Food Security
https://doi.org/10.1007/s12571-026-01657-6

RESEARCH

Prediction of nutritional impact of the mango sector in Côte d'Ivoire: past, present and future

Aurélie Bechoff[1] · Mary Nkongho Tanyitiku[1] · Jean-Mathias Konan Koffi[2] · Yardjouma Silue[3,4,5] · Ery Marilyne Christina Hien[2,5] · Eric Malézieux[6,7] · Emile Faye[6,7] · Victoria Bancal[8,9,10] · Claudie Dhuique-Mayer[8,10]

Received: 19 May 2025 / Accepted: 21 January 2026

Abstract

Mango is an important tropical fruit, rich in essential micronutrients. In Côte d'Ivoire, the harvested fruit is either exported to international and regional markets, processed, or remains on the local market. Nutritional flows across value chains and their resulting nutritional impact are poorly understood. The purpose of this study was to estimate the past, present, and future nutritional impact of the mango value chain in Côte d'Ivoire. We adapted the NUTRI-P-LOSS methodology that predicts nutritional postharvest losses across crop value chains, to assess nutritional flows in the mango value chain. Mango production quantities were estimated, and fruits at harvest, during ripening, and after drying, were analysed for macro- and micronutrients. Findings indicate that mango domestic nutritional contribution is likely to increase in the future, helping address vitamin A and C deficiencies and anaemia related-issues that remain prevalent, particularly among vulnerable groups such as children under five, pregnant teenagers and women (*i.e.* meeting requirements for vitamin C, from approximatively 60,000 people in 2000, to 1 million people in 2050). Whilst vitamin A is concentrated in dried mango, vitamin C—the fresh fruit's primary micronutrient—is lost in drying. Therefore, increased domestic consumption of dried mango would increase vitamin A from mango but not improve the overall nutritional impact of mango on the local population (vitamins A and C, iron). Our work leads to the development of a user-friendly tool that predicts the past, present, and future nutritional impact of crop production with mango in Côte d'Ivoire as an example.

Keywords Nutrient flow · Postharvest · Value chain · Nutritional requirements · Prediction models · Mango

1 Introduction

Côte d'Ivoire, like other African countries, faces the triple burden of malnutrition—coexistence of undernutrition, micronutrient deficiencies, and overweight or obesity. According to the Global Hunger Index (2024), Côte d'Ivoire's food security situation remains fragile. Approximately 23% of children under five are stunted, 8%

✉ Aurélie Bechoff
a.bechoff@gre.ac.uk; aureliebechoff@hotmail.com

1 Natural Resources Institute, University of Greenwich, Chatham, UK

2 Université Jean Lorougnon Guédé, Daloa, Côte d'Ivoire

3 South African Research Chairs Initiative in Sustainable Preservation and Agroprocessing Research, Faculty of Science, University of Johannesburg, Auckland Park 2006, South Africa

4 Postharvest and Agroprocessing Research Centre, Department of Botany and Plant Biotechnology, University of Johannesburg, Auckland Park 2006, South Africa

5 Centre Suisse de Recherches Scientifiques (CSRS), Abidjan, Côte d'Ivoire

6 Centre de Coopération Internationale en Recherche Agronomique Pour Le Développement (CIRAD), UPR HortSys, 34398 Montpellier, France

7 HortSys, Univ Montpellier, CIRAD, Montpellier, France

8 CIRAD, UMR Qualisud, Abidjan, Côte d'Ivoire

9 UFR Sciences Et Technologies Des Aliments, Université Nangui Abrogoua, Abidjan, Côte d'Ivoire

10 Qualisud, Univ Montpellier, Avignon Université, CIRAD, Institut Agro, Université de La Réunion, Montpellier, France

Published online: 03 March 2026

are wasted, and 10% of the population is undernourished (Jesson et al., 2021). Despite 89% of children being covered by vitamin A supplementation in Côte d'Ivoire (Global Nutrition Report, 2022), figures show that around 60% of 6–59 months-old children are vitamin A deficient (Santé Côte d'Ivoire, 2018). Iron deficiency is largely responsible for about 80% and 66% of anaemic cases in children under five years old, and women of childbearing age, respectively (DHS, 2021; FAO, 2022; Jesson et al., 2021; Rohner et al., 2016). The prevalence of obesity (17.8%) among women in Côte d'Ivoire (vs. 7.3% among men) is a growing concern, particularly in urban areas. Overnutrition is associated with non-communicable diseases such as diabetes (7.2% of women and 8.5% of men in Côte d'Ivoire) (Global Nutrition Report, 2022). Dietary diversity remains low: minimum dietary diversity (MDD) score was 23.7% (DHS, 2021), principally due to limited consumption of essential micronutrients, i.e. from fruits and vegetables (Engidaw et al., 2023; Giller & Zingore, 2021; Prieto-Patron et al., 2020) (MDD is defined as the percentage of children aged 6–23 months who consumed the previous day foods and drinks from at least 5 of the 8 defined groups). This issue may stem from the inaccessibility or unaffordability of fresh produce during off-season periods, particularly for those with limited financial resources (Faye et al., 2024). A holistic approach (education, policy changes, physical activity) and greater access to healthier foods such as local fruits and vegetables could contribute to reducing the prevalence of the triple burden of malnutrition in Cote d'Ivoire.

Mango (Mangifera indica L.) is a seasonal fruit widely grown in tropical and subtropical countries for its economic and nutritional benefits (Halder et al., 2024; Neguse et al., 2019). It is rich in essential micronutrients such as vitamin C (ascorbic acid improves bioavailability of iron and increases its intestinal absorption), provitamin A carotenoids, as well as fibres that could help reduce obesity (Guiamba, 2016; Lauricella et al., 2017; Yahia et al., 2023). Its consumption could help lower macro and micronutrient deficiencies common in low-income countries (Guiamba, 2016; Lauricella et al., 2017; Neguse et al., 2019). Mango is often called the 'king of fruits' as it ranks as the second most popular tropical fruit and the fifth most consumed fruit globally, after citrus, bananas, grapes, and apples (Halder et al., 2024; Neguse et al., 2019; Normand et al., 2015; Yusuf et al., 2019). With an annual production approximating 1.4 metric million tonnes (t) annually in West Africa, mango is one, if not the only fruit able to satisfy the greater part of the population demand and need at peak production in dry savannas areas (Sidibe, 2023).

Côte d'Ivoire is the largest exporter and one of the largest producers of mangoes in sub-Saharan Africa, with an annual production ranging between 140,000 and 160,000 t (CBI, 2019; Innovations, 2021; Neguse et al., 2019). In fact, it is the third largest mango supplier to the European Union after Brazil and Peru, which accounts for 4% of the country's national GDP and 10% of its agricultural GDP (Grumiller et al., 2018; Kouakou et al., 2024; Pugnet, 2024). Mango cultivation is now widespread across Côte d'Ivoire, with the commercial production concentrated in the northern regions around Korhogo, 600 km from the port of Abidjan, the country's economic capital. In Korhogo, 2,050 mango producers and 200 exporters are listed (Kouakou et al., 2024). Most common varieties are Kent, Keitt, and Amélie. Kent variety is the variety commonly sent for export because of its taste and low moisture content that confers it longer shelf life than other varieties (Koffi et al., 2021). Each year the starting date of the exportation 'campaign' or season is officially set by the Ministry of Agriculture that also helps fix mango price. The 'campaign' closure date depends on climatic conditions (rainfall) that favour pest infestation (i.e. fruit fly). Whilst Mango harvesting and selling spans from March to July, the exportation 'campaign' is usually limited from March/April to May. Total mango tree cultivated area for Côte d'Ivoire is around 20,000 ha, corresponding to currently 140,000 and 60,000 t per year in high and low-mango seasons, respectively (biannual bearing) (Koffi et al., 2023).

When mangoes are harvested, they go through postharvest processes such as maturation, pretreatments, drying as well as diverse storage and transportation conditions that could affect their nutritional value (Diop et al., 2021). Handling, packaging, transportation, storage, and processing, mostly without any temperature or humidity control along the Ivorian supply chains, further contribute to mango spoilage, accounting for approximately 30% of postharvest losses, and could affect the fruit's nutritional composition (FAO, 2019; Guiamba, 2016; Yahia et al., 2023). Mangoes are highly sensitive to unpredictable climatic conditions such as extreme heat, drought, and vapour pressure deficit. These stresses cause rapid stomatal closure, which negatively affects photosynthesis (Halder et al., 2024; Normand et al., 2015; Yahia et al., 2023). Fruit flies *Bactrocera dorsalis* are more prevalent with climate change due to irregular weather according to local farmers in Côte d'Ivoire (Yeo et al., 2022). The presence of fruit fly in African mango producing countries affects mango production and exports, as great economic losses can be supervened due to quarantine restrictions and loss of export opportunities to countries, where this fruit fly is under regulation, especially Europe (Mutamiswa et al., 2021).

Mango is one of the most consumed fruits in Côte d'Ivoire, following oranges and matching the popularity of papaya, avocado, banana, and pineapple in the capital city, Abidjan. The population boom in Côte d'Ivoire stimulates demand for fresh fruit on the local market (Yogone et al., 2024).

Postharvest nutritional flows and losses during such processes, and the nutritional and health significance of mango consumption especially to the local population in developing countries remain under-researched. Our study uses a predictive model based on in-country collected nutritional data and production quantities to examine how mango production translates into nutritional flows and assesses its nutritional impact on the population in Côte d'Ivoire. This novel approach aims to understand the impact of the mango value chain on food security. The same approach could be applied to assess the nutritional impact to other crops and commodities on local populations' food security in various countries or regions, and help map the relative food security contribution of commodities grown in-country versus those imported or exported. The goal is to make local commodity value chain more nutrition-sensitive and resilient in the future.

2 Materials and methods

2.1 Data and sample collection

The study was carried out between May and June 2023 in Korhogo, Côte d'Ivoire. Fruit samples were collected twice during mango season: early in the season (month of May) of the 'campaign' (season 1) and late in the season (end of June) of the 'campaign' (season 2) for mangoes of the year 2023.

