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Analytical framework on climate projection and its illustration of risks to nutritional health in the Solomon Islands

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The connection between agriculture and food security is well recognized, nonetheless, the long-term effects of climate change on the nutritional value of tropical produce in the Pacific are not well understood. Firstly, to understand the food and nutritional security in the Pacific, the study highlights a significant gap in existing food security frameworks between the impact of climate change, nutritional change in food crops and vegetables, and consumption. Emphasizing the need for more integrated approaches. Secondly, an analytical framework is proposed, built from systematic literature reviews, following a six-step: defining the research question, performing keyword-based searches, screening results, assessing full-text eligibility, extracting and synthesizing data, and reporting findings. Literature was sourced from academic databases, institutional repositories, and organizational websites, resulting in 73 relevant studies being included from platforms and databases such as PubMed, ScienceDirect, ProQuest, and others. This framework aims to connect climate projections with soil nutrients, crop and vegetable quality and nutrients, and dietary outcomes. Thirdly, the study stresses the importance of improving collaboration among governmental ministries and experts, as well as embracing technological innovations, to ensure effective nutrient flow from soil to crops and ultimately to consumers. It emphasizes the need to evaluate the potential nutritional consequences of climate change to safeguard nutritional security for affected populations. Finally, the framework is tailored to the Solomon Islands to inform policy recommendations that enhance food security and nutrition from the production to consumption phase. This approach highlights the interconnectedness of environmental sustainability, agricultural practices, and public health, advocating for a holistic strategy to tackle these pressing challenges.

KEYWORDS

analytical framework, crop nutrient content, nutritional security, food security, policy recommendations

1 Introduction

Climate change, extreme climate events, food production, and human nutrition research are becoming increasingly crucial, as noted by various researchers (Baumgard et al., 2012; Campbell et al., 2018; FAO, 2019; Pieters et al., 2013; Tuomisto et al., 2017; Schnitter and Berry, 2019). Although climate change is one of the biggest threats to the global health crisis, the lack of focus on climate projections and projected impacts on the nutritional content of crops and vegetables, with dietary requirements for human diets remains a gap in the current knowledge

(Costello et al., 2009; Springmann et al., 2016) for the Pacific Region. With the growing development of models on the parameters for crops and vegetable yields and the climate scenarios determining yield (losses or increase), it is becoming very essential as it can predict the risk to food security and nutritional security (Zhao et al., 2019).

1.1 Global food nutrition and implications on the pacific food systems

According to Ferdaus et al. (2023), roots and tuber crops are contributors to global carbohydrate consumption, second to cereal food groups. Globally, tropical roots and tuber crops such as taro (*Colocasia esculenta*), yam (*Dioscorea* spp.), potato (*Solanum tuberosum* L.), sweet potato (*Ipomoea batatas*), cassava (*Manihot esculenta*), and yams (*Amorphophallus paeoniifolius*) are typically consumed (Ferdaus et al., 2023) by the general populations. However, the implications on root and tuber crops and vegetables are complex and less understood compared to other crops such as wheat, maize, rice, soybean (four main exported crops), barley, and field peas (Han et al., 2015; Li et al., 2018; Manners and Van Etten, 2018) related climate change impact on the nutrient content and health-related when consumed.

The four main exported crops above were well analyzed due to their global food trade which produces approximately one-third of the protein energy for the human population, whereas 33% was received from legumes and grains (Janni et al., 2024). With elevated temperature and CO_2 influencing the nutrient level such as starch content for maize, protein increases resulting in high grain yield while soybean boosts protein and micronutrient content (Yang et al., 2018). It was projected that in response to global warming at 2°C, the global production of maize will decline by 53 million tons for exporting countries, equivalent to 43% of global maize export volume (Tigchelaar et al., 2018). On a global aspect, climate change impacts on food nutrition will have implications for the Pacific food systems, specifically the importation of rice and wheat. For example, according to Lal (2021), regional analysis of rice and wheat imports, between 2015 and 2020, the Pacific itself, mainly Cook Islands, Fiji, French Polynesia, Kiribati, Papua New Guinea (PNG), Samoa, Tonga, and Tuvalu, imported an average of 83.5% of rice and 72.1% of wheat. In the Solomon Islands, rice makes up 55% of all imported agricultural products (Solomon Islands Agriculture Sector Growth Strategy and Investment Plan ASGSIP 2021–2030).

However, the evidence of elevated CO_2 and temperature proved beneficial as it increased growth, speeding up the thermal time for the grain-filling stage of phenology, with an increase of 46% in sugar and other carbohydrate products in plants. Nevertheless, little is known concerning the mineral and other nutrient concentrations in plants, regardless of the reduction in protein levels (Loladze, 2014). This will affect Pacific Islanders including the Solomon Islands who rely on imported flour and other products from the impacted crops. Moreover, in terms of green leafy vegetables, according to Gleadow et al. (2016), the authors observe a reduction in leaf area, photosynthetic rate, biomass, and low concentrations of micro-and macronutrients in *Manihot esculenta* tubers due to high salt concentrations.

Although vegetables and root and tuber crops are staple foods in the Pacific, nutritional deficiency is a major problem that requires further research to determine dietary requirements (Albert et al., 2020; Darnton-Hill, 2019). Little is known, especially how crop/food nutrition will be affected by future climate change.

