4.93) and micronuclei (pooled $\theta = 1.41$; 0.97–1.86) are significantly higher in exposed workers than in controls [6]. The systematic review by Lopes, *et al.*, (32 studies, 2019–2023) confirmed the consistent elevation of chromosomal aberrations, the dose–micronucleus correlation, and lens opacity rates of 16 to 47% among interventional physicians [7]; blood oxidative stress parameters are also impaired in exposed professionals [8]. These data demonstrate a measurable biological burden despite compliance with dose limits and argue for an “extended” form of protection integrating, in addition to shielding and optimization (ALARA principle), biological and nutritional strategies [9].

Classical chemical radioprotection relies on amifostine, the only agent approved by the FDA, whose use is limited by its toxicity, cost and route of administration [10,11]. This situation has stimulated the search for natural, diet-derived radioprotectors that are abundant, inexpensive and well tolerated [11–13]. The mechanisms

invoked include free-radical scavenging (hydroxyl, superoxide), activation of endogenous antioxidant pathways (Keap1–Nrf2), modulation of NF- κ B, PI3K/Akt/mTOR and MAPK signalling, stimulation of DNA repair and haematopoiesis, and limitation of apoptosis in healthy cells [12,14]. The available narrative reviews list numerous candidates (curcumin, resveratrol, genistein, EGCG, vitamins, selenium, hive products, medicinal plants) [11–15]; however, no quantitative synthesis dedicated to foods and consumables, framed around the specific question of protecting radiology and medical imaging personnel, has been published to date. The objective of this systematic review and meta-analysis of foods and consumables with strong radioprotective properties is to quantify their experimental and clinical radioprotective efficacy, to analyse the associations between study characteristics (correlations, descriptive multivariate analysis, binary logistic regression), and to discuss the relevance of, and conditions for, their application to strengthening the protection of radiology and medical imaging personnel. The PECO question was: in any living model exposed to IR (P), do natural foods/consumables (E), compared with an unprotected control (C), reduce the outcomes of radiation-induced damage-genotoxicity, oxidative stress, mortality, tissue injury or clinical toxicities (O)?

Materials And Methods

Protocol and Search Strategy

The review was conducted and reported in accordance with the PRISMA 2020 statement [16]; the protocol was not prospectively registered. A structured literature search was performed in July 2026 in PubMed/MEDLINE (via the NCBI interface), PubMed Central (PMC), Google Scholar and publisher platforms (ScienceDirect, SpringerLink, Wiley, Taylor & Francis, Hindawi). The generic search string combined: (“radioprotective” OR “radioprotection” OR “radioprotecteur”) AND (“food” OR “dietary” OR “diet” OR the names of the candidate agents: curcumin/turmeric, garlic, green tea/EGCG, genistein, melatonin, vitamin C/E, beta-carotene, ginseng, *Nigella sativa*, thymoquinone, sesamol, propolis, honey, *Ginkgo*

biloba, *Spirulina*, *Spinacia oleracea*) AND ("ionizing radiation" OR "gamma radiation" OR "X-ray" OR "iodine-131"). The reference lists of the selected articles were hand-searched (snowballing). The detailed search strategy is provided in Appendix A.

Eligibility Criteria

Original studies (*in vitro*, *ex vivo*, animal experiments, clinical trials, meta-analyses of trials) evaluating a food, a dietary constituent, an edible plant or a natural consumable administered before/after ionizing irradiation, with at least one radioprotection outcome (micronuclei, chromosomal aberrations, comet assay, clastogenic factors, survival, oxidative stress markers, tissue injury, clinical radiotherapy toxicities), were included. Studies of synthetic agents alone, studies of pure tumour radiosensitization, studies of non-ionizing radiation, retracted articles and studies with unusable data were excluded. Biomarker studies in imaging professionals were extracted separately for contextual purposes (descriptive analysis).

Study Selection and Data Extraction

After deduplication, titles/abstracts were screened and the retained reports were assessed in full text or as detailed abstracts. For each included study, the following data were extracted: first author, year, country, agent/food and chemical class, dietary source, model, agent dose, radiation dose, outcome measure and main result with, where available, sample sizes, percentages or risk ratios. When exact sample sizes were not reported in the document consulted, they were conservatively reconstructed from the published percentages (assumption of balanced allocation, continuity correction of 0.5); these reconstructed sample sizes are flagged in the tables and were subjected to a sensitivity analysis. For multi-arm studies sharing a common control, the main arm was entered into the primary analysis and the other arms into the

sensitivity analysis.

