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Perspective: could Ethiopian potatoes contribute to environmental sustainability, the Ethiopian economy, and human health?

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Environmental data are rapidly accruing on the unsustainability of diets based on animal products, such as dairy and meats. Shifting to alternative sources of protein is inevitable given an increase in the projected global population and protein demand. Left unchecked, a collision between food security and sustainability is imminent. Potatoes could be the strategic food and cash crop to harmonize food security and sustainability worldwide. Recently, there has been a growing interest in extracting proteins from the byproduct of the potato starch industry known as potato fruit juice. These proteins are garnering attention due to their nutritional value, characterized by a well-balanced amino acid profile, as well as their functional properties including emulsifying, foaming, and gelling capabilities. Moreover, these proteins are considered to be less allergenic than some other protein sources. Extracting potato protein, which is sourced as a byproduct, reduces food loss and waste, thereby eliminating pathogenic microorganisms from the environment and mitigating greenhouse gas emissions. Ethiopia is a major potato producer in East Africa. Potatoes help the country increase household income, ensure food security and revenue generation, and produce starch. However, Ethiopia's potato starch industry has not yet begun protein extraction, despite the vital role of the proteins and the country's huge cultivation potential. Furthermore, the global potato protein market is experiencing significant growth. This information urgently calls for innovative approaches to assess the impact of extracting protein from potatoes produced in Ethiopia. Therefore, this perspective article has two main objectives. First, to scan the extent of potato production in Ethiopia in relation to environmental sustainability and the economy. Second, to provide prospects on the impact of extracting protein isolate from potatoes produced in Ethiopia on environmental sustainability, Ethiopia's economy, and human health.

KEYWORDS

economy, environmental sustainability, Ethiopia, health, potato protein

1 Introduction

By the year 2050, the world population is projected to reach approximately 10 billion (United Nations and Population Division, 2019). Among East African countries, Ethiopia is estimated to have the largest population (United Nations and Population Division, 2019). Consequently, this population growth will lead to increased food demand, particularly proteins due to their nutritional value, necessitating increased crop production, agricultural land use, and greenhouse gas (GHG) emissions (Henchion et al., 2017; Searchinger et al., 2019). These create food, land, and emission mitigation gaps (Searchinger et al., 2019).

Globally, different menus of solutions have been incubated to fill these gaps, such as managing food demand (by reducing food loss and waste and shifting the diet toward plant-based foods), enhancing production-related climate mitigation, inducing technological innovation, and intensifying agriculture on existing land coupled with conserving biodiversity (Alexandratos and Bruinsma, 2012; Fedoroff, 2015; Searchinger et al., 2019). Ironically, agricultural development needs to consider food loss and waste, which is an under-recognized opportunity for mitigating greenhouse gas emissions, increasing productivity and household income, and achieving food security (Galford et al., 2020). Ensuring food security is a vehicle to meet all the Sustainable Development Goals (SDGs) (Pérez-Escamilla, 2017). The potato crop is one of the strategic crops to achieve food security in the world. As a result, the International Year of Potato was celebrated in 2008 to increase awareness of the relationship that exists between food security and the crucial role of potatoes (*Solanum tuberosum*) in defeating hunger (Lutaladio et al., 2009; Devaux et al., 2014; Wijesinha-Bettoni and Mouillé, 2019; Degebasa, 2020; Raigond et al., 2020). Its cultivation and consumption are strongly expanding in developing countries (Scott et al., 2000; Lutaladio et al., 2009).

Potato is a wholesome food and cash crop characterized by a short maturity period (3–4 months), high yield potential, less susceptibility to market shock, a high proportion of edible biomass (high harvest index), excellent nutrient source, ease of preparation for consumption, wide acceptance as daily food, a wide variety of cultivars, adaptability for intensive cultivation in small areas, extensive production technology, security of production under stress (Guenthner, 2001; Campos and Ortiz, 2020), and a low environmental (ecological) footprint (Clark et al., 2022).