Nonetheless, the impact of climate change on micronutrient-rich vegetables, fruits, and crops may likely vary between regions and may lead to an increase in global food insecurity or vulnerability (Semba et al., 2022). This is why more research in this nexus and developing climate-crop-nutrition models to explore the interactions and projected impact is of great need. Understanding the climate-crop-nutrition nexus helps with adaptations that address both food and nutritional security in the Pacific Islands. Here the study identifies the lack of linkage between climate projections impacts and crop and vegetable nutrients (sufficient or insufficient), and how these nutrients will affect the required nutrients the human body needs to function.

Thus, this paper aims: (1) to identify gaps in existing food security frameworks and policies in the Pacific region, and (2) to add to the existing knowledge of climate change impacts on crops and vegetable nutrients, and human diets under the 2100 climate projection in the Solomon Islands.

1.2 Identifying gaps through the existing frameworks

Looking into the Pacific Regional climate projections, according to the CSIRO and SPREP (2021), temperatures have risen, sea levels have increased, and while tropical cyclones have become less frequent, they are now more intense; however, observed rainfall trends remain uncertain due to high natural variability from the El Niño Southern Oscillation. Future warming is projected to reach about 0.7°C by 2030 relative to 1986–2005, regardless of emissions, with further increases to around 0.8°C under a low-emission scenario (RCP2.6) and up to 1.5°C under a high-emission scenario (RCP8.5) by 2050, and 0.8°C to 2.2°C, respectively, by 2070. Rainfall projections are uncertain, with little change expected south of 10°S and likely increases between 10°S and 10°N. Sea levels will continue rising, with projected increases of 0.09–0.18 m by 2030, 0.17–0.36 m by 2050, and 0.24–0.63 m by 2070, depending on emissions. Heavy rainfall intensity is expected to rise, and although fewer tropical cyclones are projected, their average intensity could change by 5 to +10% under 2°C global warming, potentially leading to greater impacts due to the combined effects of stronger cyclones, sea level rise, and more intense rainfall. The projection is no different for the research study site, the Solomon Islands.

In the Solomon Islands, there is a lack of comprehensive studies on the relationship between climate projections, soil, crop, and vegetable nutrients, and their effects on diet. This gap hinders the development of effective management strategies to ensure sustainable crop nutrition and dietary needs in the future. Developing an analytical framework is essential to highlight the vulnerability and nutritional shift from production to health risks associated with projected climate change. This framework would clarify the threats that climate change poses to local food production and health, particularly regarding nutrient intake from crops consumed by the population.

From the existing frameworks and research done, the following gaps (Figure 1) were identified to better understand what is required to address community-based nutritional vulnerability for the future nutritional value of local food production. From existing frameworks on food and nutritional security, soil and agriculture, and health, there is still a lack of data and information available to mitigate a long-term solution to safeguard and address the health, soil, food, and human wellbeing.

2 Methodology

A systematic review was conducted to develop the analytical framework for the study. Relevant literature was identified through comprehensive searches across academic databases and other platforms from the institutional repositories and organizational websites. The process was structured into six key steps (1) formulation of the research question; (2) execution of a systematic search strategy using predefined keywords; (3) screening of search results based on inclusion and exclusion criteria relevant to the research question and objectives; (4) eligibility assessment of full-text articles for relevance and quality; (5) data extraction and synthesis; and (6) summarization and reporting of findings.

Searches were conducted across the following databases: Ageconsearch (1), CIRAD (1), ProQuest (6), PubMed (21), ResearchGate (4), ScienceDirect (14), Scopus (1), Springer Nature (6), Taylor & Francis Online (1), and Wiley Online Library (5). Additional sources included: City Research Online (City, University of London) (1), FAO Document Repository (2), IPCC website (1), SIG Ministry of Agriculture and Livestock (1), UNFCCC website (1), RCCAP website (1), and the USP Library Online Catalog (4). In total, 73 relevant studies were identified and cited in this review.

Through screening for relevancies, to develop the Analytical Framework. Four existing food security frameworks were adopted and amended by identifying gaps in the framework, which established this study's Analytical framework. The Analytical Framework serves as a risk-based assessment tool to evaluate the potential impacts of future risks on local crop production, spanning from farmers to consumers. It considers the consequences of projected climate change to assess nutritional security. By examining the relationship between climate change and crop production, the framework identifies potential nutritional deficiencies and food insecurity risks between 2050 and 2,100 based on climate projections for the country.

From a general search of keywords under the theme: food security framework, nutritional security, soil nutrient, climate change, climate projections, health risk, global food network and frameworks, the proposed framework builds on existing frameworks from Baumgard et al. (2012), Campbell et al. (2018), Pieters et al. (2013), and Tuomisto et al. (2017) to create a cross-dimensional analysis of the relationships between climate change, agriculture, and the food nutritional chain. It aims to identify gaps in current frameworks regarding future nutritional outcomes. The study highlights that many existing frameworks address the purpose of the work but fail to evaluate or analyze the components and their interrelationships. They often neglect how climate projections impact the nutritional content of agricultural production—specifically growth, yield, and nutrient content—affecting food and nutritional security.

The existing frameworks illustrate the pathway or connection between climate change, health, and nutrition, which is a pre-existing concept for the assessment of food security. Nonetheless, no one framework is suitable for assessing different countries' local food contexts. Thus, this framework will focus on the national and subnational levels as it is also unclear how climate change will affect the quality of beneficial nutrients in plants essential for human health in the Solomon Islands. A similar problem was identified by Nicholson et al. (2020) when assessing 36 frameworks. Thus, identifying the gaps earlier can limit the additional health, food, and nutritional risk.

