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Plantation products: Global uses, markets, health-related claims and adulteration - A narrative review of major tropical and subtropical commodities

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ABSTRACT

Plantation commodities link tropical land use, global trade, food systems, industrial materials and traditional medicine. Tea, coffee and cocoa are consumed worldwide; natural rubber underpins transport and healthcare; oil palm and coconut supply edible oils and oleochemicals; sugarcane yields sugar, ethanol and bagasse; and spices such as pepper, cardamom, clove and vanilla provide flavour, fragrance and traditional remedies. This narrative review reveals the principal geographic uses and products of 12 crops, the interpretation and drivers of commodity prices, the strength of evidence behind health-related claims, and the forms, detection and governance of adulteration and economically motivated fraud, distinguishing these from food-safety contamination. Price evidence is drawn from the World Bank Pink Sheet (editions to October 2026): Between 2022 and 2025 the annual average cocoa price rose 3.3-fold (US$2.39 to US$7.80/kg) and arabica coffee 50% (US$5.63 to US$8.47/kg), after which cocoa fell by 59% from its 2025 Q1 quarterly peak to 2026 Q1 before partly recovering, while natural rubber (RSS3) in 2026 Q3 was 26% above its 2025 average. Health-related statements are separated into four categories: established benefits or risks (randomised trials, meta-analyses and regulatory opinions; for example caffeine safety, cocoa flavanols and vascular function, coconut-oil effects on LDL cholesterol), preliminary findings (observational, mechanistic, animal or in-vitro evidence), traditional uses, and commercially promoted claims that lack adequate substantiation. Adulteration risks include dilution, substitution, undeclared fillers and colourants, exhausted material and false origin claims; reliable control combines representative sampling, traceability, microscopy, chromatography, spectroscopy, isotopic and DNA-based methods and risk-based enforcement. Five figures, eight tables and a reference list with DOIs are provided and research priorities are identified, including open reference libraries, inter-laboratory validation of portable spectroscopy and transparent price reporting.

Keywords: Plantation crops; tea; coffee; cocoa; natural rubber; palm oil; coconut; sugarcane; spices; medicinal use; adulteration; food authenticity; commodity prices; food safety; health claims; evidence grading

1. Introduction

Plantation agriculture historically denotes large-scale, market-oriented production, often of perennial crops in humid tropical regions. In contemporary usage, a “plantation product” may come from estates, smallholders or mixed systems. The term is not a single standardised scientific or statutory category, and definitions differ among countries and agencies; this narrative review therefore treats it functionally, covering internationally traded commodities whose production and processing are strongly associated with tropical and subtropical regions: Tea, coffee, cocoa, natural rubber, oil palm, coconut, sugarcane, black pepper, cardamom, clove, vanilla and cashew. Production and trade statistics for these crops are compiled by FAO [1] and by commodity organisations [2–6].

Value chains transform harvested crops into foods, beverages, industrial feedstocks and ingredients, and processing changes composition: Fermentation and roasting generate flavour compounds in coffee and cocoa; oxidation shapes black tea; vulcanisation converts latex to an elastic solid; refining alters oil composition and removes impurities; and crystallisation separates sucrose from molasses. Consequently, crop identity alone cannot predict exposure, health effect or fraud risk.

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Three themes recur in the literature and in public debate and motivate this review. First, prices of these commodities are volatile and often misinterpreted, because benchmark quotations refer to specific grades, forms, locations and units and are not retail prices. Second, health-related claims range from well-characterised pharmacology and regulatory-grade evidence to traditional use and marketing assertion, and these categories are often conflated in public and commercial communication. Third, high-value, long and fragmented supply chains create opportunities for economically motivated adulteration (EMA), which must be distinguished from accidental contamination and from non-conformity with a specification [7–9]. The objectives were to: (i). describe the main products and global uses; (ii). explain price formation and present dated, sourced benchmark data; (iii). classify health-related claims as established, preliminary, traditional or commercially promoted and grade the supporting evidence; and (iv). summarise adulteration types, analytical detection and governance.

2. Methods and scope

2.1 Review design

This is a narrative review and not a registered systematic review or meta-analysis. Evidence was selected non-systematically, prioritising: (a) peer-reviewed systematic reviews, meta-analyses and randomised trials; (b). scientific opinions of the European Food Safety Authority (EFSA) and monographs of the International Agency for Research on Cancer (IARC); (c). international standards and legislation; and (d). official commodity-price publications. Sources without a DOI (for example some standards, agency reports and databases) are identified as such rather than assigned an identifier.

2.2 Price data

Benchmark prices were taken from the World Bank Commodity Price Data ("Pink Sheet") [10], using the October 2026 edition (published 2 October 2026) and earlier monthly editions from January 2024 to September 2026 to assemble annual averages (2020–2025), quarterly averages (2024 Q1–2026 Q3) and monthly values. Prices are nominal US dollars as published and no inflation or currency adjustment was applied. The Pink Sheet notes that the palm-oil series was replaced from January 2026; palm-oil values from 2026 are therefore plotted with a marker and should not be treated as strictly continuous with earlier values. Tea prices are auction- and origin-specific and are not plotted. Percentage changes were calculated from the published (rounded) values. Forecast statements are taken from the World Bank Commodity Markets Outlook of April 2026 [11].

2.3 Evidence grading

Health-related statements were first assigned to one of four categories: (1) established benefits or risks, defined as effects supported by randomised trials, meta-analyses or regulatory scientific opinions that accepted a cause-and-effect relationship; (2) preliminary findings, defined as associations from observational studies and results from mechanistic, animal, in-vitro or small, short-term human studies that are hypothesis-generating rather than confirmatory; (3) traditional uses, defined as uses recorded in traditional or complementary medicine systems [59] that have not been confirmed in clinical studies; and (4) commercially promoted claims, defined as advertising, labelling or retail statements that exceed, or are not supported by, the available evidence. The categories were then graded with five author-defined evidence levels (Figure 4): Level A, randomised trials, meta-analyses or regulatory scientific opinions (category 1); Level B, prospective cohort studies and umbrella reviews of observational data, and Level C, mechanistic, animal or *in-vitro* evidence (both category 2); Level D, traditional use only (category 3); and Level E, commercial or marketing claim only (category 4). A regulatory opinion that found a cause-and-effect relationship not established was not counted as support for the claim, and authorisation of a claim under a regulation such as [57] was treated as a judgement on a specific constituent, wording and conditions of use, not on the whole commodity. This is a pragmatic classification for narrative synthesis and is not a formal GRADE assessment [58].

3. Major plantation products and global uses

Table 1 summarises the twelve crops, indicative producing regions, principal uses and key by-products. Regional use patterns reflect culinary tradition, income and industrial demand: Black tea predominates in South Asia, the United Kingdom and parts of Africa while green tea is typical in East Asia; coffee is consumed as brewed, espresso, soluble and ready-to-drink products; chocolate and confectionery drive cocoa demand in Europe and North America; and tyres dominate natural-rubber demand, with gloves, medical devices and seals as smaller but critical outlets. Oil-palm and coconut products serve both food

and oleochemical markets, whereas sugarcane supplies sugar, ethanol and bagasse-based energy. Producer lists vary by year and by metric (area, production or exports) [1].

Table 1. Major plantation products, indicative producing regions, uses and by-products.