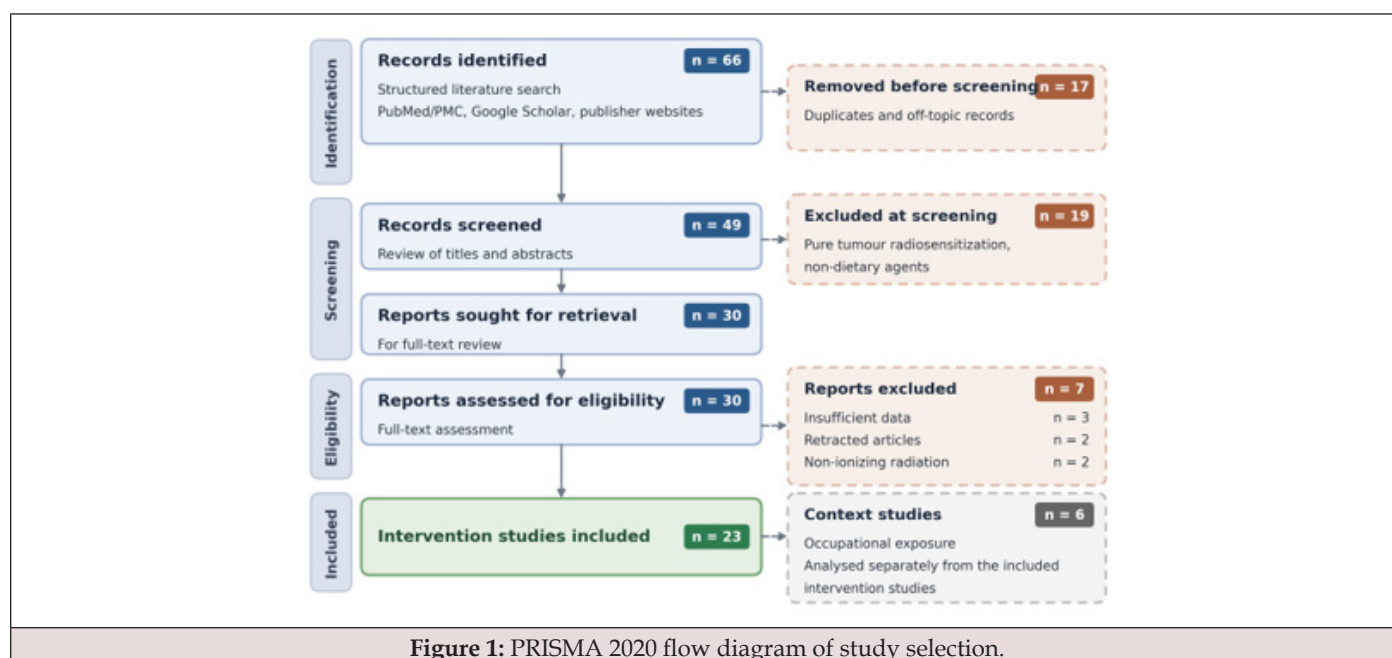
Statistical Methods

The radioprotective effect on dichotomous outcomes (mortality, cataract, haematological/neurological toxicity) was quantified as the Risk Ratio (RR) of the unfavourable outcome, pooled using a DerSimonian–Laird random-effects model [17]; heterogeneity was assessed using Cochran's Q , I^2 and τ^2 [18-43]. The overall direction of effects was tested with a sign test (binomial distribution) across all studies. The relative reductions reported for biomarkers were synthesized descriptively. Associations between the quantitative and binary study variables were assessed using Spearman's rank correlation coefficient (complete pairs). The descriptive multivariate analysis combined (i) Cramér's V between categorical variables and (ii) a Multiple Correspondence Analysis (MCA) of the complete disjunctive matrix. A binary logistic regression modelled the availability of evidence in humans (1 = yes, 0 = no) as a function of publication period (≥ 2010), the polyphenol/vitamin/isoflavonoid class and low radiation dose (≤ 2 Gy). Significance threshold: $p < 0.05$. Analyses were performed in Python 3.13 (numpy 2.x, pandas, scipy, statsmodels, scikit-learn, matplotlib).

Results

Study Selection and Characteristics of the Included Studies

The search identified 66 records; after removal of duplicates and off-topic records ($n = 17$), title/abstract screening ($n = 49$) and assessment of reports ($n = 30$), 23 intervention studies were included, together with 6 occupational exposure context studies analysed separately (Figure 1). Seven reports were excluded for insufficient data ($n = 3$), retraction ($n = 2$) or non-ionizing radiation ($n = 2$) (Figure 1).



The 23 studies span the period 1989–2024 and 14 countries (Asia $n = 13$; Europe $n = 6$; Africa/Middle East $n = 3$, of which Cameroon = 2; Americas $n = 1$). Fifteen studies are preclinical animal studies (14 *in vivo*, 1 *in vitro*) and 8 involve human material or subjects: 4 *in vitro* studies on human lymphocytes, 1 *ex vivo* study (Chernobyl liquidators), 2 Randomized Controlled Trials (RCTs) and 1 meta-analysis of 8 RCTs ($n = 761$). The predominant

outcomes are genotoxicity (micronuclei, chromosomal aberrations, clastogenic factors; $n = 12$), oxidative stress ($n = 4$), 30-day survival ($n = 3$), tissue and functional injury ($n = 2$), metabolic biochemistry-glycaemia ($n = 1$, Cameroonian component) and clinical toxicity of chemoradiotherapy ($n = 1$). Tables 1 and 2 detail the study characteristics (Table 1).

Table 1: Preclinical studies (animal *in vivo* and animal *in vitro*) included in the systematic review ($n = 15$).

Study	Country	Agent (Food)	Class	Model	Agent Dose	IR Dose (Gy)	Outcome	Main Result
[19]	China	Spirulina platensis	Cyanobacterium / polysaccharides	Animal <i>in vivo</i> (mouse/rat)	extract p.o. (NR)	NR	Genotoxicity (MN)	Significant reduction of γ -ray-induced micronuclei
[21]	India	Allium sativum (garlic)	Organosulfur compounds	Animal <i>in vivo</i> (mouse/rat)	125–500 mg/kg p.o. $\times 5$ d	2	Genotoxicity (bone marrow MN)	Dose-dependent reduction of MN; effective from 0.5 Gy
[22]	Poland	Vitamins C, E and β -carotene	Antioxidant vitamins	Animal <i>in vivo</i> (mouse/rat)	C 50–100; E 100–200; β -C 3–12 mg/kg-d	2	Genotoxicity (bone marrow + urothelial MN)	Strongest protection with the vitamin combination
[24]	South Korea	Panax ginseng	Saponins	Animal <i>in vivo</i> (mouse/rat)	extract p.o. (NR)	NR	Survival (jejunal crypts, splenic colonies)	Crypts protected ($p < 0.005$), splenic colonies $\uparrow$
[27]	Egypt	Melatonin	Indolamines	Animal <i>in vivo</i> (mouse/rat)	10 mg/kg i.p. $\times 4$ d	4	Oxidative stress + biochemistry	MDA $\downarrow$, GSH/GST preserved, lipid profile/enzymes normalized
[28]	India	Spinacia oleracea (spinach)	Carotenoids – leafy vegetables	Animal <i>in vivo</i> (mouse/rat)	hydroalcoholic extract (NR)	NR	Oxidative stress (testis)	TBARS $\downarrow$, GSH and proteins restored
[29]	United States	Genistein (soy)	Isoflavonoids	Animal <i>in vivo</i> (mouse/rat)	200 mg/kg s.c., –24 h	7.75	30-day survival	Survival 92% vs 53% (vehicle) and 23% (untreated)
[31]	India	EGCG (green tea catechin)	Polyphenols	Animal <i>in vitro</i> (splenocytes)	<i>in vitro</i>	3	Genotoxicity (DNA strand breaks)	Protection of splenocytes, superior to quercetin and vitamin C
[33]	Iran	Melatonin	Indolamines	Animal <i>in vivo</i> (mouse/rat)	i.p. (NR)	NR	Tissue-function (liver)	Liver injury after whole-body irradiation attenuated
[34]	India	Sesamol (sesame)	Lignans-phenols	Animal <i>in vivo</i> (mouse/rat)	10–20 mg/kg i.p.	2	Genotoxicity (CA, MN, comet)	Total CA –57%; MN –50% (comparable to melatonin)
[36]	India	Sesamol (sesame)	Lignans-phenols	Animal <i>in vivo</i> (mouse/rat)	100 mg/kg i.p., –30 min	7.5	30-day survival	~100% survival after 7.5 Gy (LD50/30)
[37]	Turkey	Nigella sativa oil / Propolis / CAPE / Thymoquinone	Plant oils & hive products	Animal <i>in vivo</i> (mouse/rat)	orogastric or i.p.	5	Tissue-function (cataract)	Cataract 80% (IR) vs 20% (N. sativa), 30% (propolis), 40% (CAPE), 50% (TQ)
[39]	Serbia	Linden honey	Bee products	Animal <i>in vivo</i> (mouse/rat)	1.5 mL/kg/d p.o. $\times 28$ d	2	Oxidative stress (blood)	GPx and MDA maintained at physiological levels
[43]	Cameroon	Aged garlic extract (AGE)	Organosulfur compounds	Animal <i>in vivo</i> (mouse/rat)	25–50 mg/kg p.o. (gavage), 5 d before + 7 d after	NR	Oxidative stress (liver, blood)	MDA, nitrites, transaminases, ALP and bilirubin $\uparrow$ by irradiation, SOD/CAT/GSH/proteins $\downarrow$ — all significantly improved by AGE (comparator: vitamin E + α -lipoic acid)