Mangoes were followed at different stages of maturation and processing along the value chain: harvested fruits at commercial maturity (physiological green maturity) from a commercial mango orchard (originated from the same harvest lot and from the same orchard) were transported to a local processing unit (dried mango value chain) or a distant market (Abidjan) (fresh value chain). Experimental design and food composition analysis are described in detail in Aka (2024). Nutritional data were obtained from the most common cultivar: Kent and from the most important producing area: Korhogo (Poro region).

At each stage, nine mangoes were randomly selected and divided into three lots of three mangoes (3×3 for biological and analytical replications) (Fig. 1). These stages were the following: (A) Harvest stage (green mango); (B) After two days of storage in ripening chamber; (C) Ripe mango (at day 6 for early season and day 4 for late season); and (D) Dried mango after oven drying. The drying was conducted at a semi-industrial drying unit (Dryers for Africa CD1500, South Africa) set at 65°C for 18 to 24 h (cooperative Gninnangnon, Korhogo). To simulate local transport, a batch of green fruits (E) were packed by wholesalers in cardboard and loaded in a non-refrigerated commercial trailer truck that took around 36 h to travel from Korhogo to the Abidjan market.

Upon collection, fresh mango fruits were then manually washed with running water. Whole fruit mass was measured at the laboratory of Biochemistry and Food Technology at the Université Peleforo Gon Coulibaly, Korhogo. Skin and stones of the mangoes were discarded, and edible weight was calculated. Mangoes were sliced, labelled, and aseptically packed in freezer bags, and stored at—80 °C. Sliced and frozen samples were transported frozen in a cool box, one week later, to the Centre Suisse de Recherches Scientifiques (CSRS), Abidjan to conduct biochemical analysis, sample slices were thawed and homogenised using an electric Binatone blender (Oakland & Johnson, London).

2.2 Mango nutritional composition analysis

Collected samples were analysed for both macro- and micronutrients. All nutritional analyses were conducted in triplicate on the three lots of three mangoes collected.

Dry matter, total fats and crude proteins were determined according to AOAC (1990). Fibre content was measured by Soxhlet extraction according to Wolff (1968). Total sugars and starch were determined by spectrophotometry based on Dubois et al. (1956) and Jarvis and Walker (1993), respectively. Vitamin C was measured using iodine colorimetric titration, as described by Benhidi (2016). Mineral analysis (Iron, Zinc, Calcium, Phosphorus, Potassium, Magnesium, Sodium) was conducted using X-ray fluorescence analyser (MESA-50) at the University of Man, Côte d'Ivoire.

Provitamin A was analysed at the French Agricultural Research Centre for International Development (CIRAD), France: frozen pureed and dried samples were shipped from the CSRS, Abidjan, under ice and remained frozen until their arrival. Provitamin A carotenoid extractions and HPLC analyses were performed according to the method previously described by di Corcia et al. (2022), which was optimized and applied to mango samples. In brief, 2 g of fresh mangoes or 0.5 g of dried mangoes were extracted with hexane after saponification with KOH to remove ester forms. Subsequently, HPLC analysis was carried out with an Agilent 1100 system equipped with a diode array detector and autosampler. The column used was a C30 YMC column (250×4.6 mm; 5 µm, YMC Europe GMBH, Germany). Vitamin A was expressed as RAE of carotenoids in mangoes (Retinol Activity Equivalent-µg trans-β-carotene/12 and 13-cis-β-carotene/24).

Nutritional data were processed on SPSS 29.0 software for Windows using analysis of variance (ANOVA). Significant differences between data were assessed by a Tukey HSD test ($p < 0.05$).

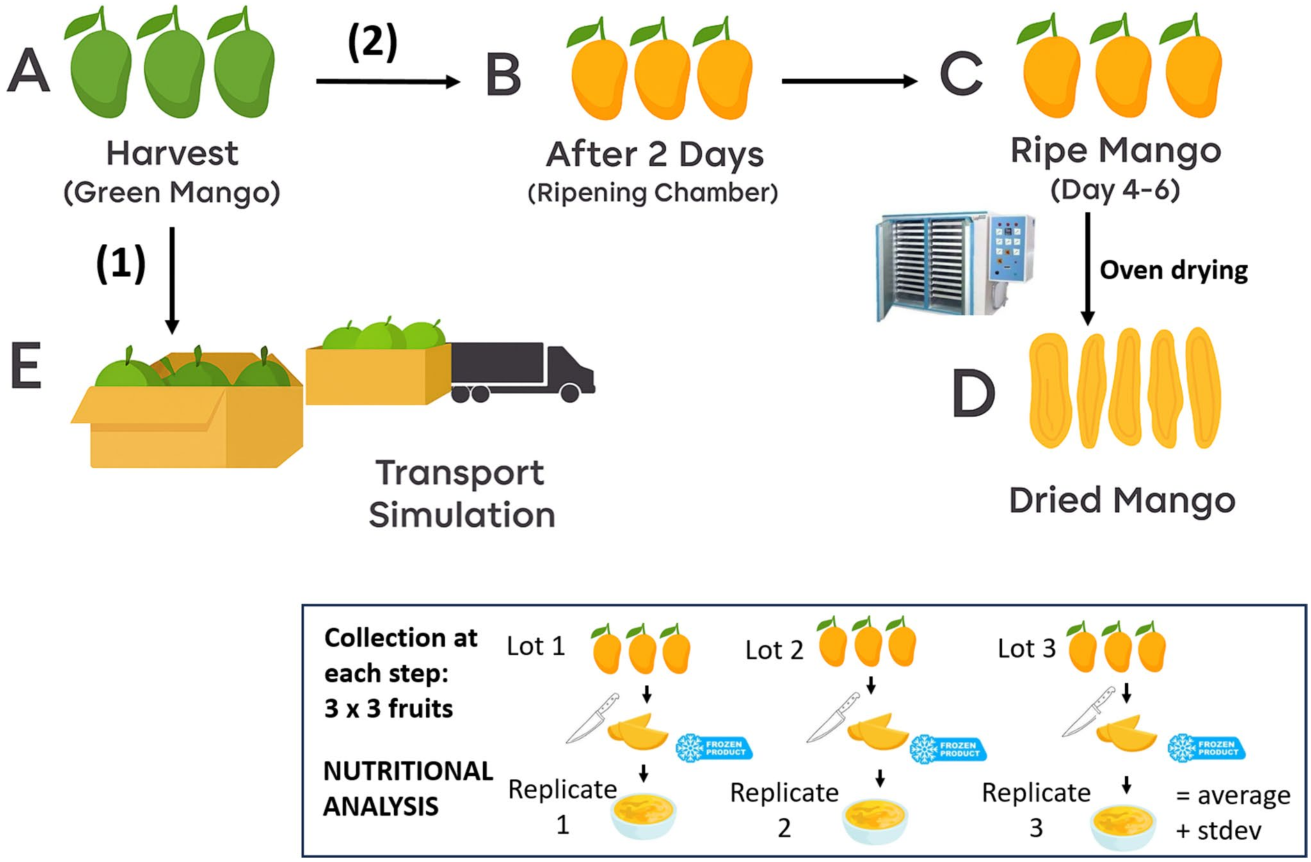

Fig. 1 Experimental design and mango collection along value chain. (1) freshly harvested green mango before and after transport; (2) mango from harvest to drying. Note: the initial collection point is the same for value chains (1) and (2). Letters were added to indicate stage of maturity or processing: A=green mango, B=mango during ripening, C=ripe mango, D=dried mango, E=green mango after local transport from Korhogo to Abidjan. Images of mango fruits A, B, C, D, E were generated using Artificial Intelligence (Copilot) whilst additional images were selected manually from google search. Those images were connected using human intelligence

2.3 Model predictions

Our approach is derived from the NUTRI-P-LOSS (NUTRItional Postharvest Loss) methodology (Bechoff et al., 2022) to estimate nutritional postharvest losses throughout crop value chain (from harvest to market). The tool is an original predictive model that uses a combination of literature, laboratory and field data to predict nutrient loss in staple crops such as maize, cowpea, and sweet potato. It estimates the loss in nutrients due to quantity and quality changes in the food product (e.g. nutrient degradation due to air or temperature oxidation because of extended storage). Key nutrients are energy, protein, and micronutrients such as vitamin A, iron and zinc. NUTRI-P-LOSS aims to provide information about the value chain losses for improving food and nutrition security in developing countries.

In this present study, we used the model to estimate nutritional postharvest flows (rather than losses) and predict scenarios of nutritional impacts. The model builds from robust data on mango production flows from Koffi et al. (2023): value chain actors (n=91) detailed surveys were conducted over a period of 9 months (June 2022 to April 2023) in four leading mango producing towns in northern Côte d'Ivoire (Ferkessédougou, Sinématiali, Korhogo and Boundiali) as part of the SAFOODS project: Koffi et al. (2023) developed a production flow model split into five value chains: the export value chain (60% of mango production from the field), the regional value chain (5%), the processed products (4%), the local value chain (30%), and the household consumption (1%) (Bancal et al., 2024; Koffi et al., 2023) (Table 1).

The nutritional data from mango was collected as described in 2.1 and 2.2. Data on mango production flow was combined with nutritional data from samples at various stages of the value chain: various maturity levels or dried state (A, B, C, D, and E).

A predictive model was subsequently developed (*Supplementary materials*). Predictions of national annual mango production (past, present, future) were made based on data from literature. Quantities of nutrients produced per year per edible part of the mango on a fresh weight basis at the national scale for the different value chains were calculated.

