Chapter

The Role of Crop Protection in Sustainable Potato (*Solanum tuberosum* L.) Production to Alleviate Global Starvation Problem: An Overview

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Abstract

Among food crops in terms of consumption, potato ranks fourth, most important and valuable crop worldwide in terms of production and area harvested after maize, wheat and rice. In the coming years, potato production must keep pace with global population expansion nutritiously and sustainably which can partially be achieved by reducing the yield losses caused by the destructive pest and disease activities to the crop. The challenge of 70–80% total microbial crop yield loss posed by pathogens must be addressed for sustainable potato production in order to properly alleviate the global starvation problem. Potato as a food security crop can help to achieve the four food security requirements: food availability, quality, accessibility and stability. Health benefits of potato have shown the presence of phytochemicals as well as resistant starch which serve as anticancer and antidiabetic. The role of potato in the global food security should not be over emphasized, hence in this chapter we want to give an overview on the global hunger and food security at present, and the role played by potato as a food security crop. In addition, potato yield losses caused by pests and diseases especially phytopathogens, their etiology and the role of crop protection in sustainable potato production to alleviate global starvation problem will be discussed.

Keywords: Crop protection, food security, potato, starvation, yield losses

1. Introduction: global hunger and agricultural growth at present

Mankind cannot survive without food which is one of the three basic necessities of life. Potato (*Solanum tuberosum*) ranks fourth most important food crop in the world after maize, wheat and rice in terms of human consumption (**Figure 1**) [1]. Potato as a food crop can help to achieve the four food security requirements: food availability, quality, accessibility and stability. At present, agri-food systems do not sufficiently provide nutritious food in a sustainable and eco-friendly way to the growing global population [2, 3]. Potatoes continue playing a very important role in

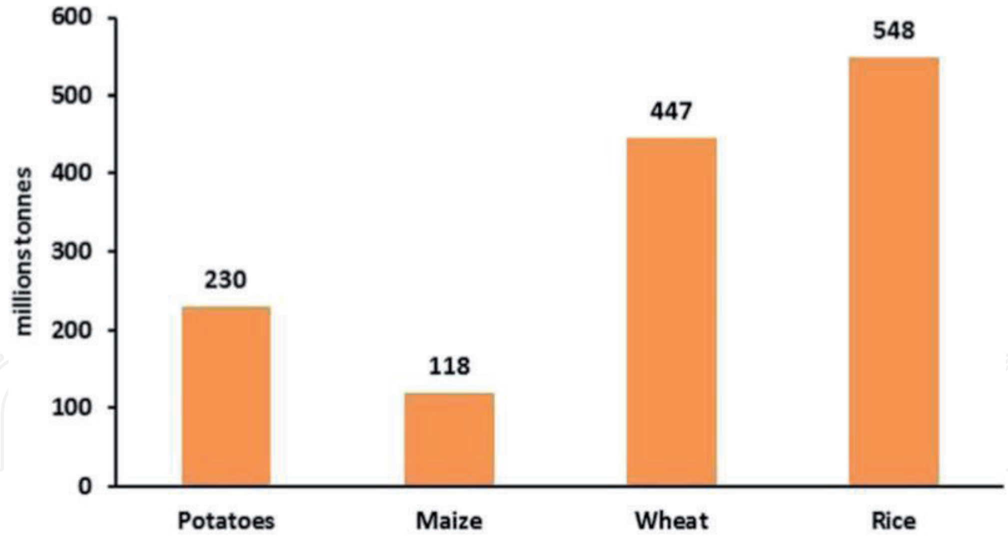

Figure 1.
Global consumption of maize, wheat, rice and potato. Source: FAO [1].

feeding the human population. According to [4], by 2050 an estimated global population of 9.7 billion people will demand 70% more food than is consumed today and feeding this expanded population both sustainably and nutritiously will require substantial improvements to the global food system. The food system should be one that provides livelihoods for farmers as well as nutritious products to consumers while conserving the environment and passing it *in situ* to the coming generations [5]. The Global Hunger Index (GHI) as reported by [6], showed substantial progress in terms of hunger reduction for the developing world and the GHI ranks countries on a 0–100-point scale with 0 being the best score (no hunger) and 100 being the worst. Whereas the 2000 GHI score for the developing world was 29.9, the 2017 GHI score is 21.8, with 27% reduction. Although, there are pronounced disparities in hunger at all levels and progress has been uneven. Poverty is the clearest manifestation of societal inequality and this supported the GHI report of 2017 that emphasizes the fact that inequality and hunger are extremely linked and both are rooted in uneven power relations that often are exacerbated and perpetuated by laws, policies, attitudes, and practices. GHI in 2013 showed that fifty-six countries are at alarming levels of hunger as published by the International Food Policy Research Institute [7]. The GHI aggregates three equally weighted indicators: (i) Prevalence of underweight in children (ii) Proportion of undernourished (iii) Mortality rate of children under five. Today more than 850 million people are suffering from hunger in addition to the several hundred million children categorized as malnourished children or as "hidden hungry".

Growth in agricultural sector can particularly be effective in reducing hunger effect, starvation and malnutrition problem because most of the extremely peasant poor farmers depend solemnly on agriculture and other related activities for their livelihoods. At the 2014 World Economic Forum (WEF), Shenggen Fan, Director of the IFPRI, advanced that tackling hunger and malnutrition is not only a moral issue but also one that makes economic sense as mentioned in a debate on "Rethinking Global Food Security". The world loses Gross Domestic Product (GDP) of 2–3% per year because of hunger, while investing US$1 in tackling hunger that yields a return of US$30. Additionally, it was mentioned in a debate on Rethinking Global Food Security by Ajay Vir Jakhar, Farmers' Forum Chairman (Bharat Krishak Samaj) in India that farmers think on food security at their household level, but not global level. Globally, if small-scale farmers were supported, they could become self-sufficient and also food insecurity problem would be solved by 40 to 60%. Therefore policies should be geared towards localized solutions, worldwide issues and solutions, and motivation from the private and public groups required to help the huge number of peasant farmers who are cultivating small areas of land and which have an important role to play in the chain of food production and social development. The International Year of Family Farming declared in 2014 supported the acknowledgement made by the United Nations on the importance of family farming in improving worldwide food security and poverty reduction. Hence localized, technical, and commercial solutions with the support of both public and private sectors are needed in combination with global food security policies. An important way forward to design research in agriculture is to understand where hunger and poverty are converged. Potato is produced in poor areas globally including China and the Andes of South America; hence, innovations particularly on potato science can be a very important tool for targeting the poor and hungry as part of a broader set of research and development activities.

2. Potato as a food security crop

According to [8, 9] "Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life." Food security has four major key dimensions: (a) food availability (b) quality and use (c) stability and (d) accessibility to food.

- Availability of food implies that supply of food at both levels (regional and national) that determines the ultimate price of food should be improved in order to reduce food insecurity and hunger.
- Accessibility to food implies the ability for one to buy or produces his food, which has to do with having the purchasing power to do so.
- Quality of food and use implies the level of nutrition obtained from food intake (consumption) at a nutritional, sanitary, sensory, and sociocultural point of view.
- Stability of food implies the idea of having food accessibility at all times thus incorporating issues such as price stability and securing incomes for affected populations [9].