Product / crop	Major producing regions (examples)	Uses and regional patterns	Important products and by-products
Tea (*Camellia sinensis*)	China, India, Kenya, Sri Lanka, Türkiye, Vietnam	Black tea prominent in South Asia, the UK and parts of Africa; green tea common in East Asia; specialty and herbal blends globally	Black, green and oolong tea; instant tea; extracts; pruning biomass and spent leaf
Coffee (*Coffea arabica, C. canephora*)	Brazil, Vietnam, Colombia, Ethiopia, Indonesia, Honduras	Brewed coffee, espresso, soluble coffee and ready-to-drink beverages; café cultures vary by region	Roasted and soluble coffee; caffeine; extracts; pulp, husks and spent grounds
Cocoa (*Theobroma cacao*)	Côte d'Ivoire, Ghana, Ecuador, Nigeria, Cameroon	Chocolate and confectionery worldwide; cocoa beverages and baking ingredients	Cocoa liquor, butter, powder and shells; fermentation residues
Natural rubber (*Hevea brasiliensis*)	Thailand, Indonesia, Côte d'Ivoire, Vietnam, India, Malaysia	Tyres dominate demand; gloves, medical devices, seals, footwear and engineering goods	Latex concentrate, ribbed smoked sheet (RSS), technically specified rubber (TSR); rubberwood at replanting
Oil palm (*Elaeis guineensis*)	Indonesia, Malaysia, Thailand, Nigeria, Colombia	Cooking oil, processed foods, soaps, cosmetics, oleochemicals and biodiesel; use varies with regulation and markets	Crude and refined palm oil; palm-kernel oil; glycerol; biomass and mill residues
Coconut (*Cocos nucifera*)	Indonesia, Philippines, India, Sri Lanka, Vietnam	Fresh coconut, milk and cream, desiccated coconut, oil, water and coir; central to South and Southeast Asian cuisines	Copra; virgin and refined coconut oil; coir fibre; shell charcoal; husk
Sugarcane (*Saccharum* spp.)	Brazil, India, China, Thailand, Pakistan, Mexico	Sugar, jaggery/panela, molasses, rum and ethanol; bagasse for heat, power and fibre products	Raw and refined sugar; molasses; ethanol; bagasse; filter cake
Black pepper (*Piper nigrum*)	Vietnam, India, Indonesia, Brazil, Sri Lanka	Global seasoning; traditional digestive and warming preparations	Whole and ground pepper; oleoresin; essential oil
Cardamom (*Elettaria cardamomum*)	India, Guatemala, Sri Lanka, Tanzania	South Asian and Middle Eastern cuisine; coffee and tea flavouring; confectionery; traditional preparations	Green and bleached pods; seeds; essential oil
Clove (*Syzygium aromaticum*)	Indonesia, Madagascar, Tanzania, Comoros, Sri Lanka	Spice blends, flavouring, dental products and fragrance	Dried flower buds; clove oil (eugenol)
Vanilla (*Vanilla planifolia* and related species)	Madagascar, Indonesia, Uganda, Papua New Guinea, Comoros	Confectionery, dairy, beverages and perfumery; natural vanilla is costly and competes with vanillin	Cured pods; extracts; oleoresins; spent pods
Cashew (*Anacardium occidentale*)	Côte d'Ivoire, India, Vietnam, Tanzania, Benin	Edible kernels, confectionery and plant-based foods; shell liquid has industrial uses	Kernels; cashew nut shell liquid; cashew apple products

Country lists are indicative examples drawn from FAO and commodity-organisation statistics [1] and change with year, metric (area, production, export, processing) and data source. Species names follow common botanical usage.

4. Production, processing and value creation

Economic value depends on cultivar, climate, soil, labour, yield, harvest maturity, post-harvest handling, certification, logistics and processing. Smallholders may sell through intermediaries, cooperatives or direct export channels, whereas estates may integrate cultivation and processing. A commodity's export price is not the price paid by consumers: retail prices incorporate processing, packaging, freight, taxes, brand premiums, retailer margins and currency movements. Figure 1 maps a generic value chain against the stages at which fraud typically arises and the principal controls available at each stage; it is a conceptual framework rather than an empirical ranking.

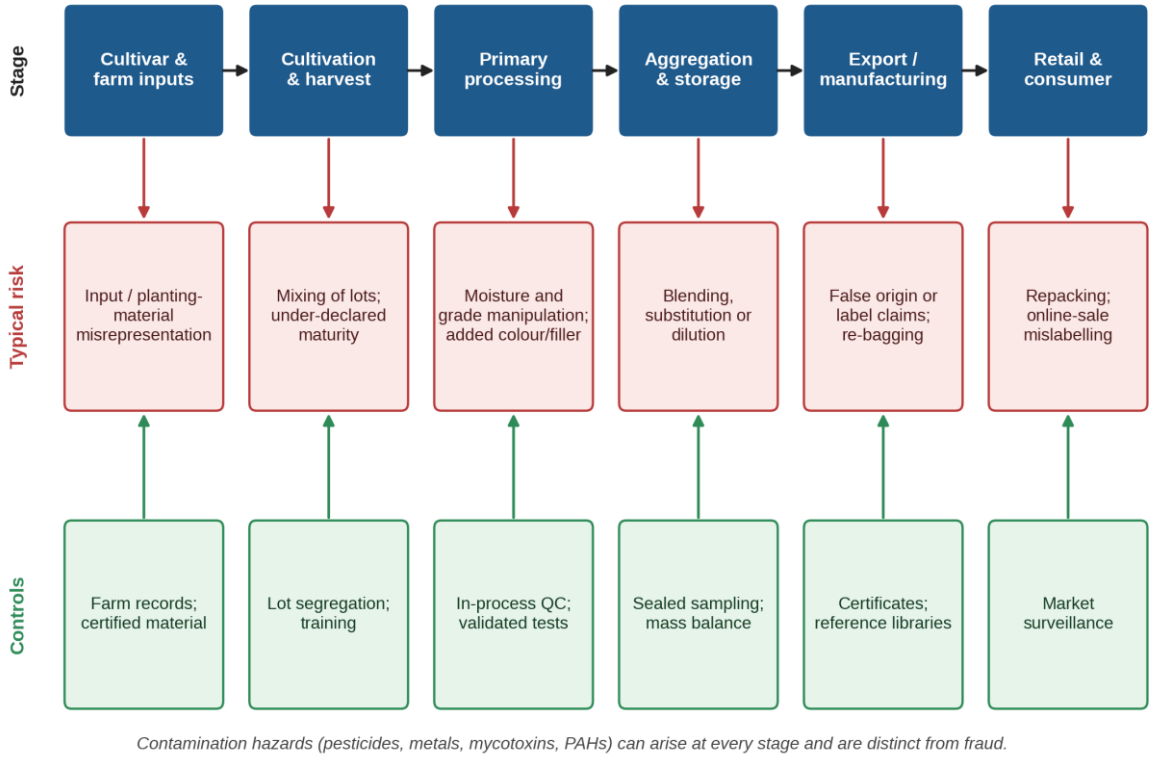


Figure 1. Generic plantation-product value chain showing typical fraud or adulteration risk points and principal controls. Conceptual diagram; it does not represent measured incidence.