Table 1 Mango Value Chain in Côte d'Ivoire

Mango value chain (country level)	Export	Regional	Processing*	Local (National)	Household consumption
Part of production (%)	60%	5%	4%	30%	1%
Loss during sorting	20.0%	25.0%	25.0%	25.0%	25.0%
Loss during warehouse storage or processing	0.0%	5.0%	0.0%	0.0%	0.0%
Initial stage (start of value chain)	A	A	A	A	A
Final stage at selling point (end of value chain)	B**	B or C	C or D	B or C	B or C

Data were obtained from Koffi et al. (2023); Bancal et al. (2024). Letters were added to indicate stage of maturity or processing: A = green mango, B = mango during ripening, C = ripe mango, D = dried mango, E = green mango after local transport from Korhogo to Abidjan

*Form of processed mango (%): Dried: 94%; Juice: 6%: Puree: 0.1%. Split of the market for processed mango: 79% dried mango exported; 18% dried mango sold regionally; 3% of mango sold locally. 56% juice sold regionally; 44% juice sold locally; 100% of puree sold locally. **on arrival in Europe following shipment

Nutrient estimates calculations were performed on C stage (mature fruit) or D stage (dried fruit) if applied (green mango in stage A or B was considered negligible). To measure the nutritional impact at the population level, those quantities of nutrients were translated into number of people who potentially would have met their daily nutritional requirements using the population-weighted estimated average requirements (EARs), as previously described (Bechoff et al., 2022; Stathers et al., 2018). In brief, the quantities of nutrients, either macronutrients or micronutrients produced at the national scale, were divided by the EARs (per nutrient) of an average person in the population (or specific groups such as children under 5 years old or pregnant women), resulting in calculating the number of people that could have their daily nutritional requirements met for specific nutrients (*Supplementary materials*).

3 Results

3.1 Mango nutrient flows in the various value chains

Nutritional content (provitamin A carotenoids and vitamin C) of mango products at stages A, B, C, D, E at the early and late mango season (Seasons 1 and 2) is described in Fig. 2. Carotenogenesis was observed from stage A to C. In green mango (A) carotenoid content remained low and steadily increased (B) until mango reached ripe stage (C), from 0.1 to 0.5 mg/100g, respectively. The increase was not significant in Season 2, possibly because mangoes collected on the tree (A) were at uneven stages of maturity. In dried mango (stage D) provitamin A was concentrated eight times: from 0.5 mg/100g to 4 mg/100g on average (because of the removal of water) and partly trans–*cis* isomerised: dried mango contained significant amounts of *cis*-isomers (0.8 mg/100g of 13-*cis* and 0.6 mg/100g of 9-*cis*) produced due to heat from the intensive oven drying.

Similarly, vitamin C accumulated during mango ripening (from 4 mg/100g to 12 mg/100g wet basis) on average over the two seasons. However, as opposed to provitamin A, the amount of vitamin C decreased (from 75 mg/100g to 17 mg/100g dry basis) [calculated data not shown on the figure]. There is no significant difference between provitamin A carotenoids and vitamin C before (A) and after local transport (E). After drying (D), vitamin C (on a dry basis) reduced to the same level as A and E stages.

The annual mango production and its nutritional composition is shown in Fig. 3. From an annual mango production of 140,000 t, 60% were for export. The downgraded mango discarded from export (20%) was split into equal quantities distributed to each of the four other value chains, adding 4,200 t per value chain (25%): according to Koffi et al. (2023) (Table 1). This translates as the initial part of export decreasing from 60.0% to 48.1% whilst the other value chains' part increased from 5.0 to 7.8%, 4.0 to 7%, 30.0% to 33.1%, and 1.0% to 4.0% for the regional market, processing, local market, and household consumption, respectively (Fig. 3a). Postharvest losses of mango were quite negligible, according to Koffi et al. (2023) (Table 1): only 0.25% of the total production was lost and this was due to regional sorting (5% of loss); the losses at the other value chains being considered negligible.

Only about 60% of the whole mango weight was available for human consumption due to the skin and stone being removed from a ripe mango (stage C). Therefore, from an annual production of 67,200 t destined to export, approximately 44,000 t were edible, and for regional and local markets from 10,850 t and 46,200 t to 7,127 t and 30,347 t, respectively were edible (Fig. 3b). Also, over 80% of the fruit was composed of water (36,000 t for export, 5,945 t for subregional market, and 23,315 t for local market), with carbohydrates (starch and sugar) accounting for most of the other macronutrients (5,747 t, 928 t, and 3,951 t for export, regional, and local markets, respectively, annually) (Fig. 3c). In terms of quantity, vitamin C was the main

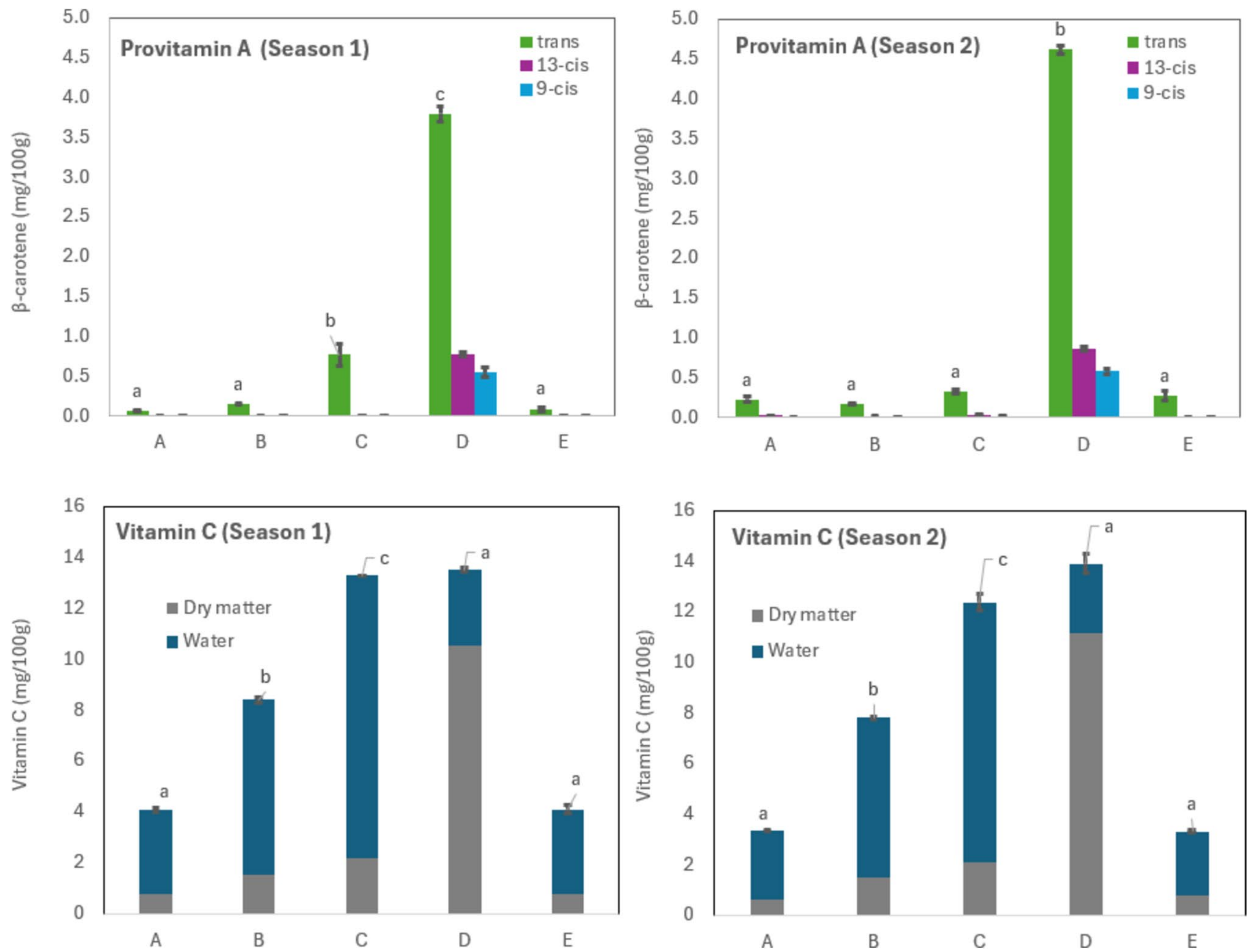

Fig. 2 Provitamin A carotenoids (trans and cis-isomers) and vitamin C contents (fresh weight basis) measured at different steps of the mango value chain. n=3 lots×3 analysis replicate per lot=9 analyses per sample where A=green mango, B=mango during ripening, C=ripe mango, D=dried mango, E=green mango after local transport from Korhogo to Abidjan. Different letters (a, b, c) indicate significant differences in concentrations between the stages (ANOVA, Tukey test; $p<0.05$). Please note that the differences are indicated on a dry weight basis for Vitamin C

micronutrient (e.g. ≈6,000, 900 and 4,000 kg going annually to export, regional, and local markets, respectively), followed by potassium (K) (≈2000 kg, 400 kg, and 1500 kg for export, regional, and local markets, respectively). Vitamin A quantity was in lesser quantities, 21 kg; 3 kg and 15 kg, whilst the amount of fibre was ≈ 100 t, 20 t, and 75 t, for export; regional and local markets, respectively (Fig. 3d).

3.2 Mango nutrient flows: past, present, and future

Ivorian Kent cultivar of mango is majorly destined to export market (i.e. to Europe), and a spillover goes to neighbouring countries (regional market). Finally, over the total mango production, according to our model, slightly more than a third of the mango production (37%) remains in-country (domestic production). This includes the local production (33%), the household consumption (4%) and a negligible part of the processed products (dried, juice, and pureed mango) (0.20%).

