ADVANCEMENTS IN POTATO SCIENCE: AGRONOMY, GENETICS, AND BIOTECHNOLOGY FOR SUSTAINABLE FOOD SECURITY

Beenzu Siamalube[1*], Esther Lambert[1], Chinedu Anyaji[1] and Emmanuel Ehinmitan[1]

ABSTRACT: Irish potato (*Solanum tuberosum* L.) is a globally significant crop, valued for its high nutritional content, adaptability, and contribution to food security. This study explores its role in addressing global challenges such as malnutrition, poverty, and climate change. Despite its importance, knowledge gaps persist regarding its full nutritional potential, bioavailability of nutrients, and sustainable production practices. By employing a multidisciplinary approach, this research evaluates the potato's nutritional value, its potential to combat micronutrient deficiencies, and strategies for enhancing productivity under changing environmental conditions. Key findings highlight the potato's pivotal role in improving diet quality, supporting livelihoods, and promoting sustainable agriculture. However, challenges such as pest susceptibility, production variability, and cultural barriers to dietary integration remain. Addressing these limitations through improved breeding, biofortification, and targeted education campaigns can further optimize the potato's impact. This article reviews the agronomical aspects of the Irish potato and its taxonomy nomenclature. Together, these findings highlight the importance of potatoes in providing food security to the international community, alongside the global fight against malnutrition. The aim of this study is to underscore the need for renewed focus on the Irish potato as a tool for global food security and sustainable development, offering a foundation for future research and policy innovation.

KEYWORDS: Agronomy, Climate change resilience, Pest control, Plant breeding, Potato biotechnology, *Solanum tuberosum* L.

INTRODUCTION

The Irish potato (*Solanum tuberosum* L.) is one of the most important staple crops worldwide, renowned for its high productivity, adaptability, and substantial role in global food security. It is the most produced crop after maize and ranks fourth in terms of universal tonnage, with wheat, maize and rice in the top three positions globally (Muthoni & Shimelis, 2023). Potatoes fall under the family Solanaceae and belong to the genus Solanum; they have a standard set of twelve chromosomes [x = 12] (Gaiero *et al.*, 2021). Potatoes are versatile crops that serve not only as staple vegetables but also as key ingredients in various processed foods (Devaux *et al.*, 2021). Additionally, they are utilized in industrial applications, such as starch production and the manufacture of alcoholic beverages (Zięba *et al.*, 2020). One of the significant challenges facing potato breeders is the development of varieties that possess desirable agronomic traits and excellent storage quality (Seid & Tessema, 2021). A crucial step in any crop improvement program is the assessment of genetic diversity, which enables the selection of suitable parents for successful hybridization and ultimately leads to the development of enhanced potato varieties.

As a nutritionally dense food, it is an excellent source of carbohydrates, vitamins, minerals, and dietary fiber, making it a crucial dietary component for millions, particularly in regions where malnutrition and scarcity persist. Its significance extends beyond human consumption, contributing to the livelihoods of farmers and the global

*Corresponding author; email: siamalube.beenzu@students.jkuat.ac.ke
[1]Department of Molecular Biology and Biotechnology, Pan African University Institute for Basic Sciences, Technology and Innovation, Nairobi, Kenya

agricultural economy (Giampiccoli *et al.*, 2023). However, despite its historical and present-day importance, there remain considerable gaps in research concerning its full nutritional potential, its role in diverse diets, and its capacity to combat emerging food security challenges (Devaux *et al.*, 2021). Food systems globally are under pressure from a range of factors, including population growth, climate change, and shifts in dietary patterns. Potatoes offer a unique opportunity to address these challenges due to its relatively short growth cycle, high yields per unit area, and adaptability to different climatic conditions (Devaux *et al.*, 2021). Yet, its potential remains underutilized, particularly in developing regions where its cultivation and consumption could significantly alleviate hunger and poverty. Furthermore, the lack of comprehensive data on the potato's contribution to diet quality, nutrient bioavailability, and its integration into diverse food systems poses a barrier to maximizing its benefits (Lizana *et al.*, 2021).