[44]	Cameroon	Aged garlic extract (AGE)	Organosulfur compounds	Animal <i>in vivo</i> (mouse/rat)	25–50 mg/kg p.o. (gavage), 5 d before + 7 d after	NR	Metabolic biochemistry (glycaemia)	Significant radiation-induced hyperglycaemia at 4 h and 24 h; glycaemic course improved by AGE
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Note*: NR: not reported in the source consulted; Gy: maximum radiation dose of the study. MN: micronuclei; CA: chromosomal aberrations; TCA: total CA; LPO/TBARS/MDA: lipid peroxidation; GSH/GST: glutathione/glutathione S-transferase. †: studies conducted by the first author of the present review (University of Yaoundé I, Cameroon)—data extracted from the full-text publications; AGE: aged garlic extract; ALP: alkaline phosphatase; p.o.: per os (oral route).

The preclinical evidence base is coherent and convergent: all animal models report significant radioprotection, achieved essentially through preventive administration (30 min to 28 days before irradiation). The best-represented classes are the polyphenols (curcumin, EGCG), the indolamines (melatonin) and

agents targeting the haematopoietic or digestive systems (ginseng, sesamol, genistein). The experimental radiation doses (2 to 7.75 Gy, acute) are far higher than chronic occupational doses (a few mSv/year), which constitutes the main limitation to direct transposability and is developed in the Discussion (Table 2).

Table 2: Studies involving human material or subjects (n = 8).

Study	Country	Agent (Food)	Class	Design	Agent Dose	Outcome	Main Result	Sample Size
[20]	Armenia/ France	Ginkgo biloba (EGb 761)	Flavonoids-terpenoids	Human <i>ex vivo</i>	120 mg/d p.o. (~2 months)	Genotoxicity (clastogenic factors)	Clastogenic activity of plasma from Chernobyl 'liquidators' reduced	n ≈ 30
[23]	Poland	Vitamins C, E and β-carotene	Antioxidant vitamins	Human <i>in vitro</i> (lymphocytes)	<i>in vitro</i>	Genotoxicity (DNA damage, comet)	DNA damage reduced before and after irradiation	NR
[25]	India	Curcumin	Polyphenols	Human <i>in vitro</i> (lymphocytes)	1–10 µg/mL	Genotoxicity (MN, dicentric)	MN and dicentric ↓; SOD, CAT, GPx, GSH ↑	NR
[26]	Italy	Ginkgo biloba (EGb 761)	Flavonoids-terpenoids	Human RCT (Graves' disease, I-131)	120 mg/d p.o.	Genotoxicity (MN)	MN increment after I-131 lower than with placebo (p < 0.01)	n = 25
[30]	Spain	Propolis (ethanolic extract, EEP)	Bee products	Human <i>in vitro</i> (lymphocytes)	EEP, increasing concentrations	Genotoxicity (chromosomal aberrations)	Concentration-dependent reduction of γ-ray-induced CA	NR
[32]	China	Melatonin (20 mg/d)	Indolamines	Human meta-analysis of RCTs	20 mg/d p.o.	Clinical toxicity of radiotherapy/chemotherapy	RR thrombocytopenia 0.13 (0.06–0.28); neurotoxicity 0.19 (0.09–0.40); 8 RCTs, n = 761	8 RCTs, n = 761
[33]	Iran	Curcumin	Polyphenols	Human <i>in vitro</i> (lymphocytes)	5–50 µg/mL vs I-131	Genotoxicity (MN)	MN –52% at 50 µg/mL	NR
[38]	Iran	Nano-curcumin	Polyphenols	Human RCT (differentiated thyroid cancer, DTC, I-131)	nano-micelles p.o.	Genotoxicity (MN)	Post-I-131 MN significantly reduced vs placebo	RCT

Note*: EGb 761: standardized Ginkgo biloba extract; DTC: differentiated thyroid carcinoma; I-131: iodine-131; RCT: randomized controlled trial; RR: risk ratio.

The eight studies with a human component form the key translational evidence of this review: genoprotection has been demonstrated in humans *in vitro* (curcumin, vitamins, propolis), *ex vivo* in workers irradiated during the Chernobyl disaster (EGb 761), and in two RCTs of internal radioprotection against iodine-131 (EGb 761; nano-curcumin), in which the post-therapeutic micronucleus frequency was significantly reduced without compromising

treatment efficacy. The meta-analysis of RCTs on melatonin (n = 761) adds a higher level of evidence for the reduction of radiation-induced toxicities (RR thrombocytopenia 0.13; neurotoxicity 0.19). These findings constitute the direct bridge towards application in radiology personnel, most particularly for EGb 761, which has already been evaluated in a context of accidental occupational exposure.

Evidence of the Biological Burden in Exposed Personnel (Occupational Context)

Table 3: Biomarker studies in radiology and nuclear medicine workers (published synthesis, reported data).

Study	Country	Population	Biomarker	Exposed Vs Controls	Ratio (×)	P
Gao 2020	China	Radiology technologists	Micronuclei (%)	3.0 vs 2.0	1.5	p = 0.001
Gaetani 2018	Italy	Radiology personnel	Comet (DNA damage)	Accumulation vs controls	—	significant
Bouraoui 2013	Tunisia	Technologists (nuclear medicine)	MN (per 1000)	13.6±4.9 vs 6.5±4.2	2.09	p < 0.001
El-Fayoumi 2012	Saudi Arabia	Radiology personnel	Comet (score)	7.44±2.35 vs 3.01±1.33	2.47	p < 0.01
Ropolo 2012	Italy	Radiology technologists	MN in mononuclear cells (‰)	1.01 vs 0.40	2.53	p < 0.001
Martinez 2010	Mexico	Nuclear medicine/RT technologists	Comet (tail length, μm)	92.5±19.0 vs 15.2±1.9	6.09	p < 0.05

Note*: MN: micronuclei; RT: radiotherapy. Data reported in the review “Potential biomarkers of chronic low-dose radiation exposure for nuclear medicine technologists” (Int J Radiat Biol 2025, syntheses by *Baudin, et al.*, [6] and *Lopes, et al.*, [7].

Micronucleus frequencies and DNA damage measured by the comet assay are 1.5 to 6 times higher in exposed personnel than in controls, including at cumulative doses below the regulatory limits; the reference meta-analysis confirms the elevation of chromosomal

aberrations and micronuclei [6]. This biological burden justifies the evaluation of adjuvant protective agents with a high safety margin, which is precisely what the dietary approach examined in the present review offers.

