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REVIEW ARTICLE

ORIGIN, DOMESTICATION, TAXONOMY, BOTANICAL DESCRIPTION, GENETICS AND CYTOGENETICS, GENETC DIVERSITY AND BREEDING OF POTATO *(solanum tuberosum L.)*

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ABSTRACT

Potato (*Solanum tuberosum*), also known as white or Irish potato, is the most important and useful member of the family Solanaceae. The cultivated potato is an autotetraploid with 2n=2x= 48. It has been recognized as a wholesome food and one of the richestsources of energy in most countries of the world where it forms important part of the human diet. It is one of the efficient starch producing plants and yields more carbohydrates per unit area and time, is rich in protein, minerals, vitamins and high quality dietary fiber. Potatoes are also used as feed for livestock and in the industry for the manufacture of starch and alcohol. An insight intothe magnitude of variability present in the gene pool of a crop species is of utmost importance to a plant breeder for starting a judicious plant breeding program and selection of parents for a hybridization programas the development of an efficient plant breeding program is dependent upon the existence of genetic variability. It is native to the Andes Mountains in South America and have been grown for thousands of years. Potatoes are a staple food in many countries around the world and are used in a wide variety of dishes. They are high in carbohydrates, fiber, and vitamins C and B6. The potato is a herbaceous perennial plant grown for its edible tubers. The plant has a branched stem and leaves consisting of leaflets that are both unequal in size and shape and can be oval to oblong in shape. The leaves can reach up to 10–30 cm in length. Tubers grow about 25 cm underground in the soil and can be yellow, red, or purple depending on the variety. The potato plant produces white or blue flowers and yellow-green berries. The plants can go up to 1m in height. The crop can be propagated from seed potatoes, which are small tubers that are planted in the soil. They can also be propagated from potato seed, which is a less common method. Once the seed potato or seed is planted, the plant will grow leaves and flowers, and then it will produce tubers underground. Potato is the most important food crop of the world in terms of human consumption after rice, wheat and maize. The cultivated potato of world commerce, *Solanum tuberosum* L., is a primary food crop grown and consumed worldwide, forming a basic food and source of primary income for many societies. Till 16th century it was unknown to the people of Europe, Asia, Africa and North America. Today, potato is the world's major non-cereal food crop grown in nearly 161 countries in a wide variety of soils and climate. There are close to 4,000 varieties of potatoes, each of which has specific agricultural or culinary attributes. Around 80 varieties are commercially available in the UK. In general, varieties are categorized into a few main groups based on common characteristics, such as russet potatoes (rough brown skin), red potatoes, white potatoes, yellow potatoes (also called Yukon potatoes) and purple potatoes. Potato tubers are a staple food source in temperate regions and are eaten after cooking. They may be cut or sliced and made into potato chips or fries. Potatoes can also be processed into starch, alcohol or flour. Potatoes are a good source of carbohydrates, potassium, and vitamin C; they are also a source of fiber, vitamin B6, and folate. They are low in fat, calories, and sodium. The values shown in the following table are approximate and may vary depending on the variety, growing conditions, and preparation method of the potatoes. Additionally, cooking and processing methods such as frying or mashing can change the nutritional value of potatoes and increase their calorie and fat content. Even though potatoes are commonly used for diabetes, heart disease, high blood pressure, indigestion (dyspepsia), and other conditions, there is no good scientific evidence to back up these claims. In addition to treating stomach disorders, raw potato juice is also used to treat water retention (oedema). Weight loss is achieved by mixing potato protein powder with water and controlling appetite. People apply raw potatoes directly to sore eyes, boils, burns, arthritis, and infections. Potatoes are used as sources of starch as well as fermented into alcohol . During the late 19th century, numerous images of potato harvesting appeared in European art. An American toy that consists of a plastic potato and attachable plastic parts, such as ears and eyes, to make a face. It was the first toy ever advertised on television. In this review article on Origin, Domestication, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Breeding, Uses, Nutritional Value and Health Benefits of Potato are discussed.

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INTRODUCTION

Potato (*Solanum tuberosum*), also known as white or Irish potato, is the most important and useful member of the family Solanaceae. The cultivated potato is an autotetraploid with 2n=2x=48. It has been recognized as a wholesome food and one of the richest sources of energy in most countries of the world where it forms important part of the human diet. It is one of the efficient starch producing plants and yields more carbohydrates per unit area and time, is rich in protein, minerals, vitamins and high quality dietary fibre. Potatoes are also used as feed for livestock and in the industry for the manufacture of starch and alcohol. An insight into the magnitude of variability present in the gene pool of a crop species is of utmost importance to a plant breeder for starting a judicious plant breeding programme and selection of parents for a hybridization programme as the development of an efficient plant breeding programme is dependent upon the existence of genetic variability (Ummyiah *et al*., 2010). Western South America is the primary center of the origin and diversity of the potato crop and its wild relatives. Contemporary landrace gene pools occur from 45° south in Chile to 12° northern latitude in Colombia (Hawkes, 1990). Wild relatives of the potato (*Solanum* section *Petota*; Solanaceae) have a much wider distribution range and occur from northern Patagonia to the southern US and the western Atacama desert to eastern South America. The genetic diversity of landraces and wild relatives has been and continues to be an extremely valuable source of variation for genetic enhancement, crop improvement, and understanding of chemical variability. At the same time, ongoing evolution of potato diversity in farmers' hands is anticipated to allow for adaptation to climate change and continued food security in extreme agro-ecologies (de Haan and Rodriguez, 2016). Potato is the most important food crop of the world in terms of human consumption after rice, wheat and maize. The cultivated potato of world commerce, *Solanum tuberosum* L., is a primary food crop grown and consumed worldwide, forming a basic food and source of primary income for many societies. Till 16th century it was unknown to the people of Europe, Asia, Africa and North America. Today, potato is the world's major non-cereal food crop grown in nearly 161 countries in a wide variety of soils and climate (Luthra *et al.,* 2020). Farmers in the highlands produce 60% of the crop, which is a staple food and a source of income for them. There are several industrial uses for potatoes, including starch production and alcohol production. In textile mills, potato starch is used to size yarn, while dextrin and glucose are also produced from potatoes. Approximately hundreds of thousands of jobs will be generated directly and indirectly as a result of U.S. potato production in 2021. Commercially grown potatoes in nearly every state are primarily produced by multi-generational family farms, unlike most speciality crops. Potatoes are one of America's largest agricultural exports, contributing to world food security, with one out of five rows going overseas (HND, 2022). Never consume potatoes that are spoiled or green beneath the skin. Potent toxins are found throughout the plant, especially in green potatoes and new sprouts. Remove any sprouts from potato skins before eating them. Only potatoes without green skins and sprouts should be eaten (HND, 2022). It is native to the Andes Mountains in South America and have been grown for thousands of years. Potatoes are a staple food in many countries around the world and are used in a wide variety of dishes. They are high in carbohydrates, fiber, and vitamins C and B6. (Plantvillage, 2023). The English word *potato* comes from Spanish *patata* (the name used in Spain). Potatoes are occasionally referred to as *Irish potatoes* or *white potatoes* in the United States, to distinguish them from sweet potatoes. The name *spud* for a potato comes from the digging of soil (or a hole) prior to the planting of potatoes. The word has an unknown origin and was originally (c. 1440) used as a term for a short knife or dagger, probably related to the Latin *spad-*, a word root meaning "sword"; compare Spanish *espada*, English "spade", and *spadroon*. It subsequently transferred over to a variety of digging tools. Around 1845, the name transferred to the tuber itself, the first record of this usage being in New Zealand English. The origin of the word *spud* has erroneously been attributed to an 18th-century activist group dedicated to keeping the potato out of Britain, calling itself the Society for the Prevention of Unwholesome Diet. It was Mario Pei's 1949 *The Story of Language* that can be blamed for the word's false origin. Pei wrote "the potato, for its part, was in disrepute some centuries ago. Some Englishmen who did not fancy potatoes formed a Society for the Prevention of Unwholesome Diet. The initials of the main words in this title gave rise to spud." Like many other claimed pre-20th century acronymic origins, this is false, and there is no evidence that a Society for the Prevention of Unwholesome Diet ever existed. At least seven languages—Afrikans, Dutch, French, (West) Frisian, Hebrew, Persian and some variants of German—are known to use a term for "potato" that translates roughly (or literally) into English as "earth apple" or "ground apple" (Wikipedia, 2023). *Solanum tuberosum* is commonly known as Irish potato, potato, white potato, yellow potato, red potato, and *pomme de terre* **(**Inspection, 2015**).** The name of potato in different languages are, namely, English: Potato, Spanish: Papa, French: Pomme de terre, German: Kartoffel, Italian: Patata, Portuguese: Batata, Chinese: mǎ líng shǔ, Russian: картофель (kartofel), Arabic: al-batata, Hindi: aalu, Bengali: aalu, Urdu: ailu, Greek: patata (Plantvillage, 2023). The potato is a widely cultivated root vegetable in the Solanaceae family. They are native to the Andes Mountains in South America and have been grown for thousands of years. Potatoes are a staple food in many countries around the world and are used in a wide variety of dishes. They are high in carbohydrates, fiber, and vitamins C and B6 (Plantvillage, 2023). The potato is a herbaceous perennial plant grown for its edible tubers. The plant has a branched stem and leaves consisting of leaflets that are both unequal in size and shape and can be oval to oblong in shape. The leaves can reach up to 10–30 cm in length. Tubers grow about 25 cm underground in the soil and can be yellow, red, or purple depending on the variety. The potato plant produces white or blue flowers and yellow-green berries. The plants can go up to 1m in height (Plantvillage, 2023). The crop can be propagated from seed potatoes, which are small tubers that are planted in the soil. They can also be propagated from potato seed, which is a less common method. Once the seed potato or seed is planted, the plant will grow leaves and flowers, and then it will produce tubers underground (Plantvillage, 2023). In this review article on Origin, Distribution, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Breeding, Uses, Nutritional Value and Health Benefits of Potato are discussed.

ORIGIN AND DOMESTICATION

The most popular cultivated potato is *S. tuberosum*, which is also known as "common potato" in most parts of the world. Spooner *et al.* (2005a) assumed a single origin, from a wild species progenitor present in the *S. brevicaule* complex, in southern Peru. However, multiple origins of cultivated potatoes have been suggested by different authors potatoes were originally introduced into Europe from the Chiloé region in Chile. In contrast, Hawkes (1994) suggested that common potato descends from potatoes widely cultivated in the Andean highlands of Bolivia, Peru, and northern Argentina. Molecular analysis has revealed that the Andean potato predominated in the 1700s, and later the Chilean potato was introduced into Europe and became predominant long before the late blight epidemics (Spooner *et al*. 2005b). Potato landraces cultivated in Mexico and Central America have been considered to be the result of repeated introduction in the post-Columbian era (Spooner *et al.* 2007).

Solanum tuberosum ultimately traces its origin to Andean and Chilean landraces developed by pre-Colombian cultivators. These landraces exhibit tremendous morphological and genetic diversity and are distributed throughout the Andes, from western Venezuela to northern Argentina, and in southern Chile. The wild species progenitors of these landraces have long been in dispute, but all hypotheses centre on a group of approximately 20 morphologically similar wild species referred to as the *Solanum brevicaule* complex. The first record of *S. tuberosum* subsp. *andigena* outside South America was in the Canary Islands in 1567 and shortly thereafter in continental Spain in 1573. Forms of the introduced *S. tuberosum* subsp. *andigena* were adapted to the longer day lengths and climate of European latitudes through selection. These converted forms are known today as *S. tuberosum* subsp. *tuberosum* (or *S. tuberosum*). From Europe, *S. tuberosum* was transported to North America. *S. tuberosum* may first have been transported from England to Bermuda in 1613 and then from Bermuda to the North American mainland in 1621. *S. tuberosum* was present in India by 1610 and mainland China by 1700. *S. tuberosum* was taken to New Zealand in 1769 by Captain Cook and gained agronomic significance for the native Maori by 1840. Missionaries may have played a crucial role in the distribution of *S. tuberosum* from Europe throughout the world (Inspection, 2015). The Andes are a center of origin and diversity for many crop species, including the potato. Potatoes were domesticated between 10,000 – 7,000 years ago, likely around Lake Titicaca, in the Andes between Peru and Bolivia. The first record of cultivated potatoes outside South America is their introduction in 1567 from Gran Canaria in the Canary Islands to Antwerp in Belgium. These authors concluded that the potato was first introduced from South America into the Canary Islands around 1562, and from there to mainland Europe. Potato is a carbohydrate rich crop that provides significant amounts of protein, with a good amino acid balance, vitamins C, B6 and B1, minerals potassium, phosphorus, calcium and magnesium and micronutrients iron and zinc. The tuber is high in dietary fiber, especially when eaten unpeeled with its skin, and is rich in antioxidants comprising polyphenols, carotenoids, and vitamin C. Fresh potatoes are virtually free of fat and cholesterol. The nutrient-rich potato can contribute to improved diets, thus to reducing mortality rates caused by malnutrition especially among women and children and can improve food security and health. Increases in potato yields are essential to improve the livelihoods and food security of poor farmers (Hussen, 2019).

The center of origin of potato is known to be the Andes of southern Peru and northern Bolivia. Potatoes were domesticated in the Andes of southern Peru about 10,000 years ago. The ceramics excavated from the Moche cultures in northern Peru (c. AD 1-600), the Chimu people (c. AD 900-1450) depicting many forms of potato and radiocarbon dating of actual remains of potato from the Chilca valley near Lima provide credible archaeological evidence for origin of potato in South America. In South America, potato was the most productive source of main food for centuries in the high Andes and Chile. Potatoes were dried by Andean Indians to make *Chuno*, still an important food in highlands of Peru, for use during food shortage between successive crops. Potato grows in its natural habitat in Central America and Andean region of North western Argentina, Peru and Southern Bolivia. The distribution of wild tuber-bearing *Solanum* species ranges from the South western states of the USA to Guatemala, Honduras, Costa Rica and western Panama. Some wild potato species are adapted to grow in the cold very high Andean regions from 3000 to 4500 m, where frosts are very common (*e.g*., *S. acaule* Bitt. and *S. megistacrolobum* Bitt.), whilst others occur in dry semi-desert conditions (*e.g., S. berthaultii* Hawkes, *S. tarijense* Hawkes and *S. neocardenasii* Hawkes). Some are found in cool temperate rain forest (*e.g., S. violaceimarmoratum* Bitt. and *S. colombianum* Dun.), and others on the coastal plains of Argentina and surrounding countries (*S. commersonii* Dun. and *S. chacoense* Bitt.). Due to their wide distribution and adaptation to extreme climatic conditions, wild species have become adapted to stress environments and have strong resistances to a wide range of pests and diseases (Luthra *et al*., 2020).

The potato is a starchy food, a tuber of the plant and is a root vegetable native to the Americas. Wild potato species can be found from the southern United States to southern Chile. The potato was originally believed to have been domesticated by Native Americans independently in multiple locations, but later genetic studies traced a single origin, in the area of present-day southern Peru and extreme Northwestern Bolivia. Potatoes were domesticated there approximately 7,000–10,000 years ago, from a species in the *Solanum brevicaule* complex. In the Andes region of South America, where the species is indigenous, some close relatives of the potato are cultivated. Potatoes were introduced to Europe from the Americas by the Spanish in the second half of the 16th century. Today they are a staple food in many parts of the world and an integral part of much of the world's food supply. As of 2014, potatoes were the world's fourth-largest food crop after maize (corn), wheat, and rice. Following millennia of selective breeding, there are now over 5,000 different types of potatoes. Over 99% of potatoes presently cultivated worldwide descend from varieties that originated in the lowlands of South-central Chile (Wikipedia, 2023). Potatoes are thought to have been independently domesticated several times and were largely cultivated in South America by the Incas as early as 1,800 years ago. Encountered by the invading Spaniards, potatoes were introduced into Europe during the second half of the 16th century. By the end of the 17th century the plant was a major crop in Ireland, and by the end of the 18th century it was a major crop in continental Europe, particularly Germany, and in the west of England. It continued to spread, in both Western and Eastern hemispheres, during the first four decades of the 19th century, and the Irish economy itself became dependent upon the potato. However, the disastrous failures of the Irish crops in the mid-19th century (especially in 1846 and 1848), because of late blight (*Phytophthora infestans*), and the resulting Irish Potato Famine generated a more-cautious attitude toward dependence on the plant (Britannica, 2023).