While its importance in the Andean region, Australia, Europe (Salmensuu, 2021), North America, and the Union of Soviet Socialist Republics (Osipov & Zeldner, 2023) is well known, large-scale production and rapid development are less common in low- and middle-income countries (Lindqvist-Kreuze *et al.*, 2024). According to the Food and Agriculture Organization (FAO) statistics, potato production in developing market economy countries has increased drastically, surpassing the growth rates of other roots and tubers (44%) together with cereals (47%) (Lizana *et al.*, 2021). Potatoes offer a wide range of importance (Dolničar, 2021); they convert the raw material of tubers into finished ready-to-consume high-quality food products such as table chips and crisps (Pavlista & Ojala, 2023). Potatoes are not only substantial in terms of food security and nutrition but also in the job market (Giampiccoli *et al.*, 2023), consequently creating an economically stable society. Additionally, they offer several advantages, including higher yields on less land and in harsher climates than most major crops do, and they are also quick to mature because of their rapid growth rate (Jennings *et al.*, 2020). The edible material is harvested in just sixty days, depending on the variety. Similarly, potatoes have a greater nutritional value per unit of land and resources (Šulc *et al.*, 2021).

Despite occupying smaller areas in most developing countries, the increasing popularity of potatoes has prompted policymakers to reevaluate their role in national food production systems (Ohanenye *et al.*, 2021). Recent efforts have focused on improving potato production, storage (Gikundi *et al.*, 2023), and marketing, as well as understanding and enhancing their nutritional contributions. However, balancing production improvements with nutritional quality is crucial (Koch *et al.*, 2020; Naumann *et al.*, 2020). While breeding for higher yields and disease resistance is essential, neglecting nutritional quality can compromise food security. This study seeks to bridge these gaps by exploring the nutritional and functional properties of the Irish potato and its role in global food security. Specifically, the research aims to (i) assess the nutritional value of potatoes in comparison to other staple crops, (ii) evaluate their potential for addressing micronutrient deficiencies, and (iii) investigate sustainable production practices that enhance yield and quality under changing environmental conditions. A multidisciplinary methodological approach was employed, encompassing nutritional analysis, agronomic evaluation, and an assessment of consumer perceptions and dietary integration.

The findings of this research highlight the pivotal role of the potato in meeting nutritional needs and promoting sustainable agricultural practices. By addressing existing knowledge gaps, this study provides a foundation for future research and policy development, enabling the potato to play an even more critical role in combating global food insecurity. The broader implications underscore the need for a renewed focus on underutilized crops like the potato to build resilient food systems, inspire innovation in crop research, and contribute to achieving global development goals (Stark *et al*., 2020).

Brief History of Irish potatoes

Potatoes are ancient crop plants whose sole purpose of cultivation is food (Earle, 2023); they are referred to by the name Mama Jatha as the mother of growth. The first wild potatoes presented traits of disease and insect resistance due to the presence of glycoalkaloid (Musita *et al*., 2020) (α-chaconine and α-solanine) compounds (Ordoñez-Araque *et al*., 2024). Different colors, sizes and shapes of tubers are presented. They were harvested and eaten almost 10,000 years ago in the humid plains of coastal South America. However, their taste is bitter (Martínez *et al*., 2022), as they contain toxicity levels that are unsafe for humans (Burgos *et al*., 2020). Thus, to qualify potatoes for human consumption, it is critical to choose and cultivate potatoes that are consumer-friendly (Timpanaro *et al*., 2021). To domesticate and preserve potato plants in the Andes, a biological technique known as freeze-drying was employed (Merivaara *et al*., 2021), which was principally to extract the unpleasant attributes from potato plants and retain only non-harsh characteristics for propagation.