5. Prices: Interpretation, benchmarks and drivers

5.1 Interpreting commodity prices

A single global price is rarely meaningful. Coffee is quoted by species, grade, exchange contract and differential; tea is sold through auctions and private contracts; cocoa has futures benchmarks and origin differentials; rubber is quoted in several physical and futures markets; palm-oil prices vary by crude or refined product and location; and spice markets are thin, volatile and quality-specific. Table 2 lists the principal reference series, units, drivers and cautions. Retail products cannot be compared directly with raw commodity prices, and series should not be combined without converting units and documenting methodological breaks.

Table 2. Common price references, main drivers and cautions for plantation commodities.

Commodity	Common price reference / unit	Main drivers	Cautions when comparing
Coffee	ICO composite and group indicator prices (US cents/lb or US$/kg); exchange futures; origin differentials [2,10]	Weather, stocks, currency, freight, disease, harvest cycles, arabica–robusta substitution	Indicator prices are not a specific grade or retail price
Tea	Auction prices by origin, grade and sale (currency/kg); World Bank compilation of Kolkata, Mombasa and Colombo auctions [10]	Quality, flush, origin, weather, auction supply, blending demand	No single fully representative global spot price
Cocoa	ICCO daily price; ICE futures (US$/tonne) plus origin and quality differentials [3,10]	Crop disease, weather, stocks, grindings, regulation, farm-gate policy	Futures are not farm-gate or chocolate shelf prices
Natural rubber	SICOM RSS3 and TSR20 (US$/kg) and other physical or futures quotes [6,10]	Tyre demand, crude-oil prices, weather, inventories, exchange rates	Latex, TSR and RSS are not interchangeable
Palm oil	Malaysian crude palm oil futures (MYR/tonne); World Bank series (US$/tonne); MPOB statistics [5,10]	Competition from other vegetable oils, biodiesel mandates, inventories, weather, policy	Refined fractions and retail oil differ from crude palm oil
Coconut products	Copra, crude coconut oil (CFR NW Europe) and desiccated coconut [10]	Philippine and Indonesian supply, weather, competing oils, freight	Oil, copra and desiccated coconut are different products
Sugarcane / sugar	Raw sugar futures (US cents/lb); World Bank world raw sugar (US$/kg); white sugar (US$/tonne); local cane prices [4,10]	Crop yields, ethanol parity, weather, trade policy, currency	Cane payment formulas differ by country
Spices	Origin-specific wholesale or export prices, often US$/kg	Crop disease, grade, cleaning, moisture, origin, export demand	Thin markets and quality differences create wide spreads

For a reproducible price analysis, download a dated series, record access date, frequency, unit, currency and product specification, and find out any conversion.

5.2 Recent benchmark price dynamics (2020–2026)

Table 3 gives World Bank benchmark prices for selected commodities, and Figures 2 and 3 show their quarterly evolution and relative change. The data illustrate the volatility that complicates any single "price" statement. Annual average cocoa rose from US$2.39/kg in 2022 to US$7.80/kg in 2025 (3.3-fold), peaked at a quarterly average of US$9.56/kg in 2025 Q1, and then declined to US$3.93/kg in 2026 Q1 (−59%) before recovering to US$5.83/kg in 2026 Q3 [10]. The World Bank reported a 32% quarter-on-quarter fall in cocoa prices in 2026 Q1 and linked its outlook to improved supply prospects [11]. Arabica coffee averaged US$4.54/kg in 2023 and US$8.47/kg in 2025 (+87%), and robusta US$2.63/kg and US$4.86/kg (+85%); by 2026 Q3, arabica (US$7.71/kg) and robusta (US$3.92/kg) were 9% and 19% below their 2025 averages [10].

Natural rubber moved in the opposite direction in 2026: RSS3 averaged US$2.18/kg in 2025 and US$2.75/kg in 2026 Q3 (+26%), and TSR20 rose from US$1.77/kg to US$2.27/kg (+28%), the highest quarterly values in the 2024–2026 window [10]. Palm oil averaged US$1,007/tonne in 2025 and US$1,148/tonne in 2026 Q3 (+14%); the World Bank noted that higher crude-oil prices supported palm-oil prices earlier in 2026 [11], but the series was replaced from January 2026 and the break should be borne in mind [10]. Coconut oil averaged US$1,075, US$1,519 and US$2,480/tonne in 2023, 2024 and 2025 respectively, before easing to US$1,996/tonne in 2026 Q3 [10]. World raw sugar, by contrast, drifted down from US$0.52/kg (2023) to US$0.37/kg (2025) and US$0.32/kg in the first half of 2026, rising to US$0.38/kg in Q3 [10]. All values are nominal benchmark quotations, not farm-gate or retail prices, and the proportional changes in Figure 3b are calculated from rounded published figures.

Table 3. World Bank benchmark prices (nominal US$) for selected plantation commodities: annual averages 2020–2025, 2026 Q3 average and September 2026 monthly value.

Commodity (unit)	2020	2021	2022	2023	2024	2025	2026 Q3	Sep 2026
Cocoa (US$/kg)	2.37	2.43	2.39	3.28	7.33	7.80	5.83	5.92
Coffee, arabica (US$/kg)	3.32	4.51	5.63	4.54	5.62	8.47	7.71	7.26
Coffee, robusta (US$/kg)	1.52	1.98	2.29	2.63	4.41	4.86	3.92	3.69
Palm oil (US$/tonne)†	752	1,131	1,276	886	963	1,007	1,148	1,180
Coconut oil (US$/tonne)	n.r.	n.r.	n.r.	1,075	1,519	2,480	1,996	2,083
Sugar, world raw (US$/kg)	0.28	0.39	0.41	0.52	0.45	0.37	0.38	0.41
Rubber, RSS3 (US$/kg)	1.73	2.07	1.81	1.58	2.28	2.18	2.75	2.75
Rubber, TSR20 (US$/kg)	1.33	1.68	1.54	1.38	1.75	1.77	2.27	2.41

Source: World Bank Pink Sheet, October 2026 and earlier editions [10]. Annual 2020–2022 values from December 2023 and January 2024 editions. n.r., not retrieved for this review. †World Bank replacement series for palm oil applies from January 2026; 2026 values are not strictly continuous with earlier values. Cocoa is the ICCO daily price (average of first three positions, New York and London); coffee values are ICO indicator prices; rubber is SICOM nearby contract; sugar is the world raw-sugar price. Tea is not shown because auction prices are origin- and grade-specific.