History of the potato: With more than 5,000 varieties worldwide, the potato is one of the most ubiquitous and reliable crops on the planet. Today, it is the fourth most cultivated staple food crop after wheat, corn and rice. Its origins in South America and eventual global spread tell the story of a versatile staple good that is intertwined with global connectivity and advancements in cultivation, crop protection and biotechnology. This is the story of the humble potato (Croplife, 2021):

- The exact time period remains unknown, but the earliest recorded traces of potatoes were found in the Peruvian Andes and date to sometime between 4000-3000BC. The first wild potatoes contained toxic compounds, likely as a defence mechanism, that are resistant to heat. This meant that cooking wild potatoes would not affect their toxicity. However, wild animals in the region would lick clay before consuming poisonous plants as the toxins would adhere to the clay particles in the animals' digestive systems and pass through the body without causing harm. Andean mountain peoples would mimic this, consuming their potatoes with a clay and water mix. Eventually, however, less toxic potatoes were created through trial and error to discover plants that were less bitter and caused less illness. These varieties would then be selected for cultivation.
- Between 500-1400 AD the Andean farmers prized the potato for its ability to flourish at high altitude and for its versatility and longevity of use. The emergence of two reliable staple crops in potatoes and maize would allow for the Andean region to support large populations across its valleys and mountain ranges, laying the groundwork for the emergence of the Incan civilization. During this period the Incas were one of the fastest growing populations in the Americas and this was linked to their improvements in agricultural production and treating and storing of foodstuffs. Potato production had been boosted through improved farming techniques, such as selective breeding and crop rotation, and this vital food was firmly embedded in Andean culture.
- During (1500-1800 AD) the first Spanish invasion of the region in 1532, the Spaniards led by Francisco Pizarro observed the native peoples eating potatoes. Emulating them, they quickly discovered the robustness and versatility of the potato for themselves and across the late 1500s, the potato began to be cultivated around Europe, being introduced in Germany, Belgium, England and Ireland. The success of the potato in Europe would be driven by science and botanists, who reproduced potatoes and distributed them among their fellow enthusiasts. Without experimentation, these early species of potato would have produced poor yields under European environmental conditions. Unlike all previous crops in Europe, potatoes are not grown from seeds, but from small chunks of tuber, the size of which are regulated by the length of day. The variable day length in Europe affected potato size, but many potato varieties had reached Europe from South America, including Chilean potatoes which were already adapted to non-equatorial summer/winter climates. Botanists would take a

careful, scientific approach to their potato breeding, mixing varieties and repeatedly selecting for yield and earliness. This would result in potatoes that were well adapted to their environment, paving the way for this crop's wide adoption by farmers in Europe. With the potato being grown by major western colonising nations, this enabled the crop to spread across the world, becoming well established in Asia, Africa and North America by the end of the 1700s.

- This period (1800-1900 AD) established the potato as the most important new crop in Europe, which combined with the adoption of chemical fertilizers helped contribute to the massive 19th century population boom. The potato had a number of advantages, including its low cost, bulky nature that helped stave off hunger, and its longevity that meant it took much longer to spoil. However, in the 1840s disaster struck as a potato blight afflicted crops across Northern Europe. This water mould causes serious disease that would shrink potatoes, giving them a rotted, corky interior and rendering them inedible. Ireland suffered the most, with casualties reaching one million, with even more of the population emigrating to escape the famine. Now thought to have originated in South America, the blight destroyed healthy potatoes and brought a halt to their trade at the time. Blight continues to impact potato crops to this day and without modern crop protection techniques as much as 40% of annual yields could be lost to the disease.
- During the period 1930s-1970s modern pesticides enter usage and have a significant impact on potato yields, with modern insecticides helping tackle pests, such as the Colorado potato beetle. New technologies arise starting in the 1940s and continue a steady progression through the 1970s, providing farmers with new protections. The success of the potato is not just based on the plant breeding techniques that have transformed its yield and adapted it so that it now flourishes in more than 150 countries. Potatoes are a high cost, risky crop that require careful cultivation, particularly in areas with high pest pressure. As potatoes are vulnerable to a number of insects, diseases and weed pests, it is estimated that a 50 per cent reduction in pesticide use would result in a 27 per cent reduction in output, while a 100 per cent reduction in pesticide use would lower yields by as much 57 per cent. Advancements in agricultural technologies and the ongoing success of the potato go hand-in-hand.
- The dawn of plant biotechnology (2000S-onwards) allowed for targeted plant breeding that selects for desirable traits. New crop varieties offer a range of benefits to farmers, consumers and society and the potato was no different. Supporting traditional crop protection methods, biotech pioneers explored the potential for producing potatoes with more desirable traits. These potatoes, such as the White Russet, exhibit less browning and bruising and contain less asparagine. While browning and bruising are cosmetic issues, they result in large amounts of perfectly edible potatoes being discarded unnecessarily. More robust and cleaner looking potatoes reduce food waste and lower the number of additives used. The lower levels of asparagine also mean that White Russets can be fried without producing harsh by products. Potatoes are now integral to cuisines and farming communities across the globe, with nearly a third now grown in China and India. This vital crop isn't done yet, though, and GM varieties can help fight potato blight and reduce cancer-causing chemicals that occurs when certain foods are cooked at high temperatures. With genome editing building on the success of biotechnology, scientists are working to improve the world's potatoes, boosting their nutritious content and improving their longevity and robustness. After thousands of years of improvement and expansion into new environments, the potato is here to stay (Croplife, 2021).

The potato was first domesticated in the region of modern-day southern Peru and northwestern Bolivia by pre-Columbian farmers, around Lake Titicaca. It has since spread around the world and become a staple crop in many countries. The earliest archaeologically verified potato tuber remains have been found at the coastal site of Ancon (Central Peru), dating to 2500 BC. The most widely cultivated variety, *Solanum tuberosum tuberosum*, is indigenous to the Chiloé Archipelago, and has been cultivated by the local indigenous people since before the Spanish conquest. According to conservative estimates, the introduction of the potato was responsible for a quarter of the growth in Old World population and urbanization between 1700 and 1900. In the Altiplano, potatoes provided the principal energy source for the Inca civilization, its predecessors, and its Spanish successor. Following the Spanish conquest of the Inca Empire, the Spanish introduced the potato to Europe in the second half of the 16th century, part of the Columbian exchange. The staple was subsequently conveyed by European (possibly including Russian) mariners to territories and ports throughout the world, especially their colonies. The potato was slow to be adopted by European and colonial farmers, but after 1750 it became an important food staple and field crop and played a major role in the European 19th century population boom. However, lack of genetic diversity, due to the very limited number of varieties initially introduced, left the crop vulnerable to disease. In 1845, a plant disease known as late blight, caused by the fungus-like oomycete *Phytophthora infestans*, spread rapidly through the poorer communities of western Ireland as well as parts of the Scottish Highlands, resulting in the crop failures that led to the Great Irish Famine. However, thousands of varieties still persist in the Andes , where over 100 cultivars might be found in a single valley, and a dozen or more might be maintained by a single agricultural household (Wikipedia, 2023).

Potato, indigenous flowering plants of the South America and the Andes mountains (modern-day Southern Peru and Northwestern Bolivia) managed to prove its usefulness to our ancestors, who cultivated it, nurtured it, and ensured its survival during the last 10,000 years of our history. Centuries after they were introduced to Europe and North America, potatoes represent one of the most important parts of world's cuisine and the fourth-largest food crop in the entire world (following maize, rice and wheat). Today, extensive research and the centuries of selective breeding, we now have access to over thousand different types of potatoes that are grown all around the word. The story of potato started around 350 million years ago, when they started to evolve from the poisonous ancestor of the plant nightshade (this family of plants eventually evolved not only into potatoes, but also into tobacco, chilli peppers, bell peppers and tomatoes). Potato slowly evolved into its current form in the South American Andean highlands between Peru and Bolivia. Human settlers reached that part of our world around 15 thousand years ago, and managed to domesticate wild potato around 8 millennia BC. From that point on, potato slowly started its journey across the continent, but it received great attention in the 1500s when first Spanish conquistadors started exploring beyond the coasts of South America, especially after 1530s when they searched for gold in Peru. Among their numerous discoveries, potato received a very notable attention, and they brought that plant to Europe between the years of 1570 and 1593 (Canary Islands received it in 1562). European adoption of potato was slow but steady. In the beginning, Spanish government used potato as a reliable and easily transported food for their military and navy who while using them did not succumb to the scurvy. Potato arrived to Britain in 1585, Belgium and Germany in 1587, Austria in 1588, Ireland in 1589 and France in 1600. Sadly, local population of those countries looked at potato as absolutely unneeded, weird, poisonous (only roots of the plant were edible, which was totally unheard of in Europe), and in some cases as downright evil. For many years, potato was accused for causing leprosy, syphilis, early death, sterility, rampant sexuality, scrofula, narcosis and for destroying the soil where it grew. This sentiment receded from the Europe only after large scale efforts of France to find food that would sustain not only their military, but also population that was starved from continuous warfare. Long examination of the potato by the famous French botanist and chemist Antoine-Augustin Parmentier finally paid off when he persuaded King of France Louis XVI (1754–1793) to encourage mass cultivation of this plant my tricking the population. King gave Parmentier funds and land to grow 100 acres of potato, which were carefully guarded by military guards. Such large military and government attention on guarding these potatoes instantly sparked the attention of the people, who after that started adopting potato more and more until it became one of the most popular food sources in the Europe. The wife of the French king Marie Antoinette (1755-1793) also contributed by pining potato flowers in her curls, a move that was quickly emulated by noble ladies all across the Europe. In early 1800s, potato became a commonplace crop that was used in entire Europe, but such popularity became severely tested between 1845 and 1849 when disease destroyed entire potato production of Ireland. During this "Great Starvation" around one million people died from starvation, and forced large amount of people to emigrate out of Ireland (500 thousand left for North America and Australia). United States of America was the last major country who adopted potato in their cuisine. For many years they regarded this crop for horses and other animals. Only after the 1872 efforts of famous horticulturist Luther Burbank (1849-1926), American potato industry managed to gain some traction. This was enabled by Burbank's discovery of disease resistant potato hybrid, and another hybrid that was used in Ireland to help combat blight epidemic. In 20th century, potato became accepted across entire world as one of the most beloved and produced food sources, effectively becoming the most essential crop of Europe. Its high caloric value and wide variety of types enabled it to appear in every cuisine in the world (Vegetable Facts, 2023).

The potato was the first domesticated vegetable in the region of modern-day southern Peru and extreme Northwestern Bolivia between 8000 and 5000 BCE. Cultivation of potatoes in South America may go back 10,000 years, but tubers do not preserve well in the archaeological record, making identification difficult. The earliest archaeologically verified potato tuber remains have been found at the coastal site of Ancón (Central Peru), dating to 2500 BC. Aside from actual remains, the potato is also found in the Peruvian archaeological record as a design influence of ceramic pottery, often in the shape of vessels. The potato has since spread around the world and has become a staple crop in most countries. It arrived in Europe sometime before the end of the 16th century by two different ports of entry: the first in Spain around 1570, and the second via the British Isles between 1588 and 1593. The first written mention of the potato is a receipt for delivery dated 28 November 1567 between Las Palmas de Gran Canaria and Antwerp. In France, at the end of the 16th century, the potato had been introduced to the Franche-Comté, the Vosges of Lorraine and Alsace. By the end of the 18th century, it was written in the 1785 edition of Bon Jardinier: "There is no vegetable about which so much has been written and so much enthusiasm has been shown ... The poor should be quite content with this foodstuff." It had widely replaced the turnip and rutabaga by the 19th century. Throughout Europe, the most important new food in the 19th century was the potato, which had three major advantages over other foods for the consumer: its lower rate of spoilage, its bulk (which easily satisfied hunger) and its cheapness. The crop slowly spread across Europe, becoming a major staple by mid-century, especially in Ireland (Wikipedia, 2023a).

The potato diffused widely after 1600, becoming a major food resource in Europe and East Asia. Following its introduction into China toward the end of the Ming dynasty, the potato immediately became a delicacy of the imperial family. After the middle period of the Qianlong era (1735–96) in the Qing dynasty, population increases and a subsequent need to increase grain yields coupled with greater peasant geographic mobility led to the rapid spread of potato cultivation throughout China, and it was acclimated to local natural conditions. Peter Boomgaard looks at the adoption of various root and tuber crops in Indonesia throughout the colonial period and examines the chronology and reasons for progressive adoption of foreign crops: sweet potato (widespread by the 1670s), ("Irish") potato and bengkuang (yam beans) (both locally abundant by the 1780s), and cassava (from the 1860s). In India, Edward Terry mentioned the potato in his travel accounts of the banquet at Ajmer by Asaph Khan to Sir Thomas Roe, the British Ambassador in 1675. The vegetables gardens of Surat and Karnataka had potatoes as mentioned in Fyer's travel record of 1675. The Portuguese introduced potatoes, which they called 'Batata', to India in the early seventeenth century when they cultivated it along the western coast. British traders introduced potatoes to Bengal as a root crop, 'Alu'. By the end of the 18th century, it was cultivated across northern hill areas of India. Potatoes were introduced to Tibet by the 19th century through the trade route from India (Wikipedia, 2023a).

TAXONOMY

Solanum tuberosum belongs to the *Solanaceae* family. This family includes, among 2000 other species, tomato (*S. lycopersicum L.*), sweet pepper (*Capsicum annuum L.*), eggplant (*S. melongena* L. var. *esculentum*), tobacco (*Nicotiana tabacum* L.), and petunia (*Petunia hybrid L.*). The genus *Solanum* is a polymorphous and largely tropical and subtropical genus containing more than 1000 species. (Inspection, 2015).

Taxonomic position of poato is given below (Inspection, 2015):

Family: Solanaceae

Subfamily: Solanoideae

Genus: *Solanum* L.

Section: *Petota*

Subsection: *Potatoe*

Series: *Tuberosa*

Species: *Solanum tuberosum* L.

Taxonomists have experienced difficulty in the ordering of species within the *Solanum* genus. Species definitions are confounded by a number of factors, including similar morphologies between distinct species, high levels of hybridization followed by introgression, and phenotypic plasticity in variable environments. *S. tuberosum* has been placed in the section *Petota*, which includes all of the tuber-bearing wild and cultivated potatoes. It is also informally classified in the Potato clade, which includes tomato and its wild relatives in section *Lycopersicon* as well as the closely related section *Etuberosum* (Inspection, 2015). One of the more widely used classifications identified seven species of cultivated potato: *S. tuberosum*, *S. curtilobum* Juz. & Bukasov, *S. chaucha* Juz. & Bukasov, *S. juzepczukii* Bukasov, *S. ajanhuiri*, Juz & Bukasov, *S. phureja* Juz. & Bukasov, and *S. stenotomum* Juz. & Bukasov. However, this classification is not universally accepted. A recently updated classification suggests there are only four cultivated species: *S. tuberosum*, *S. ajanhuiri*, *S. juzepczukii* and *S. curtilobum* (Inspection, 2015). Domestic *S. tuberosum* are highly heterozygous autotetraploids ($2n = 4x = 48$); however some *S. spp.* landraces cultivated primarily in South America are diploid ($2n = 2x = 24$), triploid ($3x = 36$), or pentaploid ($5x = 60$). Continued self-pollination of *S. tuberosum* can lead to large inbreeding depression due to the fact that many characteristics are determined by non-additive genetic effects (Inspection, 2015). *S. tuberosum* is divided into two subspecies: *tuberosum* and *andigena*. The subspecies *tuberosum* is the cultivated potato widely used as a crop in North America and Europe. The subspecies *andigena* is also a cultivated species, but cultivation is restricted to Central and South America (Inspection, 2015)

Potato belongs to the Family *Solanacesae*, Genus *Solanum,* and the *Speciase tuberosum* (HND, 2022; Britannica. 2023; Wikipedia, 2023; Plantvillage, 2023). The family *Solanaceae* is comprised of 3,000–4,000 species placed within about 90 genera. Potato (*Solanum tuberosum* L.), tomato (*S. lycopersicum* L.), aubergine or eggplant (*S. melongena* L.), chili pepper (*Capsicum* sp.), and husk tomato (*Physalis* sp.) are the well-known and most cultivat-ed crops in the *Solanaceae* family. Besides, a number of species are locally cultivated for their edible fruits, tubers, or leaves, as well as for horticultural purposes. Cultivated potato and its wild relatives belong to the genus *Solanum*, the largest genus with 1,500–2,000 species. Within the genus *Solanum*, over a thousand species have been recognized (Burton

1989). Generally, tuber-bearing *Solanum* species are grouped in the *Petota* section. This section is subdivided into two subsections, *Potatoe* and *Estolonifera* (Hawkes 1990). The subsection *Potatoe* contains all tuber-bearing potatoes, including common potato (*S. tuberosum*, belong- ing to series *Tuberosa*). Two non-tuber-bearing series (*Etuberosa* and *Juglandifolia*) are placed in subsection *Estolonifera*. Potato has an extremely large secondary gene pool consisting of related wild species. Therefore, its taxonomy has been a subject of study for many years. Consistency of names assigned to species and higher ranks, identification ofidentical materials, and the classification of materials reflecting genetic similarities are major objectives in potato systematics (Spooner and Bamberg 1994).