With this breakdown, efforts in research may likely assist food security in the categories below:

- Access: Encouraging farm production competition, farmers' income improvement and other agri-food systems.
- Availability: Rising agricultural production via good cropping systems, integrated pest control for loss minimization and genetic improvement.
- Food use and quality: Quality food safety as well as food quantity by value addition to traditional local products.
- Stability: Improving agriculture and food production through sustainable management of such natural resources such as soil, water, and biodiversity.

Some peculiar features of potato crop such as adaptation range coupled with high nutritional value and production ease has aroused the interest of many people to embark on its cultivation which has led to the steady increases in potato production and consumption in many developed and developing countries. In the last few years, there is an increase in production of potato and its demand in Asia, Africa, and Latin America from less than 30 million tons to more than165 million tons. Today, the biggest potato producer is China followed by India. According to FAO, potato yields more food per unit of cropland in less time than any other major crop [10]. Millions of farmers depend on potatoes for food as well as cash income. Potato is a highly reliable food security crop that can help ease future turmoil in world food supply and demand [10]. Potato cropping systems help improve resilience especially among smallholder farmers by providing direct access to nutritious food, increasing household incomes, and reducing their easiness to food price volatility (**Figure 2**).

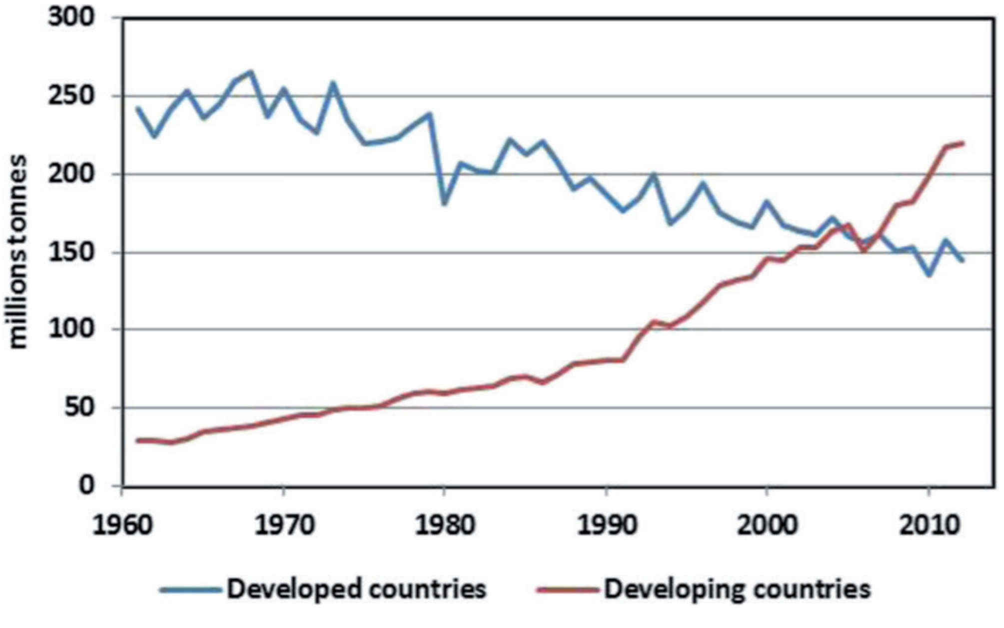

Figure 2.
Shift in potato production. Source: FAO [1].

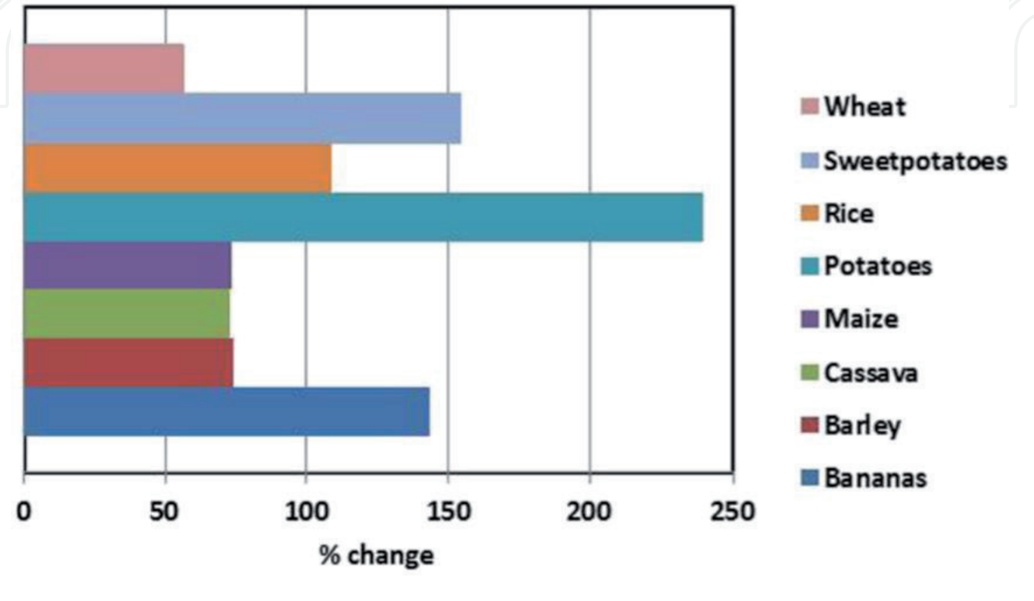

Figure 3.
Percent change in crop production of staple food crops in sub-Saharan Africa, 1994–2011. Source: FAO [1].

Farmers in Africa have responded to increased demand for food by increasing the production area for numerous crops that include banana, potato, sweet potato, and rice. This production increase was as a result of an increase in the production area of potato, which has doubled from 1994 to 2011 and now exceeds that of the Caribbean and Latin America (**Figure 3**) [1].

3. Otato in the global food system: production and demand trends by region

At present the global stands for potato production is 378 million tons on an estimated 19 million hectares of farmland worldwide (**Table 1**). Temperate area of northern hemisphere is where potato is mostly produced during the summer period (frost-free period). In these regions, potato is cultivated mainly as a cash crop and an important income source. Potato is significant in the Rift valley of the tropical regions of the African highlands, the highlands of the Andes, and the volcanic mountains of West Africa and Southeast Asia, where production is both for cash and food [12]. The crop is cultivated at the heat-free period as a winter crop in the subtropical regions such as in the southern China, Mediterranean region and North India. The crop is not considered as a staple crop in the lowlands of the tropics due to the high temperatures in the areas that do not favor potato growth and development [13]. **Figure 4** illustrates the recent pattern of the potato distribution worldwide [14, 15].

In order to boost the impact on the lives of the peasant farmers on investment in potato-related research and innovation, it is important to identify who are the peasant farmers, where they are dwelling, and that potato crop is crucial in the local food chain. In areas where production of the crop is in existence with poor income, there is a good chance to use potato as a tool to slashed poverty. In order to get optimal potential effect on living welfare of peasant farmers, International Potato Center (CIP) has prioritized its programs based on a pro-poor research-for-development paradigm where scientific research adhere to specific needs to address the peasant poor, other than a science driven paradigm which generates outputs of research, that may or may not adhere to real demands, and hands them to the partners.