Using the predictive model, we estimated the nutritional impact on the Ivorian population of mango domestic production in the past (2000), nearer to the present, when the experiment was conducted (2023), and in the future (2050) (Fig. 4). An observation of the shape of the Ivorian population pyramid reveals that the demographic composition has changed between 2000 and 2023, and is projected to continue aging by 2050, aligning with an Occidentalised demographic trend. The total mango production was approximately 20,000 t in 2000 (COLEACP, 2000) and a much larger production is predicted in the future: 350,000 t in 2050 (FAO, 2024). Here, mango domestic production was kept constant at 37% of total production. As a result, domestic mango production is estimated to have been 7,440 t in 2000, increasing to 52,077 t in 2023, and projected to reach 130,191 t by 2050 (Fig. 4).. In

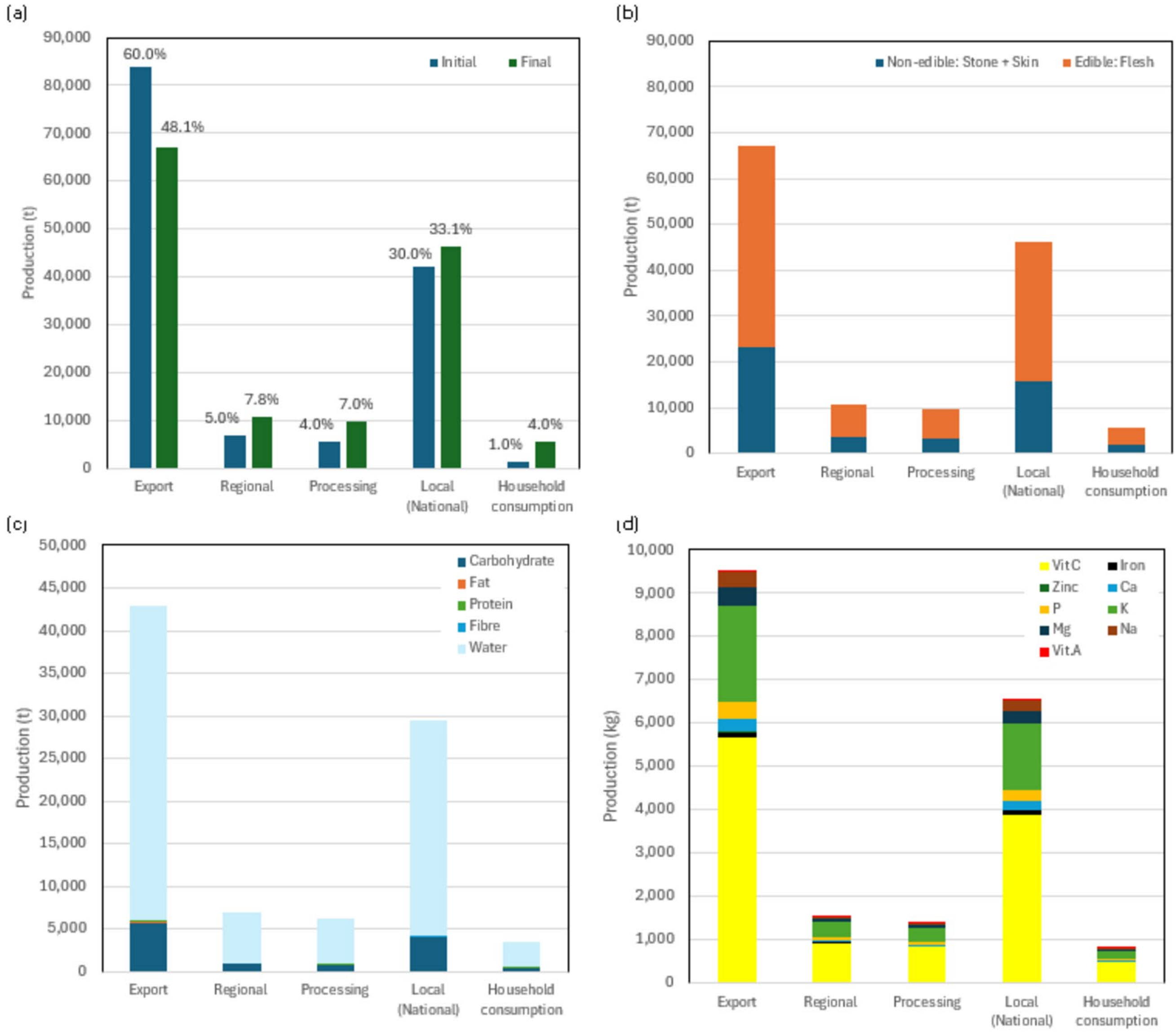

Fig. 3 Annual mango production share in Côte d'Ivoire in 2023, from general to specifics, (**a**) production quantities (initial: before sorting; final: after sorting) (**b**) quantity of mango produced including edible and non-edible (stone/skin*) parts, (**c**) macronutrients*, and (**d**) micronutrients*. *Calculated from C and D stages

terms of nutrient content, carbohydrates were the most abundant, rising from 627 t in 2000 to 11,148 t in 2050. Vitamin A was the second least abundant nutrient (increasing from 2 kg in 2000 to 42 kg in 2050), followed only by zinc (1 kg in 2000 to 22 kg in 2050). When considering nutritional impact—measured by the number of people whose recommended daily intake could be met—vitamin C had the highest impact, benefiting an estimated 58,043 people in 2000 and growing to 1,010,383 people by 2050. This was followed by vitamin A (13,814 people in 2000 to 229,702 people in 2050), carbohydrates (6,886 people to 113,299 people), and iron (5,445 people to 93,845 people). These differences highlight the importance of assessing nutritional impact rather than just nutrient quantities.

Based on our predictive model, which calculates the number of individuals whose dietary needs could be met by mango consumption, the potential nutritional contribution of mangoes is projected to increase substantially. For example, in 2000, mango production could meet the iron, vitamin A, and vitamin C requirements of approximately 5,445; 13,814; and 58,043 people, respectively. By 2023, these numbers rise to 37,926; 94,428; and 405,269 people, and by 2050, to 93,845; 229,702; and 1,010,383 people, respectively.

Table 2 presents the potential nutritional impact of mangoes remaining in-country for essential micronutrients, for which the Ivorian population is deficient in, vitamin C, vitamin A, and iron, and in vulnerable groups (children under

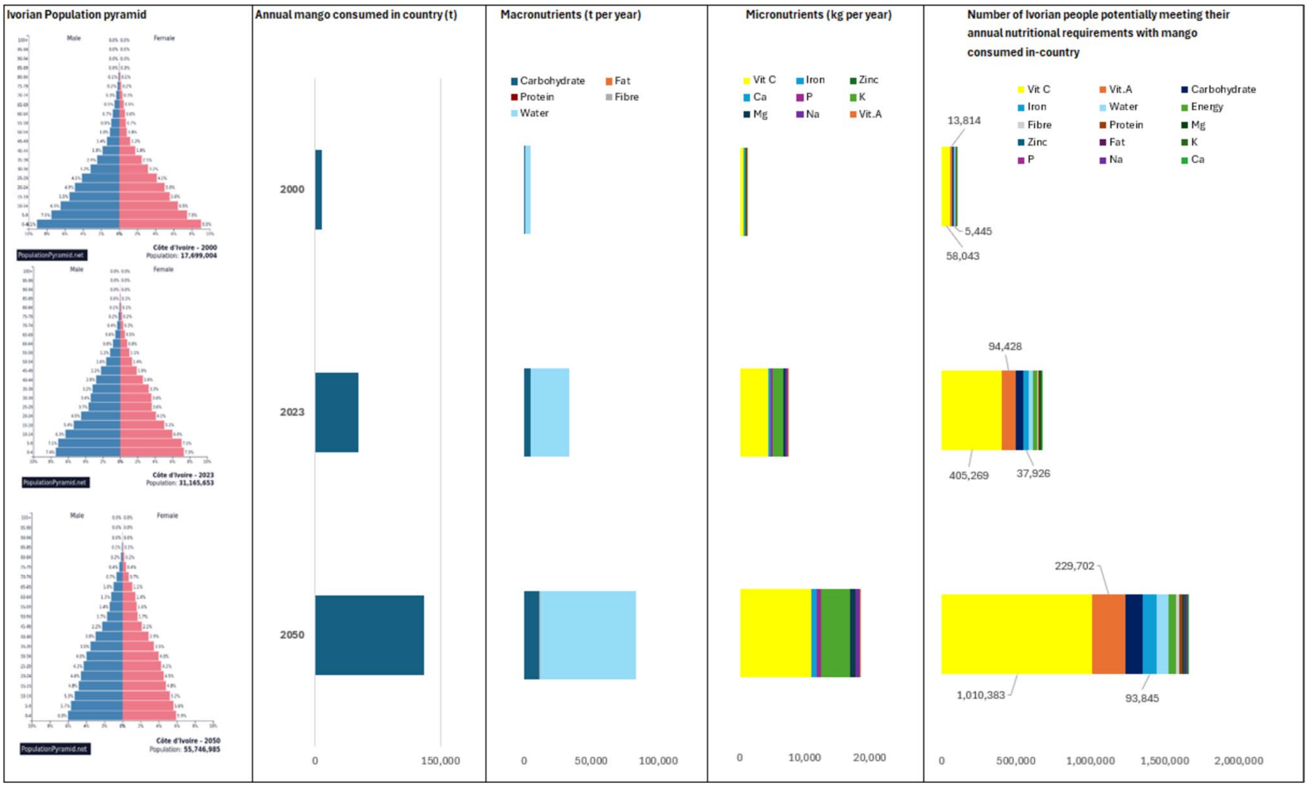

Fig. 4 Number of Ivorian people's annual nutritional requirements met from the mango domestic production in 2000, 2023, and predicted in 2050(Source of population pyramids: populationpyramid.net)

Table 2 Past, present, and future projections of the number of Ivorian children and pregnant teenagers and women (and respective percentage of people in their focal age group) meeting their annual nutritional requirements* for vitamin C, vitamin A, and iron with mango domestic production

Year	Population group	Vit C	Vit.A	Iron
2000	Children (<5-year-old)	64,441 (2.0%)	22,732 (0.7%)	6,186 (0.2%)
	Pregnant teens & women (15–59-year-old)	82,924 (20.1%)	24,261 (5.9%)	3,209 (0.8%)
2023	Children (<5-year-old)	451,085 (9.8%)	159,125 (3.5%)	43,301 (0.9%)
	Pregnant teens & women (15–59-year-old)	580,466 (77.0%)	169,824 (22.5%)	22,463 (3.0%)
2050	Children (<5-year-old)	1,127,713 (17.0%)	397,812 (6.0%)	108,252 (1.6%)
	Pregnant teens & women (15–59-year-old)	1,451,165 (99.9%)	424,560 (29.2%)	56,158 (3.9%)

*EAR = Estimated Average Requirements

5-year-old, and pregnant teenagers (15–19-year-old) and pregnant women (20–49-year-old) in years 2000, 2023, and 2050. According to the model predictions, the annual mango domestic production could meet the annual Estimated Average Requirements (EARs) of over 60,000 children for vitamin C, around 23,000 children for vitamin A and around 6000 children for iron in the year 2000, representing 2%, 0.7% and 0.2% of their respective population focal group. The same production could meet the Estimated Average Requirements of over 80,000 women for vitamin C, around 24,000 women for vitamin A and around 6,000 women for iron in the year 2000, representing a large proportion of their population group, 20.1%, 5.9% and 0.8% of their respective population focal group. In 2023, the production of mango had been multiplied by 7 (from 20,000 t to 140,000 t) and the Ivorian population doubled (from 18 to 31 million people). Therefore, domestic production could meet the nutritional requirements of more people, respectively 9.8%, 3.5% and 0.9% of the country's children for vitamins C, A, and iron, respectively. This represented the nutritional requirements of 77%, 22.5%, and 3% of the country's pregnant teenagers and women for vitamins C, A and iron, respectively. It is projected that mango production will further increase by 2050 (by 2.5 times). The Ivorian population will also almost double (increase of 1.8 times) (56 million people). Therefore, in this scenario, the part of mango in meeting the nutritional requirements of those vulnerable groups will further augment bringing it to 99.9%, 29.2%, and 3.9% of the pregnant teens and women's annual nutritional requirements for vitamins C, A, and iron, respectively. This is explained by the fact that mango production is increasing faster than the population. According to our model's prediction, mango will play a more critical role on the nutritional security of Ivorians in the future.