Given the importance of taxonomic consistency, different taxonomic classifications of wild and cultivated potatoes have been presented by several authors. This complication of potato taxonomy at the species level may have arisen by introgression, interspecific hybridization, auto- or allopolyploidy, sexual compatibility among many species, a mixture of sexual and asexual reproduction, recent species divergence, phenotypic plasticity and consequently high morphological similarity among species (Spooner 2009, Spooner and Bamberg 1994). Currently,228 species are recognized by Hawkes (1990), 196 species by Spooner and Hijmans (2001) and approximately 110 species by Spooner (2009). Various researches in recent years, using large number of samples covering a wide range of species and implementations of advanced molecular tools, have suggested reconsideration of taxonomic classifications (Spooner 2009). However, it seems that, asyet, people researching on potatoes worldwide have not reached on an agreement.

The most recent suggestion was made by Spooner *et al.* (2007). They genotyped 742 landraces of all cultivated species and wild progenitors with SSR and chloroplast markers, and suggested reclassification of cultivated potatoes into the following four species: (i) *S. tuberosum*, with two cultivar groups (theAndigenum group of upland Andean genotypes containing diploids, triploids, and tetraploids and the Chilotanum group of lowland tetraploid Chilean landraces); (ii) *S. ajanhuiri* (diploid); (iii) *S. juzepczukii* (triploid); and (iv) *S. curtilobum* (pentaploid) (Spooner *et al.* 2007). Updating taxonomic classificationand reevaluation of the materials stored in the gene bank is essential for managers as well as the depositors of the gene bank to assure consistency of their genetic materials. Table 1 shows a synopsis of taxonomic treatments of the cultivated potatoes, describing the classifications provided by Hawkes (1990), Ochoa (1990, 1999), and Spooner *et al.* (2007). Here, with the aim of practical utility, species descriptions by Hawkes (1990) with their relationship to the most recently proposed classifications by Spooner *et al.*(2007) are described below.

Table 1. Taxonomic treatments of cultivated potatoes

Hawkes (1990)	Ochoa (1990, 1999)	Spooner *et al.* (2007
Solanum ajanhuiri	*S. ×ajanhuiri*	*S. ajanhuiri*
S. curtilobum	*S. ×curtilobum*	*S. curtilobum*
S. juzpeczukii	*S. ×juzepczukii*	*S. juzepczukii*
S. tuberosum	*S. tuberosum*	*S. tuberosum*
subsp. *andigena* Hawkes	subsp. *andigena* Hawkes	Andigenum Group
subsp. *tuberosum*	subsp. *tuberosum*	Chilotanum Group
	S. hygrothermicum	
S. chaucha	*S. ×chaucha*	*S. tuberosum* (Andigenum Group)
S. phureja	*S. phureja*	*S. tuberosum* (Andigenum Group)
	S. stenotomum	
S. stenotomum	*S. goniocalyx*	*S. tuberosum* (Andigenum Group)

Hawkes (1990) divided *S. tuberosum* into the following two subspecies: *tuberosum* and *andigena*; both are tetraploid (2n = 4x = 48). The subspecies *tuberosum* is the cultivated potato used worldwide, whereas the subspecies *andigena* is restricted to Central and South America (Hawkes 1990). Hawkes (1990) described these two subspecies as follows:

- *S. tuberosum* subspecies andigena (tetraploid): The spe- cies is cultivated over a broad range in the Andes of South America and displays a wide range of morphological variations, including diversity in the colors of the flower and tuber shapes. Theories about the origin of the species, include natural hybridization events between *S. stenotomum* and *S. sparsipilum*, followed by chromosome doubling or simple chromosome doubling of *S. stenotomum*, and later hybridization between *S. stenotomum* and *S. chacoense* (Hawkes 1994).
- *S. tuberosum* subspecies tuberosum (tetraploid): This is the most popular cultivated species of potato and now is distributed worldwide. The geographical origin of *S. tuberosum* subsp. *tuberosum* is in Chiloé Island, the largest island in the Chiloé Archipelago off the coast of Chile. The species evolved from the subsp. *Andigena*, introduced into southern Chile followed by adaptationto longerday lengths (Hawkes 1994).

Revised classifications of *S. tuberosum*: Huamán and Spooner (2002) reexamined the morphological support for classification of potato landraces. They concluded that formally recognized cultivated potato species should be treated as a single species, *S. tuberosum*,with eight cultivar groups: Ajanhuiri, Andigenum, Chaucha, Chilotanum, Curtilobum, Juzepczukii, Phureja,and Stenotomum. Later, Spooner *et al.* (2007) suggested a classification of four species based on the morphological and molecular evidence following the *International Code ofNomenclature for Cultivated Plants: S. tuberosum* divided into the Andigenum group (including diploids, triploids andtetraploids) and Chilotanum group (including tetraploids) oflowland tetraploid Chilean landraces, from which modern cultivars were selected. Three species listed below were described as independent by Hawkes (1990), but Spooner *et al.* (2007) suggested including them into the *S. tuberosum* Andigenum group. Wild potatoes have been used for disease resistance in breeding programs for over 100 years (Hawkes, 1958). Potato has many wild relatives and primitive cultivars and these genetic resources have proven to be valuable in breeding programs in addition to disease resistance, environmental tolerance, and other agronomic traits and processing qualities of interests (Bamberg and del Rio, 2005; Hawkes, 1958) . Sources of resistance have been screened, identified,and listed by several authors

Linnaeus (1753) recognized cultivatedpotatoes,known to him from both Europe and Peru, as a single species, *S. tuberosum*. The genus is very large and contains over 2000 species of which nearly 235 are tuber bearing (Hawkes, 1990). The potato and various other taxonomically related species are placed in section Petota (earlier called Tuberarium) under subgenus *Potatoe.* Section Petota contains two subsections, viz., *Estolonifera* and *Potatoe* (Hawkes, 1994). The species of subsection *Estolonifera* do not produce stolons or tubers. This subsection includes two series namely *Etuberosa* and *Juglandifolia*. Whereas, the species included in *Etuberosa* can be hybridized with the tuber-bearing species, those in *Juglandifolia* do nothybridize and appear to be closer to tomato genus *Lycopersicon*. The second subsection *Potatoe* (earlier called *Hyperbasarthrum*) is divided into two superseries, *Stellata* and *Rotata*, characterized by star-shaped and rotate or wheel-shaped corollas, respectively. These superseries include 19 series containing tuber-bearing species. This subsection is of potential interest to breeders. The cultivated potato *S. tuberosum* is placed in the series *Tuberosa*. *S. tuberosum* is generally divided into two subspecies namely subsp. *tuberosum*, the universally cultivated potato,and subsp. *andigena*, a primitive taxon cultivated to limited extent in the Andes region.The recent classification by Spooner *et al.* (2007) classifies the cultivated potato species as following: i) *Solanum tuberosum* AndigenumGroup of upland Andean genotypes containing diploids (2*x*), triploids(3*x*) and tetraploids (4*x*); and *Solanum tuberosum* Chilotanum Groupof tetraploid (4*x*) of lowland Chilean landraces; ii) *S. ajanhuiri* (2*x*); iii) *S. juzepczukii* (3*x*); iv) *S. curtilobum* (5*x*) (Table2) (Luthra *et al*.,2020). The modern cultivated potato is generallyviewed as having an autopolyploid or segmental polyploidy origin. Besides *S. tuberosum*, there are other

Table 2. Classification of potato and its wild relatives

Genus: *Solanum* L.	*Solanum* species (basic chromosome no. $x = 12$)
Subgenus: *Potatoe* (G. Don) A'Arey	
Section: *Petota* Dumortier	
Subsection: *Estlonifera* Hawkes	
Series	
I: *Etuberosa* Juzepczuk	2*x*: *S. brevidens, S. etuberosum*
II: *Juglandifolia* (Rydb.) Hawkes	2*x*: *S. lycopersicoides*
Subsection: *Potatoe* G. Don	
Superseries: *Stellata* Hawkes	
Series	
I: *Morelliformia* Hawkes	2*x*: *S. morellifome*
II: *Bulbocastana* (Rydb.) Hawkes	2*x*: *S. clarum* 2x/3x: S. bulbocastanum
III: *Pinnatisecta* (Rydb.) Hawkes	2*x*: *S. brachistotrichum, S. pinnatisectum,* *S. trifidum* 2*x*/3*x*: *S. cardiophyllum, S. jamesii*
IV: *Polyadenia Bukasov ex Correll*	2*x*: *S. polyadenium, S. lesteri*
V: *Commersoniana Bukasov*	2*x*/3*x*: *S. commersonii*
VI: *Circaeifolia Hawkes*	2*x*: *S. capsicibaccatum, S. circaeifolium*
VII: *Lignicaulia Hawkes*	2*x*: *S. lignicaule*
VIII: *Olmosiana Ochoa*	2*x*: *S. olmosense*
IX: *Yungasensa Correll*	2*x*: *S. chacoense, S. tarijense, S. yungasense*
Superseries: Rotata Hawkes	
Series	
X: *Megistacroloba* Card e Hawkes	2*x*: *S. boliviense, S. megistacrolobum, S. sanctarosae, S. toralapanum*
XI: *Cuneoalata* Hawkes	2*x*: *S. infundibuliformae*
XII: *Conicibaccata* Bitter	2*x*: *S. chomatophilum, S. santolallae, S. violaceimarmoratum* 4*x*: *S. agrimonifolium, S. colombianum,* *S. longiconium, S. oxycarpum* 5*x*: *S. moscopanum*
XIII: *Piurana* Hawkes	2*x*: *S. piurae* 4*x*: *S. tuquerrense*
XIV: *Ingifolia* Ochoa	2*x*: *S. ingifolium*
XV: *Maglia* Bitter	2*x*/3*x*: *S. maglia*
XVI: *Tuberosa* (Rudb.) Hawkes	
• Wild	2*x*: *S. alandiae, S. berthaultii, S. brevicaule,* *S. bukasovii, S. canasense, S. gandarillasii,* *S. hondelmannii, S. kurtzianum, S. leptophyes,* *S. marinasense, S. multidissectum, S. neocardenasii, S. sparsipilum, S. spagazzini,* *S. vernei, S. verrucosum*
	2*x*/3*x*: *S. microdontum* 4*x*: *S. sucrense* 2*x*/4*x*: *S. gourlayi* 2*x*/4*x*/6*x*: *S. oplocense*
• Cultivated	2*x*: *S. x ajanhuiri, S. phureja, S. stenotomum* 3*x*: *S. x chaucha, S. juzepczuki* 4*x*: *S. tuberosum subsp. Tuberosum, S. tuberosum subsp. Andigena* 6*x*: *S. x curtilobum*
XVII: *Acaulia Juzepczuk*	4*x*: *S. acaule* 6*x*: *S. albicans*
XVIII: *Longipedicellata Bukasov*	3*x*: *S. x vallis-mexici* 4*x*: *S. fendleri, S. hjertingii, S. papita, S. polytrichon, S. stoloniferum*
XIX: *Demissa Bukasov*	2*x*: *S. x semidemissum, S. x edinensi* 5*x*: *S. brachycarpum, S. demissum* 6*x*: *S. guerreroense, S. hougasii, S. iopetalum,* *S. schenckii*

seven primitive species viz., *Solanum ajanhuiri, S. goniocalyx, S. phureja* and *S. stenotomum* (all diploids); *S. chaucha* and *S. juzepczukii* (both triploids); and *S. curtilobum* (pentaploid) under cultivation (Table 3). *S. hygrothermicum* listed below is now almost extinct (Ochoa, 1984). The cultivated species cross either directly or through bridging species with several species belonging to other series. Somatic

Table 3. Cultivated Potato species

Ploidy	Species	Area of cultivation	Trait of interest
Diploid	*S. stenotomum*	South Peru and Bolivia	Frost resistant, yellow flesh good flavor
	S. goniocalyx	Mostly central northern Peru	Yellow flesh, good flavor, now has been placed as a sub species of *S. stenotomum*
	S. ajanhuiri	High elevations	Frost resistant, bitter
	S. phureja	South America, mostly at moderate elevations	No tuber dormancy, high dry matter; genes for unreduced gametes
Triploid	*S. x chaucha*	Bolivia and Peru	Natural hybrids *S. tuberosum* subsp. *andigena* and *S. stenotomum*
	S. x juzepczukii	High elevations	Natural hybrids *S. stenotomum* and *S. acaule*, frost resistant, bitter
Tetraploid	*S. tuberosum* subsp. *andigena*	Andes of Venezuela, Colombia, Equador, Peru, Bolivia and North-West Argentina	Adaptation to short days conditions, Variability for many traits, especially disease resistance and quality
	S. tuberosum subsp. *tuberosum*	Most widespread and cultivated in Europe Asia and elsewhere	Adaptation to long days or short days conditions in subtropics, disease resistance, good appearance
	S. hygrothermiaum	Amazon Basin of Peru	Adaptation to lowland tropics, said to be almost extinct
Pentaploid	*S. curtilobum*	High elevations	Natural hybrid of *S. tuberosum* subsp. *andigena* and *S. juzepczukii*, frost resistant, somewhat bitter

hybridization with conventionally non-crossable species has also been successfully carried out in the potato to develop interspecific potato somatic hybrids for various traits(Luthra *et al*. 2016, 2018b and Tiwari *et al*. 2018; Luthra *et al*., 2020). A considerable number of highly diverse species exist in genus *Solanum*. Because they can adapt to a broad range of habitats, potato wild relatives are promising sources of desirable agricultural traits. Potato taxonomy is quite complex because of introgression, interspecific hybridization, auto- and allopolyploidy, sexual compatibility among many species, a mixture of sexual and asexual reproduction, possible recent species divergence, phenotypic plasticity, and the consequent high morphological similarity among species. Recent researchers using molecular tools have contributed to the identification of genes controlling several types of resistance as well as to the revision of taxonomical relationships among potato species. Historically, primitive forms of cultivated potato and its wild relatives have been used in breeding programs and there is still an enormous and unimaginable potential for discovering desirable characteristics, particularly in wild species. Different methods have been developed to incorporate useful alleles from these wild species into the improved cultivars. Potato germplasm comprising of useful alleles for different breeding objectives is preserved in various gene banks worldwide. These materials, with their invaluable information, are accessible for research and breeding purposes. (Machida-Hirano, 2015)

Synonyms

Synonyms for *Solanum tuberosum* include (Inspection, 2015):

1. *Battata tuberosa* Hill,
2. *Lycopersicon tuberosum* (L.) Mill.,
3. *Solanum andigenum* Juz. & Bukasov,
4. *S. apurimacense* Vargas,
5. *S. ascasabii* Hawkes,
6. *S. boyacense* Juz. & Bukasov,
7. *S. cardenasii* Hawkes,
8. *S. chaucha* Juz. & Bukasov,
9. *S. churuspi* Hawkes,
10. *S. chocclo* Bukasov & Lechn., nom. nud., *S. coeruleiflorum* Hawkes,
11. Solanum diemii Brücher,
12. *S. cultum* (A.DC.) Berthault,
13. *S. esculentum* Neck.,
14. *S. estradae* L.E.López,

15. *Solanum goniocalyx* Juz. & Bukasov,
16. *S. herrerae* Juz.,
17. *S. hygrothermicum* Ochoa,
18. *S. maglia* Schltdl. var. *guaytecarum* Bitter,
19. *S. leptostigma* Juz. ex Bukasov, nom. nud.,
20. *S. mamilliferum* Juz. & Bukasov,
21. *S. molinae* Juz.,
22. *S. oceanicum* Brücher,
23. *S. ochoanum* Lechn.,
24. *S. paramoense* Bitter,
25. *S. parvicorollatum* Lechn.,
26. *S. phureja* Juz. & Bukasov,
27. *S. rybinii* Juz. & Bukasov,
28. *S. sanmartinense* Brücher,
29. *S. sinense* Blanco,
30. *S. stenotomum* Juz. & Bukasov,
31. *S. subandigenum* Hawkes,
32. *S. tascalense* Brücher,
33. *S. tenuifilamentum* Juz. & Bukasov,
34. *S. yabari* Hawkes,
35. *S. zykinii* Lechn.