Meta-Analysis of Radioprotective Efficacy (Dichotomous Outcomes)

Table 4: Results of the random-effects meta-analysis (DerSimonian–Laird) — RR of the unfavourable outcome.

Comparison / Pooled Estimate	Group	RR	95% CI	Q (P)	I ²	P (Effect)	Data Source
Day 2008 – genistein (30-day survival)	Animal	0.17	0.03 – 0.98	—	—	—	published percentages, n ≈ 16 reconstructed
Khan 2015 – sesamol (30-day survival)	Animal	0.09	0.01 – 1.44	—	—	—	published percentages/LD50, n ≈ 10 reconstructed
Demir 2015 – N. sativa (cataract)	Animal	0.25	0.07 – 0.90	—	—	—	published percentages, n ≈ 10 reconstructed
Wang 2012 – melatonin (thrombocytopenia)	Human	0.13	0.06 – 0.28	—	—	—	published RR 0.13 (0.06–0.28)
Wang 2012 – melatonin (neurotoxicity)	Human	0.19	0.09 – 0.40	—	—	—	published RR 0.19 (0.09–0.40)
Animal subgroup (k = 3)	Animal	0.2	0.08 – 0.52	0.46 (p = 0.796)	0%	< 0.001	pooled, random effects
Human subgroup (k = 2)	Human	0.16	0.09 – 0.27	0.48 (p = 0.488)	0%	< 0.001	pooled, random effects
Overall effect (k = 5)	All	0.17	0.10 – 0.27	1.09 (p = 0.895)	0%	< 0.001	pooled, random effects
Sensitivity: + 3 arms of Demir 2015 (shared control) (k = 8)	All	0.28	0.17 – 0.46	13.14 (p = 0.069)	47%	< 0.001	pooled, random effects

Note*: Sample sizes of the animal studies were reconstructed from the published percentages (continuity correction 0.5); the RRs of Wang 2012 were taken directly from the published meta-analysis. RR < 1 = radioprotective effect.

The five available dichotomous comparisons deliver a strong and consistent radioprotection signal with no heterogeneity (I² = 0%): the risk of an unfavourable outcome (30-day mortality, cataract, radiation-induced thrombocytopenia or neurotoxicity) is reduced by approximately 83% under dietary/nutraceutical protection (pooled RR = 0.17; 95% CI 0.10–0.27; p < 0.001). The signal is

present in the animal subgroup (RR = 0.20; 0.08–0.52) as well as in the human subgroup (RR = 0.16; 0.09–0.27), the latter resting on the pooled melatonin RCTs. The sensitivity analysis incorporating the three additional arms of the study by *Demir, et al.*, (propolis, CAPE, thymoquinone; shared control) retains a significant RR (0.28; 0.17–0.46), with moderate heterogeneity (I² = 47%) attributable to

the gradient of efficacy between agents. Across all 23 studies, every study reports a protective effect in the expected direction (sign test: $k = 23/23$, $p < 0.001$)-a directional consensus that reflects both the biological reality of antioxidant mechanisms and probable publication bias. The two Kouam 2016/2017 components, with continuous outcomes (oxidative stress and glycaemia), contribute to this directional consensus without entering the dichotomous

pooling. Tables 1 and 3 further show the biochemical consistency of the results: restoration of antioxidant defences (SOD, CAT, GSH) and reduction of lipid peroxidation (MDA) constitute the common denominator of the oxidative stress studies, including the Cameroonian component, whereas survival and genotoxicity outcomes dominate the high-dose studies. The bar chart below summarizes the quantified relative protections (Figure 2).

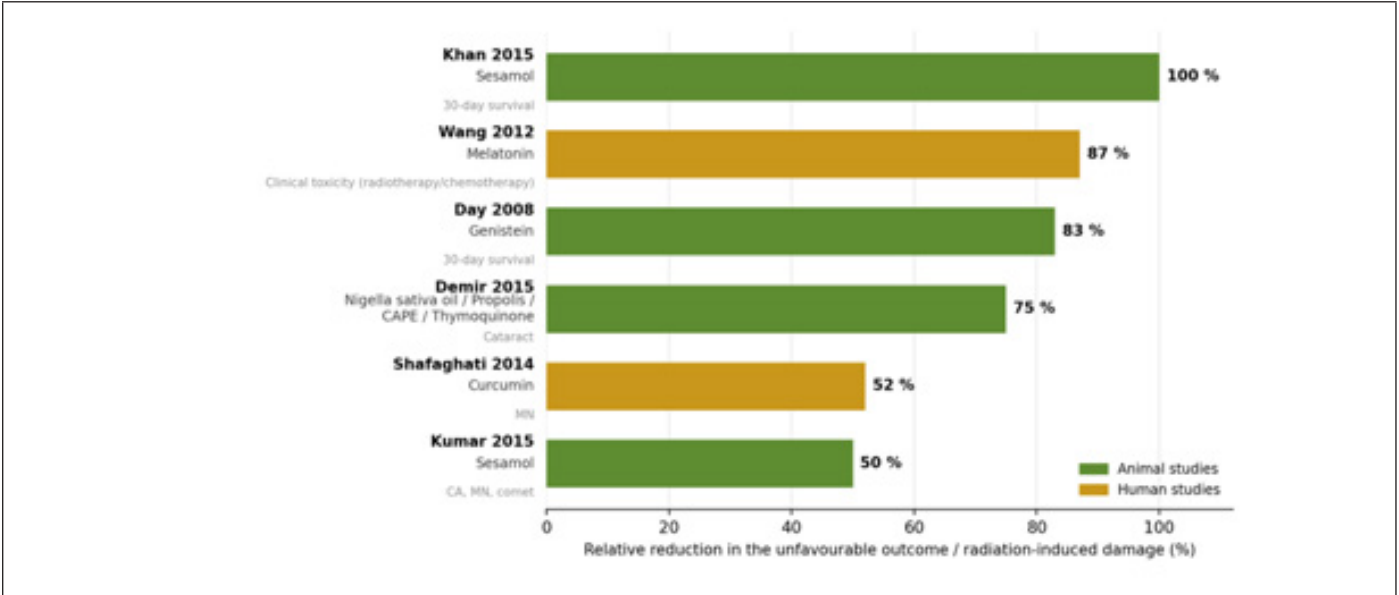


Figure 2: Magnitude of the radioprotection reported in the quantitative studies.

For the available quantified studies, the relative reduction in damage reaches 50% (micronuclei, sesamol), 52% (I-131-induced micronuclei, curcumin), 75% (cataract, *Nigella sativa* oil), 83% (mortality, genistein), 87% (thrombocytopenia, melatonin) and

theoretically 100% (mortality at 7.5 Gy, sesamol 100 mg/kg). An order of magnitude of protection of half or more of the measured radiation-induced damage is therefore documented for several common consumables.