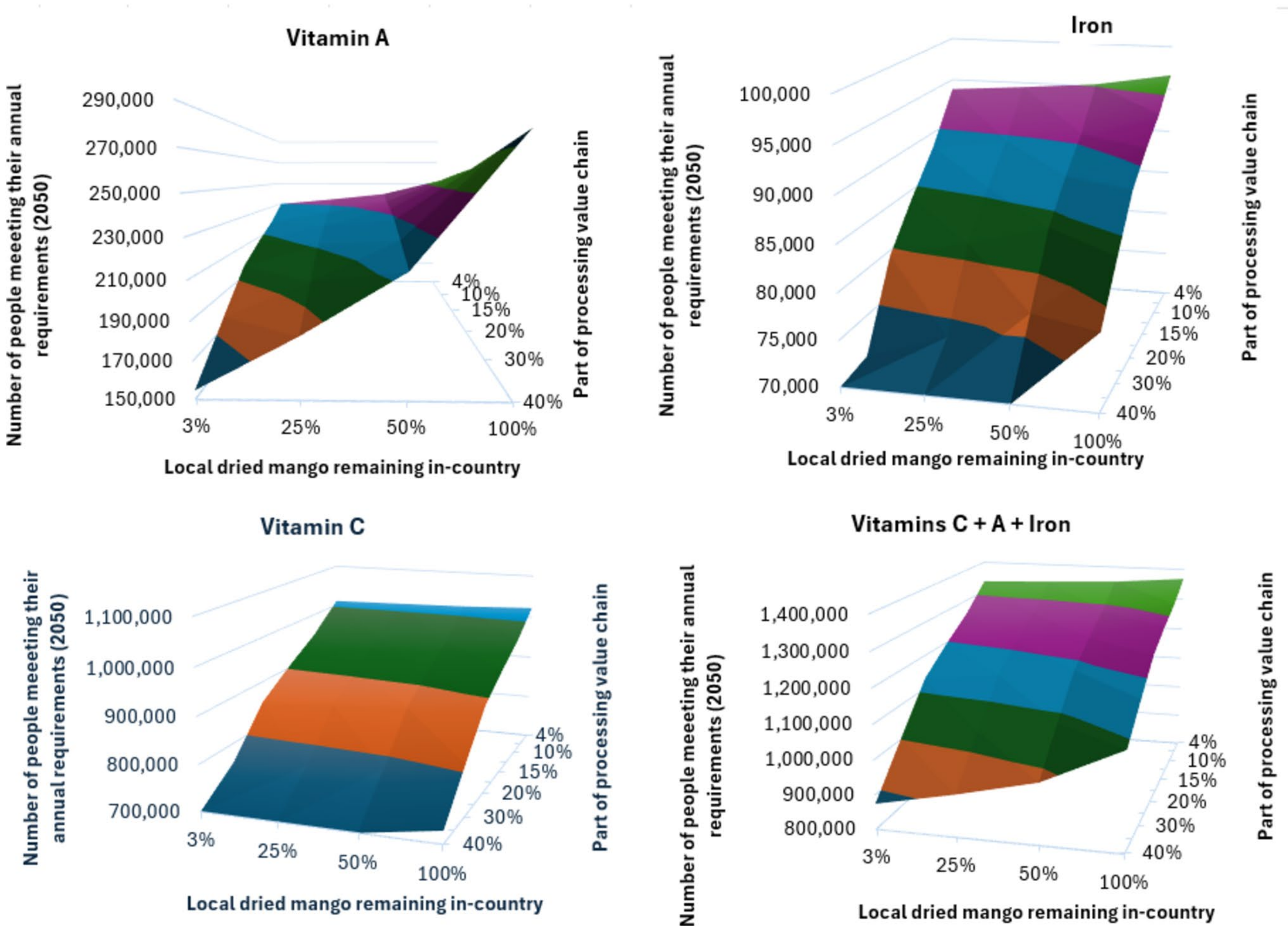

Fig. 5 Number of Ivorian people's annual nutritional requirements met from the mango domestic production predicted in 2050

3.3 Dried mango nutritional predictions

The dried mango sector is seen as high commercial potential in Côte d'Ivoire (Mulder et al., 2019). According to Bancal et al. (2024) and Koffi et al. (2023), 94% of the processed mango is dried and goes essentially for export (79%), whilst only a very small amount (3%) is domestic production. We questioned whether keeping more of the dried mango in-country could improve the nutritional intake of the local Ivorian population in the future (2050): we projected what the nutritional impact of mango (measured as the number of Ivorian people in 2050 who would meet their nutritional requirements with the annual mango production) would be if: 1)the part of the processing chain increased from 4% (current figure in 2023) to 40% of total production, and 2) the part of domestic dried mango production increased from 3% (current figure in 2023) to 100% (all the dried mango domestically produced) (Fig. 5). With this estimate, it should be noted that the part of domestic production is not constant: it will vary from 24% (for 40% of processing) to 37% of total production (for 3% of processing) because the parts of local market and subregional markets will vary accordingly.

Calculations showed that the proportion of dried vs. fresh mango domestically consumed per average capita per year was small: from 0.03% (processing:4%; percentage of dried mango: 3%; percentage of vitamin A: 0.3%) to 9% (processing:40%; percentage of dried mango:100%; percentage of vitamin A: 46%). Despite representing only 9% of total domestic production, dried mangoes could equate to almost half of vitamin A from domestically produced mangoes.

Increasing mango processing, from 4 to 40% for the same total mango produced, could only benefit vitamin A nutritional requirements (277,835 people maximum). and not vitamin C and iron. As such, keeping mango processing value chain at 4% of the total production was therefore found more nutritionally impactful, allowing more people to meet their nutritional requirements in vitamin C and iron as well (to a maximum of 1,021,952 and 96,659 people, respectively). These results are explained by the fresh mango containing higher levels of vitamin C and iron than dried mango.

4 Discussion

4.1 Nutrient flows and nutritional impacts methods and results

Several studies have examined nutrient circularity within food systems, particularly focusing on elements such as phosphorus, potassium, and carbon in agro-food waste systems. (van der Wiel et al., 2019). However, relatively few investigations have addressed the flows and losses of macro- and micronutrients essential to human nutrition. Using protein and energy as proxies for nutritional value, Abbade (2020) estimated that global food losses could potentially feed nearly 1 billion people, based on an average individual intake of 2,000 kilocalories and 50 g of protein per day. Similarly, Gatto and Chepeliev (2024) assessed nutrient flows and losses by quantifying energy, fat, protein and carbohydrate quantities. Expanding on these approaches, Lividini and Masters (2022) estimated global flows of bioactive compounds such as vitamins and minerals with the aim of guiding more health-orientated policy interventions. In all three studies, global world estimates were generated from FAO Food Balance Sheets for key food categories. At a more localised scale, Wesana et al. (2019) investigated the dairy value chain in Uganda, quantifying milk and its derivative products and calculating associated nutritional losses using a local food composition table. The nutritional impact in this study was assessed by dividing the total nutritional losses by the Recommended Dietary Allowance (RDA), defined as the average daily intake level sufficient to meet the nutrient requirements of nearly all (97–98%) healthy individuals, in line with Spiker et al., (2017). In contrast, (Bechoff et al., 2022; Stathers et al., 2018) employed the population-weighted Estimated Average Requirements (EAR) (average daily level of intake estimated to meet the requirements of 50% of healthy individuals) which offers a more conservative but arguably seems more appropriate prediction for populations (Bechoff et al., 2019).

Bechoff et al. (2022) assessed nutritional composition and nutritional changes in a pulse (cowpea), a cereal (maize) and a root (sweet potato) based on direct field measurements rather than relying on using food composition tables. In the present study, we applied a similar methodology but focused on nutrient flows rather than food losses. Compared to earlier research, the integration of actual field measurements with survey data is expected to yield more precise and context-specific predictions.

As the methodology remains relatively novel, opportunities for direct comparison with existing studies are limited. However, meaningful cross-comparisons can be drawn with findings with Bechoff et al. (2022): for example, orange fleshed sweet potato loss resulted in about 600,000 people missing their daily nutritional requirements (1.7% of Uganda population) (Bechoff et al., 2022). Our study found that the domestic production of mango in Côte d'Ivoire could meet the nutritional requirements of about 94,000 people or 0.3% of Ivorian population. This suggests that, in terms of vitamin A contribution, orange-fleshed sweet potato in Uganda has a substantially greater nutritional impact than mango in Côte d'Ivoire. Similarly, the nutritional impact for iron lost in cowpea (121,000 people in Zimbabwe) is also higher than the nutritional impact met by the domestic production of mango (37,926 people in Cote d'Ivoire). These differences may be explained by the importance of crops in the diet: whilst cowpea and sweet potatoes are key food security crops in Zimbabwe and Uganda, respectively, mango is a seasonal crop in Cote d'Ivoire. We believe that our predictive model contributes valuable insight by quantifying the relative contribution of specific nutrients to daily requirements (i.e., nutritional impact), which cannot be inferred from nutrient quantities alone.