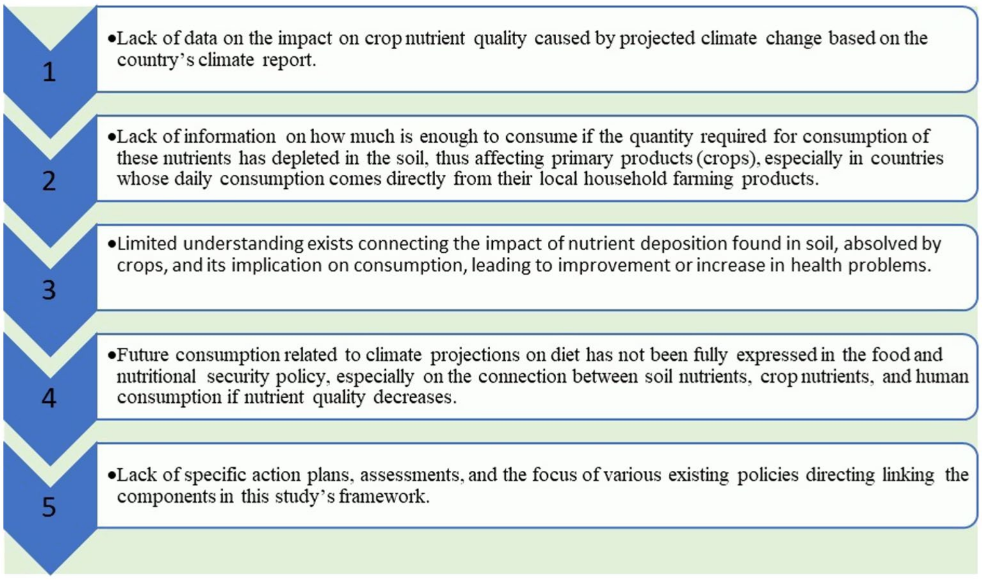

FIGURE 1
From existing frameworks on food and nutritional security, soil and agriculture, and health, there are still lack of data and information's available to mitigate a long-term solution to safeguard and addresses the health, soil, food, and human wellbeing's.

3 Result: structure of the analytical framework

Figure 2 consists of six main components.

- Projected climate change: increased temperature, precipitation, climate-related extreme events, sea-level rise, and ocean acidification that can disrupt food production.
- National and subnational socio-demographic status can contribute to food security.
- Food system; effects on crop, livestock, and fisheries output.
- Food and nutritional security: ensuring the availability, accessibility, and stability of food by assessing the quantity and quality required.
- Diet: the quantity and quality of food consumed, as well as whether it meets the diet requirements.
- Action Plan: Processes, tools, and actions to address the implications (e.g., assessment tools and policies).

4 Discussion

4.1 Recognizing the impact of climate projections on soil

Climate projection is an indicator that can determine the degree of future agricultural supply and demand at both national and subnational levels. Since limited research was conducted in the country to assess and evaluate the risk it poses to local crop production, especially the quantity and quality of nutrition, the risk of nutrient deficiency is yet to be investigated. Therefore, this needs to be included in the country's policy or objective to start looking at the impact these changes in rainfall and temperature will have on the nutritional content in the soil, as it determines the health of crops consumed by households, and whether crop nutrient content still meets people's daily nutrient requirements.

A change in weather patterns also affects soil, as it provides critical nutrients such as N, P, and K for plant growth and influences production through water distribution (Vicca et al., 2012). Other elements such as Ca, Mg, S, Fe, Zn, Cu, B, and Mo differ with different soil types and their impact on food and nutrients as well (Silver et al., 2021).

The disruption in the nutrient cycle in the soil can occur in different ways. Here, the study emphasized climate change and extreme climate events. A previous study by the authors (Bird et al., 2021) on the soil moisture in two north Malaita communists revealed 47.4 to 66.4%, respectively, affecting the growth of their local crop production.

Although climate change is a slow process, with relatively slight changes in temperature and precipitation over a long period of time, these changes have an impact on a variety of soil processes, especially those that are related to soil fertility. Changes in soil moisture content, as well as rise in soil temperature and CO_2 levels due to climate change, are projected to have the most impact on soils (Pareek, 2017), influencing nutrient utilization efficiency through direct impacts on root surface area and inflow rate, while carbon allocation to roots