Across landscapes of the globe, the adaptability of the potato combined with increases in its cultivation in different countries in the pass decades is dissimilar, even though this rise has been generated primarily by land expansion followed by improvements in yields. Statistics of the global potato production indicated a shift

Continent (Region)	2014–2016		
	Production %	Yield %	Area %
Europe	119,551	21.6	5547
Latin American and Caribbean	18,334	17.9	1023
North American	24,430	32.0	763
Asia	190,617	19.1	9975
Africa	25,270	14.4	1756
World	378,202	19.8	19,063

Source: [11].

Table 1.
Indicators of global potato production.

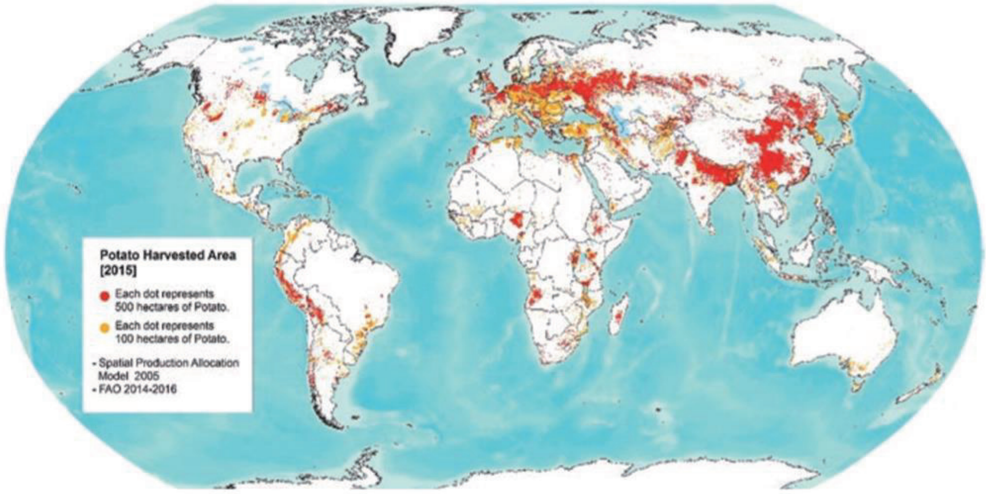

Figure 4.
Potato global distribution and harvested area. Source: You et al. and FAOSTAT [11, 14].

towards developing countries virtually with strong rise in production in Africa, more especially in East Africa. More so, the developed world's potato production is below that of developing world for the first time in 2005 [1] and this confirms the rising value of potatoes as a source of food, income and employment in Africa, Asia and Latin America. As world population levels are predicted to show the greatest rise in Africa in the coming decades, increased contribution of potato to local food systems in this region is of considerable importance [16]. Taking into consideration, production of potato in Latin American and Caribbean (LAC) over some years (at least 60 years), the average annual potato domestic production has risen from 7.2 million tons in the 1961–1963 periods up to 19.6 million tons in 2011–2013, which represents an average annual growth rate of 2%. By way of comparison, growth rates for potato production in Asia and Africa averaged over 4% for a similar period, i.e. more than double those of LAC [17]. Most of the production is oriented towards human consumption (74%, maintaining this trend throughout the period) and it highlights a relatively low processing level of 1% [11].

The fifth largest potato producer in the world is the United States in the global potato statistics with more than 420,000 ha harvested in 2013 and a total output of nearly 20 million tons [18]. Although in the United States potato is no longer the traditional staple of the past, it is nevertheless gaining increased appreciation by nutritionists because of its nutrient density and its contribution to a more balanced diet [19]. Potato yields in the United States have more than doubled over the last 50 years, rising from 22 tons ha^{-1} in 1961 to 49 tons ha^{-1} in 2016 as a result of improvements in the management practices [20]. This therefore will meet the demand of the agro- processing industry to produce chips and frozen French fries for consumers in the markets. In Asia, China became the world's largest potato producer in 1993 and currently accounts for almost one quarter of global potato production and about 28% of total cultivated areas [18] and used is mainly for food, both in processed forms and as a vegetable [21]. In India potato is cultivated mainly in the plain called Indo-Gangetic plain, intercropped in rotation with maize, rice and/or wheat or as singled crop (monoculture); and it is considered as important cash and a staple crop. Rising in potato production volumes, its yields have significantly increased in India at an average of 2% per annum, as a result of successful quality seed systems, breeding programs, and storage infrastructure that have decrease post-harvest losses [21].

Regarding Europe; France, Germany, Netherlands, Belgium and the United Kingdom are together the largest producers of potato in the European Union (EU), as potato yields more than 40 tons ha^{-1} in this area of north Western Europe and to the strong links of production with the dynamic European potato processing industry. Potato is also versatile in Eastern European countries, particularly in Ukraine, Russia, and Poland where per capita consumption has traditionally exceeded 100 kg annually. Future prospect and trends by region indicate a major production increase in Asia and Africa as compared to other regions. Taking into consideration some assumptions like increase in population, economic growth pathways, and climate change, a decline in population in China and growth of per capita (GDP) was projected by the UN which will subsequently influence their diet composition at long run. Hence, the supply of potato in China in future will not continue to grow faster as it was in the past. According to [22], it is in India where potato supply will almost triple because of the very high population growth, especially under certain socioeconomic scenarios.

4. Benefits of potato in the diet and health

4.1 Benefits in the diet

To a larger or lesser extent, the contributions of potato in the diet and health of human being for thousands of years should not be overemphasized. Proteins, fibers, carbohydrates, vitamins, lipids and minerals are present as food for human diet. Other benefits include its contribution as antioxidants, anticancer, anti-inflammatory, hypocholesterolemic, anti-obesity, and antidiabetic etc. Like other plant foods, the nutritional contribution and composition of potatoes is affected by many factors including bioavailability, bio-accessibility and cooking as well. For example cooking, the most important nutrient compounds found in potato that includes minerals, dietary fibers, and proteins are well retained after cooking as well as anthocyanins and carotenoids [23]. Vitamins C and B_6 are significantly reduced after cooking from the food matrix. Vitamin E is also contained in potato tubers at moderate amount [24]. Potatoes are mainly eaten as boiled and provide between 28 and 38% of the recommended total energy requirements for women [25]. The energy provided by 100 g of boiled tubers of potatoes varies from 96.33 to 123.17 kcal [25], which is similar to the energy provided by 100 g of cooked rice (130 kcal) but lower than the energy provided by 100 g of wheat (361 kcal), 100 g of cooked cassava (160 kcal) and soybeans (173 kcal) [26]. Total lipids in potatoes are found in low quantities ranging from 0.1 to 0.5 g–100 g^{-1} FW, consisting mainly of galactolipids and glycol (22%) and phospholipids (47%) that are structurally elements of biological membranes as well as neutral lipids (21%) like free fatty acids and acylglycerols [27]. More than 94% of the tuber lipids contain esterified fatty acids. According to [28], the protein content of potatoes generally ranges from 1 to 1.5 g/100 g^{-1} FW depending on the potato cultivar. Also [25] reported higher levels of protein in cooked tubers of Peruvian floury landraces (1.76–2.95 g-100 g^{-1} FW). Potassium is the most abundant mineral in potato with concentrations varying from 150 to 1386 mg-100 g^{-1} FW [29]. Potassium functions as an important electrolyte in the nervous system. High intake levels of potassium can help control high blood pressure and may decrease the risk of stroke [30]. Adequate Intake (AI) of boiled potatoes (100 grams) can contribute potassium recommended for adults (4700 mg per day). Phosphorus, iron, magnesium and zinc are also present in potato in small quantities ranging from 42 to 120 mg-100 g^{-1} FW for phosphorus and from 16 to 40 mg-100 g^{-1} FW for magnessium, respectively [31]. Again, potatoes are excellent source of diet in the form of iron especially in the highlands of Andean due to their high consumption and where accessibility to meat is little and levels of anemia and malnutrition are high. Typical example is that of Huancavelica, in the highlands of Peruvia, where women and children on average consume 200 to 840 g of potato per day [25].