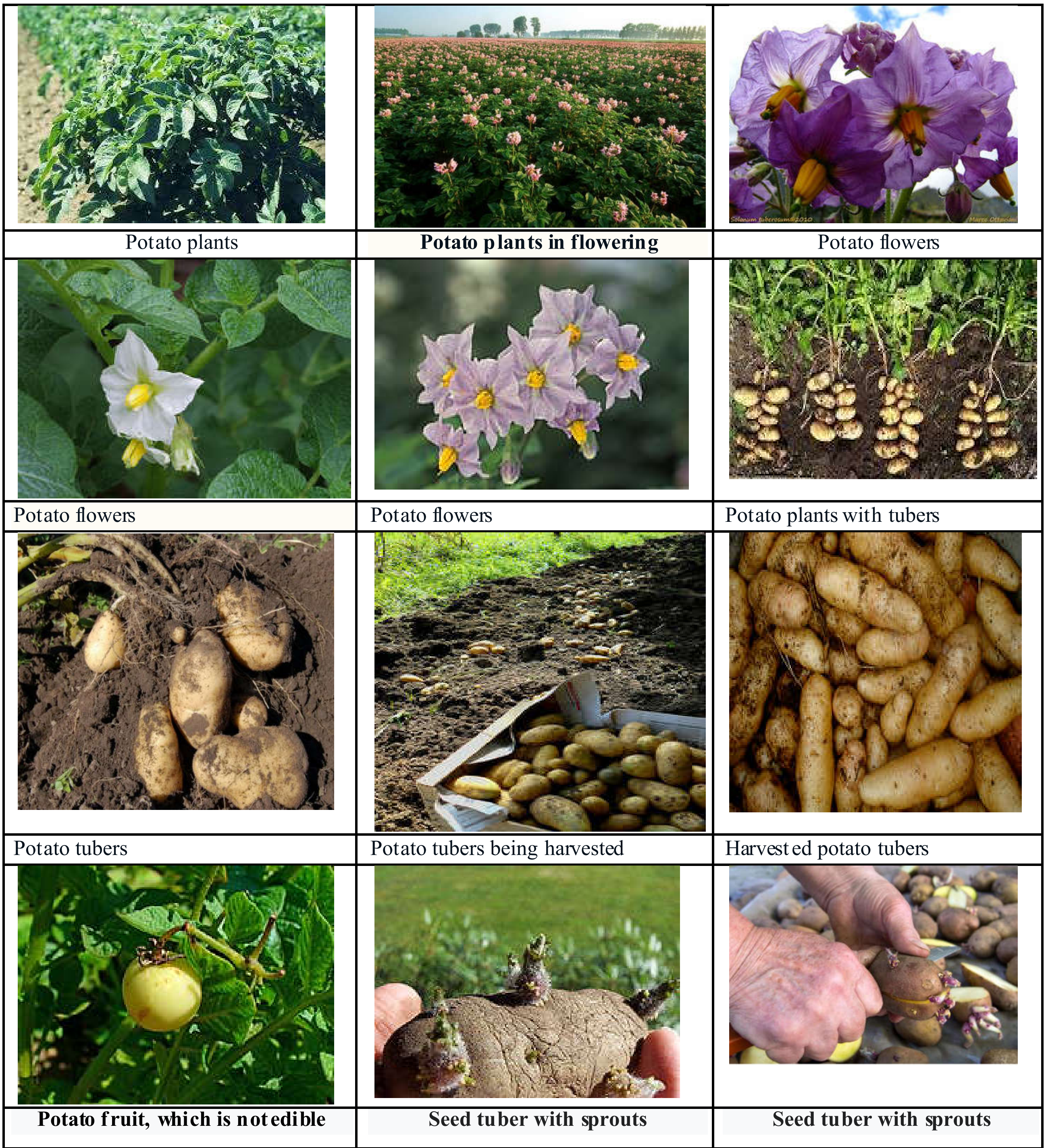
BOTANICAL DESCRIPTION

Solanum tuberosum is a herbaceous plant that grows to 0.4-1.4 m tall and may range from erect to fully prostrate. Stems range from nearly hairless to densely hairy and may be green, purple, or mottled green and purple. Leaves are pinnate with a single terminal leaflet and three or four pairs of large, ovoid leaflets with smaller ones in between. The blades range in size from 8-22 x 5-13 cm with the petioles ranging from 2-6 cm. They are medium to dark green, and like the stems, may range in hairiness from nearly hairless to densely hairy on both sides. *S. tuberosum* plants produce rhizomes (often called stolons) that have rudimentary leaves and are typically hooked at the tip. They originate from the basal stem nodes, typically below ground, with up to three rhizomes per node. Tubers, spherical to ovoid in shape, are swellings of the rhizome. The flesh of the tubers varies in colour from white to yellow to blue and the skin varies from white through yellow to tan and from red through blue. The colour of the flesh may or may not correspond to the colour of the skin. The texture of the surface may vary from smooth to netted or russetted. On the surface of the tuber are axillary buds with scars of scale leaves that are called eyes. When tubers are planted, the eyes develop into stems to form the next vegetative generation. The terminal inflorescences are cymes that are 5-11 cm long and generally found in the distal half of the plant. The inflorescences are usually branched and may contain up to 25 flowers. The peduncle is 0-22 cm long and the pedicels are 10-35 mm long in flower and fruit, spaced 1-10 mm apart. The pentamerous flowers, 3-4 cm in diameter, are all apparently perfect with styles of the same length. The corolla may be a range of colours, including white, pink, lilac, blue, purple, and red-purple. The colour may be uniform or the pointed tips of the petal lobes may be white or there may be a second colour either stippled, in bands or in a star, and this may occur on either side of the corolla. The petals are fused to create a tubular flower. The stamens have filaments that are 1-2 mm long and anthers that are 3-8 mm long. The anthers form a cone-shaped structure through lateral joinings, serving to conceal the ovary. They are typically bright yellow or orange with the exception of male-sterile plants in which the anthers are light yellow or yellow-green. The style is 9-13 mm by approximately 1 mm. The fruits are spherical to ovoid berries, about 1-4 cm in diameter. They are green or green tinged with white or purple spots or bands when ripe. The berries may lack seeds or contain up to several hundred. The seeds are ovoid and approximately 2 mm long. They are whitish to greenish when fresh and brownish when dry. The lateral walls of the testa are thick and "hair-like" and cause the seeds to be mucilaginous when wet. Some cultivars may exhibit premature dropping of floral buds, male sterility, and/or inability to set fruit. The berries are toxic due to the presence of glycoalkaloids (Fig. 1) (Inspection, 2015).

The plant has large smooth leaves close to the base of the plant and smaller more textured leaves near the top of the plant. Each leaf has tiny short hairs on the surface. The underside of a potato leaf is usually less green in colour and not as glossy as the top surface, it also has short hairs although generally, they are more difficult to see. It is much easier to see the veins and midrib of each leaf on the underside than on the top. The duller underside of the potato leaf pictured above shows the veins and midrib. Then a potato plant is first emerging through the soil it will have fine, smooth, thin stems, which as the plant grows become thicker and more textured and ribbed. The stems in the image below belong to an almost fully grown potato plant, pictured near the base of the plant next to the soil where they are thickest. Note that the stems can have some darker colours also – they are not just green. On most potato plants which are fully grown, you can make out multiple flat ribbons running along the outside of the stem from the bottom of the plant to the top. Not all potato plants flower, although many do. The colour size and shape of the flower will depend on the variety grown. The flowers in the images below belong to two different varieties- Maris Piper and Jazzy. If your potato has a flower on it, it should make it easier to identify as being a potato plant as the flowers on all potato plants are quite similar in size and shape – even though they may vary in colour (Richard , 2022). There are unequal sized and shaped leaflets on the potato plant's alternately arranged leaves, which have a branched stem. Leaves can reach a length of 10–30 cm and a width of 5–15 cm with oval or oblong leaflets. Potato tubers are generally located in the top 25 cm of the soil, and they produce white or blue flowers and yellow-green berries. Depending on the variety, potatoes can have yellow, red, or purple tubers. They have grown annually and can reach heights of over 1 m (HND, 2022).

The potato is one of some 150 tuber-bearing species of the genus *Solanum* (a tuber is the swollen end of an underground stem). The compound leaves are spirally arranged; each leaf is 20–30 cm (about 8–12 inches) long and consists of a terminal leaflet and two to four pairs of leaflets. The white, lavender, or purple flowers have five fused petals and yellow stamens. The fruit is a small poisonous berry with numerous seeds. The stems extend underground into structures called stolons. The ends of the stolons may enlarge greatly to form a few to more than 20 tubers, of variable shape and size, usually ranging in weight up to 300 grams but occasionally to more than 1.5 kg .The skin varies in colour from brownish white to deep purple; the starchy flesh normally ranges in colour from white to yellow, but it too may be purple. The tubers bear spirally arranged buds (eyes) in the axils of aborted leaves, of which scars remain. The buds sprout to form clones of the parent plant, allowing growers to vegetatively propagate desired characteristics. Indeed, vegetative reproduction is always used commercially, though the resulting decrease in genetic diversity has made the popular varieties more vulnerable to pests and diseases (Britannica, 2023). Leaves: The leaves of the potato plant are simple and alternate. They are generally dark green and glossy in color and are smooth or slightly hairy. They are lobed or ovate in shape and can grow up to 15 cm long. Stems: The stems of the potato plant are green, smooth, and slightly hairy. They grow to a height of 30–90 cm and are usually unbranched. Flowers: The potato plant produces small, white or purple flowers that grow in clusters. These flowers are typically about 2 cm in diameter and have five petals. Tubers: The tubers are the underground storage organs of the potato plant and are the part of the plant that is typically consumed as a vegetable. They are round or oblong in shape and can vary in size and color depending on the variety. They can be white, yellow, red, or purple. Root: The potato plant has a deep taproot and fibrous root system that allow the plant to absorb water and nutrients from the soil. Fruits: Potato plants produce small, green, and poisonous berries that are typically not consumed by humans (Plantvillage, 2023).

Phases of growth: Potato growth can be divided into five phases. During the first phase, sprouts emerge from the seed potatoes and root growth begins. During the second, photosynthesis begins as the plant develops leaves and branches above-ground and stolons develop from lower leaf axils on the below-ground stem. In the third phase the tips of the stolons swell forming new tubers and the shoots continue to grow and flowers typically develop soon after. Tuber bulking occurs during the fourth phase, when the plant begins investing the majority of its resources in its newly formed tubers.



Potato plants | **Potato plants in flowering** | Potato flowers

Potato flowers | Potato flowers | Potato plants with tubers

Potato tubers | Potato tubers being harvested | Harvested potato tubers

Potato fruit, which is not edible | **Seed tuber with sprouts** | **Seed tuber with sprouts**

Fig. 1. Botanical Description

At this phase, several factors are critical to a good yield: optimal soil moisture and temperature, soil nutrient availability and balance, and resistance to pest attacks. The fifth phase is the maturation of the tubers: the leaves and stems senesce and the tuber skins harden (Fig. 2) (Wikipedia, 2023).

Reproductive biology: *Solanum tuberosum* is a perennial but is grown as an annual. The commercial crop is propagated vegetatively using tuber pieces or small whole tubers that are commonly referred to as seed or seed potatoes or through plant cuttings or plantlets. *S. tuberosum* may also be reproduced by botanical seeds, which are commonly referred to as true potato seeds or TPS. True potato seed production is practised in breeding programs under greenhouse or growth chamber conditions. Some programs have also used open pollination conducted outdoors. True potato seed production in the natural environment varies with cultivar and weather conditions. The degree to which flowering occurs, the duration of flowering, and the response of flowering behaviour to environmental conditions is greatly influenced by cultivar. The environmental conditions that influence flower initiation and development include light intensity, quality and duration (day length), temperature, water supply, and available soil nutrients. Flowers of some varieties may abscise prematurely. Tetraploid *S. tuberosum* is self-compatible, although most of the related diploid species are self-incompatible. Pollen sterility occurs frequently in *S. tuberosum*, and ovule sterility occasionally; many varieties do not produce any botanical seed. Flowering starts on branches located near to the base of the plant and proceeds upwards. Each flower will typically remain open for 2 to 4 days, with the stigma being receptive and pollen being produced for approximately 2 days. Fertilization occurs approximately 36 hours after pollination. Viable seeds require a minimum of 6 weeks to develop (Inspection, 2015).

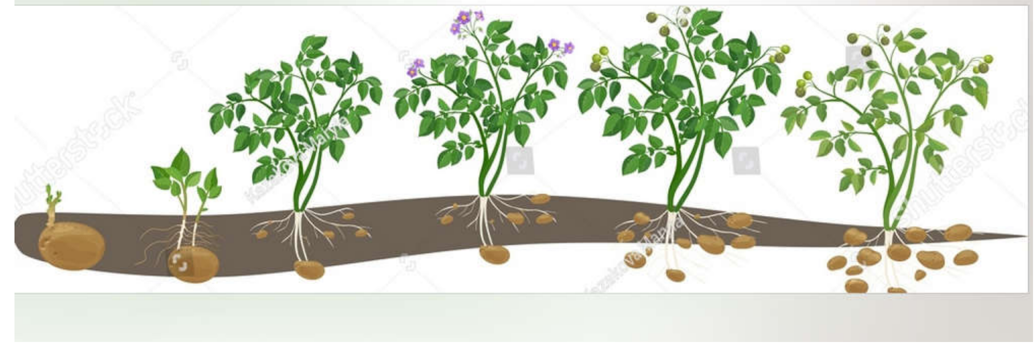


Fig. 2 : Growth cycle of potato plant

Tubers are storage organs that develop from swollen underground stems, and the eyes on the tubers are buds that can sprout and develop into new stems. New plants can be grown from whole tubers or pieces of tubers, and the number of stems produced from a planted tuber or tuber piece depends on the number of eyes and the physiological age of the tuber. The tuber acts as a source of nourishment for the new plant, and plants grown from tubers tend to have more early vigor than those grown from true potato seed. Vegetative propagation may perpetuate diseases in successive generations (Inspection, 2015). Potato plants can be propagated by seeds or by cuttings. Seeds are the easiest way to propagate potatoes, but they require a great deal of care. And some varieties may not produce enough viable seeds to keep up with the need for new plants. Cuttings are a good choice if you want to propagate potatoes quickly. The best time for taking cuttings is in spring. When the plant has gone dormant and is ready for transplanting into pots. Cuttings should be taken from healthy, mature plants that have been grown from seedlings or purchased from a nursery. You can take cuttings at any point in the season. But choose the right time for your climate. For example, if you live in an area where summer temperatures are high and fall frost dates are short. Taking cuttings in late summer won't provide much benefit because it will take too long before they can be transplanted into their final containers. When propagating potato plants, be sure to only do so in the spring or fall. This lets the plant develop before winter comes. But it's also important for the plant to get enough nutrients during its early growth stages. If you're going to propagate your potato plant. Use a sterile knife or pruning shears to cut off the top half of the plant just below where it meets the soil. Be sure not to damage any roots or stems while making this cut. As they will help keep your new plant alive after it's planted (HND, 2022).

All new potato varieties are grown from seeds, also called "true potato seed", "TPS" or "botanical seed" to distinguish it from seed tubers. New varieties grown from seed can be propagated vegetatively by planting tubers, pieces of tubers cut to include at least one or two eyes, or cuttings, a practice used in greenhouses for the production of healthy seed tubers. Plants propagated from tubers are clones of the parent, whereas those propagated from seed produce a range of different varieties. Potatoes, both *S. tuberosum* and most of its wild relatives, are self-incompatible: they bear no useful fruit when self-pollinated (Wikipedia, 2023). Potato plants are herbaceous perennials that grow about 60 cm high, depending on variety, with the leaves dying back after flowering, fruiting and tuber formation. They bear white, pink, red, blue, or purple flowers with yellow stamens. Potatoes are mostly cross-pollinated by insects such as bumblebees, which carry pollen from other potato plants, though a substantial amount of self-fertilizing occurs as well. Tubers form in response to decreasing day length, although this tendency has been minimized in commercial varieties. After flowering, potato plants produce small green fruits that resemble green cherry tomatoes, each containing about 300 seeds (Wikipedia, 2023).