Potatoes first gained significant intercontinental recognition during the first half of the 16th century, when Spanish explorers were gold-hunting (Vilardaga, 2021) in Peru. During their adventure to Europe in the late 1500s (Ríos *et al*., 2023), they took some potato tubers with them. However, some Europeans did not regard potato tubers as appropriate for consumption by elite members of society ab initio (Griffin *et al*., 2022). Rather, they conceived them as prime food for the impoverished and/or for farm animals. Furthermore, potatoes are considered toxic (Sookhtanlou *et al*., 2022) and are inedible by irrational agricultural laborers. Potatoes became among the most cultivated food sources worldwide around the 20th century, with the USA being the last major region to adopt the plant (Stark *et al*., 2020). Today, it is produced globally in more than 150 countries from regions such as North America, Europe, Africa, and some countries from the former Soviet Union (Dereje & Chibuzo, 2021). The inhabitants of the Andes view potatoes beyond food; they also use them as medicinal plants (Parra-Rondinel *et al*., 2021) that have various functions, traditionally as well.

The breeding of potato varieties that have a short maturity period commenced in South America; the newly bred varieties have excellent performance and growth due to favorable agricultural practices (Bolsheshapova *et al*., 2021). That was around the same time that the European continent was battling severe famine (Ljungqvist *et al*., 2024), when suddenly the European farmers were intrigued to delve into potato cultivation (Van Loon *et al*., 2024) to combat the food insecurities they were facing. Potatoes are quite affordable to grow and mature very early; thus, venturing into potato cultivation liberated the whole continent from famine (Earle, 2020). Additionally, potato's bountiful nutritional benefits nourished the increasing population of working-class settlers in urban areas, alongside the emancipation of factory workers from the 19th century, who came from rural areas (Devaux *et al*., 2021). There are a few varieties that have shown genetic similarity (Tang *et al*., 2022) with tubers cultivated and cloned in both Europe and North America, such as in South America (Caldiz, 2023). In addition, in 1845, late blight (Majeed *et al*., 2022), a devastating plant disease caused by *Phytophthora infestans* (Guha Roy *et al*., 2021), a fungus, attacked potatoes and wiped out crops.

This resulted in an eight-year period of famine and, consequently, the tragic death of more than a million people; the few survivors were constrained and had no option but to emigrate in search of greener pastures. The Irish calamity (Gray, 2021) prompted the implementation of management strategies such as practicing crop rotation, the use of fungicides (Kassaw *et al*., 2021) and the development of disease-resistant yet still fruitful varieties. Most potato varieties produced in Chile are germplasm (Jansky *et al*., 2021) drawn by plant breeders from Canada, the United States of America (Barrett *et al*., 2023) and Eastern Europe.

Research Methodology

The study included various related research of scientific studies, and the information was organized into specific groups of the data collected (Table 1).

RESULTS AND DISCUSSION

Solanum tuberosum

Approximately 375 million tons of potatoes were produced in 2022 worldwide and were planted on 17,788,408 hectares of land. At present, China is the major producer of potatoes, with up to 95,631,400 tons, whereas India ranks second, with 56,176,000 tons produced as reported by the FAOSTAT in the December 2023 issue (Figure 1). Together, China and India generate more than one third of the total potatoes yield worldwide. Egypt (6.1 million tons) and South Africa (2.5 million

Table 1. Overview of thematic groups and related scholarly literature for Irish potato research.