Remarkably, potato is packaged in nutrients, such as water, starch, high-quality protein, dietary fiber, vitamins (mainly vitamins C and B6), minerals (potassium, iron, magnesium, calcium, and zinc), health-promoting phytochemicals (phenolic acids, anthocyanins, carotenoids, and flavonoids) (Bassoli et al., 2008; Ezekiel et al., 2013; Campos and Ortiz, 2020; BNV and GVS, 2023) and low in anti-nutrients such as phytic acid and tannins, thereby enhancing the bioavailability of minerals (Camire et al., 2009). Furthermore, interventional studies confirmed that vitamin C and potassium found in potatoes are highly bioavailable (Kondo et al., 2012; Macdonald-Clarke et al., 2016).

Due to the optimal nutrient and phytochemical profiles of potatoes (Bassoli et al., 2008; Ezekiel et al., 2013; Campos and Ortiz, 2020; BNV and GVS, 2023) (Figure 1), they have an enormous effect on human health, such as in preventing hypertension, inflammation, oxidative stress, cancers, obesity, diabetes, stroke, heart diseases, and promoting gut health, as indicated by substantial evidence (Camire et al., 2009; Andre et al., 2014; Larsson and Wolk, 2016; Zaheer and Akhtar, 2016; Beals, 2019; Campos and Ortiz, 2020; Kowalczewski et al., 2022; BNV and GVS, 2023; Kimura et al., 2023).

Recently, the Framingham offspring study among adults showed no adverse association between potato consumption and the risks of type 2 diabetes mellitus, hypertension, or elevated triglycerides (Yiannakou et al., 2022). Interestingly, potato protein in the form of concentrate or isolate extracted from potato juice (by-products released in large quantities from the starch industry) recently gained attention in food processing due to its nutritional (well-balanced amino acid profile), functional (emulsifying, foaming, and gelling properties), and less allergenic properties (Hussain et al., 2021).

Protein extraction from potato juice potentially reduces food loss and waste, thereby eliminating pathogenic microorganisms from the environment and mitigating greenhouse gas emissions while simultaneously enhancing the economy (Galford et al., 2020; Chauhan et al., 2023). As a consequence, global protein demand is escalating (Grand View Research, 2023). Particularly, the global potato protein market size is valued at US$ 401.8 million and is expected to grow at a rate of 6.73% during 2023–2030 (IMARC Group, 2023). The market is influenced by the intensity of potato production. In Eastern Africa, Ethiopia is the major producer of potatoes, and 70% of the arable land is suitable for potato cultivation because of suitable agroecology (Tesfaye, 2016). Nevertheless, the age-standardized death rate and disability-adjusted life years rate due to protein energy malnutrition in Ethiopia in 2019 were 12.9 and 492 per 100,000 population, respectively (Teklemariam et al., 2023). This indicates the urgency of addressing protein inadequacy in Ethiopia. Therefore, this perspective article has two objectives: first, to scan the extent of potato production in Ethiopia related to environmental sustainability, and the economy; and second, to provide prospects on the impact of extracting protein from potatoes produced in Ethiopia on environmental sustainability, Ethiopia's economy, and human health.

2 Potato production in Ethiopia and environmental sustainability

In Ethiopia, agriculture contributes 80% of employment, 43% of gross domestic product (GDP), and 90% of export earnings (Byerlee et al., 2007; FDRE, 2011; Mahoo et al., 2013; Degu, 2019; Wordofa and Sassi, 2020; Woolfrey et al., 2021). Intensifying agricultural food development in Ethiopia has been recognized as a promising strategy to achieve food security (de Janvry and Sadoulet, 2020; Wordofa and Sassi, 2020), potentially meeting SDGs (Pérez-Escamilla, 2017). Unfortunately, according to the 2023 Global Hunger Index report, the state of chronic food insecurity and malnutrition in Ethiopia was categorized as serious (GHI score of 26.2) (Von Grebmer et al., 2023). Therefore, potatoes as a strategic crop would help to ensure national food and nutrition security, increase the country's economy, and climb out of poverty (Devaux et al., 2014; Mintesnot, 2016; Tesfaye, 2016; Brasesco et al., 2019; Degebasa, 2019).