4.2 Benefits in the health

Regarding health benefits, health-promoting effects attributed by potatoes were observed in human cell culture, human clinical studies, and experimental animals, including anti-inflammatory, anti-cancer, hypocholesterolemic, anti-diabetic and anti-obesity features. Compounds such as phenolics compounds, fiber, anthocyanins, and starch as well as compounds regarded as anti-nutritional compounds like lectins, glycoalkaloids, and proteinase inhibitors are considered to be attributed to the health benefits of potatoes. Many compounds found in potato are good in health promotion although some could be beneficial or detrimental to human depending on specific circumstances. Studies geared to investigate the association between potato consumption and diabetes, cardiovascular disease, obesity, and cancer while controlling for fat intake are needful [32]. As a key dietary source of potassium, vitamin C, and dietary fiber, potatoes contribute significantly to nutrients with defined roles in promoting cardiovascular health [33]. It was mentioned earlier that potato contains high amount of potassium and intake of potassium-rich foods has been shown to protect people against risk of stroke [34]. It was also reported that gelatinized potato starch containing a high level of phosphate reduced concentrations of serum-free fatty acids and triglycerides and liver triglycerides [35]. Potato consumption has often been associated in cohort studies with elevated risk of type 2 diabetes [36] and obesity [37], which has been attributed to a relatively high glycemic index in some potato varieties and processed potato products containing added saturated and trans fats. A major confounding factor in such studies is typical Western dietary patterns associated with increased disease risk typically include potato consumption along with high intake of red and processed meat, refined grains, high-fat dairy products, fried foods and sugar [38]. Reddivari et al. [39] showed that α-chaconine exhibited potent anti- proliferative properties and increased cyclin-dependent kinase inhibitor p27 levels in two prostate cancer cell lines, LNCaP and PC3. More recently, it has been reported that α-solanine, has a positive effect on the inhibition of pancreatic cancer cell growth *in vitro* and *in vivo*. Sun et al. [40] demonstrated that α-solanine inhibited cancer cell growth through caspase 3-dependent mitochondrial apoptosis and that the expression of tumor metastasis-related proteins, MMP-2 and MMP-9, was also decreased in the cells treated with α-solanine.

5. Pests and diseases of potato

5.1 Pests of potato

In addition to the present global climate change that used to worsen the situation, the potato's vulnerability to numerous pests such as tuber moth of potato (*Phthorimaea operculella*) [41], the leaf miner fly of potato (*Liriomyza huidobrensis*) [42], Guatemalan potato tuber moth (*Tecia solanivora*) [43]; the White flies (*Bemisia tabaci*), Andean potato tuber moth (*Symmetrischema tangolias*) [44] and *Trialeurodes vaporariorum* [45]. Pests, especially insects, are the major living factors affecting potato yield and tuber quality. Globally, losses are estimated on average at 16% [46]. It has been estimated that about 30–70% loss in tuber yield and quality can occurred for various pests, if pest infestation not routinely controlled [47, 48].

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Common name	Scientific name	Order	Family	Origin	Distribution	Reference
Potato Tuber Moth	*Phthorimaea operculella*	Lepidoptera	Gelechiidae	South America	North, Central, and South America, Africa, Asia, Australia, and Europe North America, New Zealand. Australia, and Indonesia	[49]
	Symmetrischema tangolia					[48]
Andean potato tuber moth	*Tecia solanivora*			South America (Peru and Bolivia)	Colombia, Ecuador and Contrai America,	[50]
Guatemalan potato tuber moth				Guatemala		
Potato Leaf miner	*Liriomyza huidobrensis*	Diptera	Agromyzidae	South America	Different countries around the world	[42, 51]
Andean Potato Weevils	*Premnotrypes suturicallus* *P. vorax* *P. latithorax*	Coleoptera	Curculionidae	Andean region	Venezuela and Argentina	[52, 53]
Potato Psyllid	*Bactericera cockerelli*	Hemiptera	Triozidae	North America	United States, Nevada Colorado, Arizona, New Mexico, Mexico, El Salvador Honduras, and Nicaragua	[54–56]
Bud Midge	*Prodiplosis longlifila*	Diptera	Cecidomyiida	Americas	North America (Florida and Virginia), South America (Ecuador, Peru and Colombia)	[57, 58]
White Grubs	*Phyllophaga spp. Melolontha melolontha Anomala spp. Popillia japonica Holotrichia javana Holotrichia oblit Anomala oriontalis*	Coleoptera	Scarabaeidae		worldwide	[59–61]
Flea Beetles	*Epitrix tuberis* *E. papa* *E. cucumeris* *E. yanazara*	Coleoptera	Chrysomelidae	North America Peru	Spain and Portugal	[52, 62, 63]
Colorado Potato Beetle	*Leptinotarsa decemlineata*	Coleoptera	Chrysomelidae	Mexico	Central America, Canada, Europe, and parts of Asia	[64, 65]

Common name	Scientific name	Order	Family	Origin	Distribution	Reference
European Corn Borer	*Ostrinia nubilalis*	Lepidopetera	Crambidae	Europe	United States, Canada, China, India, Iran, Syria, Indonesia, North Africa (Algeria, Egypt, Libya, Morocco and Tunisia)	[66, 67]
Aphids	*Myzus persicae*	Hemiptera	Aphididae	China	North America, Europe and Asia	[68, 69]
White files	*Bemisia tabaci*	Homoptera	Aleyrodidae	Brazil or Mexico	Many counties in the world	[70]
Potato ladybirds beetles	*Henosepilachna vigintioctomaculata H. vigintioctopunctata*	Coleoptera	Chrysomelidae		Japan, Korea, China, Russia, Pakistan, Pacific islands, New Zealand and Autralia	[71–73]
Armyworms	*Spodoptera frugiperda* *S. eridania* *S. ornithogalli*	Lepidoptera	Noctuidae		North, Central, and South America, Africa, India and Europe	[74, 75]
Thrips	*Frankliniella occidentalis Thrips tabaci*	Thysanoptera	Thripidae	Western North America	Tropical, Subtropical, and Temperate Regions	[76, 77]

Table 2.
General description of major and minor Pest of pot.