Toxin: Like all parts of the plant except the tubers, the fruit contain the toxic alkaloid solanine and are therefore unsuitable for consumption (Wikipedia, 2023). Like the tomato, the potato is a nightshade in the genus *Solanum*, and the vegetative and fruiting parts of the potato contain the toxin solanine which is dangerous for human consumption. Normal potato tubers that have been grown and stored properly produce glycoalkaloids in amounts small enough to be negligible for human health, but, if green sections of the plant (namely sprouts and skins) are exposed to light, the tuber can accumulate a high enough concentration of glycoalkaloids to affect human health (Wikipedia, 2023). New tubers may start growing at the surface of the soil. Since exposure to light leads to an undesirable greening of the skins and the development of solanine as a protection from the sun's rays, growers cover surface tubers. Commercial growers cover them by piling additional soil around the base of the plant as it grows (called "hilling" up, or in British English "earthing up"). An alternative method, used by home gardeners and smaller-scale growers, involves covering the growing area with mulches such as straw or plastic sheets (Wikipedia, 2023). Potatoes contain toxic compounds known as glycoalkaloids, of which the most prevalent are solanine and chaconine. Solanine is found in other plants in the same family, Solanaceae. These compounds, which protect the potato plant from its predators, are generally concentrated in its leaves, flowers, sprouts, and fruits (in contrast to the tubers). In a summary of several studies, the glycoalkaloid content was highest in the flowers and sprouts and lowest in the tuber flesh (The glycoalkaloid content was, in order from highest to lowest: flowers, sprouts, leaves, tuber skin, roots, berries, peel) (Wikipedia, 2023).

Seed potatoes: Potatoes are generally grown from seed potatoes, tubers specifically grown to be free from disease and to provide consistent and healthy plants. To be disease free, the areas where seed potatoes are grown are selected with care. In the US, this restricts production of seed potatoes to only 15 states out of all 50 states where potatoes are grown. These locations are selected for their cold, hard winters that kill pests and summers with long sunshine hours for optimum growth. In the UK, most seed potatoes originate in Scotland, in areas where westerly winds reduce aphid attack and the spread of potato virus pathogens. Potatoes can also be grown from true seeds (Wikipedia, 2023).

GENETICS AND CYTOGENETICS

There are about 5,000 potato varieties worldwide. Three thousand of them are found in the Andes alone, mainly in Peru, Bolivia, Ecuador, Chile, and Colombia. They belong to eight or nine species, depending on the taxonomic school. Apart from the 5,000 cultivated varieties, there are about 200 wild species and subspecies, many of which can be cross-bred with cultivated varieties. Cross-breeding has been done repeatedly to transfer resistances to certain pests and diseases from the gene pool of wild species to the gene pool of cultivated potato species (Wikipedia, 2023). The major species grown worldwide is *Solanum tuberosum* (a tetraploid with 48 chromosomes), and modern varieties of this species are the most widely cultivated. There are also four diploid species (with 24 chromosomes): *S. stenotomum*, *S. phureja*, *S. goniocalyx*, and *S. ajanhuiri*. There are two triploid species (with 36 chromosomes): *S. chaucha* and *S. juzepczukii*. There is one pentaploid cultivated species (with 60 chromosomes): *S. curtilobum*. There are two major subspecies of *Solanum tuberosum*: *andigena*, or Andean; and *tuberosum*, or Chilean. The Andean potato is adapted to the short-day conditions prevalent in the mountainous equatorial and tropical regions where it originated; the Chilean potato, however, native to the Chiloé Archipelago, is adapted to the long-day conditions prevalent in the higher latitude region of southern Chile. The international Potato

Genome Sequencing Consortium announced in 2009 that they had achieved a draft sequence of the potato genome, containing 12 chromosomes and 860 million base pairs, making it a medium-sized plant genome. More than 99 percent of all current varieties of potatoes currently grown are direct descendants of a subspecies that once grew in the lowlands of south-central Chile. Nonetheless, genetic testing of the wide variety of cultivars and wild species affirms that all potato subspecies derived from a single origin in the area of present-day southern Peru and extreme Northwestern Bolivia (from a species in the *Solanum brevicaule* complex).

Most modern potatoes grown in North America arrived through European settlement and not independently from the South American sources, although at least one wild potato species, *Solanum fendleri*, naturally ranges from Peru into Texas, where it is used in breeding for resistance to a nematode species that attacks cultivated potatoes. A secondary center of genetic variability of the potato is Mexico, where important wild species that have been used extensively in modern breeding are found, such as the hexaploid *Solanum demissum*, as a source of resistance to the devastating late blight disease. Another relative native to this region, *Solanum bulbocastanum*, has been used to genetically engineer the potato to resist potato blight. (Wikipedia, 2023). The tuber-bearing *Solanum* species form a polyploid series ranging from diploid ($2n = 2x = 24$) to hexaploid ($2n = 6x = 72$) with the basic chromosome number is 12 (Howard, 1970). Chromosome counts have been made for only three fourth of the species. About 73% ofthe tuber-bearing *Solanum* species are diploids, 4% triploids, 15% tetraploids and 6% hexaploids. The cultivated potato is an autotetraploid with total 48 chromosomes ($2n = 4x = 48$). The genome sequence of potato has recently been completed. The sequence information of the 844 Mb genome revealed 39,031 protein-coding genes in potato and suggested a paleohexaploid duplication event during the genome evolution. Genome sequence information will be a platform for genetic improvement of potato as well as for phylogenetic research on the genus *Solanum*.

GENETIC DIVERSITY

The germplasm base of potato is comprised of primitive indigenous landraces and wild *Solanum* species. Advances in molecular techniques have provided greater insight into the taxonomic relationships of potato and there are 100 wild species and four cultivated species. Potato is a highly heterozygous out crossing species which is asexually propagated, via tubers, for food production and germplasm maintenance. Potato genetic variation vary in ploidy levels (diploid to hexaploids) and show a high degree of diversity in tuber size, shape, skin and flesh color, storage ability and cooking quality. In addition to the indigenous and primitive landraces, there are a number of wild species of the genus *Solanum* with various ploidy levels that can be used as new sources of genetic diversity, for a range of economically important traits, to develop new potato varieties. The genetic diversity of potatoes *Solanum* Section Petota (*Solanaceae*) may be grouped in wild and cultivated potatoes; this last could be grouped in native potatoes and improved potatoes.

The flesh of the tubers varies in colour from white to yellow to blue and the skin varies from white through yellow to tan and from red through blue. The colour of the flesh may or may not correspond to the colour of the skin. The texture of the surface may vary from smooth to netted or russetted (Inspection, 2015). There are close to 4,000 varieties of potatoes, each of which has specific agricultural or culinary attributes. Around 80 varieties are commercially available in the UK. In general, varieties are categorized into a few main groups based on common characteristics, such as russet potatoes (rough brown skin), red potatoes, white potatoes, yellow potatoes (also called Yukon potatoes) and purple potatoes (Wikipedia, 2023). Dozens of potato cultivars have been selectively bred specifically for their skin or, more commonly, flesh color, including gold, red, and blue varieties that contain varying amounts of phytochemicals, including carotenoids for gold/yellow or polyphenols for red or blue cultivars. Carotenoid compounds include provitamin A alpha-carotene and beta-carotene, which are converted to the essential nutrient, vitamin A, during digestion. Anthocyanins mainly responsible for red or blue pigmentation in potato cultivars do not have nutritional significance, but are used for visual variety and consumer appeal. In 2010, potatoes were bioengineered specifically for these pigmentation traits (Wikipedia, 2023).

Cultivated potatoes can be classified as landraces, native varieties still grown in South America today, or improved varieties, grown worldwide. Potato landraces are highly diverse with a variety of tuber shapes and skin and flesh colors (Fig. 3, 4, 5). They are grown in the upland Andes from western Venezuela south to northern Argentina and in the lowlands of south-central Chile, where they are concentrated in the Chonos and Guaitecas Archipelagos (Contreras *et al.* 1993) and are adapted to middle to high elevations (3000–4000 m altitude). Cultivated potato species have a base chromosome number of $n = 12$ and may be diploid($2n = 2x = 24$), triploid ($2n = 3x = 36$), tetraploid ($2n = 4x = 48$), or pentaploid ($2n = 5x = 60$).

The evolutionary origin of the cultivated potato has not yet been conclusively unraveled, and geneticists, archaeobotanists, and taxonomists alike have explored different hypotheses for nearly 9 decades. However, at a cultivated species level it is well documented that different species (*Solanum tuberosum*, *Solanum curtilobum*, *Solanum ajanhuiri*, and *Solanum juzepczukii*) and groups (*S. tuberosum* Chilotanum and Andigenum groups) are the result of unique evolutionary pathways and have different biogeographical distribution patterns. Of all cultivated species, the *S. tuberosum* Chilotanum group ($2n=4x=48$) has contributed most to the founder effect of the European and North American gene pool and global crop improvement (Fig. 6). Two hypotheses are commonly put forth regarding the origin of Chilotanum landraces. The first suggests that theyoriginated independently in southern Chile, possibly involving the putative wild ancestor *Solanum maglia* or hybrids of *Solanum tarijense* (*Solanumberthaultii*). The second sustains an Andean origin with early introduction into Chile and a gradual adaptation of Andigenum landraces into long-day adapted Chilotanum landraces (Hawkes, 1990). The *S. tuberosum* Andigenum group as proposed in the taxonomic treatments of Spooner *et al*. (2005a) includes diploid, triploid, and tetraploid subgroups previously considered separate species by Hawkes (1990) and Ochoa (1990, 1999).The *S. tuberosum* Andigenum group contains more intraspecific diversity than all other species and the *S. tuberosum* Chilotanum group combined (Fig. 7). Based on ploidy, ethnobiological classification, altitudinal distribution, and hotspot concentration, several cultivar groups can be distinguished. A clear example of such a group is the Phureja cultivar group, which is vernacularly classified as Phureja (Northwestern Bolivia) or Chaucha (Peru), which has differential agronomic characters (early bulking, lack of dormancy, and up to three cropping cycles a year) and is spatially separated by altitude in its distribution range from other cultivar groups within the *S. tuberosum* Andigenum group (de Haan and Rodriguez, 2016).

The value of germplasm is determined by its genetic diver- sity, availability, and utility. In this sense, potato stands out among all other crops (Bamberg and del Rio, 2005). Primitive forms of cultivated potato and their wild relatives pro- vide a rich, unique, and diverse source of genetic variation, which could be a source of various traits for potato breeding. This may be because of their adaptation to a broad range of habitats and niches such as latitude (from southwest United States to Argentina), altitude (from coasts to Andean mountains), habitat (in cloud forests, in cultivated fields, on cliffs, as epiphytes, in deserts, in forests, and on Pacific islands), soil (from forest floors to sandy soils, from volcanic soils torich, loamy soils), and precipitation regimes. They are equally diverse in morphological traits (*i.e.* plant height, leaf and leaflet shape, flower color, stolon length, and size, color, and shape of tubers) (Hanneman, 1989). Andean potato varieties are cultivated in the northwest of Argentina and constitute the most important staple food for the local farmers. The genetic diversity of 155 accessions conserved at the Genebank of Balcarce (INTA) was tested using four microsatellites. Three commercial potato varieties of Tuberosum group and one accession of Curtilobum group were used as outgroups.

		
Potato cultivars appear in a variety of colors, shapes, and sizes	Potato cultivars appear in a variety of colors, shapes, and sizes	Potatoes with different pigmentation

Fig. 3. Variability for potato tuber shape, size and color

Fig. 4. Varibility for potato tuber shape, color, size and flesh color

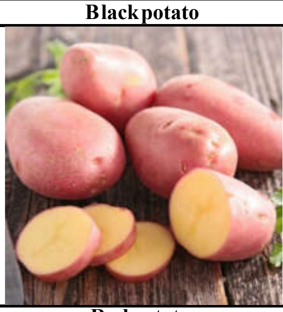
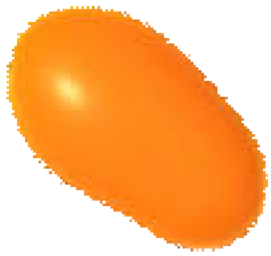
		
Blue potato	Purple potato	Deep purple potato
		
Blue potato	Black potato	Black potato
		
Pink potato	Red potato	Orange potato
		
Yellow potato	Yellow potato	White potato

Fig. 5. Variability for potato tuber shape, color and size

Fig. 6. Potato landraces with a variety of tuber shapes and skin colors

Sample of mixed Chilotanum landraces from the island of Castro, Chile.

Sample of mixed Andigenum landraces from central Peruvian Andes.

Fig. 7. Varibility in mixed Chilotanum landraces and mixed Andigenum landraces

The presence of bands was scored for each microsatellite and for each accession and the data were analysed by principal coordinate analysis. The polymorphism information content was obtained for each molecular marker from banding patterns. Analysis of molecular variance was carried out with a variable number of accessions for each landrace, from different departments and sites within departments. More than one genotype was detected in the majority of the potato landraces. Some accessions within each landrace did not differentiate. AMOVA revealed that most of the genetic variation occurred among sites within departments and among local varieties. These findings are discussed considering the agricultural practices carried out in the Andean farming system (Ispizúa *et al*., 2007). The genetic variability analysis of twenty six genotypes of potato for seventeen yield and quality traits revealed that the characters namely tuber yield plant^{-1}, leaf area, average tuber weight, stolon length, total soluble solids (TSS), yield plot^{-1} and yield ha^{-1}, number of stolons and number of tubers plant^{-1} exhibited high heritability with high genetic gain indicating that these characters could be considered reliable tools for selection as they indicate dominance of additive gene effect (Ummyiah *et al*., 2010).

The evolutionary diversity of wild potato species makes them excellent materials for improving the narrow genetic basis of the cultivated potato *Solanum tuberosum*. Understanding their genetic diversity is important not only to choose the best parents for breeding, but also to design proper crossing schemes and selection strategies. The objectives of this study were to determine the resistance response to *Ralstonia solanacearum*, *Potato virus Y* and low temperatures of 21 clones of 12 potato species, and to determine their genetic diversity through simple sequence repeat (SSR) markers. Sources of resistance have been found for all the investigated traits, with high resistance variability not only between but also within species. Combined resistances were also identified, with positive implications for efficient breeding. SSR analysis allowed the detection of 12 loci and 46 alleles across all genotypes, with an average value of 3.8 alleles per locus. Both unique and rare alleles useful for marker-assisted selection were found. SSR-based cluster analysis revealed that resistant genotypes were distributed among all clusters, suggesting that genetically different resistant genotypes were identified. The information obtained in this study is discussed from a breeding perspective (Carputo *et al*, 2013). Owing to the complexities in genetics and inheritance pattern of potato, the conventional method of cross breeding for developing improved varieties has been difficult. Identification and tagging of desirable traits with informative molecular markers would aid in the development of improved varieties. Insertional polymorphism of *copia*-like and *gypsy*-like long terminal repeat retrotransposons (RTN) were investigated among 47 potato varieties from India using Inter-Retrotransposon Amplified Polymorphism (IRAP) and Retrotransposon Microsatellite Amplified Polymorphism (REMAP) marker techniques and were compared with the DNA profiles obtained with simple sequence repeats (SSRs). The genetic polymorphism, efficiency of polymorphism and effectiveness of marker systems were evaluated to assess the extent of genetic diversity among Indian potato varieties. A total of 139 polymorphic SSR alleles, 270 IRAP and 98 REMAP polymorphic bands, showing polymorphism of 100%, 87.9% and 68.5%, respectively, were used for detailed characterization of the genetic relationships among potato varieties by using cluster analysis and principal coordinate analysis (PCoA). IRAP analysis resulted in the highest number of polymorphic bands with an average of 15 polymorphic bands per assay unit when compared to the other two marker systems. Based on pair-wise comparison, the genetic similarity was calculated using Dice similarity coefficient. The SSRs showed a wide range in genetic similarity values (0.485–0.971) as compared to IRAP (0.69–0.911) and REMAP (0.713–0.947). A Mantel's matrix correspondence test showed a high positive correlation (r = 0.6) between IRAP and REMAP, an intermediate value (r = 0.58) for IRAP and SSR and the lowest value (r = 0.17) for SSR and REMAP. Statistically significant cophenetic correlation coefficient values, of 0.961, 0.941 and 0.905 were observed for REMAP, IRAP and SSR, respectively. The widespread presence and distinct DNA profiles for *copia*-like and *gypsy*-like RTNs in the examined genotypes indicate that these elements are active in the genome and may have even contributed to the potato genome organization. Although the three marker systems were capable of distinguishing all the 47 varieties; high reproducibility, low cost and ease of DNA profiling data collection make IRAP and REMAP markers highly efficient whole-genome scanning molecular probes for population genetic studies. Information obtained from the present study regarding the genetic association and distinctiveness provides an useful guide for selection of germplasm for plant breeding and conservation efforts (Sharma and Nandineni, 2014).