Thematic Group	Research Topic	References
Nutritional profile	– Nutritional components: carbohydrates, proteins, fiber, vitamins (C, B-complex), minerals (potassium, magnesium). – Bioactive compounds: phenolics, antioxidants.	(Dereje & Chibuzo, 2021; Franková *et al*., 2022)
Role in Food Security	– Contribution to global food security: high yield potential, adaptability. – Economic accessibility. – Reducing hunger and malnutrition in vulnerable populations.	(Osuji *et al*., 2023; Rashid *et al*., 2024)
Agricultural sustainability	– Resilience of varieties to climate change. – Disease resistance, pest management. – Modern agricultural technologies: biofortification, precision farming.	(Jennings *et al*., 2020; Rashid *et al*., 2024)
Socioeconomic importance	– Economic value in markets. – Role in rural employment and livelihoods. – Gender dimensions in farming and production chains.	(Mickiewicz *et al*., 2022; Tadesse *et al*., 2020)
Innovation in food products	– Development of processed products (chips, flour, starch). – Use in functional foods and nutraceuticals – Consumer perceptions and market trends.	(Pavlista & Ojala, 2023; Zięba *et al*., 2020)
Prospects and challenges	– Impacts of climate change. – Breeding strategies for improved varieties. – Policies promoting Irish potato as a staple food	(Dolničar, 2021; Lindqvist-Kreuze *et al*., 2024)

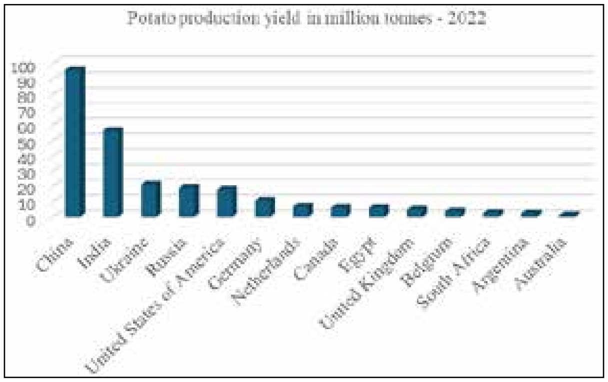

Fig.1. Top 14 potato-producing countries worldwide (FAOSTAT, 2022)

tons) ranked 9th and 12th – respectively. The two African countries produced the most potatoes that year.

In Africa, potatoes were domesticated toward the end of the 17th century, after Christian missionaries established petite plantations on the continent (Muthoni & Shimelis, 2023). Potato production has continued to expand drastically, increasing to 20 million tons in 2017 from only approximately 2 million tons during the last half of the 20th century. A total of 1.9 million hectares of harvested land were recorded in Africa in 2017, accounting for up to 10% of the world's cultivated area that year. The FAOSTAT 2018 reported a double increase in potato production on the African continent, with nearly three quarters of the growth rate being from East Africa. In contrast, 21% of potato production is from southern Africa, and West Africa accounts for 8% of the total potato production in Sub-Saharan Africa (Muthoni & Shimelis, 2023).

In Kenya, for instance, Irish potato is chiefly grown by small-scale farmers, mostly women. However, commercial production is conducted by larger-scale growers, who cultivate only areas above sea level, ranging between 1,200 and 3,000 m high (Makau *et al.*, 2023). A vast majority of potatoes grown in Kenya are locally consumed (Gikundi *et al.*, 2021): approximately 25 kg per capita per year. Viazi (meaning potatoes in Swahili, one of the official languages of the African Union) is cultivated by local communities (Kwambai *et al.*, 2024; Musita *et al.*, 2020) and is a delicacy enjoyed by many people in Kenya (Gikundi *et al.*, 2021).

Potato Agronomy: Enhancing Cultivation Practices for Optimal Yield

Potatoes perform well in diverse crop science systems, such as intercropping and multiple setups, together with laterite, alluvial, red, hill and black soils (Hemkemeyer *et al.*, 2024) at pH values ranging from 4–7.5 (Atanaw, 2021; Mugo *et al.*, 2020). Stolons, roots and tubers can also grow in loamy soils as well as sandy or coarse soils (C. Wang *et al.*, 2022), as these soils are able to supply ample oxygen and sufficient organic matter for good plant health (Gavrilescu, 2021). Potatoes grow better during cooler nights and slightly sunny days with temperatures below 24°C or 75.2°F. Between the 20th and 25th days of post planting, tuber formation commences, and the plants develop better at 20°C (68°F) during the day and at 14°C (57.2°F) at night (Gutiérrez-Quequezana *et al.*, 2020). Hence, settlers in mountainous regions grow their potatoes more in autumn or summer. However, those in plains cultivate potatoes mainly during spring or winter and sometimes autumn.