Disease	Incitant	Symptoms	Reference
Fungal diseases			
Late blight	*Phytophthora ifestans*	• water-soaked light to dark brown spots on leaves • brown spots on stems • (slightly depressed areas with reddish-brown color on tubers)	[2, 80–82]
Early blight (EB)	*Alternaria solani* *A. alternate*	• dark brown to black necrosis on the lowest oldest leaves • a series of dark concentric rings are visible within the ring • The symptoms of EB on tubers are dark, slightly sunken lesions • It is not possible to distinguish between the different *Alternaria spp*	[83, 84]
Black scurf	*Rhizoctonia solan*	• It affects roots, stolen, stems and tubers • formation of sclerotia on the surface of the tubers • girdling on the stem with brown color • upward rolling of the leaves	[85]
Wart	*Synchytrium endobioticum*	• small greenish warts on the top of plants: stem, foliage and in extremely conditions on inflorescences • the typical symptoms of the disease on tubers are the proliferating warts which may vary markedly in form but are primarily spherical to irregular • the color of the vary with the variet	[86, 87]
Powdery Scab	*Spongospora subterranean*	• it infect all underground organs of porato (i.e. stolons, tubers, and roots) • purplish brown lesions are observed as initial symptoms on tubers • infection can be susceptible to root or stolon gall production	[88]
Bacterial diseases			
Bacterial wilt	*Ralstonia solanacearum*	• Wilting is the common symptoms	[89, 90]
Bacterial Blackleg and Tuber Soft Rot	*Pectobacterium aroidearum P. atrosepticum* *P. betavasculorum* *P. brasiliense* *P. cacticida* *P. carotovorum* *P. odoriferum* *P. parmentieri* *P. peruviense* *P. polaris* *P. punjabense* *P. wasabiae*	• stem necrosis • pith of the stem is often decayed • Infected plants produce few or no tubers • Plant leaves may turn bright yellow and the plant will eventually and die	[91–93]

Disease	Incitant	Symptoms	Reference
Potato Ring Rot	*Clavibacter michiganensis*	• Young infected leaves expand more slowly in the infected zones and become distorted • Leaves affected by xylem blockages further down the stem often develop chlorotic, yellow to orange, interveinal areas- • Leavers and tubers may simply be reduced in size and occasionally whole plants can be stunted	[94]
Common Scab	*Streptomyces spp.*	• necrosis on all underground parts of a potato • pitted scab, erumpent scab, and mild netted scab on the tuber	[95, 96]
Zebra chips	*Liberubacter spp.*	• severe Zebra chips on both the foliage and the tubers • Tuber development slows or ceases in symptomatic plants, resulting in yield losses • Infected tubers either do not sprout or have only hair sprouts	[97]

Table 3.
Summary of fungal and bacterial diseases of potato.

In this book chapter we provided some major and minor insect pests present in tropical, subtropical and temperate regions of the world (**Table 2**). Many pests have their evolution in the potato centre of origin, and farmers in the Andean region are confronted by numerous insect pests than those in Asia or Africa. Some species like the leaf miner fly (*Liriomyza huidobrensis*) and potato tuber moth (*Phthorimaea operculella*) has become highly invasive pests in many tropical and subtropical regions. In contrast, the strong adaptation of Andean potato weevils (*Premnotrypes spp.)* to the climate of the Andean region and its monophagous feeding habitat on potato and its wild relatives has restricted its distribution. Similarly, bud midge (*Prodiplosis longifilia*) presently with a distribution restricted in Florida, Virginia and South America (Peru, Colombia, and Ecuador) could be an invasive pests adapted by its polyphagous feeding habit. The Colorado potato beetle (*Leptinotarsa decemlineata*) native to Mexico, has spread across most of the United States, and was introduced into France in the 1920s from where it spread further reaching also parts of China [64]. Farmers in tropical and subtropical countries must contend with a higher number of pest species, and with some exceptions, a minimum of 2–4 pests often reach pest status requiring the application of control methods [52].

5.2 Diseases of potato

A disease is series of harmful physiological processes caused by continuous irritation of the host by a primary agent called a pathogen and exhibited as morbiphic cellular activity known as symptoms [78]. Potato diseases can be caused by fungi, bacteria, and viruses. Globally, the major potato diseases are late blight caused by *Phytophthora infestans*, early blight caused by *Alternaria solani*/, *A. alternata*, Fusarium dry rot caused by *Fusarium spp.*, Potato common scab caused by pathogenic *Streptomyces spp.* Black leg of potato caused by *Erwinia spp.* and bacterial wilt

Distribution	Genus/family	Virus	Transmission
Southern Andean region	Tepovirus. Betaflexiviridae	Potato virus T (PVT)	Contact, seed
Andean region, Brazil	Comovirus. Secoviridae	Andean potato mottle virus (APMoV)	Beetles
Peru	Nepovirus. Secoviridae	Potato black ringspot virus (PBRSV = TRSV-Ca)	true seed, nematodes
Peru		Potato virus U (PVU)	Nematodes
Peru		Potato virus B (PVB)	Nematodes
Europe		Cherry leaf roll virus (CLRV)	Nematodes, TPS, pollen?
Australia, Europe and New Zealand		Tomato black ring virus (TBRV)	Nematodes
Europe, North and South America		Lucerne Australian latent virus (LALV)	Unknown
Worldwide	Polerovirus	Potato leaf roll virus (PLRV)	Aphids
Worldwide	Potexvirus, Alphaflexiviridae	Potato virus X (PVX)	Contact
		Potato aucuba mosaic virus (PAMV)	
Worldwide	Cartavirus, Betaflexiviridae	Potato virus S (PVS)	Contact, Aphids
China		Potato virus H (PVH)	Unknown
Argentina and Brazil		Potato virus P	
Worldwide		Potato virus M (PVM)	Aphids
North America		Potato latent virus (PotLV)	
Europe. South America	Potyvirus, Potyviridae	Potato virus V (PW)	Aphids
Worldwide		Potato virus A (PVA)	
		Potato virus Y (PVY)	
Andes, only reported in wild potatoes		Wild potato mosaic virus (WPMV)	
Andean region	Tymovirus, Tymoviridae	Andean potato latent virus (APLV)	Beetles
		Andean potato mild mottle virus (APMMV)	
Carribean	Begomovirus. Geminiviridae	Potato yellow mosaic virus (PYMV)	Whiteflies
North America	Nucleorhabdovirus, Rhabdoviridae	Potato yellow dwarf virus (PYDV)	Leafhoppers
Worldwide	Pospiviroid, Pospiviroidao	Potato spindle tuber viroid (PSTVd)	Aphids, contact
Americas, Europe, Asia in cool and humid environments	Pomovirus, Virgaviridae	Potato mop-top virus (PMTV)	Spongospora
Colombia		Colombian potato soil-borne virus (CPSbV)	

Table 4.
Summary for viral diseases of potato.

caused by *Ralstonia solanacearum* [79] etc. The summary of the diseases caused by both fungal and bacterial pathogens is presented in **Table 3** and viral diseases in **Table 4**. Annual losses have been estimated for late blight (*Phytophthora infestans*) alone to be about €6.1 billion with resulting effects on food security, especially in developing countries. Disease symptoms can be noticed in the leaves as spots with light to dark brown water-soaked appearance. In the stems spots are usually brown in color and tubers appeared with slightly depressed areas with reddish-brown color. Mild temperatures and high humidity are requisite for disease development and, under optimal conditions; the disease can destroy a field in a few days.