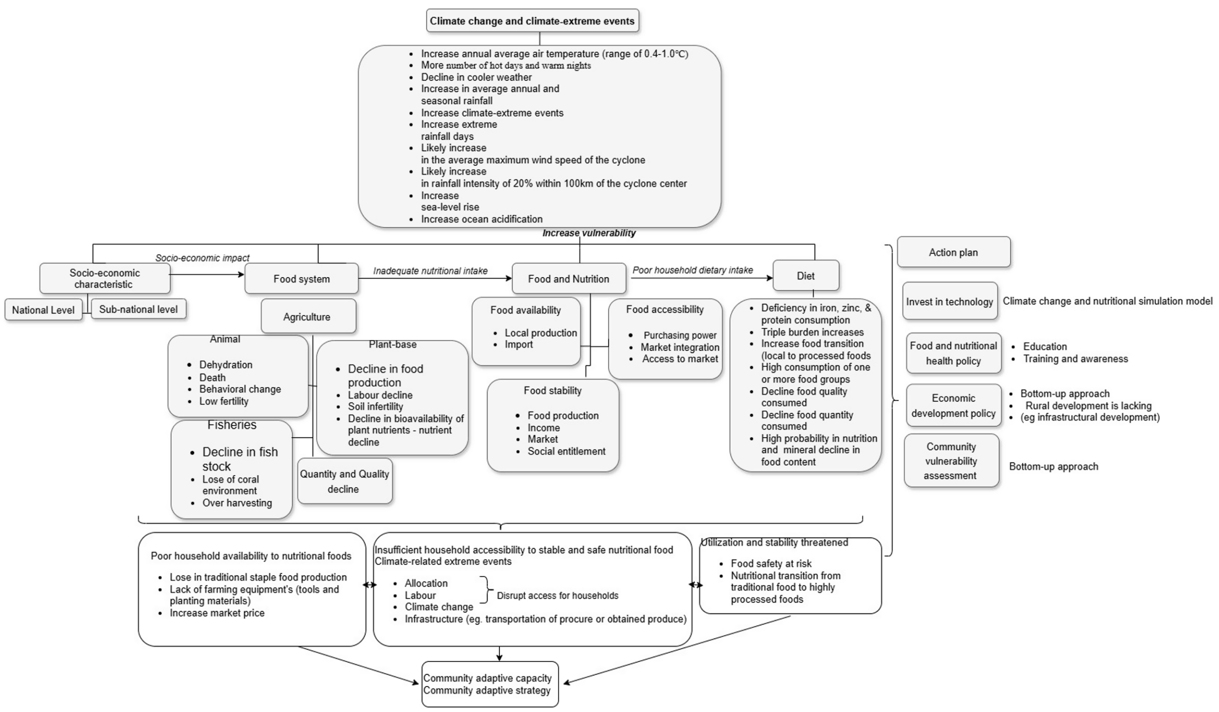

FIGURE 2
This analytical framework illustrates the key indicators derived from the Solomon Islands climate projections, highlighting their direct and indirect impacts on social demographics, the food system, and the environment, including the agricultural sector. These interconnected sectors influence nutritional outcomes and human consumption patterns. Each sector serves as a critical link within an integrated system, where understanding these connections helps inform both short-term interventions and long-term strategic planning for national resilience.

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influences nutrient absorption. These are the energy consumption estimates for soil formation and water balances in soil, organic-mineral interaction processes, organic and mineral material transformation, and soil solution fluxes. Thus, if policymakers want to address human nutritional deficiency, it is advisable to start with the impact climate change has on soil nutrients. As it builds, it will assist in understanding and distinguishing the quality and quantity of crops that contain and are consumed in human diets. As shown in Chapter 4, measuring the soil moisture content was conducted. Other studies (Mataki et al., 2013; Quity, 2012) also conducted soil experiments determining the nutrient content showing how an increase in temperature and rainfall can affect the soil profile and thus can affect the level of crop outputs in the Solomon Islands. However, there are still limited studies conducted in this area for substantial data.

4.2 Recognizing the influence of socio-economic factors

Identifying socio-demographics is crucial for influencing decision-making at both national and subnational levels. Local farmers often attribute negative impacts to non-climatic factors based on their experiences over time (Bird et al., 2021). These factors can include socio-economic conditions and unsustainable practices (Van der Ploeg et al., 2020), which affect their basic needs and production capabilities. They influence farmers' abilities to adapt to climate change, market conditions, land security, labor availability, soil fertility, pest and disease management, and beliefs.

Research (Gopalakrishnan et al., 2019; Kidane et al., 2022) emphasizes the importance of recognizing both climate change perceptions and socio-economic concerns that impact farmers' adaptation strategies. Socio-economic factors, such as education, significantly affect decision-making related to agricultural practices and information access. In the Solomon Islands, issues like illiteracy and language barriers complicate the understanding of scientific concepts, pushing reliance on traditional knowledge to interpret weather patterns and disasters. Therefore, socio-economic factors must be integrated into any comprehensive framework.

4.3 Crop and vegetable nutrient value vs. climate change

The Solomon Islands and other Pacific Island Countries, known for their diverse food environment are facing significant challenges from climate change. It affects the micronutrients in plants including nitrogen and sulfur solution concentrations, reduces Potassium (K), Calcium (Ca), Zinc (Zn), Magnesium (Mg), Iron (Fe), and affects plant tissues' nutritional content required for plant growth (Prieto and Querejeta, 2020). The micronutrient reduction may then affect human consumption according to Nakandalage and Seneweera (2018), which are essential for growth, development, reproductive purposes, cell metabolism, and also in building the immune system in response.

The decline in micronutrients in plants can lead to dietary deficiencies, contributing to hidden hunger and significant public health issues (Haddad et al., 2016). For example, a Zn deficiency can increase the risk of anemia by 50%, particularly affecting 40% of pregnant women and young children (Bouis and Saltzman, 2017). This highlights the need for further research to better understand the decline in both micro-and macronutrients in crops, vegetables, and fruits.

4.4 Impact of climate change on crop nutrient

Climate change and rising atmospheric CO_2 levels can significantly impact crop yields and nutrient availability (Rauff and Bello, 2015; Rosenzweig et al., 2013). These changes affect soil conditions, influencing nutrient accessibility and crop growth (Pugnaire et al., 2019). While higher CO_2 may enhance the Leaf Area Index (LAI) of some crops, it can also negatively affect the nutritional quality of others by reducing certain macronutrients (Dong et al., 2018; Li et al., 2018).

Research indicates that high CO_2 levels decrease the concentrations of essential nutrients like protein, Fe, Zn, and other minerals (Pareek, 2017), which are crucial for human growth and development. Table 1, outlines the impact of climate change on micronutrients in various commonly consumed crops in the Pacific Islands. Given these risks, populations in the Pacific, such as those in the Solomon Islands, are likely to experience nutritional deficiencies, as their diets predominantly consist of high-carbohydrate starchy root and tuber crops, along with vegetables as seen in Horsey et al. (2019).