While these agronomic features are true for most potato varieties, the exact duration differs from cultivar to cultivar, with the conditions of the environment playing a large role in the turnaround time (Li *et al.*, 2021). Before planting, farmers breakdown clods and plough fields up to 30 cm deep (Stark & Thornton, 2020) to facilitate the management of perennial weeds (Jabran *et al.*, 2023) and pathogens found in the soil (Tsror, 2023). The famous ridge-and-furrow planting method is commonly used for potato farming (Bhardwaj & Sharma, 2020). Potato tubers are cut in preparation for propagation, and the farmer's preferred seeds for sowing are usually those having at least three healthy eyes, also known as true potato seeds (Kacheyo *et al*., 2021). Between 30 and 40 grams with a diameter of more than 3 cm were weighed. One month after planting, soil turning is conducted by a plough with a two-way moldboard to enable total and fair shielding of the tubers by the soil (Jin *et al*., 2023).

Depending on the maturity period, weather conditions and soil type, approximately 350–550 mm of water should typically be provided to plants (Dietz *et al*., 2021). To prevent fungal infections, water on the leaves of the plants should be avoided, and drip irrigation should be used to reach the base of the plants (Abd Elhady *et al*., 2021). Do not overwater the plants (Jabran *et al*., 2023), and mulch around the plants (Sekhon *et al*., 2020) to retain moisture and suppress weeds (Jabran *et al*., 2023). The harvest of potato plants is variety dependent; that is, it can be initiated after two months for early maturing plants (Bolsheshapova *et al*., 2021; Ma *et al*., 2024) and after two and a half months for medium-maturing plants (Githieya *et al*., 2021), and late-maturation varieties can mature for up to three months (Ma et al., 2024). At maturity, the plants grow as high as 1 m or 3.5 feet, and the tubers are unearthed when the temperature is below 30°C (86°F) (Czerko *et al*., 2023). In most cases, it is a fortnight following the last irrigation. Importantly, the yield percentage is not uniform for all potato varieties (Silva *et al*., 2020). The production per hectare is estimated to be between 20–25, 25–30 and 30–35 for the early, medium and late varieties, respectively (Franková *et al*., 2022).

Botany of potato: Morphological Diversity

Irish potato is generally an autogenous plant; nonetheless, it experiences a handful of cross-pollination events, usually bumblebee insects. Potato plants are yearly herbaceous crops (Sharma *et al*., 2021), and they have threadlike roots because of the fibers around them (Dixon & Fitch, 2022). Stolons constitute another vital part of the potato; they are broad stems that grow inside the soil and are responsible for the formation of the starchy edible tubers that are chiefly used as vegetables (Abeytilakarathna, 2022). The leaves are usually green in color and grow close to 30 cm, one after the other, on angular stems branching from the main plant with flowers of different colors (Maiti & Singh, 2022), including pink, purple, yellow, red or white.

Overall, potato varieties with white flowers form tubers that have white skins; on the other hand, pink-like tubers are formed from varieties with colored flowers (Salunkhe *et al*., 2021). Stamens are rare in potato plants because of weather conditions, but when they are present, they appear in a light shade of yellow and are fixed on corolla tubes that are short in length (Aksoy *et al*., 2021).