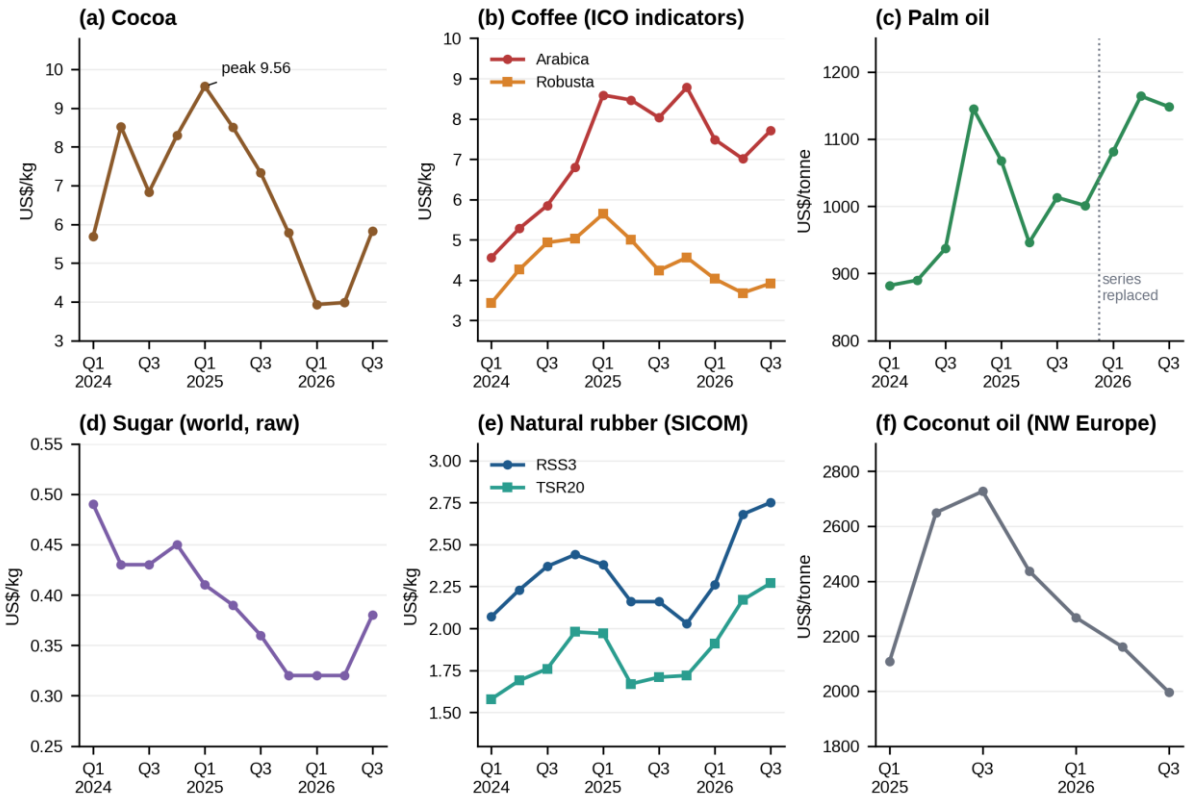


Figure 2. Quarterly average benchmark prices, 2024 Q1–2026 Q3 (panel f: 2025 Q1–2026 Q3): (a) cocoa; (b) arabica and robusta coffee; (c) palm oil (dotted line marks the January 2026 series replacement); (d) world raw sugar; (e) natural rubber RSS3 and TSR20; (f) coconut oil. Data: World Bank Pink Sheet [10]. Nominal US dollars.

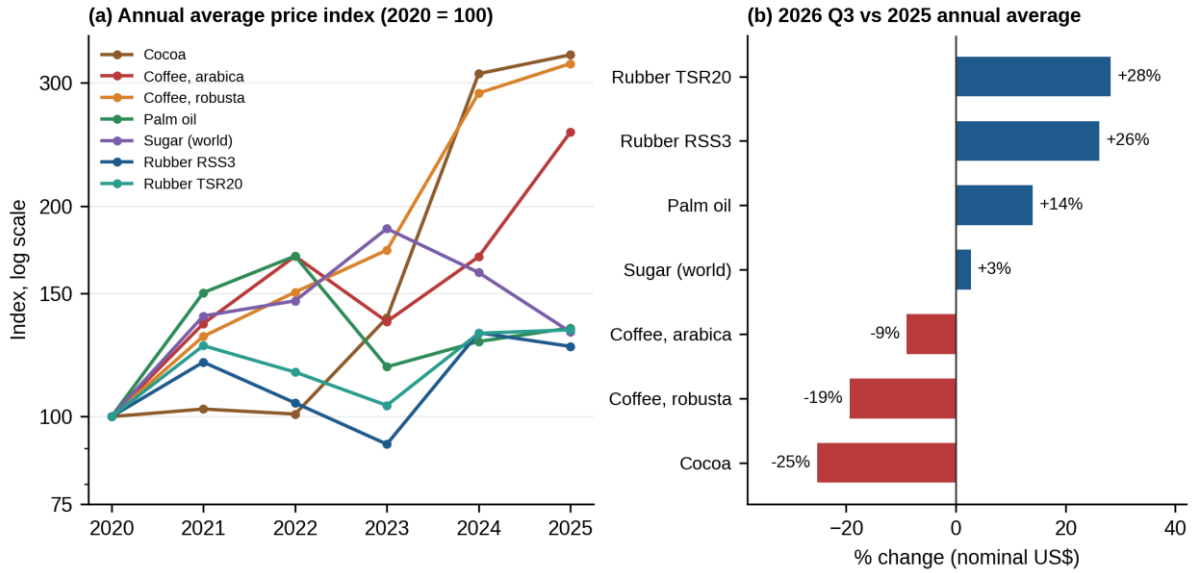


Figure 3. (a) Annual average price index (2020 = 100, logarithmic scale), 2020–2025; (b) percentage change between the 2025 annual average and the 2026 Q3 average. Data: World Bank Pink Sheet [10]; calculated by the authors from published (rounded) values.

5.3 Drivers and implications

Perennial crops respond to price with long lags because new plantings take years to bear, so supply shocks, disease and weather can produce prolonged price spikes that are then corrected when yields recover or demand adjusts. Climate stress is a structural driver: modelling suggests substantial pressure on areas suitable for arabica and robusta [12] and for cocoa in West Africa [13]. Price spikes also raise the incentive for substitution, dilution and false origin claims, linking the market analysis in this section to the authenticity issues in Section 7 [9,14].

6. Medical and health-related uses: Evidence and limits

Food and plant-derived compounds may have physiological effects, but “medicinal use” ranges from a well-characterised active ingredient to a traditional practice or an unsupported marketing claim. Evidence from cell cultures or animals does not establish clinical efficacy, and benefits must be weighed against dose, product quality, interactions, allergy, contaminants and the needs of vulnerable groups. Section 6.1 defines how statements were categorised, Table 4 summarises constituents, uses, evidence level (Figure 4) and cautions for each product, and Table 5 assigns the main statements for each product to the four categories.

6.1 Four categories of health-related statement

Established benefits or risks (Level A) are effects supported by randomised trials, meta-analyses or regulatory scientific opinions that accepted a cause-and-effect relationship, and they are specific to a constituent, dose, population and outcome. Examples include the acceptance by EFSA of a relationship between defined cocoa-flavanol intake and normal endothelium-dependent vasodilation [21], the safety limits for habitual caffeine intake [17], the LDL-raising effect of coconut oil relative to non-tropical vegetable oils [30], and the allergenicity of latex proteins and tree nuts [25,37]. Established risks are as important as established benefits and belong in this category.

Preliminary findings (Levels B and C) include associations from prospective cohorts and umbrella reviews, which cannot exclude confounding, and results from mechanistic, animal, in-vitro or small short-term human studies, which show plausibility but not clinical effect. Observational associations of coffee with liver, metabolic and mortality outcomes [18], the secondary-analysis signal for cardiovascular death in the COSMOS trial [23], and the antioxidant or antimicrobial activity of spice extracts are of this kind. Such findings justify further research and cautious wording, not recommendation.