4.2 Future nutritional impact predictions

According to FAO projections, mango production in Côte d'Ivoire is expected to increase significantly, with the potential to expand cultivation areas by two to three times their current size (FAO, 2024). The strong commitment of the Agricultural Sector Development Support Program (PADFA) to sustainably improve food and nutritional security and income from farming in the northern regions (Aka, 2024; Coulibali, 2023), supporting strategic sectors—such as the mango sector receiving considerable support from PADFA and its European partners (Aka, 2024)—gives us confidence that the mango sector will continue to grow, i.e. in the north of the country.

Nonetheless, our projections do not take into account the potential impact of climate change, which could lead to irregular mango production patterns (Halder et al., 2024). One significant threat is the increased prevalence of pests and diseases, especially fruit flies, which are likely to become more widespread under changing climatic conditions (Yeo et al., 2022). These challenges could shorten the mango harvesting season and reduce export potential, particularly given Europe's stringent fruit quality regulations. On the other hand, a decline in exports might increase the availability of mangoes for domestic and regional consumption. Onyutha et al. (2018) relates that despite projected increases in food production, sub-Saharan Africa is likely to continue facing food security challenges by 2050, largely due to limited market access for smallholder farmers and the need to diversify income-generating activities beyond agriculture. Building more resilient and nutrition-oriented value chains will therefore be essential to improving food access and achieving better food security outcomes in resource-limited settings.

4.3 Fresh vs. dried mango nutritional predictions

According to Mulder et al. (2019), Côte d'Ivoire has a strong potential for rapid development of its processed mango sector because of its well-developed agricultural economy and favourable business environment compared to its neighbouring countries. Currently, however, the number of dried mango processors remains limited, and operations are largely small-scale. Among agricultural value chains, mango was identified as one of the most promising for processing. Between 2017 and 2021, the volume of mangoes processed into dried products increased significantly-from 89 to 593 tonnes-representing an average annual growth rate of 66% (Kouakou et al., 2024). Dried mango has become the most widely exported processed tropical fruit from the country, with growing demand in the European market, particularly among vegan and vegetarian consumers. As Mulder et al. (2019) noted: "*Côte d'Ivoire remains home to large untapped potential. With high availability of the prised Kent variety at low prices, and ample experience in the logistics of fresh fruit export, it should be a dried mango powerhouse. But progress has been slow, and it remains a small player for now*". Our findings highlight a nutritional trade-off associated with increased mango processing. While it presents a valuable economic opportunity, the process drying significantly reduces vitamin C, a nutrient labile and sensitive to heat. In contrast, vitamin A becomes more concentrated in dried mango (Maldonado-Celis et al., 2019). The availability of unprocessed fresh mangoes remains crucial for supplying vitamin C, which plays an important role in enhancing iron absorption—particularly relevant in a country such as Côte d'Ivoire, where anaemia is highly prevalent.

4.4 Limitations of the model

One limitation of our predictive model is that it focuses solely on the Kent mango variety, which is commonly used for both export and domestic consumption. However, a wide range of local mango varieties—including wild types and traditional cultivars not intended for export—are also widely consumed throughout Côte d'Ivoire, from rural communities to urban centres. These local varieties, which are often smaller and more fibrous, are highly valued locally, yet there is currently no available data on their production or consumption. Furthermore, some of these cultivars are consumed at earlier stages of maturity (e.g. "B stage") rather than at full ripeness ("C stage"), but no data exist on the distribution of consumption across maturation stages.

Another limitation is that our model does not account for the full Ivorian diet. Mango is a seasonal fruit and constitutes only a small portion of total dietary intake. According to our model, one ripe mango provides approximately 318 g of edible pulp, delivering 176 kcal. This amount supplies roughly 138% of the Estimated Average Requirement (EAR) for vitamin C, 32% for vitamin A, and 13% for iron for an average individual in the Ivorian population. However, given that the average daily energy requirement is estimated at 2,332 kcal (based on our 2023 model), consuming one mango per day would fulfil only 7.5% of the daily energy requirement.

Our model also relies on imputed data, which introduces further limitations. Data collection was restricted to early and late mango seasons within a single year. Expanding the dataset to cover multiple years and additional sampling points would improve the model's robustness. For instance, the vitamin C content we measured ranged from 12–13 mg/100 g, which is at the lower end of the spectrum reported in the literature: our low content of vitamin C could be attributed to either naturally low levels in the fruit or loss during transport and sample preparation. Maldonado-Celis et al. (2019) reported a broader range of 13–93 mg/100 g for vitamin C in mango. This suggests our estimates of vitamin C's nutritional contribution may be significantly underestimated—potentially by up to sevenfold. Based on our current data, mango consumption in 2023 could have met the vitamin C requirements of approximately one million people; if higher vitamin C content were assumed (93 mg/100 g), this figure could rise to 8 million people (*Supplementary Materials*).

Finally, spatial distribution and access to mango markets present another modelling constraint. Currently mango production is concentrated in the north of the country, and the fruit is primarily distributed to urban centres. Many regions in Côte d'Ivoire -particularly outside the north—have limited or no access to mangoes. Future improvements to the model should incorporate geospatial data on population distribution and market access to provide a more comprehensive and accurate assessment.

5 Conclusions

Our work described an application of the NUTRI-P-LOSS methodology to mango production flows in Cote d'Ivoire. We showed that mango is likely to have a greater nutritional impact in the future because mango production will feed more people locally and hence provide a greater quantity of essential micronutrients such as vitamin A and vitamin C (that helps iron absorption). Increasing the part of dried mango domestically is not necessary the best strategy for the future: although vitamin A is more concentrated in dried mango, vitamin C, mango's main essential micronutrient, is lost during drying and the number of people benefiting from nutritional input from mango is globally less with dried mango as compared to fresh mango.

Our study demonstrates that the NUTRI-P-LOSS method, originally developed mainly for cereals, roots, and legumes, can be successfully extended for predicting future nutritional impact on populations to other commodities such as fruits and vegetables. To enhance the robustness of the NUTRI-P-LOSS prediction model, further data and work are needed, including the incorporation of additional data points and the calculation of model error (variability). The NUTRI-P-LOSS tool can serve as a practical resource for practitioners to predict postharvest losses and flows for specific crops or commodities studied. Model estimations can inform key agricultural and food security decision-makers to help make crop food systems more nutrition and health-orientated and efficient.

Acknowledgements This research was supported by the European FOSC ERA-NET Co-fund on Food systems and Climate as part of the SAFOODS (Strengthening African Food Systems in the face of climate change and food insecurity) project. We appreciate the logistical and analytical support provided by Dr. Solange Aka and Dr. Charlemagne Nindjin from CSRS. We thank Dr. Mathieu Léchaudel for his insights about the mango nutritional composition data and Dr. Damien Beillouin for his insights about the influence of climate change on mango production in the future. We are thankful to the cooperative Gninnangnon, Korhogo that welcomed the research team for data collection. We are also grateful to Prof. Apurba Shee (NRI) and Prof. Arlène Alpha for their scientific advice on this research. The opinions expressed in this paper do not necessarily reflect the views of our donor or partners.

Funding This research was supported by the Department for Environment, Food, and Rural Affairs (DEFRA) Contract Ref: Ecm_62536 under the FOSC ERA-NET Co-fund on Food systems and Climate: SAFOODS—Strengthening African Food Systems in the face of climate change and food insecurity.

Data availability Raw data will be available on request.

Code availability Not applicable.

Declarations

Ethics approval Not applicable. The research did not involve human participants.

Consent to participate Not applicable.

Consent for publication Not applicable.

Conflict of interest The authors declare that they have no conflict of interest.

References

Abbade, E. B. (2020). Estimating the nutritional loss and the feeding potential derived from food losses worldwide. *World Development, 134*, Article 105038. https://doi.org/10.1016/j.worlddev.2020.105038

Aka, S. (2024). *Analyses physico-chimiques et biochimiques des purées de mangues: Rapport d'Expertise*. Laboratoire de chimie du Centre Suisse de Recherches Scientifiques en Côte d'Ivoire (CSRS) (p. 24).

AOAC (1990). *Official Method of Analysis of the Association of Official Analytical Chemists* (No. 934.06, AOAC).

Bancal, V., Koffi, K .J. M., Faye, E., Sirdey, N., Belmin, R. & Malézieux, E. (2024). Assessing postharvest losses in Sub-Saharan food systems: The case of Ivorian mango. Global Food Security Conference, Louvain, Belgique, 1pp. Available at: https://agritrop.cirad.fr/609379/. Accessed 2 Jan 2025.

Bechoff, A., Shee, A., Mvumi, B. M., Ngwenyama, P., Debelo, H., Ferruzzi, M. G., Nyanga, L. K., Mayanja, S., & Tomlins, K. I. (2022). Estimation of nutritional postharvest losses along food value chains: A case study of three key food security commodities in sub-Saharan Africa. *Food Security, 14*, 571–590. https://doi.org/10.1007/s12571-021-01238-9

Bechoff, A., Mayanja, S., Mvumi, B., Nyanga, L., Ngwenyama, P., Stathers, T., . . . Tomlins, K. (2019). The NUTRI-P-LOSS (NUTRItional Postharvest Loss) methodology: a guide for researchers and practitioners, 24pp.