A global collection of 288 potato germplasmswere genotyped with 20 SSR and 10 AFLP markers to evaluate genetic diversity and population structure. Thesegermplasm showed high genetic diversity among all molecu-lar marker loci, and were assigned into three to eight major genetic groups based upon population structure and cluster analysis, and principal component analysis. The majority of Chinese potato cultivars shared the similar genetic diversity and population structure with germplasm from CIP. The molecular marker and genetic lineages obtained in this study provide useful information for potato improvementand conservation programs. (Wang Jian *et al.,* 2017). To understand the genetic diversity of potato germplasms and to enrich the current gene pool for potato improvement, we made a global collection consisted of 288 potato germplasms from eight countries and the International Potato Center (CIP). Using SSR and AFLP techniques, we evaluated the genetic diversity and population structure of these 288 potato accessions. A total of 190 alleles on 20 SSR loci were detected and all of the SSR alleles were polymorphic among these potato germplasms with an average of 9.5 alleles per SSR locus ranging from 2 to 23. The effective number of alleles per locus (*Ne**), Nei's genetic diversity (H*), and Shannon's information index (I*) was from (0.1709±0.3698) to (1.6166±0.3414), (0.076±0.1388) to (0.3812±0.1886), and (0.1324±0.1970) to (0.5347±0.1440), respectively, and the mean polymorphic information content (PIC) value was 0.7312. A total of 988 AFLP alleles were detected by 10 AFLP primer combinations with 983 polymorphic alleles, and 99.49% alleles was polymorphic with an average of 98.3 polymorphic alleles per primer combination ranging from 91 to 116. The values of *Ne*, H** and *I** were from (1.5162±0.311) to (1.6423±0.3278), (0.3114±0.145) to (0.3675±0.1121), and (0.4761±0.1792) to (0.547±0.1322), respectively, and the average PIC value was 0.9871. Bayesian analysis discriminated the accessions into seven subgroup and an admix group. The majority of accessions from CIP and China were assigned into SG1, SG5, SG6, SG7 and admix group. Accessions in SG3 were mainly from CIP and two small groups SG2 and SG4 were mainly from northeastern China. In general, the results obtained from Bayesian statistical analysis, cluster analysis and principal coordinate analysis consistently revealed the lack of geographical differentiation among country-wide collections, indicating germplasm introduction was common for the countries out of potato origin center. The polymorphic markers and the differentiate genetic lineages found in this study provide useful information for potato improvement and conservation programs (Jian Wang *et al*., 2017). The present review conclude for French fry and chips industries, breeding for reduced sugar content, acceptable specific gravity, dry matter and starch contents is indispensable. Research efforts carried in Ethiopia related to processing quality were limited in their scope of quality parameters considered. The acceptability of potatoes for processing as French fries is largely dependent on the quality of the end products. Processing industry is totally dependent on the quality parameters of tuber to satisfy the increasing demand of consumers. The cultivated potatoes *Solanum tuberosum* are tetraploid (2n=4x= 48) due to high specific gravity. Varieties with long tubers are used for French fries, while varieties with round tubers are preferred for crisps. A potato variety with dry matter content below 19.5% and 20% is not acceptable for French fries and for chips, respectively. Similarly, a dry matter content of more than 25% is not suitable for French fries manufacturing. The level of reducing sugars that are generally acceptable for chips processing is 0.2–0.3% and for French fries is 0.3–0.5%. Generally, selection of varieties should not be limited only for high yield, but also for internal (specific gravity, dry matter, starch contents) and external quality (tuber shape, eye depth, tuber fresh color and tuber skin color) of tubers (Hussen, 2019). To improve the available genepool for future potato breeding programs, a diverse population containing 292 genotypes (including foreign elite lines, local landraces and cultivars) was developed and genotyped using 30 SSR markers covering the entire potato genome. A total of 174 alleles were detected with an average of 5.5 alleles per locus. The model-based structure analysis discriminated the population into two main sub-groups, which can be further subdivided into seven groups based on collection sites. One sub-group (P1) revealed less genetic diversity than other (P2) and contained a higher number of commercial cultivars possibly indicating a slight reduction in diversity due to selection in breeding programs. The P2 sub-group showed a wider range of genetic diversity with more new and unique alleles attained from wild relatives. The potato landraces, clustered in sub-population P1 may be derived from historical population imported from ancient European and International Potato Center genotypes while sub-population P2 may be derived from modern populations from InternationalPotato Center and European genotypes. It is proposed that in the first step, the potato genotypes were introduced from Europe to China, domesticated as landraces, and then hybridized for modern cultivars (Wang *et al*., 2019).

To broaden the genetic diversity, Andigena was utilized through a single event of hybridization, from which long- day-adapted F_1 hybrid clones were selected. After evaluating these F_1 hybrids as pollen parents, 95 F_1 hybrid clones wereselected and named PGEL clones, which were released to breeders. The mean tuberyield among families of Atlantic × long-day-adapted F_1 hybrid was significantly higher than thatamong F_1 hybrid families of Andigena × 10H17 (Table 2), andmost of the families of Atlantic × PGEL clones outyielded the control family (Supplementary Fig. 2). Thus, using PGEL clones as parents in commercial breeding, a heterotic effect for tuber yield can be expected. An additional advantage of thePGEL clones is disease resistance, which can be managed bymolecular markers. However, since total tuber yield was a primary selection criterion, other agronomic traits, such as tuber appearance, stolon length, and maturity, are still poor. Improving general agronomic traits and stacking multiple re- sistance genes in multiplex conditions are underway. (Hosaka, and Sanetomo, 2020). It is of critical importance to understand the genetic diversity and population structure for effective collection, conservation, and utilization of potato germplasm. Thus, the objective of the present study was to investigate the genetic diversity and population structure of potato germplasm conserved in the National Agrobiodiversity Center (NAC) of South Korea to provide basic data for future preservation and breeding of potato genetic resources. A total of 24 simple sequence repeat (SSR) markers were used to assess the genetic diversity and population structure of 482 potato accessions. A total of 257 alleles were detected, with an average of 10.71 alleles per locus. Analysis of molecular variance showed that 97% of allelic diversity was attributed to individual accessions within the population, while only 3% was distributed among populations. Results of genetic structure analysis based on STRUCTURE and discriminant analysis of principal components revealed that 482 potato accessions could be divided into two main subpopulations. Accessions of subpopulation 1 mainly belonged to cultivars and breeding lines. Accessions of subpopulations 2 basically corresponded to wild relatives of potatoes. Results of this study provide useful information for potato improvement and conservation programs, although further studies are needed for a more accurate evaluation of genetic diversity and phenotypic traits of potatoes (Kyung-Jun Lee *et al*., 2021). Phenotypic evaluation and molecular biotechnology are both important in the identification and utilization of crop germplasm resources. In this study, the phenotypic variation and genetic diversity of 149 main potato cultivars in China were investigated with 12 phenotypic traits and 24 SSR markers. The coefficient of variation of 12 phenotypic traits ranged from 12.11% to 156.93%. The results of SSR markers exhibited a relatively high level of genetic variation (Na =5.458 ± 1.499, Ne =3.300 ± 1.087, I=1.397 ± 0.298, Ho =0.797 ± 0.178, He = 0.660 ± 0.117, and PIC=0.702 ± 0.087). Population structure and phylogenetic tree analysis divided the varieties into three subgroups. The results indicated that ninety percent of the molecular variance was attributed to within-group differences, and the remaining 10% was attributed to variation among groups. Consistent with previous report, alleles of the STI032 marker were significantly associated with tuber starch content and growth period traits in the population. The results of this study could facilitate the utilization of potato germplasm resources, molecular breeding and improvement (Jun Hu *et al*., 2022). DNA fingerprinting is a tool for plant breeder rights protection, and variety registration in Plant Breeder Rights Repository. In the present study, we developed a DNA fingerprinting profile of 12 potato cultivars grown in Punjab Pakistan using 214 informative Simple Sequence Repeat (SSR) markers. A total of 1720 alleles were amplified by 214 SSR with an average of 8.04 alleles per marker. Approximately 72% of amplified alleles (1329 alleles) were polymorphic with 6.88 polymorphic alleles per SSR marker. The number of alleles ranged from 1 to 31. Similarly, polymorphic alleles per marker ranged from 0 to 24. A maximum number of alleles and polymorphic alleles were reported by IBR13 marker. The Polymorphic information content (PIC) value ranged from 0 to 0.96. The average PIC value for 214 amplified markers was 0.73. Collectively, 72 SSR markers amplified unique allelic patterns for DNA fingerprinting. Potato varieties Rubby and Sadaf were identified by 15 SSR markers whereas Faisalabad Red and SH-5 were identified by 12 SSR markers. Cluster and structure analysis classify the potato genotypes into two distinct groups. This information will be useful for the variety registration process and will provide a platform for future DNA fingerprinting and genetic diversity studies for the choice of SSR markers (Rahman *et al.,* 2022). Although the potato is a crop that was introduced in India, it has become a staple food and is grown in both the hills and plains. Potato breeding started in India in the 1950s' and has contributed significantly to improving production. However, it is important to ascertain genetic progress in terms of changes in its yield over time. This study used the 'Era trial' methodology, wherein 22 potato varieties released in different decades ranging from 1968-2012 were evaluated in replicated multi-location trials for three consecutive years (2014-15, 2015-16 and 2016-17) in four potato growing zones of the country. The traits recorded were total tuber yield, marketable tuber yield and tuber dry matter content. Mixed model REML analysis showed significant differences among varieties and environments. Tuber dry matter content showed the least variation among varieties. The highest tuber yields were observed in the West-Central plains (WCP), while mean tuber yields were high in the North-Western plains (NWP). The zone-wise entry mean based broad-sense heritability estimates for all the three traits were high, although individual environment estimates observed low and moderate heritability too. Genetic gain results showed a positive trend for total and marketable tuber yields in NWP, WCP and Hill region (HR), while no gain was observed in the Eastern plains (EP) zone. The maximum annual rate of genetic gain for total tuber yield was 0.4%, 0.3% and0.2% in WCP, HR and NWP. Positive genetic gain for tuber dry matter content was 0.2% in HR and 0.08% in WCP, while the other two zones had negative genetic gain for the trait. The annual rate of genetic gain for tuber yields and dry matter in potatoes does not commensurate with the future demand for the crop, underlining the need for holistic modern breeding techniques to boost genetic gains in potato breeding in India. (Salej Sood *et al*., 2022).

BREEDING

Breeding Objectives: The breeding of crop plants is a highly effective means of increasing agricultural productivity in a sustainable and environmentally safe way. Pre-breeding and population improvement not only capture essential genetic resources and move desired traits along variety development pipelines but also help assure the creation of broad and dynamic gene pools to meet future, unanticipated needs. To efficiently meet multiple breeding objectives requires both interdisciplinary collaboration and a grasp of a wide range of scientific knowledge and expertise. The main objectives of breeding include increased yield, improving quality characteristics of tubers such as skin and flesh colour, tuber size and shape, eye depth, nutritional properties, cooking/after cooking properties, processing quality, and introducing resistance to biotic and abiotic environmental stresses (Inspection, 2015; Devi, 2023; Mishra *et al*., 2023). The majority of breeding with *Solanum tuberosum* involves crosses between tetraploid genotypes followed by phenotypic recurrent selection. Parents are selected to be diverse in order to minimize homozygosity and inbreeding depression, and test crosses may be performed in order to determine which parent combinations are desirable. Selection is typically applied at the phenotypic level, although molecular markers are increasingly used. Due to the heterozygosity and tetraploidy of *S. tuberosum*, traits are expected to segregate in the F1 generation, and large populations are typically generated, on the order of tens of thousands. From the F1 generation, tubers will be removed and planted, representing the first clonal generation. The clones will then be put through a series of field trials in an increasingly diverse range of environments over a number of years, and selection will be applied to reduce the number of clonal lines until only one or a few remain. Breeding may also be done using diploid lines. Maternal haploid lines can be made by crossing *S. tuberosum* with diploid clones of *S. Phureja*. These can then be used in crosses with 2x tuber-bearing *Solanum* species. Direct crosses between diploid tuber-bearing *Solanum* species and tetraploid *S. tuberosum* may also succeed if the diploid can produce unreduced (2*n*) gametes, which is common for these species. Other techniques such as mutagenesis, somatic hybridization, and genetic engineering may also be employed (Inspection, 2015).

Genetic Variation for Tuber Quality Traits: Analysis of tuber traits that make up the quality aspect of potato tubers or the underlying genetics is very complex. Of all the traits breeders are working on, breeding for quality traits is often the most complex than resistance breeding. For quality traits the observed phenotype is often results of interactions of a multitude of genes acting together in complete metabolic pathways, like in the case of cold sweetening where both the starch biosynthesis as well as the starch degradation pathway play a role in the observed variation for cold sweetening. The presence of wide variations among varieties for tuber specific gravity, dry matter and starch contents indicates that genetic factor is important to influence the tuber internal quality traits. Breeding for quality requires a basic understanding of the pathways underlying the trait of interest. Furthermore, identifying the genes involved and how they function and are regulated within the biosynthetic routes is an important prerequisite to understand the biology of phenotype expression. To this effect, it is crucial to identify the existing allelic diversity that generally governs the transcription and ultimately expression of these useful traits (Hussen, 2019).

Breeding Methods

Mishra *et al*. (2023) and Devi (2023) have reported the following breeding methods in potato:

1. Introducion
2. Clonal selection
3. Hybridization
4. Heterosis breeding
5. Back cross method
6. Mutation breeding.

Potato varieties devloped by different methods of breeding are given in Table4 .

Table 4. Varieties developed by differen methods

Breeding Mehod	Varieties developed by differen methods
Introduction	Most of the popular varieties
Clonal Selection	Kufri Reb, Kufri Safed
Hybridizatov	Kufri Sinduri, Kufri Chandramuki, Kufri Shreetma, Kufri Badshah, Kufri Jyoti, Kufri Bahar
Mutation Breeding	Mariline 2, Konkei No. 45, Desital, Sarme, Jagakids Purple, White Baron, Nahta

The World Potato Germplasm Collection: The high utility of wild and landrace potatoes has led to a series of collection expeditions in the centers of origin which are currently available for breeders and researchers through gene banks. Approximately 98,000 accessions are conserved *ex situ*. These collections have been described for agromorphological traits following the descriptor lists of the International Plant Genetic Resources Institute (IPGRI) and the International Union for the Protection of New Varieties of Plants (UPOV). The International Potato Center, based in Lima, Peru, holds 4,870 types of potato germplasm, most of which are traditional landrace cultivars (Wikipedia, 2023). In India, the ICAR-CPRI presently holds a modest collection of over 4,500 accessions, comprising of cultivated species (subsp. *tuberosum* and *andigena*), parental lines and wild/semi-wild tuber bearing *Solanum*species (Table 5).