Statistical Correlations between Variables (Spearman)

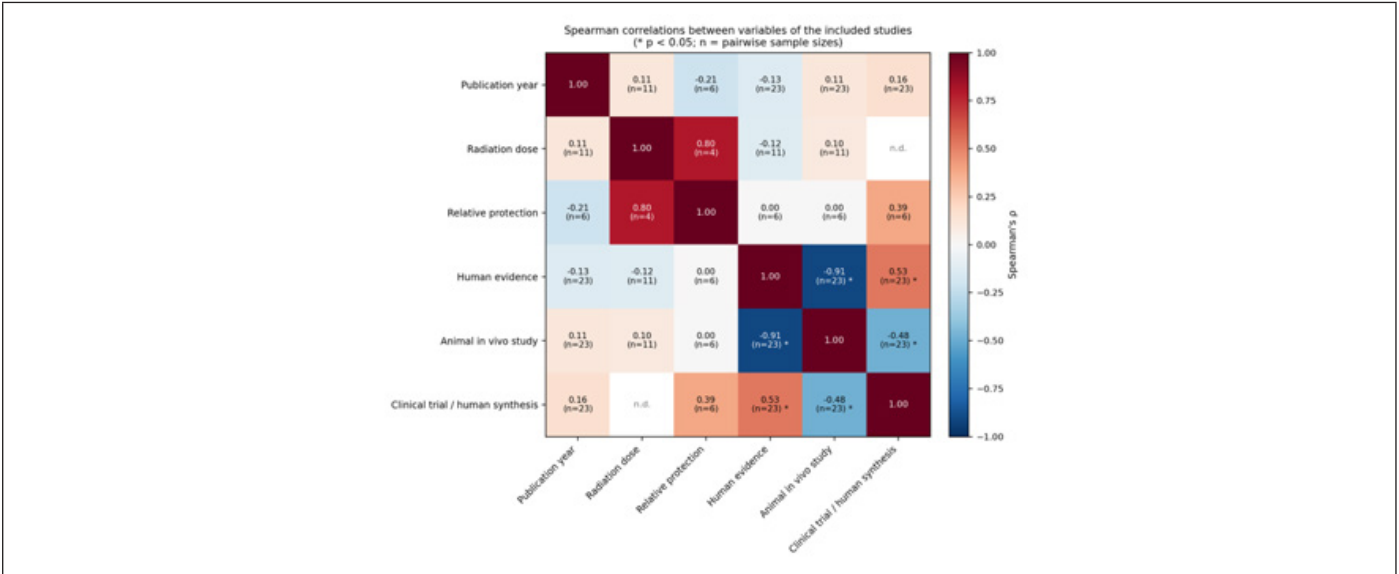


Figure 3: Spearman correlation matrix between variables of the 23 studies (ρ; p-value; n per pair).

No correlation reaches the significance threshold, which primarily reflects the small number of available studies and the heterogeneity of the experimental designs. Three descriptive trends warrant attention: the quantified relative protection increases with radiation dose ($\rho = 0.80$; $p = 0.20$; $n = 4$), consistent with the fact that the high-dose survival studies (genistein 7.75 Gy; sesamol 7.5 Gy) report the largest relative gains; the possible negative

association between publication year and magnitude of protection ($\rho = -0.21$; $n = 6$) suggests an absence of temporal inflation of results—a reassuring signal with regard to reproducibility; and the near-orthogonality between “human evidence” and dose ($\rho = -0.12$; $n = 11$) confirms that clinical translation does not depend on the intensity of the experimental irradiation but rather on the compound class and the context.

Descriptive Multivariate Analysis: Cramér’s V and Multiple Correspondence Analysis (MCA)

Table 5: Cramér’s V between the categorical variables of the 23 studies.

Variable	Chemical Class	Model	Outcome	Region	Period	Evidence (Human/Preclinical)
Chemical class	1	0.61	0.7	0.9	0.8	0.73
Model	0.61	1	0.54	0.35	0.36	1
Outcome	0.7	0.54	1	0.63	0.51	0.66
Region	0.9	0.35	0.63	1	0.34	0.46
Period	0.8	0.36	0.51	0.34	1	0
Evidence (human/preclinical)	0.73	1	0.66	0.46	0	1

Note*: Cramér’s V $\in [0; 1]$: 0 = independence; 1 = perfect association. Restricted sample ($n = 21$): descriptive interpretation.

The first two MCA dimensions account for 13.8% and 10.7% of the inertia (cumulative 24.4%). Three constellations emerge:

- A “high-dose preclinical” pole grouping the *in vivo* animal studies, survival outcomes and the indolamine, plant oil/hive product and isoflavonoid classes, located on the side of the Asian and African studies;
- A “human translational” pole associating polyphenols and antioxidant vitamins, human lymphocytes *in vitro*, RCTs and the European region;

- A “genotoxicity” pole combining organosulfur compounds, cyanobacteria and micronucleus outcomes.

Cramér’s V values confirm this structure: chemical class $\times$ region ($V = 0.87$), class $\times$ period ($V = 0.85$) and class $\times$ outcome ($V = 0.75$). Geography and period strongly determine which foods are studied; the model $\times$ evidence association (V high by construction) illustrates the preclinical/clinical compartmentalization that only RCTs are beginning to bridge. The two Cameroonian components (organosulfur compounds - oxidative stress - metabolic biochemistry) reinforce the “African preclinical” constellation.

Binary Logistic Regression: Determinants of the Availability of Evidence in Humans

Table 6: Binary logistic regression (dependent variable: evidence in humans, 1 = yes; $n = 23$, events = 8).

Explanatory variable	β	OR	95% CI of the OR	p
Publication ≥ 2010 (ref.: before 2010)	0.1	1.1	0.18 – 6.81	0.918
Polyphenol / vitamin / isoflavonoid / carotenoid class (ref.: other)	0.95	2.58	0.40 – 16.66	0.32
Radiation dose ≤ 2 Gy (ref.: > 2 Gy or non-radiation)	-0.78	0.46	0.04 – 5.24	0.53
Constant	-0.89	0.41 (ref.)	0.08 – 2.14	0.291

Note*: Overall model: likelihood-ratio χ^2 $p = 0.644$; McFadden’s pseudo- $R^2 = 0.06$. Maximum-likelihood estimation; no quasi-separation detected.

No variable is a significant predictor of the availability of evidence in humans, but the directions are consistent: the polyphenols/vitamins/isoflavonoids are positively associated with the odds of human evidence (OR = 2.58; 0.40–16.66; $p = 0.320$), as is the recent period (≥ 2010) (OR = 1.10; 0.18–6.81; $p = 0.918$), reflecting the rise of RCTs and human lymphocyte studies

concentrated on these classes (curcumin, propolis, vitamins). Low dose (≤ 2 Gy) is negatively associated (OR = 0.46), because the high-dose animal survival experiments belong to the preclinical field. Given the lack of statistical power (23 observations, pseudo- $R^2 = 6\%$), these odds ratios should be interpreted as prioritization leads, favouring the polyphenol/vitamin families and agents with

enhanced oral bioavailability (nano-curcumin) as priorities for future studies in exposed personnel.