In Ethiopia, potatoes are mainly cultivated by rural smallholders in Central, Eastern, North Western, and Southern regions at an altitude of more than 1,500 m above sea level (Tesfaye, 2016). Although the productivity of potatoes is affected by various factors, the trend of the production volume, harvested areas, and the average yield of

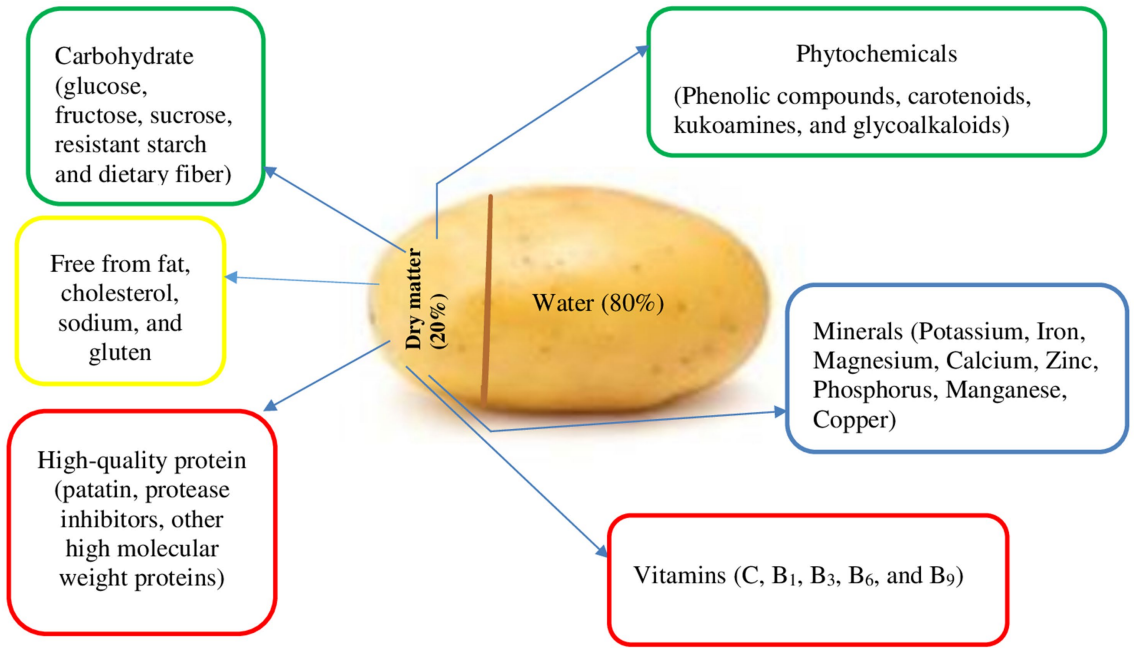

FIGURE 1
Nutritional composition of 100 g raw potato (based on Refs. Camire et al. (2009), Andre et al. (2014), Zaheer and Akhtar (2016), Beals (2019), Campos and Ortiz (2020), Kowalczewski et al. (2022), BNV and GVS (2023).

TABLE 1 Production volume, harvested areas, and average yield of potatoes in Ethiopia from 2017 to 2022.

Year	Production volume (million tons)	Harvested areas (thousand hectares)	Average yield in tons per hectare
2017	0.97	69.61	13.92
2018	0.93	66.64	14
2019	0.92	70.36	13.14
2020	1.14	85.99	13.28
2021	1.14	85.01	13.43
2022	1.14	85.5	13.36

potatoes in Ethiopia from 2017 to 2022 showed an increment (IndexBox, 2024) as indicated in Table 1.