Traditional uses (Level D) are practices recorded in traditional and complementary medicine systems such as Ayurveda. The World Health Organization regards traditional medicine as an important part of

health care in many countries while stressing the need to promote its safe and effective use through the regulation of products, practices and practitioners [59]. Longevity of use is evidence of cultural significance and, at best, a hypothesis for investigation; it does not establish efficacy, and it does not guarantee safety, particularly for concentrated preparations.

Commercially promoted claims (Level E) are statements in advertising, labelling, social media or retail that exceed, or lack, scientific substantiation, including “detox”, “immunity-boosting”, “fat-burning” and “superfood” claims. In the European Union, health claims on foods must be scientifically substantiated and authorised for specific wording and conditions of use [57], and EFSA concluded that a cause-and-effect relationship had not been established for several tea and green-tea-catechin claims [15]. The widespread public view that coconut oil is healthy, for example, is not matched by its effect on LDL cholesterol [60].

A single product can occupy several categories at once (Table 5): coconut oil, for example, carries an established LDL-raising effect, preliminary data on other outcomes, a long traditional use and extensive commercial health claims. Classification is therefore made per statement (constituent, dose and outcome), not per commodity.

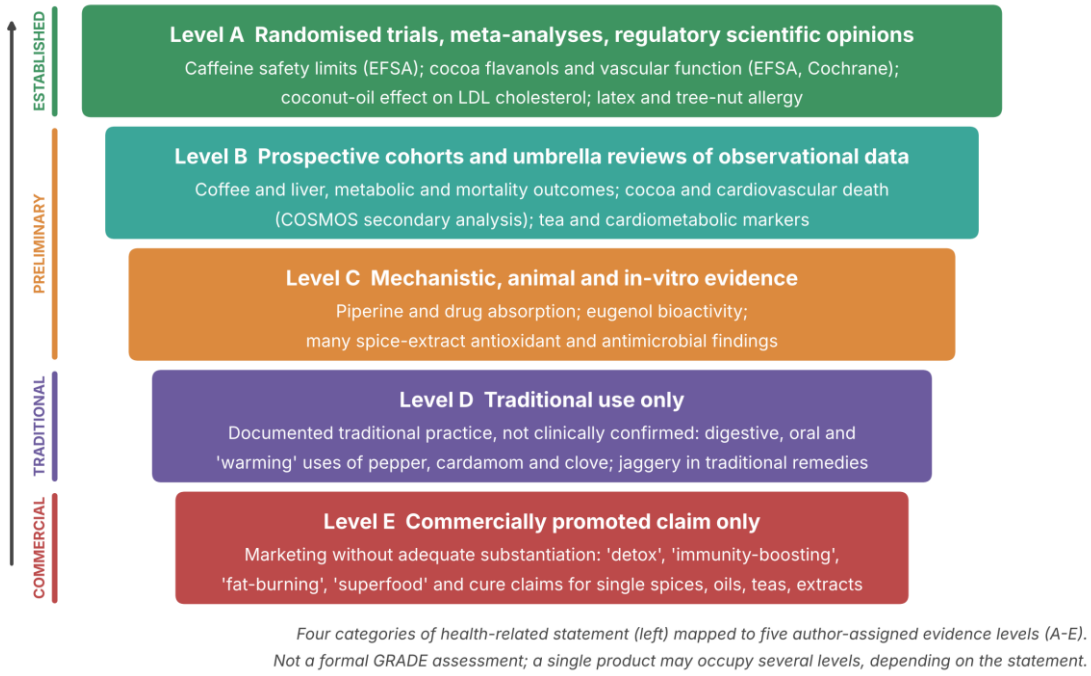


Figure 4. Four categories of health-related statement (established, preliminary, traditional and commercially promoted) and the five evidence levels (A–E) used to grade them in this review, with examples from Tables 4 and 5. Conceptual scheme; not a formal GRADE assessment.

6.2 Product-level evidence and classification

Table 4. Health-related uses of plantation products: constituents, evidence and cautions.

Product	Relevant constituents / plausible effects	Medical or health-related use	Evid. level	Evidence and cautions
Tea	Catechins (green tea), theaflavins and thearubigins (black tea), caffeine, L-theanine	Beverage; studied for cardiometabolic markers, alertness and polyphenol intake	A/B	EFSA concluded that a cause-and-effect relationship had not been established for several tea and green-tea-catechin claims, including blood pressure [15]. Traditional green tea infusions are generally considered safe at usual European intakes, but rare liver injury has been reported and concentrated catechin preparations raise concern [16]. Caffeine may affect sleep and heart rhythm in sensitive people.
Coffee	Caffeine, chlorogenic acids, roasting-derived compounds	Alertness; extensively studied for liver, metabolic and mortality outcomes	A/B	Habitual caffeine intakes up to 400 mg/day (single doses up to 200 mg) are not of safety concern for healthy adults [17]. An umbrella review found largely beneficial or neutral associations at usual intakes but possible harm in pregnancy [18]; associations are observational and may be confounded. Coffee itself is unclassifiable as to carcinogenicity, whereas very hot beverages (>65 °C) are probably carcinogenic [19,20].
Cocoa	Flavanols, theobromine, fat, minerals	Flavanols studied for vascular function; chocolate is also an energy-dense food	A	EFSA accepted a relation between defined cocoa-flavanol intake and normal endothelium-dependent vasodilation [21]. A Cochrane review found a small short-term blood-pressure reduction [22]. In a large trial of cocoa-extract flavanols, total cardiovascular events were not significantly reduced, although cardiovascular death was lower in a secondary analysis [23]. Alkalisation reduces flavanols [24]; sweetened chocolate is not equivalent to standardised flavanol preparations.
Natural rubber latex	Latex proteins and polymer	Medical gloves, catheters and devices; not a medicinal food	A	Latex proteins can cause immediate (IgE-mediated) allergy; reported prevalence is about 10% in healthcare workers, 7% in susceptible patients and 4% in the general population [25]. Non-latex alternatives are essential for sensitised individuals.
Palm oil	Palmitic and oleic acids; carotenoids and tocotrienols (red palm oil)	Cooking oil; red palm oil is a provitamin-A source	A	A meta-analysis of dietary trials found both favourable and unfavourable lipid-marker changes depending on the replaced fat [26]; composition and health aspects are reviewed in [27]. Refining reduces carotenoids; process contaminants (3-MCPD, glycidyl esters) are a safety consideration [28,29].
Coconut oil	High saturated-fat content, especially lauric acid	Food and topical products; marketed for many health claims	A/E	Trials show higher LDL cholesterol than with non-tropical vegetable oils [30]. Lowering saturated fat reduces cardiovascular events [31]. The American Heart Association advises against its use for this reason [60]; promoted therapeutic claims are not supported.
Sugarcane	Sucrose; molasses with variable minerals	Energy source; molasses in food and fermentation	A	Free sugars above WHO-recommended limits increase dental caries risk and energy intake [32–34]. Sugar is not a therapeutic product.

Product	Relevant constituents / plausible effects	Medical or health-related use	Evid. level	Evidence and cautions
Pepper, cardamom, clove	Piperine, terpenes, eugenol and other volatiles	Traditional digestive, oral and aromatic uses; eugenol in dental preparations	C/D	Piperine increased curcumin bioavailability in human volunteers [35], illustrating potential for interaction with drug absorption. Clove oil is dominated by eugenol [36]; concentrated oils can irritate and are toxic if misused. Clinical evidence for most traditional uses is limited.
Vanilla	Vanillin and other aroma compounds	Flavouring and fragrance	D/E	Little direct medicinal evidence; claims beyond flavour and aroma lack robust clinical support.
Cashew	Unsaturated fats, protein, minerals; phenolic shell liquid	Nutrient-rich food; shell liquid used industrially	A	Tree nuts, including cashew, are major regulated allergens [37]; allergy can be severe. Shell liquid is a caustic irritant and is not an edible material.