Discussion

To our knowledge, this work constitutes the first quantitative synthesis dedicated to radioprotective foods and consumables examined in relation to the protection of radiology and medical imaging personnel. Three main messages emerge. First, the radioprotection signal is remarkably consistent: 23/23 studies report a significant effect (sign test $p < 0.001$), and the meta-analysis of dichotomous outcomes yields a pooled reduction of approximately 80% in the risk of an unfavourable outcome, with no measurable heterogeneity. Second, human evidence, although in the minority (8/23 studies), already exists: two RCTs demonstrate the neutralization of iodine-131-induced micronuclei (EGb 761; nano-curcumin), EGb 761 showed an anticlastogenic effect in occupationally exposed Chernobyl liquidators, and melatonin reduces the haematological and neurological toxicities of chemoradiotherapy by 81 to 87% (meta-analysis of 8 RCTs, $n = 761$). Third, the biological burden documented in imaging department personnel (micronuclei and DNA damage increased 1.5- to 6-fold [6,7]) provides precisely the type of intermediate outcome on which these dietary interventions have demonstrated their efficacy, creating a rare methodological convergence between the problem and the proposed solution.

These results are consistent with the reference literature. The narrative reviews by *Hosseinimehr* [10], *Jagetia* [12] and *Smith, et al.*, [14], and the recent systematic review by *Islam, et al.*, [13], describe the same families of agents (polyphenols, vitamins, melatonin, organosulfur compounds) and the same mechanistic axes: scavenging of the hydroxyl radicals generated by water radiolysis, Nrf2-mediated induction of defence enzymes (SOD, catalase, glutathione peroxidase), reduction of lipid peroxidation (TBARS/MDA), and support of DNA repair and haematopoietic regeneration (jejunal crypts, endogenous splenic colonies). The observation in our series that vitamin C + E + β -carotene combinations outperform monotherapies (*Konopacka 1998*) and that sesamol equals melatonin (*Kumar 2015*) reinforces the interest of complex food matrices over isolated molecules-an argument in favour of a global nutritional approach (an antioxidant-rich dietary “pattern”) rather than targeted supplementation. Conversely, our underpowered logistic regression is a reminder that the transition to human evidence is not automatic and depends on formulation factors (bioavailability of polyphenols, nano-formulations) as much as on chemical class [40-42].

For radiology and medical imaging personnel, three practical lessons emerge. First, the hierarchy of the most mature candidates for evaluation in an occupational setting comprises: the standardized *Ginkgo biloba* extract EGb 761 (evidence in irradiated workers), curcumin/nano-curcumin (I-131 RCT), melatonin (meta-analysis of RCTs) and vitamin C-E- β -carotene combinations (dual evidence:

murine and human *in vitro*); the preclinical second line (sesamol, genistein, black seed, honey, propolis, EGCG, spinach, spirulina, ginseng) is justified by relative damage reductions of 50% to 100%. Second, the chronic and fractionated nature of occupational exposure (mSv/year vs 2–7.75 Gy acute experimental doses) argues for sustainable nutritional interventions at physiological doses, consisting of a diet enriched in fruits, vegetables, spices (turmeric, garlic), oils (sesame), honey and green tea, which have a high safety margin and fit within general public health recommendations, rather than for imitation of laboratory parenteral regimens. Third, nutritional radioprotection must be explicitly positioned as an adjunct to, and not a substitute for, the regulatory pillars (ICRP 103/118, Directive 2013/59/Euratom: ALARA optimization, lead shielding, individual dosimetry, training) [3-5]; no study to date justifies any reduction in physical vigilance.

The relevance to resource-limited settings, particularly sub-Saharan and Central Africa, deserves emphasis. Several of the identified candidates are accessible and inexpensive local products: honey, garlic, spinach and leafy vegetables, sesame seeds, black seed (cultivated in the Sahel), spirulina (produced for decades in Chad and marketed as a supplement), and low-cost imported turmeric. In departments where budgetary constraints limit the renewal of protective equipment, the promotion of radioprotective dietary patterns within workers’ medical surveillance programmes represents a virtually cost-free complementary measure, to be set against the African biomonitoring findings (elevated micronucleus frequencies in technologists, e.g. Bouraoui 2013 in Tunisia). Moreover, the African evidence is no longer merely observational: the present review incorporates two components of an original experiment conducted at the University of Yaoundé I by *Kouam Foubi, et al.*, 2016 and 2017 [43,44]. In whole-body-irradiated Wistar rats, aged garlic extract (AGE, 25–50 mg/kg p.o., 5 days before and 7 days after irradiation) significantly improved all of the impaired parameters, namely restoration of superoxide dismutase, catalase and glutathione, reduction of malondialdehyde and nitrites, normalization of transaminases, alkaline phosphatase and bilirubin, and improvement of the post-irradiation glycaemic course, with an efficacy comparable to the reference treatment (vitamin E + α -lipoic acid). Beyond the biological signal, this series demonstrates the feasibility of experimental research on nutritional radioprotection conducted entirely in Central Africa from local food resources, and provides the first link of African preclinical evidence integrated into an international meta-analysis in this field.

This review has limitations. Publication bias is likely: the unanimously positive findings (23/23) and the absence of published negative studies call for a cautious weighting of the magnitude of the pooled effects; moreover, heterogeneity reappears as soon as the secondary arms are included ($I^2 = 47\%$). The sample sizes of some animal studies were reconstructed from published percentages and their variance is therefore approximate; the outcome measures differ (survival, biomarkers, histology) and are combined here as a

global signal rather than as a targeted estimate; the experimental dose and route of administration exceed what is achievable through the usual diet; no formal risk-of-bias assessment (SYRCLE, RoB 2) was applied at this stage; finally, single-reviewer screening, although PRISMA-structured, is no substitute for blinded dual screening or PROSPERO registration, which will have to precede any submission. The correlations, the MCA and the logistic regression, computed on 23 studies, are essentially of exploratory and prioritizing value.

Looking ahead, three research directions are required:

- Randomized controlled trials of supplementation (e.g. EGb 761 or bioavailability-optimized curcumin) in interventional radiology personnel, with biodosimetry outcomes (micronuclei, γ H2AX, comet assay) coupled with physical dosimetry;
- An individual participant data meta-analysis of the occupational biomonitoring studies to quantify the potential benefit and calibrate trial power;
- The integration of nutrigenomics (polymorphisms of DNA repair pathways and antioxidant metabolism) to target the most radiosensitive workers. Outside such trials, caution dictates that high-dose antioxidant self-medication should not be encouraged from the outset, as its interaction with oncological treatments remains debated [14].

Transparency

some numerical data are derived from public abstracts/reports; reconstructed sample sizes are flagged; the full texts and pagination were verified before submission to a peer-reviewed journal.