Table 5. Potato germplasm holding at ICAR-CPRI, Shimla

Material	No. of accessions				No. of donor countries
	Tuber	In vitro	Trueseed	Total	
a) Tuberosum (Cultivars / parental lines) Indian					
Cultivars bred atCPRI	56	60	-	60	
Advanced hybrids	86	50	-	96	
Indigenous varieties	51	107	-	107	
Indigenous samples	97	42	-	97	
Exotic	1837	2700	-	2840	30
b) Andigena	723	77	-	762	5
c) Wild/ semi- cultivated sps.	123 (42 species)	130 (29 species)	294(70 species)	540 (125 pecies)	5
Total germplasm				4502	

This is the largest potato collection in South Asia. These germplasm accessions have been imported from 30 countries based on national requirement. The institute, at present, has in its collection about 125 wild species consisting of diploids, triploids, tetraploids, pentaploids and hexaploids. (Luthra *et al*., 2020)

Consevation of potato germplasm: As described above, primitive potato cultivars and wild species are promising gene pools for crop improvement. The genetic diversity is threatened by land use change caused byurbanization, erosion, and climate change. There are many reasons diminishing the incentives for farmers to grow land races, including the availability of improved varieties, avail ability of purchased inputs (fertilizer and pesticides), low cost/benefit ratio from planting traditional varieties, and opportunities to increase income by changing crops. Conservation of wild species and their availability for use in breeding programs provide the foundation for future crop improvement

Uses in breeding programs: Today, most Latin American breeding programs are working on durable resistance to late blight, virus resistance, heat and drought tolerance, quality traits, and adaptation to low–external input agriculture. To accomplish this goal, the use of wild relatives of the cultivated potato and landraces has intensified. For example, in the year 2000, INIA-Uruguay initiated a prebreeding program for late blight resistance using crosses involving *S. bulbocastanum*, *S. microdontum*, and *S. circaeifolium*. Selections have been made in collaboration with other programs in Latin America. Furthermore, in collaboration with the University of the Republic (UdelaR), INIA developed 4*x S. tuberosum* hybrids from crosses with *Solanum commersonii*—an endemic wild species in Uruguay—and *Solanum chacoense*, with heat tolerance and bacterial wilt resistance, using Phureja as a bridge with the aim of transferring resistance to bacterial wilt to cultivated germplasm and broadening the genetic base of the crop and incrementing resistance to abiotic stresses . EMBRAPA in Brazil has also developed prebreeding lines for bacterial wilt resistance from populations derived from the wild species *S. sparsipilum*, *S. chacoense*, *S. microdontum*, and cultivated Phureja. Parental clones and derived progenies with bacterial wilt resistance and good agronomical traits have been selected under warm conditions. Similarly, CIP has developed 4*x S. tuberosum* hybrids from crosses with wild species from the Piurana group that possess novel genes for late blight resistance and developed initial crosses with sources of resistance to bacterial wilt. The tuberosum background of these hybrids involves breedinglines with heat and/or drought tolerance. Taking advantage of its collection of Phureja landraces, the breeding program of the National University of Colombia (UNC) has developed modern diploid Phureja varieties with enhanced dormancy. The university has also begun a diploid potato breeding program focused on nutritional traits. Initially they determined the content of nutritional compounds (sugars, proteins, minerals, starch, moisture, fat, dietary fiber, carotenoids, vitamin C, and other antioxidants) and antinutrient compounds (glycoalkyloids) present in their Phureja core collection. Variability in the content of macronutrients, micronutrients, and functional compounds has allowed for the selection of parental materials for breeding. High levels and appropriate combinations of nutritional compounds are an important objective of global crop improvement. Relatively high levels of micronutrient contents have been documented in the diploid cultivar groups Phureja, Stenotomum, and Goniocalyx. These early domesticates possess good agronomical attributes, and along the history of potato breeding, they have been shown to form heterotic tetraploid hybrids in crosses with tetraploid potatoes by means of heterozygous unreduced gametes. This diploid landrace germplasm has been selected at CIP as the first gene pool for the development of nutritious heterotic hybrids and were subjected to three cycles of recurrent selection to increase concentrations of iron and zinc through inter- and intragroup hybridization. From a broad base of landraces and wild potatoes, CIP's two most advanced tetraploid breeding populations were subjected to divergent selection for adaptive trait complexes required for sustainable production in tropical highland (population B) and subtropical lowland (LTVR population) agroecologies. Significant positive heterosis for marketable tuber yield has already been obtained by interpopulation hybridization of these two populations. The new hybrid population exceeded the mean of both parental populations under favorable environments but not under a warm environment less favorable for potato growth. More heterotic families were identified under favorable environments, but the few heterotic families identified under the unfavorable warm environment were also heterotic under the favorable one. This indicated that for full expression of heterosis, it is important for the two gene pools to show adaptation to the environment for which new hybrids are intended. For this reason, adaptation traits such as heat and salinity tolerance, drought tolerance, and a long critical photoperiod are traits selected for gene pool enhancement and heterosis breeding at CIP (de Haan and Rodriguez, 2016).

Souces of disease resistance: Some important sources of resistance to major potato diseases and pests, and to abiotic stresses are listed in Table 6 (Luthra *et al.,* 2020).

Table 6. Wild species as sources of resistance to various diseases

Diseases	**Sources**
Viruses PVX	*S. acaule, S. berthaultii, S. brevicaule, S. chacoense, S. commersonii, S. curtilobum, S. phureja, S. sparsipilum, S. sucrense, S. tarijense and S. tuberosum ssp. andigena*
PVY	*S. acaule, S. chacoense, S. demissum, S. gourlayi, S. phureja, S. rybinii, S. stoloniferum, S. tuberosum ssp. andigena*
PLRV	*S. acaule, S. brevidens, S. chacoense, S. demissum, S. etuberosum, S. raphanifolium, S. stolonifrum and S. tuberosum ssp. andigena*
Late blight Vertical	*S. cardiophyllum, S.demissum, S. S.ediense, S. stoloniferum* and *verrucosum*
Late blight Horizontal	*S. berthaultii, S. bulbocastanum, S. chacoense, S. circaeifolium, S. demissum, S. microdontum, S. phureja, S. pinnatisectum, S. polyadenium, S. stoloniferum, S. tarijense, S. tuberosum ssp andigena, S. vernei* and *S. verrucosum*
Wart	*S. acaule, S. berthaultii.*
Common scab	*S. chacoense, S. tuberosum ssp. andigena*
Bacterial wilt	*S. chacoense,S. microdontum, S. phureja, S. sparsipilum and S. stenotomum*
Cyst nematodes	*S. acaule, S. berthaulti , S. boliviense, S. bulbocastanum, S. capsicibaccatum, S. cardiophyllum, S. demissum, S. gourlayi, S. kurtzianum, S. leptophyes, S. multidissectum, S. oplocense, S. sparsipilum, S. spegazzinii, S. sucrense, S. tuberosum ssp. Andigena* and *S. vernei*
Root knot nematode	*S. bulbocastanum, S. cardiophyllum, S. chacoense, S. curtilobum, S. hjertingii, S. kurtzianum, S. microdontum, S. phureja, S. sparsipilum and S. tuberosum ssp. andigena*
Aphids	*S. berthaultii, S. bukasovii. S. bulbocastanum, S. chomatophilum, S. infundibuliforme, S. lignicaule, S. marinasense, S. medians, S. multidissectum, S. neocardenasii, S. stoloniferum*

Frost	*S. acaule, S. ajanhuiri*
Heat and drought	*S. acaule, S. bulbocastanum, S. chacoense, S. commersonii, S. gourlayi, S. megistacrolobum, S .microdontum, S. ochoae, S. papita, S. pinnatisectum, S. spegazzinii* and *S. tarijense*
High protein content	*S. phureja* and *S. vernei.*

Characterization of germplasm: The germplasm accessions have been characterized for morphological traits like tuber skin colour, tuber shape, eye depth, flesh color (Fig. 8) and flower color as per descriptor of the International Board for Plant Genetic Resources (now IPGRI) (Luthra *et al*., 2020).

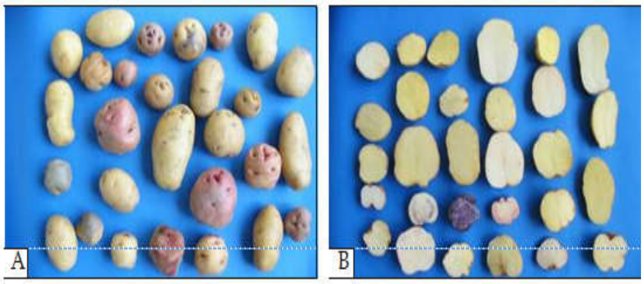


Fig. 8. Tuber size, shape, skin colour, eye depth (A), andtuber flesh colour variability (B) in potato germplasm

Early Efforts at Variety Improvement in India: Potato breeding program was initiated in India in 1935 at the Potato Breeding Station (PBS), Shimla, under the Imperial (now Indian) Agricultural Research Institute, New Delhi. Variety improvement in potato was a challenge as the introduced European varieties wereall long-day adapted, their multiplication in Indian conditions was characterized by progressive accumulation of viral diseases resulting in concomitant decrease in yield, and limitations of tuber storage and utilization in hot and humid Indian conditions. A regular breeding program was initiated in 1949 at CPRI (now ICAR-CPRI), Shimla. The available collections were evaluated for direct introduction and/or for use as parental lines in potato breeding program. Since potato flowers only under long days, potato hybridization was initiated in hills at Kufri (Shimla), Himachal Pradesh. Crosses were made betweenindigenous cultivars and promising exotic introductions to breed new high yielding hybrids suitable for sub-tropical conditions in plains and temperate conditions of the hills. Initial attempts to breed high yielding potato varieties for sub-tropical plains were,however,unsuccessful due to degeneration of progenies during evaluation period in the plains. To circumvent this problem, the seedlings were raised and maintained in hills at Kufri with only a few tubers of each clone being sent for evaluation in the plains. This plan too proved unsatisfactory due to dormancy of hill seed and limitation of land in the hills at Kufri (Luthra *et al*., 2020). The major breakthrough in potato improvement program came in 1963 with the development of “Seed Plot Technique”, which made it possible to raise, evaluate, select and multiply breeding material under disease free conditions in sub-tropical plains itself. This led to development of a system, wherein, crosses were made in hills, and segregating populations were evaluated and maintained in disease free condition in plains. This approach proved very successful and the institute worked out unique strategies for breeding potato varieties suitable for sub-tropical plains, northern hills, southern hills, processing, and heat tolerance. The institute has so far developed 66 high yielding varieties including one TPS population suitable for cultivation in different agro-ecological zones ofIndia, which ultimatelymade India the second largest potato producing nation of the world. All varieties released by ICAR-CPRI carry the prefix ‘Kufri’ after the name of the place where hybridization work is done for the development of new potato varieties in India (Luthra *et al*., 2020). The varieties should be widely adaptable, resistant to major diseases and pests, possess good keeping quality and acceptable for table,processing, or for both purposes (Luthra *et al*2006b). Low glycoalkaloidscontent and ability to withstand cold induced sweetening are added advantages. The quality traits and their importance to users are given in Table 7 (Luthra *et al*., 2020).

Table 7. Quality characteristics of importance to processor and consumer and relative importance to each: H=High, M=Medium, L=Low priority

Character	Processing	Table use
Tuber defects	H	H
Damage external	M	H
Damage internal	H	M
Glycoalkaloids	H	H
Greening	H	H
Nutritional value	H	H
After-cooking blackening	M	H
Texture	M	M
Enzymatic browning	H	M
Sugar content	H	L
Dry matter	H	L
Flavour	M	H

The varietal requirements of different regions are summarized in Table 8

Table 8. Variety requirement of different potato zones of India

Zone	Varietal requirements
North-western plains	Short day adaptation, early bulking, heat tolerance and late blight resistance. Tolerance to frost is an added advantage.
West-central plains	Short-day adapted, early bulking, moderate resistant to late blightand slow degeneration rate.
North-eastern plains	Short day adapted, early bulking and late blight resistant. Redskin tubers arepreferred in some areas.
Plateau region	Early bulking, able to tuberize underhigh temperatures and resistant to bacterial wilt, mites & potato tuber moth and slow rate of degeneration.
North-western and central hills	Long day adaptation (14 h days), highly resistant to late blightand bacterial wilt.
North-eastern hills	Long day adaptation (14 h days), highly resistant to late blightand bacterial wilt.
Southern hills	Long day adaptation, early bulking, late blight and cyst nematoderesistance.
Sikkim and north Bengal hills	Resistance to late blight and immunity to wart. Red skin potatoesare also preferred.

Varieties: Potatoes that are good for making potato chips or potato crisps are sometimes called "chipping potatoes", which means they meet the basic requirements of similar varietal characteristics, being firm, fairly clean, and fairly well-shaped. Immature potatoes may be sold fresh from the field as "creamer" or "new" potatoes and are particularly valued for their taste. They are typically small in size and tender, with a loose skin, and flesh containing a lower level of starch than other potatoes. They are distinct from "baby", "salad" or "fingerling" potatoes, which are small and tend to have waxy flesh, but are grown to maturity and can be stored for months before being sold (Wikipedia, 2023). Potato varieties recommended for cultivation indifferent agro-ecological zones of India are given in Table 9.

Table 9. Potato varieties recommended for cultivation indifferent agro-ecological zones of India

Agro-ecologicalzones	Duration*	Recommended varieties
North-Western plains	Early	Kufri Ashoka, Kufri Chandramukhi, Kufri Jawahar, Kufri Khyati, Kufri Lima, Kufri Pukhraj,Kufri Surya.
	Medium	Kufri Anand, Kufri Arun, Kufri Badshah Kufri Bahar, Kufri Chipsona-1, Kufri Chipsona-3, KufriFryoM, Kufri Ganga, Kufri Garima, Kufri Gaurav Kufri Jyoti, Kufri Mohan, Kufri Neelkanth, Kufri Pukhraj Kufri Pushkar, Kufri Sadabahar, Kufri Sutlej
West-Central plains	Early	Kufri Chandramukhi, Kufri Jawahar, Kufri Khyati, Kufri Pukhraj, Kufri Lauvkar, Kufri Lima, Kufri Surya
	Medium	Kufri Arun, Kufri Anand, Kufri Badshah Kufri Bahar, Kufri Chipsona-1, Kufri Chipsona-3, Kufri Ganga, Kufri Frysona Kufri Garima , Kufri Jyoti, Kufri Mohan Kufri Neelkanth, Kufri Pukhraj, Kufri Pushkar, Kufri Sadabahar, Kufri Sutlej
	Late	Kufri Sindhuri
North-eastern plains	Early	Kufri Ashoka, Kufri Chandramukhi, Kufri Khyati, Kufri Lima, Kufri Pukhraj, Kufri Surya

	Medium	Kufri Arun, Kufri Bahar, Kufri Chipsona-1, Kufri Chipsona-3, Kufri FryoM, Kufri Frysona , Kufri Ganga, Kufri Gaurav, Kufri Jyoti, Kufri Manik, Kufri Mohan, Kufri Neelkanth, Kufri Kanchan, Kufri Lalima, Kufri Lalit, Kufri Pukhraj, Kufri Pushkar, Kufri Sutlej
	Late	Kufri Sindhuri
Plateau region	Early	Kufri Chandramukhi, Kufri Jawahar, Kufri Khyati, Kufri Lauvkar, Kufri Pukhraj, Kufri Surya
	Medium	Kufri Badshah, Kufri Garima, Kufri Jyoti KufriLauvkar, Kufri Pukhraj, Kufri Karn
North-western hills	Medium	Kufri Girdhari, Kufri Giriraj, Kufri Himalini, Kufri, Kufri Karn, Himsona, Kufri Jyoti Kufri Shailja
North eastern hills	Medium	Kufri Girdhari, Kufri Giriraj, Kufri Himalini, Kufri Jyoti, Kufri Megha, Kufri Shailja
North Bengal and sikkim hills	Medium	Kufri Girdhari, Kufri Jyoti, Kufri Kanchan
Southern hills	Medium	Kufri Girdhari, Kufri Giriraj, Kufri Himalini, Kufri Jyoti, Kufri Neelima, Kufri Shailja, Kufri Sahyadri, Kufri Swarna

* Plains: Early (70-90 days), Medium (90-100 days) and Late (>100 days); Hills: Early (100-110 days), Medium (110-120 days) and Late (> 120 days).

Indian potato varieties/ hybrids being grown in other countries are given in **Table 10**.

Table 10. Indian potato varieties/ hybrids being grown in other countries

Country	Varieties/Hybrids
Afghanistan	Kufri Chandramukhi
Nepal	Kufri Jyoti, Kufri Sundhuri
Bhutan	Kufri Jyoti
Bangladesh	Kufri Sindhuri
Mexico	I-654 as CCM-69.1
Sri Lanka	I-822 as cv. Khrushi, I-1085 as cv. Sita
Philippines	I-1035 as cv. Montanosa, I-1085 as cv. BSUP-04
Madagascar	I-1035 as Mailaka
Bolivia	I-1039 as cv. India
Vietnam	I-1039 as cv. Red skin

Seed production: Seed potato production often occurs in regions that are separate from those used to produce the crop for consumption. Precautions are taken during seed potato production to minimize disease incidence. Insecticides and other insect control measures will be used to reduce aphid populations, which are the main agents for spreading viral diseases. Any plants showing symptoms of disease are rogued; rogueing may be supplemented with laboratory detection methods when symptoms may be poorly expressed. Management and sanitation practices will also be put into place to minimize the spread of disease through contact with machinery, tools or with surfaces encountered during transport and storage. Seed potatoes must be certified before they can be sold commercially. The seed certification process ensures that the seed potatoes originated from nuclear stock, which means that they were produced from sterile tissue culture propagules and subjected to a number of tests that demonstrate it to be disease-free. The seed potato certification system relies on the continuous introduction of disease free material in the seed supply continuum and limits multiplication of seed potato stocks to a maximum of six field generations to minimize disease build-up. Further disease and varietal purity standards are ensured through additional field inspections, laboratory testing, post-harvest testing, and agronomic practices (Inspection, 2015).