Evidence levels (Evid.) A–E follow the scheme in Section 2.3 and Figure 4 are assigned judgements for narrative synthesis, not formal GRADE ratings; where two letters are given, evidence differs by outcome (for example, A/E for coconut oil indicates an established lipid effect alongside commercially promoted claims). Table 5 assigns the main statements to the four categories.

Table 5. Classification of the main health-related statements for each plantation product into established, preliminary, traditional and commercially promoted categories.

Product	Established benefits or risks (Level A)	Preliminary findings (Levels B–C)	Traditional use (Level D)	Commercially promoted claims (Level E)
Tea	Caffeine content and dose-based safety limits [17]; rare liver injury with concentrated green-tea catechin preparations [16].	Cardiometabolic and polyphenol-intake benefits from observational and short-term data; for several catechin-related claims, including blood pressure, EFSA concluded that cause and effect had not been established [15].	Long-standing use as a stimulating and digestive beverage in many cultures.	Weight-loss, “detox” and immunity claims for tea blends and green-tea extracts; to be checked against authorised claims [15,57].
Coffee	Habitual caffeine intake up to 400 mg/day (single doses up to 200 mg) is not of safety concern for healthy adults [17]; very hot beverages (>65 °C) are probably carcinogenic [19,20].	Observational associations with liver, metabolic and mortality outcomes, possibly confounded; possible harm in pregnancy [18].	Traditional stimulant and digestive uses in several coffee-drinking cultures.	“Detox”, colon-cleansing and slimming claims for coffee products and extracts.
Cocoa	Defined cocoa-flavanol intake and normal endothelium-dependent vasodilation (EFSA) [21]; small short-term blood-pressure reduction [22].	Prevention of cardiovascular events: total events not significantly reduced in COSMOS, with lower cardiovascular death in a secondary analysis [23] (hypothesis-generating).	Historical medicinal and ceremonial use of cacao beverages in Mesoamerica.	“Superfood” and “heart-healthy” claims for ordinary sweetened or alkalised chocolate and cocoa powder, which are not equivalent to standardised flavanol preparations [24].
Natural rubber latex	Immediate (IgE-mediated) latex allergy in exposed groups [25].	—	—	—
Palm oil	Blood-lipid effects depend on the fat replaced [26]; refining contaminants (3-MCPD, glycidyl esters) are a safety consideration [28,29].	Benefits of tocotrienols and red palm oil beyond provitamin-A supply rest largely on mechanistic or short-term data [27].	Long-standing food and traditional use in West and Central Africa.	“Heart-healthy”, “antioxidant-rich” and “natural” positioning of palm products and tocotrienol supplements.

Product	Established benefits or risks (Level A)	Preliminary findings (Levels B–C)	Traditional use (Level D)	Commercially promoted claims (Level E)
Coconut oil	Raises LDL cholesterol relative to non-tropical vegetable oils [30]; the American Heart Association advises against its use for this reason [60]; lowering saturated fat reduces cardiovascular events [31].	Other proposed benefits (for example for weight, metabolism or skin) rely on small, short-term or mechanistic evidence, and no offsetting favourable effect is established [30,60].	Central to traditional diets and topical practices in South and Southeast Asia and the Pacific.	"Superfood", immunity, weight-loss and disease-prevention claims; public perception of coconut oil as healthy is not matched by its LDL effect [60].
Sugarcane products	Free sugars above WHO-recommended limits raise dental-caries risk and energy intake [32–34].	Mineral or antioxidant content of unrefined products (jaggery, molasses) is compositional; no outcome trials were identified in the sources reviewed.	Jaggery and molasses in traditional diets and remedies, including digestive uses.	"Healthy", "natural" or "detox" sugar-alternative claims for jaggery, raw and brown sugar.
Pepper, cardamom, clove	Composition (clove oil is eugenol-dominated [36]); concentrated oils can irritate and are toxic if misused; clinical evidence for most uses is limited.	Piperine raised curcumin bioavailability in a small human-volunteer study, indicating potential interaction with drug absorption [35]; antioxidant and antimicrobial findings are largely in-vitro or animal.	Digestive, oral, warming and aromatic uses in traditional medicine systems.	"Immunity-booster", "detox" and "fat-burner" claims for spice extracts, oils and blends.
Vanilla	Flavouring and fragrance use; no established medicinal effect identified.	Isolated-compound laboratory findings only; no robust clinical evidence.	Folk uses as an aromatic and tonic in some regions.	Calming, mood-enhancing or "natural remedy" claims for vanilla products and aromatherapy.
Cashew	Tree nuts, including cashew, are major regulated allergens [37]; shell liquid is a caustic irritant and not edible.	Cardiometabolic benefits are reported mainly for tree nuts as a group, from observational and short-term studies, not specifically for cashew.	Traditional folk uses of cashew apple, bark and shell oil in tropical regions.	"Superfood" and plant-based health claims for cashew products.

Entries summarise the evidence cited in Table 4 and Section 6.1; each refers to the stated constituent, dose and outcome. A dash indicates that no relevant statement was identified in the sources reviewed. Traditional-use entries describe documented practice only and are not endorsements of efficacy or safety.

Several themes cut across products. First, the strongest evidence concerns specific constituents at defined doses (caffeine, standardised cocoa flavanols, saturated fatty acids) rather than whole commodities, and results for a refined extract cannot be extrapolated to a food, or vice versa [17,21,23]. Second, safety signals sometimes accompany claimed benefit, as with concentrated green-tea catechins [16] and piperine-mediated absorption changes [35]. Third, nutritional context matters: the cardiovascular effect of palm or coconut oil depends on the fat it replaces [26,30,31]. Finally, health communication should separate established effects, preliminary findings, traditional use and commercial claims, and should state safety alongside efficacy.

6.3 Implications for health communication

Practical wording rules follow from these categories. Established effects can be stated directly, with the constituent, dose, population and outcome (for example, defined cocoa-flavanol intake and endothelium-dependent vasodilation [21]). Preliminary findings should be reported as associations or possibilities, with the study design and its limits stated (for example, observational associations between coffee intake and health outcomes [18]). Traditional uses should be described as traditional, without implying efficacy, and with safety caveats where concentrated products are involved. Commercial claims should not be repeated as fact; they should be checked against authorised claims and primary evidence [57], and where the evidence contradicts them, as with the lipid effects of coconut oil, this

should be stated [30,60]. Reviewers, editors and readers can use the same four-category screen when appraising health content in food, trade and policy documents.

7. Adulteration, substitution and authenticity

Adulteration may be intentional (economic fraud) or accidental (contamination or poor handling), and can occur at raw-material, processing, bulk-trading or retail stages [7,9]. Public-health consequences vary from none (simple dilution) to severe when the adulterant is toxic, as in the melamine and illegal-dye cases that underpin the EMA literature [8,9]. A method that detects a foreign material does not establish intent; enforcement generally requires chain-of-custody evidence and legal definitions [7]. Table 6 summarises reported or plausible concerns, screening and confirmation approaches and interpretive cautions by commodity. Documented cases for each crop vary widely: records for tea, coffee, spices and vanilla appear in fraud databases and reviews [8,14,38], whereas peer-reviewed incidence data for some products (for example cashew) are limited.