A study by Janket et al. (2021) on cassava highlights gaps in research regarding crop genotype, planting dates, nutrient uptake, and nutrient distribution, which are essential for understanding nutrient accommodation. Their study found that nutrient concentrations vary between plant tissues and growth stages, and that nutrient uptake differs based on planting dates, particularly between early and post-rainy seasons (as shown in Table 1). Thus, this paper points out the crucial points for decision-making and strategies related to food and nutritional security, especially in the context of a growing population. With climate change, the nutritional and production outputs of crops may be significantly affected. Bahrami et al. (2017) noted that increased CO_2 levels lead to reduced protein concentrations due to lower N availability, a result of nutrient uptake not matching biomass growth—a phenomenon called carbohydrate or growth dilution. This is compounded by the inhibition of photorespiration, which is necessary for nitrate assimilation into proteins. Additionally, McGrath and Lobell (2013) found a strong correlation between nutrient uptake and reduced nutrient concentrations in crops due to elevated CO_2 levels.

Furthermore, the focus on food security often emphasizes areas like crop management, adaptation, and healthy eating, but overlooks the negative effects of climate change on crop nutrition and soil health which contributes to the quality of what is consumed. While promoting local crop cultivation is beneficial, it does not necessarily improve health outcomes, as communities may still face nutritional risks with the perception that local production is healthy. To maintain necessary nutrient levels, households might need to significantly increase their intake of root crops, which calls for higher crop yields and innovative planning from agricultural ministries. A meta-analysis by Myers et al. (2014) highlighted the adverse effects of rising CO_2 levels on crop nutrient quality, yet little research has been conducted on staple foods in Pacific countries. Most studies center on crops like wheat and rice, neglecting roots and tubers common in tropical climates (Myers et al.,

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TABLE 1 Summary of climate change impact on crops, vegetable, and fruit nutrients.

Common crops	Climate change impact (Elevated CO_2/Drought) on yield	Micronutrient	Reference
Taro (Tausala Samoa) Lehua variety	Nitrogen leaching; Low yield; Resistant to nitro leaching and runoff; High yield	Drought Taro M-shoot increased from 9.2 to 10.0 g/100 g (+0.8%) ↑Taro M-Corn 4.1 & 4.7 g/100 g (+0.6%) ↑N corms 0.8 to 0.9 g/100 g (+0.1%) & shot (1.8 to 2.0 g/100 g (+0.2%) ↑27% of oxalate	Gouveia et al. (2020) and Kristl et al. (2021)
Sweet potato	Reduces root output, branching, leaf area index, stem height and length, stomatal closure, leaf size, and photosynthesis. Furthermore, it causes oxidative stress 35%↑ increase in yield (eCO$_2$↑) Drought was shown to reduce the size of sweet potatoes	↓ in CCL level under drought Insufficient amount of N & K Carotenoids ↔ Carotenoids (eCO2 431 pp.,) ↔ Carotenoids (eCO2 506 ppm) ↓ 24% (eCO2 649 ppm)	Sapakhova et al. (2023) and Hartemink (2003)
Cassava	Resilient; Yields higher tuber production under projected temperature rise; Reduce the concentration of macro and micronutrients in tuber due to salt stress. This makes the tuber yield more toxic and less nutritious. Planting in the Early Rainy Session (ERS) has more nutrient uptake compared to the rainy session (PRS).	↑°C ↑ tuber toxicity Root storage (PRS) ↑% N, P, & K Root storage (PRS) ↑nutrient removal & accumulation for Ca, Mg, & S Harvest N (26–45%), P (26–42%) & K (45–58%) accumulation in the storage roots. Ca (12–18%), Mg (20–31%) & S (12–31%) accumulation in the stems.	Brown et al. (2016)
Corn	Drought Increase seed nutrient content Decreases seed nutrient content	↑N, Ca, Mg, Cu, & N (Severe) ↓P, K, Fe, Zn, & Cu (Severe)	Da Ge et al. (2010) and Oktem (2008)
Stem vegetables		46%↑(eCO$_2$↑)	Dong et al. (2020)
Eggplant		39% ↑ (eCO$_2$↑)	Dong et al. (2020)
Cucumber		33% ↑ (eCO$_2$↑)	Dong et al. (2020)
Tomato		Total sugar ↑ (CO$_2$↑) Vitamin C ↓ (CO$_2$↑) Acidity ↓ (CO$_2$↑) Protein ↓ (CO$_2$↑) Fat ↓ (CO$_2$↑) Fiber ↑ (CO$_2$↑) Ash ↓ (CO$_2$↑) Zn, Mn, Fb, Ni, Cr, and Cd ↓ (CO$_2$↑) De and CU ↑ (CO$_2$↑) 24% ↑ (eCO$_2$↑)	Dong et al. (2020) and Khan et al. (2012)
Lettuce		39% ↑ (eCO$_2$↑)	Dong et al. (2020)
Chinese cabbage		Biomass Zn↓by 18% nitrate ↔ (eCO2) ammonium nitrate ↔ (eCO2 + eT) nitrate ↔ (eCO2 + eT) ammonium nitrateFe ↔ (eCO2) nitrateFe ↔ (eCO2) ammonium nitrateFe ↔ (eCO2 + eT) nitrateFe ↔ (eCO2 + eT) ammonium nitrate 18% ↑ (eCO$_2$↑)	Dong et al. (2020)
Leafy green vegetables Associated with soil nutrient (Pumpkin, kangkong, cassava, taro, *Amaranthus viridis, Cnidoscolus aconitifolius, Ipomoea aquatica, Abelmoschus manihot*)		K < 15,000 mg/kg 46% had Mn < 15 mg/kg.	Lyons et al. (2020)

2014; Manners and Van Etten, 2018). This gap in research hampers efforts to assess food security and nutrient needs in rural populations. Crop modeling can provide crucial insights to enhance community resilience and preparedness in the face of these challenges and be better aware of what is happening to their local productions and diet.