Biotechnology: The first decade of genetic engineering primarily focused on quantitative crop improvement. With the advances in technology, the focus of agricultural biotechnology has shifted toward both quantitative and qualitative crop improvement, to deal with the challenges of food security and nutrition. Potato (*Solanum tuberosum* L.) is a solanaceous food crop having potential to feed the populating world. It can provide more carbohydrates, proteins, minerals, and vitamins per unit area of land as compared to other potential food crops, and is the major staple food in many developing countries.. Moreover, the availability of potato genome sequence and efficient potato transformation systems have remarkably facilitated potato genetic engineering. Here we summarize the potato trait improvement and potential application of new breeding technologies (NBTs) to genetically improve the overall agronomic profile of potato (Amir Hameed *et al*., 2018).

The inherent genetic complexity of potato has made breeding time-consuming and often with unpredictable results. Polygenes are believed to underlie quantitative resistance, which is difficult to maintain intact during the breeding process. Thus, it is desirable to identify sources with high heritability and robust screening procedures. The selection cycle, from initial crosses to variety release, requires approximately 10 years or sometimes morethan 30 years. The transfer of resistance genes from wild potatoes directly into widely adapted potato varieties is currently the most promising strategy for developing long-lasting resistance to late blight. Efficiency and precision in plant breeding can be enhanced by use of diagnostic DNA-based markers and has been applied to potato breeding. Numerous genetic mapping experiments have been performed using potato and have identified DNA-based markers linked to genes for resistance to different diseases.

Genetically engineered potatoes: Genetic research has produced several genetically modified varieties. 'New Leaf', owned by Monsanto Company, incorporates genes from *Bacillus thuringiensis*, which confers resistance to the Colorado potato beetle; 'New Leaf Plus' and 'New Leaf Y', approved by US regulatory agencies during the 1990s, also include resistance to viruses. McDonald's, Burger King, Frito-Lay, and Procter & Gamble announced they would not use genetically modified potatoes, and Monsanto published its intent to discontinue the line in March 2001. Potato starch contains two types of glucan, amylose and amylopectin, the latter of which is most industrially useful. Waxy potato varieties produce waxy potato starch, which is almost entirely amylopectin, with little or no amylose. BASF developed the Amflora potato, which was modified to express antisense RNA to inactivate the gene for granule bound starch synthase, an enzyme which catalyzes the formation of amylose.[45] Amflora potatoes therefore produce starch consisting almost entirely of amylopectin, and are thus more useful for the starch industry.
In 2010, the European Commission cleared the way for 'Amflora' to be grown in the European Union for industrial purposes only—not for food. Nevertheless, under EU rules, individual countries have the right to decide whether they will allow this potato to be grown on their territory. Commercial planting of 'Amflora' was expected in the Czech Republic and Germany in the spring of 2010, and Sweden and the Netherlands in subsequent years. Another GM potato variety developed by BASF is 'Fortuna' which was made resistant to late blight by adding two resistance genes, blb1 and blb2, which originate from the Mexican wild potato *Solanum bulbocastanum*. In October 2011 BASF requested cultivation and marketing approval as a feed and food from the EFSA. In 2012, GMO development in Europe was stopped by BASF. In November 2014, the USDA approved a genetically modified potato developed by J.R. Simplot Company, which contains genetic modifications that prevent bruising and produce less acrylamide when fried than conventional potatoes; the modifications do not cause new proteins to be made, but rather prevent proteins from being made via RNA interference. Genetically modified varieties have met public resistance in the United States and in the European Union (Wikipedia, 2023).

USES

Potato tubers are a staple food source in temperate regions and are eaten after cooking. They may be cut or sliced and made into potato chips or fries. Potatoes can also be processed into starch, alcohol or flour (Plantvillage, 2023). Food-related uses are abundant and follow different primary processes including boiling, steaming, freeze-drying, drying, and fermentation. These uses alter the biochemical composition of the potato and frequently enhance storability to ensure year-round food availability. In addition, the potato is used as medicine and animal fodder and for festive or ritual purposes. One early traditional use that is still commonly practiced by Andean farmers around Lake Titicaca involves geophagy. Potatoes are boiled and consumed with a clay dip called *ch'ago*. The clay has a detoxification function and neutralizesthe human intake of potentially harmful glycoalkaloids. The transition of geophagy from a general response to toxin-related stress to a more specialized detoxification technique such as freeze-drying can be interpreted as an important step that has facilitated expanded resource exploitation and domestication. Freeze-drying, drying, and fermentation are processing techniques that facilitate long-term storage. There are many variants of traditional freeze-drying techniques; the main ones involve processing white *chuño* (*tunta*, *moraya*) and black *chuño*. The elaboration of white *chuño* involves tending, freezing, treading, washing, and drying of tubers. White *chuño* is always washed or soaked, in part to remove glycolalkaloids. On the other hand, processing of black *chuño* does not involve washing or soaking and its preparation is generally simpler compared with white *chuño*. Farmers take advantage of severe frost at night alternated with high daytime levels of solar radiation and low levels of relative humidity during the dry season to process either type of *chuño*. Freeze-drying results in a decrease in the zinc, potassium, phosphorus, and magnesium content of both types of *chuño*, whereas the iron and calcium content values of white *chuño* tend to increase after processing. Processing of *papa seca* (dried potato) is common in the relatively dry western Andes. On the other hand, anaerobic fermentation of *tocosh* is practiced exclusively by smallholder farmers from the comparatively wet eastern and northern Andes of Peru. *Tocosh* is used as a food and a natural medicine believed to contain penicillin. The biochemical composition of both *tocosh* and*papa seca* has yet to be researched. All traditional preparations of potato in the Andes and Chiloe island basically involve boiling and steaming. Potatoes consumed with *ch'ago*, and *chuño*, *papa seca*, and *tocosh*, are always boiled before consumption. Another traditional and widely practiced technique to prepare potatoes involves the preparation of earth-ovens. Numerous regional variants exist, including the *pachamanka* in central Peru, *huatia* in southern Peru to northern Bolivia, and *curanto* in southern Chile (de Haan and Rodriguez, 2016).

Preparation of potato for use: Potatoes are prepared in many ways: skin-on or peeled, whole or cut up, with seasonings or without. The only requirement involves cooking to swell the starch granules.
Most potato dishes are served hot but some are first cooked, then served cold, notably potato salad and potato chips (crisps). Common dishes are: mashed potatoes, which are first boiled (usually peeled), and then mashed with milk or yogurt and butter; whole baked potatoes; boiled or steamed potatoes; French-fried potatoes or chips; cut into cubes and roasted; scalloped, diced, or sliced and fried (home fries); grated into small thin strips and fried (hash browns); grated and formed into dumplings, Rösti or potato pancakes. Unlike many foods, potatoes can also be easily cooked in a microwave oven and still retain nearly all of their nutritional value, provided they are covered in ventilated plastic wrap to prevent moisture from escaping; this method produces a meal very similar to a steamed potato, while retaining the appearance of a conventionally baked potato. Potato chunks also commonly appear as a stew ingredient. Potatoes are boiled between 10 and 25 minutes, depending on size and type, to become soft (Wikipedia, 2023).

Uses other than for eating: Potatoes are used to brew alcoholic beverages such as vodka, poitín, or akvavit. They are also used as fodder for livestock. Livestock-grade potatoes, considered too small and/or blemished to sell or market for human use but suitable for fodder use, have been called *chats* in some dialects. They may be stored in bins until use; they are sometimes ensiled. Some farmers prefer to steam them rather than feed them raw and are equipped to do so efficiently. Potato starch is used in the food industry as a thickener and binder for soups and sauces, in the textile industry as an adhesive, and for the manufacturing of papers and boards. Potatoes are commonly used in plant research. The consistent parenchyma tissue, the clonal nature of the plant and the low metabolic activity make it an ideal model tissue for experiments on wound-response studies and electron transport. Potatoes have been delivered with personalized messages as a novelty (Wikipedia, 2023).

South Indian Preparations: In South Asia, the potato is a very popular traditional staple. In India, the most popular potato dishes are *aloo ki sabzi*, batata vada, and samosa, which is spicy mashed potato mixed with a small amount of vegetable stuffed in conical dough, and deep-fried. Potatoes are also a major ingredient as fast-food items, such as aloo chaat, where they are deep-fried and served with chutney. In Northern India, alu dum and alu paratha are a favourite part of the diet; the first is a spicy curry of boiled potato, the second is a type of stuffed chapati. A dish called masala dosa from South India is notable all over India. It is a thin pancake of rice and pulse batter rolled over spicy smashed potato and eaten with sambhar and chutney. Poori in south India, in particular in Tamil Nadu, is almost always taken with smashed potato masal. Other favourite dishes are alu tikki and pakoda items. Vada pav is a popular vegetarian fast-food dish in Mumbai and other regions in Maharashtra in India. Aloo posto (a curry with potatoes and poppy seeds) is popular in East India, especially Bengal. Although potatoes are not native to India, it has become a vital part of food all over the country especially North Indian food preparations. In Tamil Nadu this tuber acquired a name based on its appearance, 'urulai-k-kizhangu' , meaning cylindrical tuber. Aloo gosht, potato and meat curry, is one of the popular dishes in South Asia, especially in Pakistan (Wikipedia, 2023).

NUTRITIONAL VALUE

Potatoes are a good source of carbohydrates, potassium, and vitamin C; they are also a source of fiber, vitamin B6, and folate. They are low in fat, calories, and sodium.The values shown in the following table are approximate and may vary depending on the variety, growing conditions, and preparation method of the potatoes. Additionally, cooking and processing methods such as frying or mashing can change the nutritional value of potatoes and increase their calorie and fat content (Plantvillage, 2023). According to the United States Department of Agriculture, a typical raw potato is 79% water, 17% carbohydrates (88% is starch), 2% protein, and contains negligible fat. In a 100-gram portion, raw potato provides 322 kilojoules (77 kilocalories) of food energy and is a rich source of vitamin B6 and vitamin C (23% and 24% of the Daily Value, respectively), with no other vitamins or minerals in significant amount. The potato is rarely eaten raw because raw potato starch is poorly digested by humans. When a potato is baked, its contents of vitamin B6 and vitamin C decline notably, while there is little significant change in the amount of other nutrients (Wikipedia, 2023). Potatoes are high in vitamins, minerals and carbohydrates. They contain Calories: 164, Fat: 0.2g, Sodium: 24mg, Carbohydrates: 37g, Fiber: 4g, Sugars: 1.9g, Protein: 4.6g, Vitamin C: 14.4mg and Vitamin B6: 0.6mg (Lehman, 2022).

HEALTH BENEFITS

Potatoes are plants, and the fleshy part of their root is often eaten as a vegetable. Even though potatoes are commonly used for diabetes, heart disease, high blood pressure, indigestion (dyspepsia), and other conditions, there is no good scientific evidence to back up these claims. In addition to treating stomach disorders, raw potato juice is also used to treat water retention (oedema). Weight loss is achieved by mixing potato protein powder with water and controlling appetite. People apply raw potatoes directly to sore eyes, boils, burns, arthritis, and infections. Potatoes are used as sources of starch as well as fermented into alcohol (HND, 2022). Potatoes should be considered a nutritious vegetable, even though they contain a lot of starch. Their other healthful plant compounds make them a worthwhile part of a balanced diet (Lehman, 2022).

Regulates Blood Pressure: Potatoes are high in potassium, which works in opposition to sodium to help regulate blood pressure and fluid balance. Research shows that the potassium in potatoes is just as high and as usable by the body as when consumed as a dietary supplement.[4] Potassium is also essential for normal muscle and nerve function.

Supports the Immune System: Vitamin C is needed for normal immune system function, blood clotting, and strong connective tissue and blood vessel walls. Since vitamin C can't be stored in the body, it must be consumed through food. One baked potato provides about 19% of the daily value for vitamin C.

Repairs Oxidative Damage: Potatoes also have a good concentration of antioxidant phytonutrients, including vitamin C, carotenoids, and polyphenols. These compounds can help repair cells damaged by oxidative stress, which can contribute to a number of chronic diseases.

Prevents Chronic Disease: Fiber is important for digestion, blood sugar control, weight management, heart health, and more. Potatoes, especially when the peel is consumed, are a good source of dietary fiber.

Low in FODMAPs: Potatoes are low in fermentable oligo- di- mono-saccharides, and polyols (also known as FODMAPs), short-chain carbohydrates that can lead to bloating and sensitivity in the digestive tract. In some people with irritable bowel syndrome (IBS) and Crohn's disease, following a low-FODMAP diet helps relieve symptoms.

Allergies: Allergies to cooked or raw potatoes or potato pollen are rare but have been documented. Usually, these reactions are seen in people who have hay fever and are sensitized to birch tree pollen. Proteins in the potato might be chemically similar and therefore trigger a reaction when eaten. The reaction is usually tingling in the mouth and lips, but in rare cases can lead to difficulty breathing and anaphylaxis. Those who react to potato might also react to apples, hazelnuts, carrots, and other raw fruits and vegetables. If you or your child has a potato allergy, remember to read ingredient labels carefully. A surprising number of products contain potato flour and/or potato starch.

Adverse Effects: Acrylamide is a toxic substance that forms in starchy foods when they are processed or cooked at high temperatures. It affects potatoes and other starchy foods. Acrylamide has been shown to cause cancer in lab animals, but we don't know what levels of acrylamide exposures are dangerous for humans. It is important to note that the amount of acrylamide you'd get from potatoes is much lower than the quantities studied in lab animals. Frying and baking potatoes at high temperatures for a long time could result in the most acrylamide, but those levels may be reduced when potatoes are boiled first or treated with antioxidant solutions. You can also steam potatoes to avoid acrylamides. Potatoes are part of the nightshade family of vegetables, along with tomatoes, eggplants, sweet peppers, and a few others. Nightshades contain small amounts of a substance called solanine. Some people claim they have increased arthritis-type pain when they eat potatoes and other nightshade plants. But research hasn't found any substantial connection between rheumatoid arthritis pain and solanine. In large amounts, solanine is toxic, but the amount of solanine you'd get from potatoes isn't enough to make you sick unless you eat green potatoes or sprouts that grow from potatoes that have been sitting around for too long. Don't eat green potatoes—throw them out. They taste bitter and bad anyway.

IN ART WORK AND IN POPULAR CULTURE

The potato has been an essential crop in the Andes since the pre-Columbian era. The Moche culture from Northern Peru made ceramics from the earth, water, and fire. This pottery was a sacred substance, formed in significant shapes and used to represent important themes. Potatoes are represented anthropomorphically as well as naturally. During the late 19th century, numerous images of potato harvesting appeared in European art, including the works of Willem Witsen and Anton Mauve. Van Gogh's 1885 painting *The Potato Eaters* portrays a family eating potatoes. Van Gogh said he wanted to depict peasants as they really were. He deliberately chose coarse and ugly models, thinking that they would be natural and unspoiled in his finished work. Jean-François Millet's *The Potato Harvest* depicts peasants working in the plains between Barbizon and Chailly. It presents a theme representative of the peasants' struggle for survival. Millet's technique for this work incorporated paste-like pigments thickly applied over a coarsely textured canvas (Wikipedia, 2023). Invented in 1949, and marketed and sold commercially by Hasbro in 1952, Mr. Potato Head is an American toy that consists of a plastic potato and attachable plastic parts, such as ears and eyes, to make a face. It was the first toy ever advertised on television. In June, 1992 at the Muñoz Rivera Elementary School spelling bee in Trenton, New Jersey, U.S. Vice President Dan Quayle was handed a flash card that incorrectly spelled "potato" as "potatoe" and then prompted a 12-year-old student to change his correct spelling. This incident was the subject of widespread ridicule (Fig. 9) (Wikipedia, 2023).

Fig. 9. Art and painting work

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