Table 6. Adulteration and authenticity concerns, detection approaches and interpretive cautions.

Commodity	Reported or plausible concerns	Useful screening / confirmation approaches	Interpretation cautions
Tea	Spent leaves, undeclared added colour, foreign leaves and stems, misrepresented origin or grade [8,38]	Visual inspection, microscopy, moisture and ash tests, targeted dye analysis by chromatography, DNA barcoding for botanical identity [39,40]	Natural variation in leaf size and colour complicates visual-only decisions
Coffee	Roasted cereals, chicory or husks as fillers; low-grade beans sold as premium; species or origin mislabelling [8,38]	Microscopy, NIR/FTIR, chromatography, DNA methods where feasible, stable isotopes for some origin questions [39,41]	Roasting degrades DNA and alters chemical fingerprints; no single test solves all fraud
Cocoa / chocolate	Substitution with cheaper fats, undeclared vegetable fats, shell addition, origin or percentage mislabelling	Fatty-acid and triacylglycerol profiling, microscopy, NMR/FTIR [39,41]	Permitted non-cocoa vegetable fats and labelling rules differ by jurisdiction [42]
Palm and coconut oils	Blending with cheaper oils; mislabelled virgin or refined status, species or origin	Fatty-acid and sterol profiles, GC-FID, FTIR/NIR, authenticity databases [39,43]	Composition varies with cultivar and processing; reference databases must capture real variability
Sugar products	Syrup or beet-sugar substitution, undeclared sweeteners in products sold as pure cane sugar	Stable-isotope ratio analysis (C4 cane versus C3 sources), sugar profiling, NMR, traceability audits [39,44]	This is a general sweetener-authenticity issue and does not imply that cane sugar is commonly adulterated
Spices (pepper, cardamom, clove)	Exhausted spices, foreign matter, starch or mineral additions, illegal dyes, species substitution [14]	Microscopy, total and acid-insoluble ash, volatile-oil content, TLC/HPTLC, HPLC/GC-MS, elemental analysis, DNA barcoding [40,45–47]	Tests flag non-conformity but cannot alone establish deliberate fraud
Vanilla	Synthetic vanillin sold as natural vanilla; dilution or substitution in extracts [14]	GC-MS aroma profile, isotope-ratio mass spectrometry, NMR, documentary traceability [39]	Synthetic vanillin is not inherently unsafe; misrepresentation as natural is a labelling issue
Cashew	Broken or low-grade kernels sold as whole grade, excess moisture, foreign matter, origin or grade mislabelling	Visual grading, moisture and defect tests, microscopy, supply-chain audits	Grade substitution is economically fraudulent even when it is not a chemical hazard

Concerns are those reported in the cited fraud databases and reviews or plausible given supply-chain structure; the table does not rank commodities by incidence.

8. Contaminants and safety hazards distinct from adulteration

Authenticity fraud should be distinguished from food-safety contamination. Plantation products may carry pesticide residues, heavy metals, mycotoxins, polycyclic aromatic hydrocarbons (PAHs), mineral-oil hydrocarbons, microbial hazards or processing contaminants depending on crop and conditions. Foodborne hazards impose a major global disease burden [48], and maximum levels and residue limits are set by Codex and by regional law [49–51]. Table 7 lists illustrative hazard–commodity pairs. Risk assessment requires representative sampling, validated analytical methods, applicable maximum limits and exposure estimates.

Table 7. Illustrative contaminant and process-hazard concerns in plantation products and their regulatory or risk-assessment basis.

Hazard	Commodities commonly implicated	Nature of concern	Basis (examples)
Cadmium	Cocoa and cocoa products	Soil uptake in some growing areas; dietary exposure of consumers of cocoa-rich products	EFSA cadmium opinion [52]; regional maximum levels [50]
Ochratoxin A	Coffee (and some spices)	Mycotoxin formed by moulds during drying and storage	EFSA risk assessment [53]; maximum levels [50]
3-MCPD, 2-MCPD and glycidyl esters	Refined palm and other vegetable oils	Process contaminants formed at high refining temperatures	EFSA opinions [28,29]
PAHs	Smoke-dried copra and some cocoa beans; coconut oil	Formed during smoke drying or combustion	Maximum levels [49,50]
Pesticide residues	All crops, especially spices and tea	Application practices and import tolerances	Residue-limit legislation [51]
Illegal dyes and microbial contamination	Spices	Colour fraud and pathogens in dried products	Spice-fraud review [14]; burden of foodborne disease [48]

Entries are illustrative and not exhaustive. Maximum levels change; consult the current version of each regulation.

9. Analytical toolkit for quality assurance

Detection of adulteration combines classical quality tests with modern fingerprinting. Table 8 compares the main approaches. Sampling is as important as analysis: heterogeneous adulterants can be missed by a single grab sample, so lot definition, number of increments, composite and retention samples and chain of custody should be specified before testing. Spectroscopic fingerprints (FTIR, NIR, Raman, NMR) can screen rapidly but need representative reference sets and independent validation [39,41]. DNA-based tools verify botanical identity, though processed or roasted materials contain fragmented DNA and mixtures need careful interpretation [40]. Isotopic and elemental methods can support selected origin or syrup-adulteration investigations but are not universal origin detectors [39,44]. Figure 5 sets out a staged decision pathway that integrates screening, confirmation, reference comparison and documentary investigation, consistent with a risk-based governance approach that combines laboratory results with supplier audits, mass balance, transaction records and enforcement [7,43].

Table 8. Analytical approaches for authenticity and quality assurance of plantation products.

Approach	Typical targets	Strengths	Limitations
Quality tests (moisture, ash, acid-insoluble ash, volatile oil, foreign matter)	Spices, tea, cashew, cocoa; general conformity [45–47]	Inexpensive, standardised, widely accredited	Detect non-conformity rather than specific adulterants
Microscopy	Fillers, foreign plant matter, exhausted material	Rapid; low cost; direct visual evidence	Requires expertise; limited for ground or highly processed material
Chromatography (HPLC/UPLC, GC-MS, GC-FID)	Dyes, marker compounds, volatile oils, fatty acids, sterols [41,43]	Sensitive, selective, quantitative; recognised confirmatory methods	Needs reference standards and trained operators; targeted methods miss unexpected adulterants
Vibrational spectroscopy (FTIR, NIR, Raman)	Fingerprints for oils, coffee, spices, sugar [39,41]	Rapid, non-destructive, field-portable options	Needs representative reference sets and independent validation; model transfer is difficult
NMR	Oils, sugars, vanilla, complex mixtures [41]	Untargeted fingerprint; quantitative	High instrument cost; databases still limited
Stable isotopes and elemental analysis (IRMS, ICP-MS)	Sugar source, vanillin origin, geographic provenance [39,44]	Can address origin and syrup-adulteration questions	Not universal origin detectors; need regional baselines
DNA barcoding and targeted PCR	Botanical identity and substitution [40]	Species-level specificity	Fragmented DNA in processed materials; mixtures and quantification are difficult
Traceability and documentary audit	Origin, mass balance, supplier verification [7]	Addresses intent and chain of custody	Depends on record integrity; complements rather than replaces testing