Poor seed quality (Hirpa et al., 2010, 2016), potato diseases such as bacterial wilt, late blight, and viruses (Gildemacher et al., 2009; Nasir, 2016), and inadequate soil fertility management (Emana and Nigussie, 2011; Schulte-Geldermann, 2013) are claimed as the main bottleneck to increase potato productivity in the country. However, different strategies have been applied to increase potato productivity in Ethiopia, including seed quality management (seed systems management and seed production) (Gildemacher et al., 2009; Hirpa et al., 2016), water efficient and scheduled irrigation systems (Gebremariam et al., 2018; Alemayehu et al., 2023; Wabela et al., 2023), soil fertility management using nitrogen and phosphorus fertilizers (Sebnie et al., 2021; Woldeselassie et al., 2021; Amare et al., 2022), weed management (Kebede et al., 2016), integrated nutrient management (organic and inorganic mineral) (Girma et al., 2017; Mohammed and Dawa, 2018; Asaye et al., 2022), integrated disease and pest management (prevent bacterial wilt and late blight fungal disease, control of vectors and their viruses) (Wassihun et al., 2019; Andaregie and Astatkie, 2020; Wubet et al., 2022), post-harvest management (Tadesse et al., 2018; Degebasa, 2020), improved marketing systems, knowledge, and information systems, and using agricultural technologies (Gildemacher et al., 2009) are also critical for increasing potato productivity.

It is noteworthy that agriculture as a sector is responsible for carbon dioxide (CO_2) and non-CO_2 emissions (methane and nitrous oxide) (Leahy et al., 2020; Lynch et al., 2021; Feliciano et al., 2022). Furthermore, projected global climate change for 2010–2039 with associated increased temperature affects potato yields (Hijmans, 2003; Jaggard et al., 2010). The environmental conditions (soil type and compositions, temperature and humidity, and storage), cultivar or genotype (which plays a significant role), cultivation practices, harvest time, and method of processing and cooking of potato products have a tremendous impact on the physical properties of potatoes as well as their nutrient composition and retention, especially vitamins and phytochemicals (Reyes et al., 2004; Hamouz et al., 2013; Külen et al., 2013; BNV and GVS, 2023). Thus, selecting a good potato genotype coupled with a suitable growing environment enhances the nutritional profile and a greater yield, thereby meeting food demands for the current and future.

Moreover, Climate-Smart Agriculture (CSA) (FAO, 2010; Hengsdijk and Verhagen, 2013) and Good Agricultural Practices (GAPs) (Lutaladio et al., 2009) are crucial for sustainable potato cultivation. CSA refers to agriculture that sustainably increases productivity and resilience, mitigates GHG, and enhances achievement of national food security and development goals (FAO, 2010), whereas GAPs are defined as principles and codes of practice

that are applied to the value chain of foods and aim at ensuring safe and healthy food products, while taking into account economic, social and environmental sustainability (Lutaladio et al., 2009). CSA and GAPs are unequivocally interrelated (Verhagen et al., 2013). These practices are vital to achieving Ethiopia's Climate Resilient Green Economy (CRGE) strategy, which aims at building climate resilience, keeping GHG emissions low, and becoming a middle-income country by 2025 (FDRE, 2011). Additionally, CSA innovations, such as agroforestry, compost, soil and water conservation, and crop residue management, contribute to increased productivity and food security for smallholder farmers in Ethiopia (Teklu et al., 2024).

Consistent with this notion, the International Potato Center (CIP) drafted GAP guidelines for sustainable potato production in tropical and subtropical developing countries, including biodiversity and varieties, seed production and seed quality, seed systems, soil health and fertility management, nutrient management, soil conservations, water management, pest management, post-harvest management, value addition and markets, and farmer's health, safety, and welfare (Lutaladio et al., 2009). A study in the Rift Valley of Ethiopia indicated that potato cultivation agricultural practices (variety selection, rotation, land preparation/tillage, water management, nutrient management, crop protection, and harvest) resulted in low GHG emission potential (Hengsdijk and Verhagen, 2013). However, the study also recommends looking at different CSA options to increase yield, improve mitigation, and adapt to environmental change.