6. Crop protection and sustainable potato production

According to [98], sustainability is the development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs. The growing global population needs to be satisfied with food availability and accessibility through an intensive agricultural production system which signifies the need for various green revolutions. At present, our practices that involve indiscriminate use of synthetic chemicals, chemical fertilizers, and high utilization of non-renewable energy source have led to a large threat to environmental sustainability. For example use of agrochemicals to increase crop production is one way of adding unwanted substances to the environment, which eventually contributes to the emission of greenhouse gases and subsequent environmental alterations. These harmful practices can be reduced if appropriate crop protection measures are used stewardly in agricultural activities for vital approaches of improving potato crop production. Although continuous increase in the world population at an alarming rate requires more food for nutritional security [99], but the world is now facing a great challenge to adopt sustainable measures, green technologies, sustainable science, and cleaner production such that the generations to come may be able to benefit from the earth's ecology at its conserved form [100]. Conservation of the planet becomes necessary as "We don't have a Plan B, since there is no Planet B" [101]. All key processes in the biosphere and related human activities are quite interdependent, interconnected, and hence should be steered through a mutual systems approach [102]. Food security is one of the three most pressing super challenges of the twenty-first century, after climate change and overdependence on petroleum importation, and microbes are good enough in meeting out these challenges [103]. The aims or goals of sustainable production or development are People, Planet, Profit (Prosperity), Peace, and Partnerships (**Figure 5**) [105] and if good crop protection measures such as used of microbes are utilized judiciously they can make a significant contribution in the achievement of these goals [100, 106]. Microorganisms as part good crop protection measures are much of our past and our future, pivotal agents of ecosystem and planet's functioning hence are key parts of the stewards committee of planetary health and sustainability.

6.1 Crop protection and pests Management in Sustainable Potato Production

6.1.1 Chemical control of potato pests

At present, the most important challenge facing professionals in agriculture worldwide is ensuring sustainability in potato production [107]. Insect pests are major biotic constraints affecting potato tuber quality and yield. Global losses are estimated on average at 16% [46]. Locally, if not routinely controlled, reductions

Figure 5.
The five goals of sustainable production and development. Source: Tijjani and Khairulmazmi [104].

in tuber yield and quality can be between 30 and 70% for various pests [47, 48]. Likewise in other cultivated plants, control of insect pests in potato is achieved predominantly via application of pesticides. By some estimates, potatoes are the most chemically dependent crop in the world [107]. Even though insecticides have been largely successful in keeping potato production successfully going, there are well-known and serious concerns about long-term sustainability of this approach. Chemical control of pests involves the use of synthetic chemicals which have a long-standing reputation in agriculture and ensures produce protection. They produce instant effects on the pests because they are fast-acting biocides, resulting in the arrest of pest infestations [108]. Negative effects of insecticides on numerous organisms, including health risks to farmers and beneficial insects, gained considerable notoriety since 1960s [109]. Development of resistance and environmental concerns are the major reasons that lead to phasing out of many insecticides. Numerous cases are recorded for Potato pest species that are most prone to evolving resistance to a wide variety of chemicals. For example, the (2018) Arthropod Pesticide Resistance Database lists 300 cases of Colorado potato beetle (*Leptinotarsa decemlineata*) resistance to a total of 56 active ingredients; 469 cases of green peach aphid (*Myzus persicae*) resistance to a total of 80 active ingredients; 501 cases of two-spotted spider mite (*Tetranychus urticae*) resistance to 95 active ingredients; 111 cases of greenhouse whitefly (*Trialeurodes vaporariorum*) resistance to rather impressive 27 active ingredients [2].

It is a difficult and expensive task to develop replacement insecticides, and it is highly questionable that a plethora of new active ingredients will regularly appear on the market in perpetuity [110]. Therefore, good stewardship of existing chemicals is imperative and, whenever possible, their replacements with nonchemical control alternatives become an increasingly important business strategy for the pesticide industry and potato farmers. According to [110] development of resistance by insects could be managed by preventing the situation when only highly resistant homozygotes survive in a population and this can be achieved by doing the followings:

- Avoiding applications of the same or related products repeatedly throughout a growing season.
- Monitoring insecticide efficacy.
- The use of insecticide applications should not be the first option, but when the ultimate control option in an IPM approach after all other management options could not prevent to keep a specific pest population under the economic threshold.
- Whenever possible, leaving parts of the field untreated to allow susceptible pests to survive and interbreed with resistant pests.
- Applying insecticides at rates that are not lower than a recommended minimum. Otherwise, heterozygotes will survive and breed with each other.
- Applying insecticides only when pest populations are sufficiently high to cause economically important damage.

6.1.2 Integrated Pest management (IPM)

IPM is defined as an "ecosystem approach for crop production and protection that combines different management strategies and practices to grow healthy crops and minimize the use of pesticides. Kogan [111] also defined IPM as "a decision support system for the selection and use of pest control tactics, singly or harmoniously coordinated into a management strategy, based on cost/benefit analyses that consider the interests of and impacts on society, producers and the environment". It means "a careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms" [112].

The integration of control methods will ensure quality and safety and also provide retailers with desired extended shelf life. Other benefits of IPM include dramatic slowdown of evolution of pesticide resistance. Again, simultaneous adaptations to diverse and unrelated management techniques will require statistically unlikely genetic changes in pest populations [110]. Moreover, integrating various measures to control pests, it may possibly reduce our over-dependence on the "pesticide treadmill" of constantly replacing longstanding chemicals. Additionally, with all IPM advantages, it should be made close and available to farmers across all potato-growing regions of the world. For example in the management of leafminer fly, an IPM measure based on the use of seed treatment, action threshold, trapping devices, and steward application of insecticides showed a higher efficiency in the control of potato pests including *Liriomyza huidobrensis* rather than the conventional application of insecticides by farmers in the Canete valley of Peru. IPM decreased the total amount of pesticides used per season by 56% compared to the conventional management, representing a decrease of 69.2% in the environmental effect. Furthermore, IPM achieved 35% of higher marketable potato yield rather than conventional management [113].

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6.1.3 Cultural practices

A number of cultural practices commonly used for the management of potato tuber pest are many and should not be overemphasized. Such practices including deep planting, the use of pest-free seed tubers, regular irrigation to avoid soil cracking, timely harvest, high hilling to protect tubers, clearing tubers after harvest exposed in the field for a long time (especially throughout the night), i.e., immediate harvest and storage; and removal of leftover tubers to reduce the overwintering field population are all common practices. Also, early maturing varieties can contribute for reduced risk of infestation. For example, weeding and removal of alternative and overwintering hosts such as wild mustards (*Brassica spp.*), use of wheat straw or white plastic as mulch, and intercropping with onion, garlic or coriander (*Coriandrum sativum* L.) have shown to reduce aphid populations.