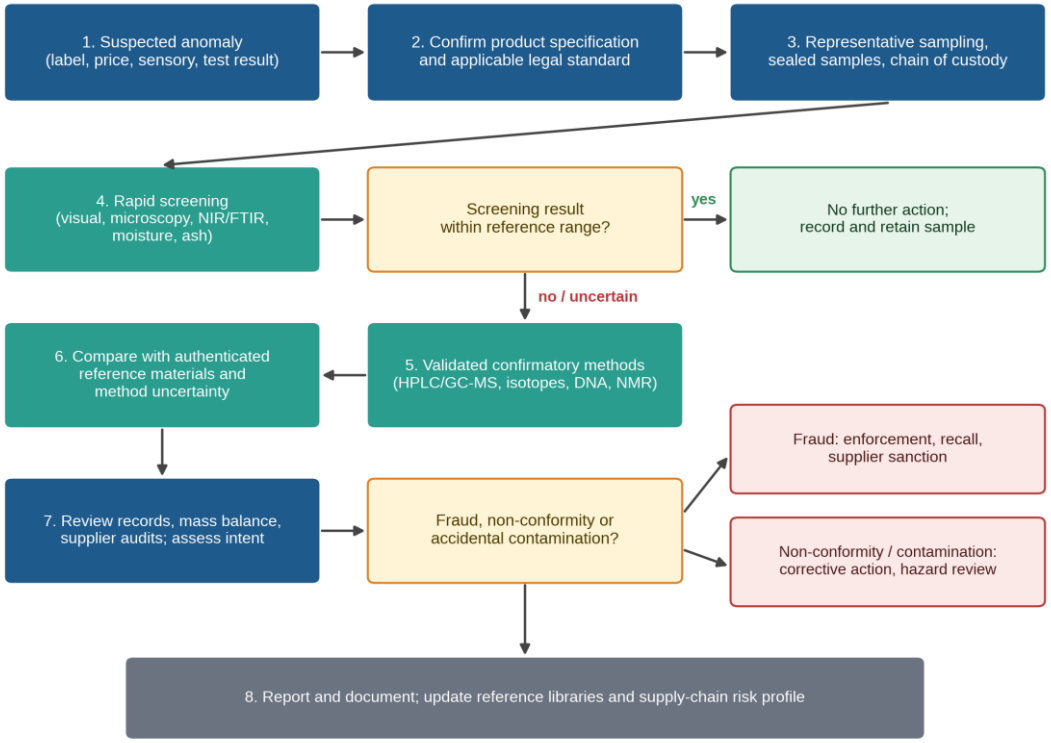


Figure 5. Decision pathway for investigating suspected adulteration, from initial anomaly to enforcement or corrective action. Conceptual workflow.

10. Environmental, social and economic considerations

Plantation supply chains face linked challenges: land-use change, biodiversity loss, water and agrochemical management, labour rights, smallholder income, price volatility and climate vulnerability. Oil-palm expansion has been associated with deforestation and biodiversity loss in some landscapes [54], while natural-rubber expansion has raised similar concern in Southeast Asia [55]; impacts differ substantially with location, prior land use and management. Rubber and cocoa systems range from monoculture to agroforestry. Certification can improve transparency but does not replace credible monitoring, fair purchasing practices or enforcement. Regulatory instruments such as the European Union deforestation regulation, which covers cocoa, coffee, oil palm and rubber among other commodities, add traceability requirements whose application dates have been revised and should be checked at the time of use [56].

Climate stress is particularly important for perennial crops because trees cannot be rapidly replanted or shifted without cost; heat, drought, irregular rainfall and disease affect yield and quality, and the resulting price spikes can create incentives for substitution and fraud [9,12,13]. Diversified agroforestry, resilient planting material, soil cover, integrated pest management, post-harvest training and accessible testing infrastructure can reduce some risks.

11. Research gaps and recommendations

1. Build open, representative spectral and chemical reference libraries covering cultivars, origins, seasons, processing methods and legitimate variation [39,41].
2. Publish commodity-specific price charts with transparent units, currency, grades and data-access dates rather than undated prices [10].
3. Strengthen inter-laboratory validation of portable NIR/FTIR devices and chemometric models used in field screening [39].
4. Separate established benefits and risks, preliminary findings, traditional uses and commercially promoted claims, and state the evidence level, in consumer-facing health communication and trade documents [16,21,57].
5. Invest in smallholder access to testing, digital lot traceability, independent audits and grievance mechanisms [14].
6. Report uncertainty and false-positive and false-negative rates, and use multiple orthogonal tests for high-consequence enforcement decisions [44].

12. Limitations

This review has several limitations. It is narrative and non-systematic, so some relevant studies may have been omitted and selection bias is possible. The evidence levels and the assignment of statements to the four categories are author-assigned judgements; commercially promoted claims were identified from the regulatory opinions and reviews cited and not from a systematic survey of marketing, and regulatory conclusions (for example EFSA opinions) apply to specific constituents, wording and jurisdictions. Fraud-incidence information derives largely from databases, trade reports and reviews that are subject to reporting bias, and commodity-level incidence rates cannot be inferred from Table 6. Price data are nominal benchmark series, not retail or farm-gate prices; they were not adjusted for inflation, and the palm-oil series changed in January 2026. Regulatory limits and application dates change and should be verified at the time of use.

13. Conclusions

Plantation products are diverse commodities whose roles extend from everyday foods and beverages to industrial materials and selected health-related applications. Price cannot be represented by one universal figure: between 2022 and 2026 the benchmark cocoa and coffee prices moved by tens of percent within a few quarters, while rubber and palm oil rose and sugar fell, and each series refers to a specific product, market and unit. Established benefits and risks must be kept distinct from preliminary findings, traditional uses and commercially promoted claims, because a constituent's biological activity, a traditional use or a marketing assertion does not establish a safe and effective treatment. Adulteration control is strongest when validated analytical methods are integrated with representative sampling, authenticated reference materials, traceability and regulatory oversight. A responsible global approach

should improve authenticity and consumer safety while addressing climate resilience, environmental impacts and fair livelihoods.

Declarations

Author contributions:

The author contributed to the conceptualisation of the review, visualization, identification and collection of relevant literature, examination of global plantation commodity uses and markets, critical evaluation of health-related claims, assessment of adulteration and quality concerns, manuscript drafting, critical revision, and approval of the final version.

1. Use of AI-Assisted Tools

AI-assisted tools were used in the preparation of this manuscript for literature organisation, refinement of the review structure, language editing, and improvement of the presentation of scientific information. The author critically evaluated, verified and edited the AI-assisted content and takes responsibility for the accuracy, originality, integrity and final content of the manuscript.

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3. Conflict of Interest

The author(s) declare that there are 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, publicly available reports and secondary information. No experiments involving human participants or animals were conducted.

5. Informed Consent

Not applicable. This review does not involve human participants, patient records or personally identifiable information.

6. Data Availability Statement

No new experimental data were generated or analysed for this review. All information discussed in the manuscript is derived from previously published research articles, scientific databases, institutional reports, market publications, and other publicly accessible sources, which are appropriately cited in the text and reference list.

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