Benhidi, I. (2016). Compte-rendu de TP : Dosage par oxydoréduction - iodométrie et manganimétrie. Faculté de Medecine et de Pharmacie de Casablanca, 12pp. https://doi.org/10.13140/RG.2.2.33837.97763

CBI (2019). Value chain analysis for processed fruits from Burkina Faso, Mali and Ivory Coast. commissioned by the Centre for the Promotion of Imports from developing countries (CBI). Ministry of Foreign Affairs. Available at: https://agri-logic.nl/portfolio/value-chain-analysis-fruit-processing-west-africa/. Accessed 22 February 2025.

di Corcia, S., Dornier, M., Palmade, L., & Dhuique-Mayer, C. (2022). Enhancement of the in vitro bioavailable carotenoid content of a citrus juice combining crossflow microfiltration and high-pressure treatments. *Food Research International, 156*, 111134. https://doi.org/10.1016/j.foodres.2022.111134

DHS (2021). Institut National de la Statistique. Côte d'Ivoire Enquête Démographique et de Santé. Rapport final. Rockville, Maryland, USA et la Côte d'Ivoire: INS et ICF. Available at https://www.dhsprogram.com/pubs/pdf/FR385/FR385.pdf. Accessed 23 March 2025.

Diop, A., Méot, J. M., Léchaudel, M., Chiroleu, F., Ndiaye, N. D., Mertz, C., Cissé, M., & Chillet, M. (2021). Impact of preharvest and postharvest on color changes during convective drying of mangoes. *Foods, 10*(3), Article 490. https://doi.org/10.3390/foods10030490

Dubois, M., Gilles, K. A., Hamilton, J. K., Roberts, P. A., & Smith, F. (1956). Colorimetric method for determination of sugar and related substances. *Analytical Chemistry, 28*, 350–356. https://doi.org/10.1021/ac60111a017

Engidaw, M. T., Gebremariam, A. D., Tiruneh, S. A., Tesfa, D., Fentaw, Y., Kefale, B., Tiruneh, M., & Wubie, A. T. (2023). Micronutrient intake status and associated factors in children aged 6–23 months in sub-Saharan Africa. *Scientific Reports, 13*(1), Article 10179. https://doi.org/10.1038/s41598-023-36497-3

FAO. (2022). Bridging the gap between nutrition and agriculture in Côte d'Ivoire – An assessment of capacity within agricultural extension and advisory services. *Rome*. https://doi.org/10.4060/cb9290en

FAO (2019). Moving forward on food loss and waste reduction. Food and Agriculture Organisation of the United Nation. Available at: https://www.fao.org/interactive/state-of-food-agriculture/2019/en/. Accessed 17 April 2025.

FAO (2024). *Major tropical fruits: Market review preliminary results 2023*. Food and Agriculture Organization of the United Nations, Rome. Available at: https://openknowledge.fao.org/server/api/core/bitstreams/c03844d3-3dc6-4465-abf3-8c49947e77d8/content. Accessed 2 Feb 2025.

Gatto, A., & Chepeliev, M. (2024). Global food loss and waste estimates show increasing nutritional and environmental pressures. *Nature Food, 5*(2), 136–147. https://doi.org/10.1038/s43016-023-00915-6

Giller, K. E., & Zingore, S. (2021). Unearthing hidden hunger in Africa. *Nature, 594*(7861), 31–32.

Global Hunger Index (2024). Côte d'Ivoire. Available at: https://www.globalhungerindex.org/2022/ivory-coast.html#:~:text=With%20a%20score%20of%2020.6%20in%20the%202024,hunger%20at%20the%20global,%20regional,%20and%20country%20levels. Accessed 17 April 2025.

Global Nutrition Report (2022). Côte d'Ivoire. Available at: https://globalnutritionreport.org/resources/nutrition-profiles/africa/western-africa/c%C3%B4te-divoire/. Accessed 2 March 2025.

Grumiller, J., Grohs, H., Raza, W., Staritz, C., Tröster, B. (2018). Strategies for sustainable upgrading in global value chains: the Ivorian and Ghanaian cocoa processing sectors. Report number: ÖFSE Policy Note 24. Austrian Research Foundation for International Development. https://doi.org/10.13140/RG.2.2.10782.38728.

Guiamba, I. (2016). *Nutritional value and quality of processed mango fruits.* Thesis for the Degree of Doctor of Philosophy, Chalmers University of Technology, Göteborg, Sweden.

Halder, R., Varma, S., Singh, M., & Dahiya, A. (2024). From orchard to table: Understanding climate change impacts on mango production in India: A review. *International Journal of Advanced Biochemistry Research, 8*, 472–478. https://doi.org/10.33545/26174693.2024.v8.i4f.1015

Innovations, B. (2021). Mango sector. Bioenergy for SMES in West Africa. Available at: https://www.biostar-afrique.org/en/the-sectors/mango-sector#:~:text=The%20countries%20of%20the%20West,produce%201.4%20million%20tons%20annually. Accessed 2 February 2025.

Jarvis, C. E., & Walker, J. R. L. (1993). Simultaneous, rapid, spectrophotometric determination of total starch, amylose and amylopectin. *Journal of the Science of Food and Agriculture, 63*, 53–57. https://doi.org/10.1002/jsfa.2740630109

Jesson, J., Kouakou, E. K., Kumaran, K., Adonis, L., Wrottesley, S. V., Leroy, V., & Fall, C. (2021). A scoping review of literature describing the nutritional status and diets of adolescents in Côte d'Ivoire. *Public Health Nutrition, 24*(16), 5261–5276. https://doi.org/10.1017/s1368980020002621

Koffi, J. M. K., Soro, D., Fondio, L., Adopo, A. N., Malézieux, E., & Faye, E. (2021). Effect of the length of the flowering-harvest interval on the ripening and quality of the "Kent" mango in Côte d'Ivoire. *Journal of Experimental Biology and Agricultural Sciences, 9*, 138–146. https://doi.org/10.18006/2021.9(2).138-146

Koffi, J. M. K., Faye, E. & Malézieux, E. (2023). *Cartographie fonctionnelle et modèle de flux de la filière mangue de Côte d'Ivoire*. Strengthening African Food Systems in the face of climate change and food insecurity (SAFOODS) Project. WP1. Task 1.3. (pp. 66).

Kouakou, C. K., Manle, T. E., Zaouli, B. T. A., & Fondio, L. (2024). Evaluation agro-morphologique des varietes precoces de la collection de manguier (*Mangifera indica* L.) de la station de recherche CNRA de LATAHA dans le Nord de la Côte d'Ivoire. *International Journal of Advanced Research, 12*(12), 552–559. https://doi.org/10.21474/IJAR01/20053

Kouakou, P. (2024). Profitability and competitiveness of the mango sector in Ivory Coast. *International Journal of Economics and Financial Research*, 12–16. https://doi.org/10.32861/ijefr.101.12.16

Lauricella, M., Sonia, E., Giuseppe, C., Michela, G., & D'Anneo, A. (2017). Multifaceted health benefits of *Mangifera indica* L. (Mango): The inestimable value of orchards recently planted in Sicilian rural areas. *Nutrients, 9*, Article 525. https://doi.org/10.3390/nu9050525

Lividini, K., & Masters, W. A. (2022). Tracing global flows of bioactive compounds from farm to fork in nutrient balance sheets can help guide intervention towards healthier food supplies. *Nature Food, 3*(9), 703–715. https://doi.org/10.1038/s43016-022-00585-w

Mulder, H., Steemers, S., Dibouloni, J. B., Tamini, J. & Niang, M. A. (2019). Analyse de la chaîne de valeur des fruits transformés au Burkina Faso, au Mali et en Côte d'Ivoire Centre pour la promotion des importations en provenance des pays en développement (CBI), Agri Logic. Available at: https://www.agri-logic.nl/sdm_downloads/value-chain-analysis-for-processed-fruits-from-burkina-faso-mali-and-ivory-coast-cbi-2/. Accessed 23 March 2025.

Mutamiswa, R., Nyamukondiwa, C., Chikowore, G., & Chidawanyika, F. (2021). Overview of oriental fruit fly, *Bactrocera dorsalis* (Hendel)(*Diptera: Tephritidae*) in Africa: From invasion, bio-ecology to sustainable management. *Crop Protection, 141*, Article 105492. https://doi.org/10.1016/j.cropro.2020.105492

Neguse, T., Rimberia, F., Wassu, M., Owino, W., & Githiri, S. (2019). Mango (*Mangifera indica* L.) production practices and constraints in major production regions of Ethiopia. *African Journal of Agricultural Research, 14*, 185–196. https://doi.org/10.5897/AJAR2018.13608

Normand, F., Lauri, P., & Legave, J. (2015). Climate change and its probable effects on mango production and cultivation. *Acta Horticulturae, 1075*, 21–32. https://doi.org/10.17660/ActaHortic.2015.1075.1

Coulibali, Z. (2023). *Description et analyse des chaînes de valeurs de la filière mangue : rapport final.* Programme d'appui au Dévéloppement Des Filières Agricoles (PADFA). Retrieved February 7, 2026, from https://padfaci.org/wp-content/uploads/2023/04/20221223_RAPPORT-FINAL-MANGUE-PROMAK-AFRIC_PADFA_mn-5.pdf

Prieto-Patron, A., Hutton, Z. V., Fattore, G., Sabatier, M., & Detzel, P. (2020). Reducing the burden of iron deficiency anemia in Cote D'Ivoire through fortification. *Journal of Health, Population and Nutrition, 39*(1), Article 1. https://doi.org/10.1186/s41043-020-0209-x

Pugnet, V. (2024). The mango in Côte d'Ivoire. Available at: https://www.fruitrop.com/en/Articles-by-subject/Full-country-profile/2024/The-mango-in-Cote-d-Ivoire. Accessed 14 February 2025.

Rohner, F., Leyvraz, M., Konan, Esso, L. J. C. E., Wirth, J. P., Norte, A., Adiko F. A., Bonfoh, B., & Aaron, G. J. (2016). The potential of food fortification to add micronutrients in young children and women of reproductive age – findings from a cross-sectional survey in Abidjan, Côte d'Ivoire. *PLOS ONE, 11*, e0158552. https://doi.org/10.1371/journal.pone.0158552

Santé Côte d'Ivoire (2018). Projet de supplementation en vitamine A et de deparasitage des enfants de 6 a 59 mois dans 24 districts sanitaires. Available at: https://sante.gouv.ci/assets/fichiers/projet-de-supplementation-en-vitamine-a-et-de-deparasitage-des-enfants-de-6-a-59-mois-dans-24-districts-sanitaires.pdf. Accessed 9 April 2025.