4.5 Impact on vegetable nutrient

While increased CO_2 can enhance the taste and flavor of vegetables like lettuce, tomatoes, and potatoes (Moretti et al., 2009), its effect on their nutritional quality is less understood. A meta-analysis by Dong et al. (2018) found that elevated CO_2 concentrations lead to a significant decline in protein levels: 9.5% for vegetables, 10.5% for fruiting vegetables, 12.6% for stem vegetables, and 20.5% for root vegetables, though leafy greens showed no decline. However, CO_2 boosts antioxidant capacity in leafy vegetables by 59%. A study in PNG on *Abelmoschus manihot* indicated that environmental factors significantly affect micronutrient levels, suggesting that breeding initiatives should consider the environment to enhance nutrient value affordably (Rubiang-Yalambing et al., 2014). However, this research did not link climate change to nutrient content, leaving a gap in understanding. Furthermore, elevated CO_2 levels can lead to nutrient dilution, reducing the concentration of essential minerals.

Kumar et al. (2020) highlight green leafy vegetables are abundant in essential minerals such as Fe, Ca, copper (Cu), sodium (Na), and Zn, which aid in nutrient absorption (Melse-Boonstra, 2020). The recommended intake is approximately 100 g of leafy vegetables (Lyons et al., 2020). However, with climate change projections suggesting potential declines in certain micronutrients, it remains uncertain if this intake will serve to meet the nutritional needs of Pacific Island Countries and Territories (PICTs). This situation raises concerns about future food security and diet quality in these regions. Consequently, the study advocates for a more thorough analysis of nutrient output to enhance nutritional security for the Solomon Islands and other PICTs.

4.6 Assessing nutrient content

Several factors, including temperature, CO_2 fertilization, and precipitation, can significantly alter plant physiology, growing seasons, technological advancements, and water availability, all of which affect agricultural productivity (Wairiu et al., 2012). Continuous research is necessary to understand these dynamics. Crop models are vital tools for evaluating the impact of climate change on crop yields (Zhao et al., 2019). Authors like Allen and Bourke (2009) and the IPCC (2023) AR6 have noted that climate change is already affecting food production in PICTs, yet the outcomes remain uncertain, particularly regarding nutrient content (both micro-and macro-nutrients) in agricultural products. This uncertainty is linked to the complexities of measuring agricultural responses to climate change and consumption patterns, making it challenging to determine the extent of nutrient loss and its implications for dietary needs.

Studies in PICTs, including Fiji, the Solomon Islands, and Vanuatu, have employed models like the Decision Support System for Agro-Technology (DSSAT) and the Agricultural Production Systems Simulator (APSIM) to assess the impact of climate change on crop production (ACIAR, 2017; Maeke, 2013; Mausio et al., 2020; Nadd, 2014; Leo, 2016; Quity, 2012). While tropical staple crops such as yam, cassava, sweet potato, taro, breadfruit, and bananas are common, there is limited data on their health-related quality associated with climate projections. Understanding the nutrient content of these staple crops is essential for ensuring future food and nutritional security in the region.

For instance, a study in the Solomon Islands indicates that taro growth is sensitive to nitrogen leaching, leading to lower yields under future climate projections (Quity, 2012). Although taro will continue to grow, its yields are expected to decline over time. In contrast, Maeke's (2013) research suggests that cassava may yield more tubers despite climate change and rising CO_2 levels. However, corn is projected to face yield reductions.

Further studies show that breadfruit, a resilient tree crop for reef islands, is likely to become more suitable under RCP 4.5 and RCP 8.5 climate scenarios (Mausio et al., 2020). Predictions for yam suggest a decline in yield by 2050 due to factors like water stress, reduced rainfall, nitrogen shortages, and varying soil types. Leaf area development significantly influences tuber growth rates and overall output. The observed yield decline, as measured by leaf area index (LAI) and radiation use efficiency, highlights the need for a better understanding of yam's impact on diets in PICTs. However, there is a significant gap in crop modeling focused on nutritional content, which is vital for dietary intake. Therefore, understanding the effects of climate change on yield, food security, and nutritional security is essential.

4.7 Strengthening policy and action plan in the PIC

Improving food and nutritional security is a key goal of PICT's agriculture policies. To achieve this, it's essential to involve food scientists, microbiologists, veterinarians, medical physicians, and toxicologists in the planning process. Their expertise can address plant nutrient quality during the planting cycle and associated health risks. Investing also in crop simulation models is crucial as they help raise awareness about various factors affecting food security and nutrition. It will:

- Increase awareness of potential agricultural nutrient deficiencies and their implications for individual dietary demands and health hazards.
- Determine how much food is required for good nutrition and whether local food quantity and quality can be increased.
- Determine the yields required for long-term sustainability and improved nutrition.
- Understand the correlation between climate change, soil nutrient levels, crop cycles, and the nutritional value of locally farmed foods.