Appendix

Radioprotective fruits, foods and consumables: indicative daily quantities for personnel NB: No food, fruit or dietary supplement replaces the physical radiation protection measures (distance, time, shielding/lead, dosimetry, ALARA principle). The quantities below are INDICATIVE: they are derived from the human doses used in clinical studies or from the allometric conversion of animal doses (estimated human equivalent dose, HED; *Reagan-Shaw, et al.*, FASEB J 2008, factors 0.081 mouse→human and 0.162 rat→human for a 60 kg adult). They have not been validated in radiology personnel. Any supplementation must be validated by the occupational physician or the attending physician, with disclosure of ongoing treatments. How to read the tables: “human evidence” = dose actually administered in a published clinical study; “HED” = human equivalent dose calculated from the animal dose (oral route only); “common use” = dosage observed in commercial supplements (insufficient evidence). Injectable doses (i.p., s.c.) from animal studies are NOT transposable to the diet and are flagged (Table B1& Table B2& Table B3) and (Box B1).

Table B1: Consumables whose radioprotective dose is directly documented in humans (clinical studies).

Consumable	Documented Daily Quantity	Administration Schedule	Level of Evidence	Major Precautions
Ginkgo biloba — standardized extract EGb 761 (leaf)	120 mg/day orally (2 × 60 mg or 3 × 40 mg)	Start ≥ 3 days BEFORE exposure and continue for 30 days (radioiodine RCT schedule); 2 months in the Chernobyl liquidators	RCT (iodine-131, n = 25) + cohort of irradiated workers (Chernobyl)	Anticoagulants/antiplatelet agents (bleeding risk), epilepsy, imminent surgery
Melatonin	20 mg/day orally, in the evening (dose used in the oncology trials)	Daily intake during the exposure period; outside a study protocol, prefer 0.5–3 mg/day in the evening	Meta-analysis of 8 RCTs (n = 761): radio-/chemotherapy toxicities reduced by 81–87%	Daytime drowsiness, driving/operating machinery, interactions (fluvoxamine, anticoagulants), corticosteroids
Nano-curcumin (micelles)	40–80 mg/day orally (2 doses 12 h apart)	7 days BEFORE exposure (iodine-131), then 21 days after	RCT (thyroid cancer, iodine-131): micronuclei ↓ vs placebo	Anticoagulants, gallstones, pregnancy (caution)

Note*: References [20,26,32,38] of the manuscript and associated randomized trial: J Nucl Med 2022;63(suppl 2):3003.

Table B2: Indicative daily quantities derived from the allometric conversion of animal studies (60–70 kg adult).

Consumable (Source)	Animal / In Vitro Study Dose	Estimated Human Equivalent Dose (HED, 60 Kg)	Practical Daily Quantity	Precautions
Fresh garlic / aged garlic (<i>Allium sativum</i>) — cloves	Aqueous extract 125–500 mg/kg·d × 5 d (mouse, p.o.); aged garlic extract 25–50 mg/kg·d × 5 + 7 d (rat) [43,44]	≈ 0.6–2.4 g/d of extract (HED); aged garlic HED ≈ 245–490 mg/d (rat × 0.162)	1–3 fresh crushed cloves (≈ 5–10 g), raw or lightly cooked, every day; or aged garlic extract 250–500 mg/d (standardized capsules)	Anticoagulants, surgery, gastro-oesophageal reflux
Vitamin C (citrus fruits, kiwi, guava, etc.)	50–100 mg/kg·d (mouse, p.o.)	≈ 250–500 mg/d	2 oranges + 1 kiwi (≈ 200 mg) + ½ raw bell pepper ≈ 250–300 mg/d; supplement 250–500 mg/d maximum	Avoid > 1 g/d (renal oxalates, iron overload)

Vitamin E (vegetable oils, nuts and seeds)	100–200 mg/kg·d (mouse, p.o.)	≈ 490–970 mg/d — EXCEEDS dietary intake and the UL (300 mg/d)	Do NOT supplement at the HED dose: cover 15–30 mg/d through the diet (1 tbsp sunflower/wheat-germ oil + 30 g almonds)	High dose: bleeding risk; documented synergy with vitamin C
β-carotene (carrot, sweet potato, spinach)	3–12 mg/kg·d (mouse, p.o.)	≈ 15–58 mg/d	Favour dietary sources: 2 carrots (≈ 10–20 mg) or 150 g sweet potato; C + E + β-carotene combination more effective (study)	SMOKERS: no β-carotene supplements (demonstrated lung cancer risk — ATBC/CARET)
Honey (e.g. linden honey)	1.5 mL/kg·d × 28 d (rat, p.o.)	≈ 15 mL/d (≈ 20 g)	1 tablespoon per day (tea, yoghurt), preferably raw local honey	Sugars (diabetes), infants < 1 year (botulism)
Sesame (sesamol) — seeds/tahini	20–100 mg/kg i.p. (mouse) — injectable route	Oral route not established (indicative HED: ≈ 100 mg/d of sesamol)	15–30 g/d of sesame seeds or 1–2 tbsp of tahini (cautious dietary approach)	Sesame allergy; caloric intake
Soy (genistein) — tofu, soy milk, edamame	200 mg/kg s.c. at –24 h (mouse) — injectable route	Oral route not established	1–2 servings/d: 100 g tofu or 250 mL soy drink (≈ 25–50 mg isoflavones, “Asian” profile)	History of hormone-dependent cancer: medical advice; hypothyroidism
Green tea (EGCG)	<i>In vitro</i> (splenocytes) — study without an oral dose	Not calculable	2–4 cups/d (≈ 150–400 mg catechins), between meals	EGCG supplements: ceiling 800 mg/d (hepatic risk, EFSA); tannins/anaemia
Ginseng (Panax ginseng)	Extract p.o. (mouse), dose not reported	Not calculable	Common use: standardized extract 200–400 mg/d or root 1–2 g/d, 8–12-week courses	Anticoagulants, hypoglycaemic agents, insomnia/hypertension at high dose
Nigella sativa oil (black seed)	Oral route (rat), dose not reported	Not calculable	Common use: oil 2.5–5 mL/d or 1–3 g/d of ground seeds (preventive, with meals)	Pregnancy (caution), possible hypoglycaemia/hypotension
Propolis (ethanolic extract, EEP)	<i>In vitro</i> human lymphocytes + mouse (p.o. 50 mg/kg)	HED ≈ 250–500 mg/d (50 mg/kg mouse × 0.081 × 60)	Common use: standardized extract 200–500 mg/d	Allergy to hive products
Spirulina (Spirulina platensis)	Extract p.o. (mouse), dose not reported	Not calculable	Common use: powder 3–5 g/d; quality-controlled product (purity)	Contaminants (microcystins, heavy metals): certified batches; phenylketonuria
Generic curcumin (turmeric powder)	<i>In vitro</i> human lymphocytes (1–50 µg/mL)	Not directly calculable	Culinary use: 3–5 g/d of turmeric powder + black pepper (piperine, bioavailability × 20); supplement: 0.5–2 g/d of formulated curcumin (medical advice); ADI for food colour E100 = 3 mg/kg/d (≈ 180 mg/d)	Anticoagulants, gallstones; low bioavailability without formulation/piperine

Note*: HED (Reagan-Shaw 2008): mouse dose × 0.081; rat dose × 0.162; × 60 kg. Source studies of the manuscript: [19,21–25,27–31,33–37,39,43,44]; piperine: *Shoba, et al.*, *Planta Med* 1998;64(4):353–6. [43,44]: Cameroonian studies by the first author (aged garlic extract, irradiated Wistar rat). UL: tolerable upper intake level; ADI: acceptable daily intake.