Evolutionary Insights of Potato Taxonomy

Irish potato is a dicotyledonous plant (Naeem *et al*., 2023), and it is part of the Solanacea*e* family (Mallia *et al*., 2021). Additionally, it belongs to the *Solanum* genus, which comprises over 2,000 species and ranks as the most populated genus of angiosperms (Kaunda & Zhang, 2019). According to the newest classification, *Leptostemonum* (Aubriot & Knapp, 2022) and *Pachystemonum* are two subdivisions of the *Solanum* genus (Verma *et al*., 2021). The tuber-bearing species mostly fall under the *Petota* section, which has been split further into two parts: *Potatoe* and *Estolonifera* (Tang *et al.*, 2022). *Potatoe* is the umbrella subsection for closely related and largely cultivated potato species belonging to the *Tuberosa* series (Maiti & Singh, 2022). Based on recent classification, only four recognized species are predominant and cultivated largely: *S. ajanhuiri*, *S. curtilobum*, *S. juzepczukii* and the famous *S. tuberosum* (Rodríguez *et al.*, 2010). Approximately one-quarter of these species are tetraploid (2n = 48), nearly three-quarters are diploid (2n = 24), and the remaining half are hexaploid (2n = 72), pentaploid (2n = 60) or triploid (2n = 36) (Sharma *et al.*, 2021).

Potato and Food Security: Ensuring Sustainable Production for a Growing Population

Malnutrition and a complete lack of food are very common in most developing countries; according to the FAO, more than one billion people are underfed worldwide. Potatoes are highly valued by many households in developing countries, mainly because of their stable and bountiful yield production, alongside their beneficial nutritional value, such as dietary energy (Rashid *et al.*, 2024). It is more cultivated than other crops because it thrives in brutal climatic conditions (Jennings *et al.*, 2020; Koch *et al.*, 2020) in which most major plants do not, making it an essential source of nourishment for sustainability (Naumann *et al.*, 2020). Furthermore, over 85% of potato plants are fit for human consumption, whereas only 50% of whole cereal plants are edible.

There has been an exponential rise in the nutritional supply of potato to developing countries (Rahim *et al.*, 2023), and the yearly per capita kilograms have increased exponentially between 2000 and 2020 (Çalışkan *et al.*, 2023). The versatility of potatoes enables mankind to prepare them in diverse forms, such as frying, boiling, mashing, steaming, baking and grilling. Potatoes can be eaten by people of all age groups and under most diet regimens (Tadesse *et al.*, 2020). Approximately 20%–25% of a newly harvested potato is composed of dry matter, whereas the remaining percentage contains water (Czerko *et al.*, 2023). The protein composition of dry potato is greater than that of roots and other tuberous plants; however, the protein composition is the same as that of cereal crops (Dolničar, 2021). Additionally, potatoes are rich in carbohydrates and other micronutrients, but it has a low-fat content (Ohanenye *et al.*, 2021). The body of an adult human needs approximately 100 mg of ascorbic acid in a day (Gutiérrez-Quequezana *et al.*, 2020), and a potato weighing 150 g is said to be of medium size and can provide close to 50 mg of vitamin C when eaten unpeeled (Burgos *et al.*, 2020).

Nutritional Benefits of Potato: A Key Staple for Global Health and Nutrition

Potatoes increase the absorption of iron and provide vitamin B complexes alongside magnesium, potassium and phosphorus to humans. In addition to these minerals, they are good sources of dietary antioxidants that help reduce the possibility of developing chronic infections (Ohanenye *et al.*, 2021). By 2030, the demand for potatoes globally is estimated to be approximately 440 million tons (Mickiewicz *et al.*, 2022). Because potatoes are rich in nutrients, it has the potential to enhance various diets, in turn increasing nutrition, increasing health, and ultimately combating food insecurity threats worldwide, especially in developing countries (Burgos *et al.*, 2020).

Potatoes have a cascade of dietary benefits, with freshly uprooted tubers containing water levels close to 75%, approximately 15% carbohydrates, 3% crude protein, 1.5%

minerals, 1% crude fats, 0.6% crude fiber and some vitamins. The nutritional quality of potatoes is better than that of cereals, despite potatoes containing minimal amounts of protein (Lutaladio & Castaldi, 2009). Potatoes also contain a reasonable quantity of principal amino acids, namely, tryptophan, isoleucine and leucine (Naumann & Pawelzik, 2023). Antioxidants that have significant roles in disease prevention are equally common in potatoes, and they are similarly employed to treat hepatic and gastrointestinal infections medically.