In summary, further impactful research is required to optimize the use of fertilizers, promote information flow among farmers, enhance publication and media on potato farming practices, involve research organizations, and engage suppliers in increasing inputs for soil fertility and managing crop protection. It is also important to establish a system that provides high-quality seeds adapted to environmental stresses (such as heat tolerance), disease, and pest pressures. Additionally, encouraging private investors to participate in seed production and potato processing can help increase potato productivity in Ethiopia.

3 Potato production and Ethiopia's economy

Ethiopia cultivates potatoes to achieve food security and to generate foreign revenue by increasing the household income of farmers (Bassa et al., 2017; Abadega and Abawaji, 2020), accelerating the local market profitability across the market chain (Awoke and Molla, 2019; Bakala and Tadesse, 2019), promoting market participation (Abadega, 2021), and enhancing export earnings (TrendEconomy, 2023). In addition, as per Trend Economy reports, the top export destinations of potatoes, fresh or chilled, from Ethiopia in 2022 were Somalia and Djibouti, with a share of 97% (US$17.1 million) and 2.87% (US$507,000), respectively (TrendEconomy, 2023). Sales of potatoes, fresh or chilled, from Ethiopia went up by 52% compared to 2021 (Figure 2). From exported potatoes in 2022, 1.81% (US$319,000) were seed potatoes. Conversely, in 2022, Ethiopia imported seed potatoes from the Netherlands with a share of 100% (US$299) (TrendEconomy, 2023).

The export trend of fresh and chilled potatoes in Ethiopia from, 2011 to 2022 clearly shows increased potato productivity. However, the country needs to produce high-quality seed potatoes to decrease imports and increase productivity. In Ethiopia, starch has a significant application in various industries, including the manufacturing of textile, paper, and pulp adhesives, pharmaceuticals, and food complexes as binding, packing, diluting adhesive, water absorber agents, and sweeteners in their production process (Abebe Desta and Temesgen Tigabu, 2015). In spite of that, approximately 60% of the starch is imported from abroad (Abebe Desta and Temesgen Tigabu, 2015). Thus, increasing potato productivity in Ethiopia would reduce the importation of starch, thereby accelerating the country's economy. Moreover, for low-income countries, inadequate nutrient intake will improve with economic growth (Liu et al., 2024).

4 Prospects on the impact of extracting potato protein in Ethiopia on environmental sustainability, Ethiopia's economy, and human health

Undeniably, potatoes are a powerhouse of nutrients (Bassoli et al., 2008; Ezekiel et al., 2013; Campos and Ortiz, 2020; BNV and GVS, 2023) and have a health-promoting effect (Camire et al., 2009; Andre et al., 2014; Zaheer and Akhtar, 2016; Beals, 2019; Campos and Ortiz, 2020; Kowalczewski et al., 2022; BNV and GVS, 2023). The protein content of potatoes ranges from 1 to 4.2%, the most common being 2% (BNV and GVS, 2023). Potato protein has a high biological value (Kowalczewski et al., 2019), and contains essential amino acids higher than soy, pea, casein, and egg (Gorissen et al., 2018). Particularly, potato protein extracted from potato fruit juice (side stream of the potato starch industry) has three types: patatin (40%), protease inhibitors (50%), and other high molecular weight proteins (10%) (Raigond et al., 2020).

To date, no starch industry extracted potato protein from potato juice in Ethiopia, simply the free resource has been given for livestock feed (Abebe Desta and Temesgen Tigabu, 2015). From an environmental perspective, experience from Sweden has shown that introducing potato protein for human consumption has a lower environmental impact (eutrophication, land, and energy use) than animal protein sources such as beef, pork, chicken, egg, and milk (Tromp, 2020). Plus, plant-based diets require minimal resources and are less taxing on the environment (Sabaté and Soret, 2014). Concurrently, the global potato protein market trend is rising (IMARC Group, 2023). Thus, extracting potato protein reduces food loss and waste, thereby increasing productivity and household income, achieving food security, and mitigating greenhouse gas emissions (Galford et al., 2020).