Table B3: Fruits, vegetables and spices: daily portions covering protective antioxidant requirements.

Fruit / Vegetable / Spice	Protective Compounds	Indicative Daily Portion	Rationale (Level of Evidence)
Orange, clementine	Vitamin C, flavanones	2–3 fruits (≈ 200–300 g) → ≈ 140–200 mg vitamin C	Vitamin C: human <i>in vitro</i> evidence (reduction of DNA damage)
Kiwi	Vitamin C, actinidin	2 kiwis → ≈ 120–180 mg vitamin C	Idem (contributes to the ≈ 250–500 mg/d target)
Guava (tropical fruit, Africa)	Vitamin C, lycopene	1 fruit (≈ 100 g) → ≈ 200 mg vitamin C	Idem — valuable in tropical regions
Carrot	β-carotene	2 medium carrots (≈ 150 g) → ≈ 10–18 mg	β-carotene: animal evidence, combined with vitamins C/E
Orange-fleshed sweet potato	β-carotene	150 g → ≈ 10–14 mg	Idem; available in Central Africa

Spinach and local leafy vegetables (ndolé, folong, koko, etc.)	Carotenoids (β -carotene, lutein), vitamin C, folates	100–200 g/d, briefly cooked or raw in salads	Spinach: animal evidence (reduced oxidative stress)
Sour (tart) cherry	Dietary melatonin, anthocyanins	240 mL juice morning + evening; fresh in season	Indirect evidence (melatonin, review)
Red grapes / red grape juice	Resveratrol, anthocyanins	1 bunch ($\approx$ 200 g) or 150 mL of juice	Resveratrol: preclinical evidence (2024 systematic review)
Red onion / shallot	Quercetin	50–100 g/d raw (salads)	Quercetin: documented radioprotection (review + comparator in the studies)
Apple (with skin)	Quercetin, pectin	1–2 apples/d	Quercetin (idem); consistent with all recommendations
Aubergine/eggplant (purple skin)	Anthocyanins (nasunin)	150–200 g, 2–3 times/week	Anthocyanins: complementary antioxidants (dietary approach)
Fresh or powdered turmeric	Curcumin	3–5 g/d + 1 pinch of black pepper + fat	Curcumin: human evidence (<i>in vitro</i> + RCT); piperine $\times$ 20
Fresh ginger	Gingerols, shogaols	5–10 g/d (herbal tea, dishes)	Botanically close to the Allium/spice studies (dietary approach)

Note*: “Dietary pattern” approach: the maximum efficacy in the studies was obtained with the COMBINATION of antioxidants (vitamins C+E+ β -carotene [22]) – favour diversity within a single day rather than a single product.

Box B1: Example of a “radioprotective day” (adult, imaging personnel, period of continuous exposure).

Time of Day	Composition
Morning	Green tea (1 cup) + kiwi or freshly squeezed orange juice + cereal flakes with 30 g of almonds or a soy drink
Midday	Raw vegetables (grated carrot + red onion), main dish seasoned with turmeric + pepper + sesame oil, 1 fruit (orange/guava)
Snack	1 apple or 1 bunch of red grapes or yoghurt with honey (1 tbsp)
Evening	Leafy vegetables (spinach/ndolé) + garlic (1–2 crushed cloves); ginger and lemon herbal tea after the shift
On medical prescription only	Periods of sustained exposure (interventional suite): EGb 761 120 mg/d ($\geq$ 3 d before $\rightarrow$ +30 d); melatonin and nano-curcumin according to the medical protocol

Note*: Abundant hydration throughout the day; limited alcohol (pro-oxidant); tobacco = major aggravating factor of pulmonary radiotoxicity.

Practical Safety Rules (to be Read before any Implementation)

- Nutritional Radioprotection is an ADJUNCT:** it changes neither the doses measured by the dosimeter nor the ALARA obligations (distance, exposure time, shielding, aprons) - ICRP 103/118 [3,5], Directive 2013/59/Euratom [4].
- Documented Human Evidence Exists only for:** EGb 761 (120 mg/d), melatonin (20 mg/d, oncological context) and nano-curcumin (40–80 mg/d). All other quantities are indicative (HED or common use).
- Demonstrated Optimal Timing:** start 3 to 7 days BEFORE intense exposure and continue for 21 to 30 days afterwards; chronic administration must remain at dietary doses.
- Never Exceed:** vitamin E 300 mg/d (UL), supplemental EGCG 800 mg/d (hepatotoxicity), curcumin as a food “additive” 3 mg/kg/d (ADI for E100), vitamin C 1 g/d on a continuous basis.
- No β -carotene supplements in smokers/recent former smokers (increased lung cancer incidence, ATBC and CARET trials).
- Major Drug Interactions:** ginkgo, garlic, curcumin, vitamin E with anticoagulants/antiplatelet agents (bleeding risk); usual discontinuation 7–14 days before surgery.
- Pregnancy and Breastfeeding:** only the dietary approach (fruits, vegetables, culinary spices) is acceptable without specialist advice.
- Quality of Supplements:** require traceability and analytical testing (spirulina: microcystins/metals; propolis: allergens; standardized extracts mandatory).
- Declare any Supplementation to the Occupational Physician:** it must be recorded in the occupational medical file without altering dosimetric monitoring.
- Clinical Trials in Radiology Personnel are Lacking:** taking part in research (micronucleus/ γ H2AX biodosimetry) is the best way to validate these intakes.

Conclusion

Foods and consumables with strong radioprotective properties—such as turmeric/curcumin, *Ginkgo biloba* EGb 761, melatonin, antioxidant vitamin combinations, sesame/sesamol, black seed, honey, green tea/EGCG, soy/genistein and propolis—produce a robust, homogeneous and quantitatively substantial protection signal (pooled RR 0.17; 0.10–0.27), already partly demonstrated in humans, including in the context of occupational exposure. Given the measurable genotoxic burden in radiology and medical imaging personnel despite compliance with dose limits, the cautious integration of the nutritional approach into radiation protection strategies constitutes a legitimate, accessible and inexpensive avenue; it must proceed through dedicated clinical trials before any formal recommendation. The corresponding indicative daily quantities (fruits, foods, documented doses and human equivalents) are presented in the Appendix at the end of the manuscript.

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Conflicts of Interest

None Declared.

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