6.1.4 Biopesticides/biological control

It can be an effective strategy in all those regions in which the pests have been unintentionally introduced and where natural enemies of the pests are absent to keep the pest population below economic threshold. The endoparasitoids *Halticoptera arduine* Walker (Pteromalidae), *Phaedrotoma scabriventris* (Nixon) (Braconidae) and *Chrysocharis flacilla* Walker (Eulophidae) were successfully introduced and established in three agro-ecological regions (low, middle, and high altitude) in Kenya [42, 114]. Also in the Andes, predators like carabids are widespread and affect the weevil population. Most common species are *Blennnidus sp.*, *Notiobia schnusei* (Van Endem) and *Harpalus turmalinus* Er. Additionally, fungi like *Beauveria bassiana* (entomopathogenic) and nematodes (*Heterorhabditis sp.*, and *Steinernema sp*.) have been identified and used to develop biocontrol strategies [52, 53, 115]. Biopesticides such as spinosins and abamectins generally provide excellent control of Colorado potato beetle (*Leptinotarsa decemlineata*) pest (but see cautionary note on insecticide resistance below). Bacterial insecticides based on delta endotoxin of bacterium *Bacillus thuringiensis* subsp. *tenebrionis* are also effective, but they must be applied against the first two instars. Plant extracts from such plants including leaves of *Nerium oleander* L., Melia azedarach L. fruits, neem leaves and seeds, *Bassia muricate* (L.) Asch., *Parthenium sp.*, *Lantana sp.*, *Hyptis sp.*, Tephrosia nubica (Boiss.) Baker, *Ipomoea carnea* Jacq., *Bidens pilosa* L. and *Rumex nepalensis* Spreng, roots have been shown to demonstrate an excellent level of toxicity to the larvae of *Agrotis ipslon* [74].

6.1.5 Physical control

It is essentially a good method used to control pests in the field or at storage. For example yellow attracts most insects; therefore, yellow sticky traps can effectively reduce the leafminer fly adult population. In the Cañete valley of Peru, a cumulative capture of up to seven million adults ha^{-1} by using fixed and mobile yellow sticky traps which resulted in a reduction of the control costs by 55.5% compared with chemical control, and an average use of six adulticide applications per season [116].

6.1.6 Resistance plant varieties

The most valuable and effective strategies to manage some pests like zebra chip is to discourage vector feeding by using plants that are resistant to psyllid feeding or less preferred by the psyllid.

6.2 Crop protection and diseases management in sustainable potato production

Control of disease in plants is defined as keeping disease severity below the level at which it may become economically significant [78]. In a bid to control these fungal pathogens causing losses to valuable crops at present, chemical control have been identified as the most common, popular and most effective strategy for managing plant diseases but public opinion demands a reduction in the use of chemical [117–119]. In addition to chemical control, there are a number of strategies including physical, biological, cultural, use of resistant varieties and in recent time plant-based pesticides that are enabling and instrumental to manage potato diseases and extend their shelf life without pollution to the environment and risk to the public health. This part of the chapter highlights the different techniques that are used to manage myco-induced potato diseases and other perishable produce viz.

6.2.1 Biological control

Biological control is the inhibition of infection, growth, survival and activity of one pathogen (organism) via the use of another organism with the result that there is a reduction in the evidence of the disease caused by the pathogen [118, 120, 121]. Biocontrol strategy can be a matter of harnessing any form of biological agent that exists in the environment or introduction of exotic species. The most important microoganisms causing serious losses annually in agriculture are the fungal plant diseases [122] but some of the fungal diseases including postharvest diseases of fruits and vegetables caused by fungal pathogens such as *P. infestans* and other disease causing organisms have been successfully controlled via the use of biocontrol agents [121–123]. The first experiment in biological control with antagonists was conducted by GB Sandford in Canada [2]. The mechanism of activity of these biocontrol agents may be by antibiosis (secretion of antibiotics as a result of an interaction with microorganisms, which at low concentration poisons or kills other microorganisms); by competition for space and nutrients; by metabolite production (production of cell wall lytic enzymes that can breakdown polymeric compounds, including chitin, cellulose, DNA, hemicellulose and proteins; by parasitism in form of hyperparasitism (in which the pathogen is directly attacked by a specific biological control agent that kills it or its propagules or mycoparasitism, that is microbial predation that results in the reduction of the pathogenicity of the pathogen [117, 121, 123, 124]. Combining biocontrol agent or antagonist with other postharvest treatments could increase the efficacy of the biocontrol agents [125, 126] Vesicular-arbuscular mycorrhizae (VAM) and Plant Growth Promoting Rhizobacteria (PGPR) are well known to reduce plant diseases and increase crop yield. Biocontrol applications on potato plants require a better understanding of the symbiotic fungal partners. Numerous bio-agents in the phyllosphere are antagonistic to *P. infestans*, which included the yeasts *Acetobacter spp.*, *Sporobolomyces spp*., isolates of *Bacillus spp.* and *Pseudomonas spp*. [127, 128]. Various naturally occurring microorganisms, that is, *Trichoderma viride*, *P. aurantiogriseum*, and *Penicillium viridicatum*, *Chaetomium brasiliense* [129], *Acremonium strictum* [130], *Myrothecium verrucaria* and *P. aurantiogriseum* [131], showed antagonistic effect against *P. infestans*. Application of *P. fluorescens* at 0.5% was found effective against early blight disease of potato for decreasing the intensity of the disease under field conditions [132]. The biological control agents *T. harzianum* and *P. fluorescens* (seed treatment + foliar spray) were effective in decreasing the intensity of early blight disease of potato and also increase tuber yield [85].

6.2.2 Use of resistant varieties

Identification of new resistance sources and functional resistance or susceptibility genes has been recently greatly accelerated by modern techniques, such as effectoromics and resistance gene enrichment sequencing technologies. After the discovery of the Mexican wild species *Solanum demissum* as an excellent source of resistance, eleven major genes were introduced in cultivated tetraploid potato breeding lines [133, 134]. Although some of these genes can be considered defeated, others, for example R8, are still effective against current pathogen populations [135]. Over 50 R genes have been identified from wild *Solanum* species as detailed by [136], and the research field remains active with a growing list of genes available for potato breeding programs [135, 137–139]. However, due to crossing barriers and linkage drag, there are only few successful cases where R genes have been introduced into improved tetraploid breeding lines by classical breeding [140]. Introduction of a single R gene from wild germplasm is a lengthy procedure as demonstrated by the examples of commercial varieties Bionica and Toluca that contain Rpi-blb2 originating from *Solanum bulbocastanum*, and were released almost 50 years after the first crosses were made [141]. However, recently it was shown that R genes can also have quantitative effects. The potato cultivar Sarpo Mira contains at least four R genes that confer complete resistance against incompatible isolates and a quantitative R gene, Rpi-Smira1 that confers broad-spectrum field resistance [142]. Durability of quantitative resistance will, however, continue to depend on the size of the cultivation area of a variety as well as the dynamics of the pathogen population.