Emerging evidence also highlighted that potato proteins have various applications for human nutrition, including cheese flavor enhancer and cheese ripening accelerator (Spelbrink et al., 2015), food emulsifying, foaming, and gelling applications (Hussain et al., 2021), synthesis of fish meal as one component (Takakuwa et al., 2020), refining wine to reduce astringency (Kang et al., 2019), serving as a nano-vehicle for vitamin D fortification (David and Livney, 2016), providing protein nano-fibrils (Josefsson et al., 2019), helping to treat peri-anal dermatitis, and serving as an alternative milk formula for infants due to less allergenicity (needs further research) (Ruseler-van Embden et al., 2004; Schuh et al., 2019).

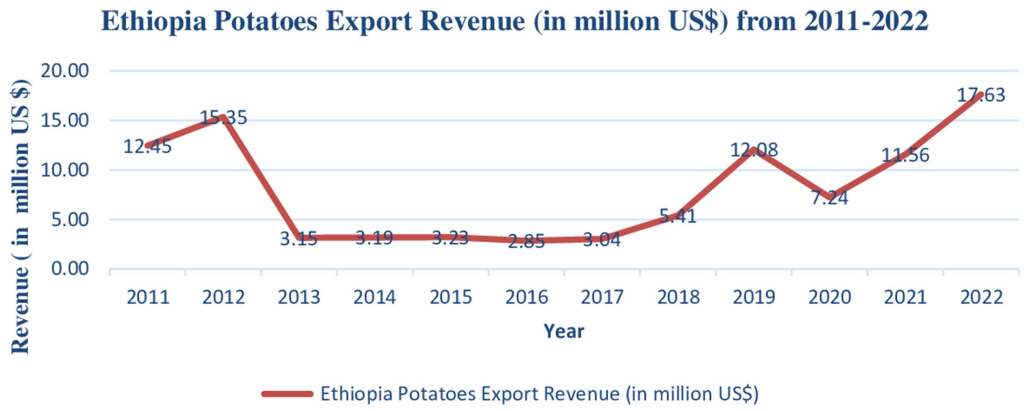

FIGURE 2
The trend of exported Ethiopia potatoes revenue from the year 2011 to 2022. Source: based on data updated from trend economy reports (TrendEconomy, 2023).

Furthermore, potato protein ingestion stimulates muscle protein synthesis rate (Larsson et al., 2019) at rest and recovery from exercise in humans (Oikawa et al., 2020; Pinckaers et al., 2022). Intriguingly, the muscle anabolic effect of potato protein was similar to milk protein (Pinckaers et al., 2022). Thus, potato protein could be the future alternative source of proteins from plant origin. In addition, these promising data strengthen the call for future avenues of research in clinical nutrition, particularly in older populations (mainly in need of increased protein intake in order to counteract loss of muscle mass and function) to assess the effect of potato proteins and other plant-derived proteins on MPS rate and the therapeutic potential of such plant proteins in mitigating the risk of age-related and disease-related body protein depletion.

In conclusion, based on the above testimonies of emerging evidence, extracting potato protein from the potato starch industry in Ethiopia after conducting a consequential life cycle assessment could have a positive impact on environmental sustainability, Ethiopia's economy, and human health. As a result, these innovation prospects could be valuable input, particularly for the Ethiopia Ministry of Agriculture, Ministry of Trade and Industry, and Ministry of Health to design ideas jointly to ensure food security, enhance environmental sustainability, and ultimately improve human health.

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.

Author contributions

MY: Conceptualization, Validation, Visualization, Writing – original draft, Writing – review & editing. MA: Conceptualization, Visualization, Writing – original draft, Writing – review & editing, Validation. SC: Conceptualization, Visualization, Writing – original draft, Writing – review & editing, Validation. MM: Conceptualization, Validation, Visualization, Writing – original draft, 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.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

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