Sidibe, A. (2023). Mangue/Afrique de l'Ouest : La campagne 2023 s'annonce meilleure que les précédentes. Available at: https://afrique-agriculture.org/articles/lessentiel/la-campagne-2023-sannonce-meilleure-que-les-precedentes. Accessed 27 March 2025.

Spiker, M. L., Hiza, H. A. B., Siddiqi, S. M., & Neff, R. A. (2017). Wasted food, wasted nutrients: Nutrient loss from wasted food in the United States and comparison to gaps in dietary intake. *Journal of the Academy of Nutrition and Dietetics, 117*(7), 1031-1040. e1022. https://doi.org/10.1016/j.jand.2017.03.015

Stathers, T., Ognakossan, K. E., Priebe, J., Mvumi, B. M. & Tran, B. (2018). Counting losses to cut losses: quantifying legume post-harvest losses to help achieve food and nutrition security. In: 12th International Working Conference on Stored Product Protection (IWCSPP) in Berlin, Germany, October 7–11, 2018. Julius Kühn-Institut, Germany, 8–18. https://doi.org/10.5073/jka.2018.463.004.

van der Wiel, B. Z., Weijma, J., van Middelaar, C. E., Kleinke, M., Buisman, C. J. N., & Wichern, F. (2019). Restoring nutrient circularity: A review of nutrient stock and flow analyses of local agro-food-waste systems. *Resources, Conservation & Recycling: X, 3*, Article 100014. https://doi.org/10.1016/j.rcrx.2019.100014

Wesana, J., Gellynck, X., Dora, M. K., Pearce, D., & De Steur, H. (2019). Measuring food and nutritional losses through value stream mapping along the dairy value chain in Uganda. *Resources, Conservation and Recycling, 150*, Article 104416. https://doi.org/10.1016/j.resconrec.2019.104416

Wolff, J. P. (1968). *Manuel d'analyse des corps gras*. Azoulay Editions, Paris (pp. 519).

Yahia, E. M., Ornelas-Paz, J., Brecht, J. K., García-Solís, P., & Maldonado Celis, M. E. (2023). The contribution of mango fruit (*Mangifera indica* L.) to human nutrition and health. *Arabian Journal of Chemistry, 16*(7), Article 104860. https://doi.org/10.1016/j.arabjc.2023.104860

Yeo, Y. S., Kone, Y., Dembele, D. D., Rey, J. Y., & Kone, D. (2022). Mango farmer's perception of climate change and its impacts on mango pests and diseases occurrences in Côte D'ivoire. *Heliyon*. https://doi.org/10.2139/ssrn.4257539

Yogone, B. J. L., Adjouman, Y. D., Adou, M., & Tetchi, F. A. (2024). Characteristics of the main fruit and vegetables grown in Côte d'Ivoire and most commonly consumed in the city of Abidjan (Côte d'Ivoire). *Journal of Food Technolology, 22*(1), 1–9. https://doi.org/10.36478/makjft.2024.1.9

Yusuf, S. M., Hossain, M. M., Zakaria, M., Hoque, M. A., & Ahiduzzaman, M. (2019). Postharvest losses of mangoes at different stages from harvesting to consumption. *International Journal of Business, Social and Scientific Research, 7*(4), 21–26.

Faye, N. F., Fall, T., Reardon, T., Theriault, V., Ngom, Y., Barry, M. B., & Sy, M. R. (2024). Consumption of fruits and vegetables by types and sources across urban and rural Senegal. *Journal of Agribusiness in Developing and Emerging Economies*, *14*(5), 958–978. https://doi.org/10.1108/JADEE-05-2022-0090

COLEACP (2000). West African mango : a disappointing season in 2000. CIRAD-FLHOR - FRA. 2000. *Fruitrop* (English ed.) (Vol. 75, pp. 6–9).

Maldonado-Celis, M. E., Yahia, E. M., Bedoya, R., Landázuri, P., Loango, N., Aguillón, J., Restrepo, B., & Ospina, G., J. C (2019). Chemical composition of mango (Mangifera indica L.) fruit: Nutritional and phytochemical compounds. *Frontiers in Plant Science*, *10*, 1073. https://doi.org/10.3389/fpls.2019.01073

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Aurélie Bechoff is an international consultant and was - until October 2025 - a senior research fellow in food technology and nutrition at the Natural Resources Institute (NRI) in University of Greenwich. Her main research interest is on building efficient local food systems to deliver nutritious products to the most vulnerable. She has recently coordinated an IMMANA-FCDO funded project called NUTRI+4AID (2022-25) that validates a previously developed tool for estimating nutritional postharvest losses along crop value chains (NUTRI-P-LOSS) and applies it to humanitarian food chains. This present research on mango nutritional flows is also an application of the NUTRI-P-LOSS tool and was conducted as part of the ERANET-funded SAFOOD project (2021-25), which aim is to strengthen fruit and vegetable food systems in West Africa in response to climate change. Dr. Bechoff has field experience in over 25 countries in sub-Saharan Africa, Asia, and Latin America.

Mary Nkongho Tanyitiku is a research fellow in food and safety at the Natural Resources Institute (NRI), University of Greenwich and a visiting food scientist at the Women's Network for Biodiversity and Food Science, Yaounde, Cameroon. Prior to this, she worked with the Netherlands Development Organisation, SNV Cameroon, to improve the performance of women cooperatives/CIG in the dairy value chain. In her MSc Dr. Tanyitiku studied the effect of processing methods on the techno functional, nutritional and sensory characteristics of African cereal-based complementary foods. Her PhD on foodborne pathogens among snail meat-consuming populations in sub-Saharan Africa was funded by the New Zealand Aid programme. Her current research interests are in the nutrition and food safety of locally produced foods.

Jean-Mathias Konan Koffi is a lecturer and researcher who works in the fields of agronomy, agroecology and digital agriculture. Dr. Koffi holds a PhD in Agriculture and Tropical Forestry, specializing in Agro physiology from the University of Daloa, Côte d'Ivoire. He completed a postdoctoral fellowship in Montpellier, France, as part of the « Make Our Planet Great Again » program (MOPGA 2022). This one-year stay allowed him to finalise publications from his thesis and to participate in a research project entitled *SAFOODS*. His research work focuses mainly on sustainable agricultural systems, agroecological transition, optimization of cultivation practices and precision agriculture. In addition to his research activities, he is involved in the training of students and young researchers, thus contributing to the development of skills in agroecology and sustainable management of agricultural systems in Côte d'Ivoire.

Yardjouma Silue is a post-doctoral researcher at the Postharvest and Agroprocessing Research Centre at the University of Johannesburg. As a dedicated researcher, he is passionate about enhancing the shelf-life and quality of fresh produce, minimising postharvest losses, and maximising the value of agricultural products through sustainable and data-driven approaches. His research interest also includes Modelling, Data Analytics, Machine Learning and Deep Learning applications that he uses to derive meaningful and actionable insights from complex datasets, enabling informed decision-making and process optimisation.

Ery Marilyne Christina Hien is a PhD student in biochemistry and food technology at Nangui Abrogoua University and a research associate at the Swiss Centre for Scientific Research in Côte d'Ivoire, where she is part of the Sustainable Agriculture and Nutrition research axis. Hien's research focuses on innovative solutions for adapting to and mitigating climate change in the fruit and vegetable food system, in particular mango and tomato. She holds a master's degree in biochemistry and food technology. Her main research interest lies in the reduction of both quantitative and qualitative losses of fruit and vegetables in the face of climate change threats for sustainable food and nutritional security. She is a member of the SAFOODS project team, through which she is conducting her thesis.

Eric Malézieux is an agronomist with 35 years of research experience in West Africa, Caribbean, Indian Ocean, Pacific, and Central America working for CIRAD (French Agricultural Research Centre for International Development). He holds a PhD in Agronomy from AgroParisTech (1988), and obtained his Habilitation to Conduct Research (HDR) from the University of Montpellier, France, in 2002. Following various roles in scientific coordination and research management at CIRAD, he led the HortSys research unit, Agroecological Functioning and Performance of Horticultural Cropping Systems, from 2008 to 2019. He currently serves as President of the Evaluation Commission for Researchers in Agronomy and Forestry at INRAE and contributes to CIRAD, INRAE, and ANR institutional scientific committees. His research revolves around agronomy and sustainability of tropical agricultural systems (i.e. horticultural and agroforestry systems). His main research interest is about connections between agroecological systems' design, multi-scale system evaluation, food security, and human health.

Emile Faye is a research scientist at the Horticultural System laboratory at CIRAD. He holds a PhD in Ecology from the Sorbonne University, and a master's degree in engineering in Agronomy from AgroParisTech in Paris, France. His core research area is in digital agriculture and spatial ecology to assess and enhance ecosystem services in tropical fruit agrosystems (fruit production, natural pest control…). Dr. Faye has extensive experience working in developing countries (South America and Africa), working specifically on implementing innovative and user-centred digital solutions to address the needs of the stakeholders of the fruit value chains (cocoa, mango, citrus, litchi…).

Victoria Bancal is a French Senegalese research engineer in food science at CIRAD's Qualisud Research Unit. Her research focuses on postharvest technology and innovation in fresh fruits and vegetables within the broader context of agroecological transition and climate change in developing and tropical countries. Her work aims to: 1) Improve the understanding of the scale and drivers of postharvest losses in domestic value chains; 2) Identify, develop, and evaluate innovative and sustainable practices and technologies to reduce postharvest losses and enhance the overall quality of fresh produce; 3) Explore how sustainable pre- and postharvest practices or treatments affect the quality and shelf life of fruits and vegetables. She is currently based in Côte d'Ivoire, working in partnership with Nangui Abrogoua University.

Claudie Dhuique-Mayer is a researcher in Nutrition and Food sciences, head of the research team « Health effects of food and bioactive compounds » in the Qualisud unit of CIRAD and an expert in carotenoid analysis, bioaccessibility, and absorption (i.e. in citrus). Her research focuses on the preventive nutrition : the design of functional food enriched in carotenoids to address metabolic syndrome and associated diseases.