6.2.3 Chemical control

The application of chemical fungicides continues to be the most common strategy for the control of most disease causing phytopathogens, for example making late blight one of the top drivers for pesticide use in the world. The demand for weekly applications generates a billion-dollar business globally every year [143]. Chemical control involves the use of synthetic chemicals to control the pathogens which have a long-standing reputation in agriculture and ensures produce protection. They produce instant effects on the pathogens because they are fast-acting biocides, resulting in the arrest of disease epidemics [118, 144]. Various synthetic fungicides that have a broad spectrum of application in the field, transit, markets or storage houses have been used for controlling postharvest fruit rot diseases of tomato caused by many fungi [118, 145]. For example, [146] reported that the use of low-weight chemical compounds of sulfur dioxide (SO_2), ozone, and acetic acid as fumigants used for postharvest protection of produce especially fruits have proved to be effective in eradicating most of the rot-inducing pathogens. To optimize the use of fungicides, it is important to know the efficacy and type of activity of the active ingredients. The frequency and timing of fungicide applications may depend on the foliar resistance of the cultivar, fungicide characteristics, rate of growth of new foliage, weather conditions, irrigation, and incidence of blight in the region [147]. The most common chemicals used include diphenyl, dichloran, sodium-*o*-phenyl phenate, 2-amino-butane, benomyl, thiabendazole, imazalil, thiophanate-methyl, triforine, iprodione, captan, vinclozolin, borax and soda ash [148]. They have fungicidal properties and are used as wash treatments and are highly effective when used "hot" at temperatures in the range from 28 to 50°C depending on the crop susceptibility to the hot injury [148]. Fungicides like biphenyl, acetaldehyde vapors dichloran, and some ammonia-emitting or nitrogen trichloride-forming chemicals are used as supplementary volatile in pakage of fungistats impregnated in paper sheets during storage and transit. Some strains fungi are resistant to one or more of the synthetic fungicides therefore broad spectrum fungicides should be used in their control [148].

6.2.4 Cultural control

Cultural control includes all the measures undertaken as agronomic activities to change the microclimate, condition of the host and also the behavior of the pathogen in order to interfere with the activity of the pathogen i.e. reproduction, dispersal and survival [149]. Include in these cultural practices are the use clean certified seed, use of adequate inter and intra-row spacing, hilling, crop rotation, destruction of plant debris, harvesting at hot conditions and when tubers are matured [82, 149]. Crop rotation is one cultural practice that influences the occurrence of many pathogens. For example *A. solani* that causes early blight disease, the fungus persists as spores or mycelium in plant debris or soil in the field from one potato-growing season to the other or next. Therefore, the practice crop rotation, including the control of host plants such as weeds (black shadow) in the nonhost crops, reduces the initial soil born inoculum. A short crop rotation with host crops (tomato, potato) results in an earlier and more severe early blight epidemic [150]. In addition, the removal or burning of infected plant debris reduces the inoculum level. The fungus does not directly infect intact periderm, and so allowing tubers to fully mature before harvest reduced the risk of tuber infection. Additionally, wounding prevention at harvest and providing good storage conditions to promote wound healing can also reduce tuber infection [151]. The use of disease- and virus-free seed potatoes is the basis for an economical potato production. Virus-infected potato plants are more susceptible to most pathoges than healthy plants. Another important thing is the legislation related primarily to prohibit the importation of infected potatoes from one country to another. Disease avoidance using uncontaminated seed in uninfested soil represents the best method of disease prevention. The relative importance of soil inoculum level in causing disease on tubers was conclusively demonstrated by [152] who showed that when arbitrary soil inoculum threshold values of 0, <10 and > 10 sporosori-g^{-1} soil were set, it was observed that the number of crops developing powdery scab increased with the level of inoculum quantified in the field soil preplanting. In field trials carried out to investigate the link between the amount of inoculum added to the soil and disease development, disease incidence and severity on progeny tubers was found to be significantly ($P < 0.01$) greater in plots with increasing levels of inoculum.

6.2.5 Integrated disease management

Integrated disease management implies the integration of two or more control methods to benefit from their additive or synergistic effects and improve the efficacy of each method in order to tailor a complete disease management [153]. The combination of various methods may provide a more durable, sustainable and practical solution to the producers who utilize the available methods to eliminate the menace of pathogens [117]. The integration of control methods will ensure quality and safety and also provide retailers with desired extended shelf life. Amalgamation of compatible and complementary approaches will lead to efficient disease control. The combination could be bio control agent with physical treatment, bio-control agents (BCAs) with chemical at low doses, plant product with soil amendment and BCAs, BCAs with another BCAs, and fungicide with natural waxes, etc. Many researchers have reported the synergistic effect of combining different control methods together for the control of postharvest decay of potato tubers. For example integrated disease management to control early blight requires the implementation of several approaches. The disease is primarily controlled by the use of cultural practices (to reduce the soil born inoculum), less susceptible cultivars and the use of pesticides. *Trichoderma spp.* are beneficial fungi in the rhizosphere of plants in which some species are reported to act as BCAs either by directly antagonizing other pathogens or indirectly by inducing ISR [154]. When applied in alteration with a fungicide, the latter does not have impact the growth of the BCAs, and performance in disease control is enhanced. Also when *B. cereus* is applied as seed treatment, it induces systemic resistance that could reduce the number of sprays of another non-systemic fungicide like chlorothalonil, to manage early blight caused by *Alternaria solani* in potato and tomato [155]. The number of fungicide sprays therefore could be scaled down from 10 to 20 applications while the yield was unaffected over a 90-day field study, confirmingthelong-lasting effect of inducers of resistance on plant defense mechanisms.

7. Concluding remarks

The role of crop protection in environmental management and sustainable potato production should not be overemphasized as it offers countless benefits. The food security challenge is to produce just as much, but waste less through better pre and post-harvest management. Pre-harvest and post-harvest management in potato, including pests and diseases management; storage, processing and value chain efficiency, is a much larger problem than cereals and deserves special attention. Reduction of food losses appears as a key opportunity. The main causes of losses are poor crop and harvest management, infested tubers by pest and diseases, high percentage of small tubers and weather conditions: frost and heavy rains etc. Since potato is a major crop for humankind, it has a global distribution and it is attacked by pests which can substantially reduce its productivity and its quality. The increasing awareness about the nutritional, agronomic, and cash creating advantages potato provides is likely to further increase its status as a global crop, particularly in developing subtropical and tropical countries. The development, adaptation and use of integrated pest management will be an important area of future research crucial for a sustainable and more resilient and economic profitable potato production in all potato growing regions worldwide. Emphasis should be given to develop and use biological approaches in pest management. This will reduce the dependence on insecticides as well as will reduce the risk that insect populations develop resistance against insecticides. Diseases of potato have remained an economically significant disease worldwide. Farmers lose millions of dollars annually due to activities of diseases. However, considering the perspective of climate change, effective utilization of crop protection measures can provide better chance of their vast application in environmental as well as agricultural sustainability.

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Conflict of interest

The authors declare no conflict of interest.

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