While studies have been conducted to predict yield changes and assess agronomic impacts (White et al., 2011; Loladze, 2014), prioritizing relevant agricultural research and development modeling is challenging. Farmers are increasingly shifting toward early-maturing crops and varieties that better adapt to changing conditions. To support this transition, there is a strong need for increased agricultural research and investment in PICTs to equip farmers with essential adaptation skills and knowledge. Moreover, collaboration among ministries is crucial to align efforts and avoid competition over individual goals.

Investment and development in technologies and finance are challenging, including in the Solomon Islands, making strategic plan implementation and achieving the goals more difficult at the national and sub-national levels. Technology development and investments are costly, so each implementer needs an in-depth assessment to identify appropriate short-term and long-term adaptation. For most of the PICT, including the Solomon Islands, technology, technical skills, financial capacity, and project management skills are still lacking, this can and was seen in the policies as gaps. This can be seen in Table 2.

Most policy planning focuses on boosting agricultural production and addressing climate change, with outside investment increasingly important for advancing agricultural technology. However, investing in new technology without first assessing potential risks related to climate change impacts on production, soil, crops, and health can lead to inefficient use of resources. Although there is considerable advocacy for healthy eating and food safety, this study notes a lack of consideration for how projected climate change might affect the nutrient content and quality of future root and tuber crops, vegetables, and fruits. Given the current decline in soil and crop nutrients (Pareek, 2017), policies should clearly outline specific nutrient aspects, indicators, solutions, and long-term objectives to effectively manage these risks.

This study underlines the importance of training agricultural officials to use crop simulation models alongside climate simulation models to predict outcomes up to 2,100. Each parameter in this analytical framework must be investigated further in the local context to fully comprehend its direct and indirect health repercussions, as they cannot be evaluated in isolation. This technique is critical for combating malnutrition in the country. Furthermore, investing in and training officials within a nutritional framework is critical, since it improves their abilities and knowledge of nutritional health evaluation. Although deploying such models may appear complex and costly, they can lead to better decision-making and human resource management. Agricultural and nutritional simulations, by raising awareness and encouraging action, can considerably improve the nation's knowledge and productivity.

Some of the policies in the Solomon Islands (Table 2) highlighted effective agricultural research and development is urgently needed to support the agriculture sector in meeting the growing population demand with an environmentally friendly technology package. One of the important factors is the policies aim to boost research and development projected to increase the productivity of food crops and animals, as well as value-added technologies to increase production for both domestic and international markets. Agricultural ministries in the Solomon Islands have had some success collaborating with the Solomon Islands National University, and other NGOs which shows how research is also an important priority area. However, the agriculture policy for the Solomon Islands lacks consideration of nutrient loss and strategies for building climate resilience, which affects the consistency of its goals. Key challenges faced by the country include a lack of technical capacity, financial resources, project management capabilities, and effective impact measurement. These gaps have hindered the implementation of the policy and the ability to meet the needs of PICTs, a situation also highlighted at UNFCCC COP meetings. Thus, the policies are well structured, it recognize the significance of research to boost agriculture and health. This can allow researchers to contribute and collaborate with the ministries to build the capacity and skills for the country.

4.8 Recommendation

The Solomon Islands has its own specific frameworks developed to address climate change, local food production, and health. These frameworks are based on the country's policies under its given ministries to carry out its work plans. However, with the given policies, there are still challenges to fulfilling the objectives and aims. There are also gaps that need to be addressed in order to fully understand the relationships between climate projection and its impact on food and nutritional security in the local rural communities.

This calls for some recommendations or approaches to strengthen adaptation knowledge in both traditional and scientific approaches.

- Incorporate traditional adaptations that can be utilized with the modern adaptations that local communities already have and assess the feasibility of the integrated adaptation practices or options.
- Capacity building among SIG, ministries, private sectors, and communities for climate change and nutrition implementation and improvement (collaboration). This means that although each ministry has its existing policies, they need to collaborate to create a work plan that connects their objectives and achieves them not as individuals but as a group. Because food and nutritional security are connected to climate change, soil science, agriculture, human diets, and health.
- Adaptation: identifying the gaps in pre-existing adaptation and policy, and how a potential adaptation approach can assist in minimizing crop losses and improving nutrition
- Strengthen existing institutions established in the local communities that can be the center point.
- Conducting laboratory equipment and studies to look into crop nutritional loss, employing controlled and open trials based on the projected climate change. This experiment could account for anticipated increases in soil moisture, temperature, and the absorption of nutrients by crops. When the crops are fully grown, their level of nutritional content can be examined to see if they are insufficient or sufficient to meet dietary nutrient needs. The experiment should investigate whether there will be a difference in the quality and quantity of nutrients consumed about health. The community, particularly local farmers, can be better prepared with a suitable strategy to sustain their food and nutritional security, as a consequence, helping to reduce malnutrition in the future.

5 Conclusion

The study draws on studies and frameworks from literature and policy to identify gaps, to develop a way forward to alleviate nutritional deficiency gaps by bringing together diverse information. Because agriculture, climate change, and nutritional security are critical components in several policy sectors, the analytical framework focuses on the ability to enhance diet through understanding the complex relationship between climate change, soil, consumption, and health. To ensure food security is achieved, it must be noted that it not only requires increasing production to meet growing demand, but also that what is produced and consumed must be safe, and contains sufficient nutrients to maintain the human body's functions for a healthy life. This is why the study's analytical framework demonstrates the significance of critical thinking about the potential impact of projected climate change on nutrient content uptake in crops and vegetables and nutritional health risks. It displays prevailing evidence of climate change's direct and indirect influence on nutrient availability in crops but little is known on the level of nutrient consumed based on some evidence of nutrient losses in crops and vegetables. The diet component is included to demonstrate the potential nutritional reduction in diet due to crop and vegetable nutrient depletion before harvest. The study suggests looking into these aspects for further consideration in policy and strategy planning as they will aid in

TABLE 2 Summary of gaps identified and potential needs to improve implementation.