Plant Biotechnology in Potato: Genetic Engineering and Molecular Advancements

Advances in molecular biology and plant cell culture have revolutionized potato research, enabling scientists to gain a deeper understanding of potato plants (Beenzu *et al*., 2025). These breakthroughs have the potential to increase yield in potato farming, ameliorate nutritional value, and lead to new non-food applications for potato starch, i.e., the manufacture of biodegradable plastics (Verma *et al*., 2021) and the development of potato-based edible vaccines (Beenzu *et al*., 2024). Furthermore, techniques of micropropagation and those of plant tissue culture are being used to eliminate bacterial, parasitic and viral infections (Bakhsh *et al*., 2023). By rapidly multiplying disease-free potato plants, robust seed tubers can be produced. Significant progress has been made in the potato genome sequencing consortium, with successful mapping of the whole DNA sequence of the potato genome (Tang *et al*., 2022). This groundbreaking project has greatly expanded people's knowledge with respect to the functional traits of potato (Gaiero *et al*., 2021), as well as plant genes and proteins. Paving the way for further innovations in potato research and applications.

Genetic diversity and climate change resilience

Genetic diversity is paramount to crop growth and development, as it allows plant breeders to improve varieties by knocking down unwanted features or knocking in desired traits (Marhadour & Prodhomme, 2023), including disease resistance (Onditi *et al*., 2021; Singh *et al*., 2020). Abiotic stress resistance is another feature that can be developed in potato plants (Demirel, 2023). Since the commencement of agriculture, crop species have been exploited for genetic variability to obtain the substantial amount of food needed for human consumption. With time, however, the production of excess food has taken the focal point, mainly to curb food insecurity threats for the ever-growing population (Bradshaw, 2024). Currently, efforts are being made to concentrate on both the excellence and yield of staple foods to provide a balanced diet to the increasing population, aiming at both quality and quantity (Osuji *et al*., 2023).

Consequently, alterations in climatic conditions have prompted plant breeders to develop varieties that can endure climatic changes (Jennings *et al*., 2020). Owing to genetic diversity, desirable alleles can be sourced from mutant lines to develop varieties that are resilient to climate change, extreme temperatures and different pollutants. Furthermore, it is important to note that breeding objectives continue evolving (Jansky *et al*., 2021); therefore, it is important to reserve various genes in the germplasm (Saeed *et al*., 2023). In potatoes, to increase the diversity of breeding varieties, introgression of genes between cultivated species and wild ones is needed (Marhadour & Prodhomme, 2023). Prior to obtaining transgressive segregants, it is important to note the genetic diversity between two parents; to achieve heterosis, it is pertinent to choose parents with outstanding traits (Seid & Tessema, 2021). In agricultural practices, selecting strategic techniques to design substantial crosses spears the growth of novel lines to be used in non-traditional applications such as the production of biofuels.

Disease resistance in Potato: Strategies for Combating Pathogens and Pests

Irish potato is an herbaceous plant that is cultivated annually under tropical as well as subtropical conditions. The optimized soil temperatures ranged from 16°C to 20°C and were coupled with adequate soil aeration (Stark & Thornton, 2020). Furthermore, it is an ideal crop for water-scarce areas because of its water use efficiency (Ierna, 2023). To promote drought tolerance in potatoes, breeders have developed drought-resistant varieties with properties such as longer roots that help bind soil and have high water holding capacity to minimize the need for water (Demirel, 2023). Integrated pest management (IPM) systems have been developed to reduce the use of chemicals made from cultivated potatoes. IPM is an ecofriendly and environmentally conducive method to protect crops from pests (Abrantes *et al*., 2023; Naqqash, 2023) and diseases (Chikh-Ali & Karasev, 2023; Tsror, 2023). This intensive management approach has proven to be efficient in increasing public health safety by reducing environmental pollution. It is a multifaceted strategy that combines genetic tools and chemical, physical, cultural, and biological aspects to produce high-quality crops.