Possible investment technology		
Technology	**Reason for adopting**	**Reference**
The crop simulation model	The crop simulation models are technology-driven by environmental variables, including climate variables and crop management. It employs quantitative descriptions of ecophysiological processes as input data to predict the outcome of plants. It determines the yield and growth under different RCPs. This can help determine the rate of production by incorporating the different parameters for crop growth. Crop modeling may help ensure food safety and nutritional security. The results are proven to be accurate in estimating growth and yield in a variety of semi-arid climates, planting techniques, management practices, and nitrogen rates. This model can be used across the provinces and is affordable.	Hodson and White (2010) and Di Napoli et al. (2022)
Nutritional model	1: Invest in a nutritional model that not only determines the health benefit but can assess and evaluate the nutrients directly linked with crop nutrients, directly and indirectly linked with climate and soil. 2: Despite extensive nutrition research aimed at identifying chronic diseases under the GFN, there is still a lot more missing in the aspects of human nutrition where science has failed to incorporate or explain the recent rise in obesity associated with cardiometabolic disease. Investing, modifying, and training local officers (Solomon Islands) is important as it will provide data applicable to evaluating nutritional trends and health.	Lihoreau et al. (2015)

Investing and improving research		
SIMAL Sector Policy 2015–2019	**Ministry focus**	**Reference**
Clearly outline how they intend to achieve their research and knowledge management objectives under their five components. Highlights of collaboration with the Solomon Islands National University students, the National Agriculture Research and Development Centre (NARDC), and other institutes. (Solomon Islands Ministry of Agriculture and Livestock, n.d.)	1: The development of new field experimental stations 2: Three labs (including a plant tissue culture lab, a soil and plant nutrition lab, and a food processing lab) 3: The relocation of NARDC (the former Taiwan Agriculture Mission to the Solomon Islands). 4: Plant and animal breeding facility 5: Climate resistance crop	Solomon Islands Government (2015)
Gaps identified and proposed approach		
With the focus on expanding field experiments, labs, and crop improvement through research, this study strongly emphasizes the need for their policy objectives to look into measuring and tracing the nutrient contents in the local crops associated with climate change and its implications for the nutrient quality consumed and its potential risk to human health. There are no written details of collaborating where SIMHMS can pick up where they have accomplished their goal of bringing awareness to the populace on the next step in preparation rather than encouraging local households to plant more and consume more local crops without identifying the potential risk of nutrient deficiency in the produce consumed. This nevertheless demonstrates how the major ministries seek to address their objectives.		

Agriculture sector and investment plan strategy plan for 2021–2030		
Strategy plan	**Benefits**	**Gap**
Program 1 Agri-tec Portal (Information Technology Development)	(1) Develop a platform or portal in which information is available in terms of practical technical and policy information and guidelines to farmers and agro-industry stakeholders. This will contain information on climate-smart agricultural technologies, sustainable farming systems for the various agro-ecological zones, permissible agrochemicals, integrated pest management (IPM), cost of production, government schemes and services, biosecurity information, traditional farming practices, food safety standards, environmental information including climate change, disaster management, women in agriculture, information on farmer organizations, and agriculture-related statistics, among other topics. (2) Equal accessibility	(1) This approach marginalizes local farmers in rural communities. (2) Equity is not considered. Examples: accessibility to the internet, educational background (primary dropouts and no formal education), whether they can read and how well they will understand the information, or their current state (disability). This strategy still makes information sharing difficult and limited to parties or organizations with access. It fails to consider an individual's differences, which leaves them more vulnerable. This is why, rather than depending on all information being accessible online, investing in and deploying more extension offices in local areas to share this information seems suitable.

(Continued)

TABLE 2 (Continued)

The overall gap identified and challenges in implementation		Reference
Lack of technical capacity	(1) Lack of technical capacity to deal effectively with Multilateral Environmental Agreements (MEAs) obligations and the implementation of the agreement provisions, climate change, and the work on capacity building including climate change implementation in the various sectors. (2) Affects implementation on agricultural progress, food security, and nutritional security	UNFCCC (2022)
Financial capacity and project management	(1) Lack of financial capacity to deal effectively with project management capacity and the implementation of the agreement provisions, climate change, and the work on capacity building to climate change implementation in the various sectors. Allocation for KJWA is still an issue to implement the decision during COP27 and under which funding under the UNFCCC. (2) Lack of financial resources available to the Pacific SIDS to implement their obligations under the UNFCCC.	UNFCCC (2022)
Measuring of impact	(1) Lack of prioritizing the regional or national need-base for adaptation and implementation when donors prioritized their support based on their obligations which may disqualify PICT from being selected for funding to deal effectively obligations to KJWA and the implementations of the agreement provisions, climate change, and the work on capacity building to climate change implementation in the various sectors. (2) Lack of project management capacities, including the ability to recognize, develop, and prepare project proposals, as well as other technical and legal abilities like formulating regulations or carrying out specific technical fundamental studies or problem-solving.	UNFCCC (2022)

addressing malnutrition, and because the process of climate change occurs over time, thus, looking into this context will begin to bring in additional knowledge gaps in nutritional diet and how to address them.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Author contributions

ZB: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. VI: Conceptualization, Methodology, Resources, Supervision, Validation, Writing – review & editing. MW: Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

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