IPM is a plant production scheme that is acknowledged and approved by both the FAO and the CIP for pest and disease prevention. Farmer Field Schools (FFS), an initiative of the FAO, has recommended IPM in many low-resource settings, enabling farmers to examine the method via diverse techniques (Naqqash, 2023). Some experiments have included specific applications of pesticides with low levels of toxins applied to various strains of potato (Naqqash, 2023). In Carchi, Ecuador, FFSs significantly reduce highly toxic pesticide use—up to 75% in potato fields—without affecting productivity. Potatoes mostly grow nearly 3.5 feet high, and tubers begin to form 25 days after planting (DAP), whereas flowering varieties require a long duration of daytime; hence, depending on the conditions to which they are subjected in the field, they may or may not produce flowers. The maturity period differs from one cultivar to another, but generally, potatoes may be harvested 60–70 days post planting (Struik, 2023).

Potato breeding: Innovations in Genetic Improvement for Yield and Quality

In 2008, during the international year of potato production, the need to use, protect, and preserve potato diversity was highlighted (Lutaladio & Castaldi, 2009). Novel strains of potatoes were sourced from the gene pool to address the fight against pests and diseases that affect the plant; these strains increase production yield on marginal lands and increase the nutritional content of the potato. Thus, a continued supply of modern potato-based agricultural practices is essential. Although potato diversity is threat, most varieties from the Andes have gone extinct, while climate change affects the wild type, risking up to 70% of their natural habitats. Breeders prioritize special traits for propagation (Seid & Tessema, 2021); commercial potato varieties, for example, have a limited ability to flower, and when they do, they attract pollinators.

However, natural pollination remains vital for maintaining diversity, and farmers prefer varieties adapted to local conditions (Makau *et al*., 2022). Similarly, the farming systems of smallholder farmers in the Andes promote cross-pollination through various flowering plants, augmenting the production of seeds alongside diversity preservation (de los Angeles Bohórquez-Quintero *et al*., 2022). To further conserve potato biodiversity and ensure that its benefits are shared equitably, the CIP has industrialized resilient cultivars fit for the conditions of subsistence farmers, who are now cultivating these potato varieties across several developing countries of Latin America, Asia (J. Wang *et al*., 2023) and Africa (Muthoni & Shimelis, 2023).

CONCLUSION

The Irish potato remains a cornerstone of global food security, offering immense potential to address nutritional deficiencies, improve livelihoods, and enhance sustainable agricultural systems. This study reaffirms the potato's role as a nutrient-dense, climate-resilient crop with significant contributions to global diets and economies. By exploring its nutritional value, agronomic adaptability, and integration into food systems, the findings underscore its potential as a key resource in tackling challenges such as malnutrition, poverty, and climate change. However, several limitations should be noted. Despite its versatility, the potato faces challenges such as susceptibility to pests, diseases, and climate variability, which can limit production in certain regions. Additionally, while this research highlights the potato's nutritional contributions, its bioavailability of micronutrients and potential synergies with other dietary components require further investigation. Furthermore, consumer acceptance and dietary integration vary widely across cultures, presenting a barrier to maximizing its impact in regions where it is not a traditional staple. Future research should focus on addressing these limitations by advancing breeding programs for pest-resistant and climate-resilient potato varieties, exploring biofortification to enhance nutrient content, and promoting awareness campaigns to increase dietary acceptance. By addressing these gaps, the Irish potato can be further optimized as a cornerstone of global food security and a key player in achieving sustainable development goals.

AUTHOR CONTRIBUTION

All the authors were equally involved in the research analysis and manuscript writing.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this article.

ETHICAL STATEMENT

This article does not contain any studies with human participants or animals performed by any of the authors.

LITERATURE CITED

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