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INCREASED POTATO PRODUCTIVITY, ITS CONSEQUENCES AND SUSTAINABLE PRODUCTION

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ABSTRACT

Potato is the fourth largest food crop grown in the World after rice, wheat and maize. India is the second largest producer after China with a total annual production of around 40 million tonnes. It is a very rich source of carbohydrate and a leading source of food energy in many countries. Potato can be converted into many processed products including chips (wafers), French fries, starch, baby foods and dehydrated. Potato is attacked by a number of pests and diseases including the devastating late blight disease which was once responsible for worst known famine of Ireland in 1845. As a result approximately one million people died and a million more emigrated from Ireland causing the island's population to fall by between 20% and 25%. To control these pests and diseases, a number of agro chemicals are used in most developing countries. Potato production has no doubt increased over the years however, at an alarmingly high cost to human health, soil health and environment. This article aims at highlighting the harmful effects of agro-chemicals used in potato production, potential damages and ways and means for healthy potato production. The article implies that clean potato production is possible in the developing nations as well through farmer awareness and a number of policy interventions.

KEYWORDS: Potato, Horticultural, Agrochemicals, Pesticides, Fungicides

SECTION 1

INTRODUCTION

Potato is one of the most important horticultural crops in India. It is used as a vegetable, staple in many parts of the world and for making other products like starch, baby foods, wafers, chips, French fries, powders etc. (Witt *et al* 2002). It is vulnerable to many pests and diseases. Agrochemicals (mainly Pesticides and Fungicides) are extensively used to control these pests and diseases in most parts of the world, particularly developing countries which has resulted in increased production. However, this increased production has come at a cost in terms of environmental degradation, pollution of water bodies and entry of many harmful chemicals into human, animal and bird food chains. This paper aims at analyzing the conventional potato production practices using agrochemicals in India (section-2). Section-3 discusses the ill effects of increased conventional potato production. Towards the end, paper shows the ways for safer potato production.

SECTION 2

CONVENTIONAL POTATO CULTIVATION

Origin of Potato

Hawkes (1990) concluded that present day cultivated potato originated from the wild diploid species *Solanum* *leptophyes* some 7000-10,000 years ago. The first domesticated species was *S. stenotomum.* But there are stronger evidences in support of allotetraploid origin of *S. tuberosum* by hybridization between *S. stenotomum* and *S. spiliparsum*. A diploid cultivated species *S. phureja* evolved from *S. stenotomum* by human selection exercised for rapid maturity and lack of tuber dormancy to develop varieties to be grown 2-3 times a year in the lower Eastern frost free Andean Valleys. During the course of evolution, diploid species *S. megistacrolobum* and the tetraploid species *A. acaule* contributed frost resistance.

History of Potato Cultivation

The history of the potato provides a grim warning of the need to maintain genetic diversity in our staple food crops. In the 19th century, Ireland was heavily reliant on only a few varieties of potato, and those types contained no resistance to the devastating disease known as late blight. When late blight destroyed the 1845-1846 potato crop, widespread famine followed. An estimated one million people starved to death and more than a million were forced to migrate abroad. In Europe and North America, potato is a staple food but in India it is still a vegetable.

Spread of Potato

Potato was introduced to Europe on two occasions firstly into Spain in 1570 AD and secondly into England 1590 AD (Hawkes, 1967). From Spanish introduction, it diffused throughout Europe and Asia. Its introduction into Spain led to an unimaginable growth and distribution of a new food crop with profound economical and historical results. From Spain potato was taken into neighbouring European countries and in less than 100 years, it was being grown fairy extensively in many regions of Europe. Distribution beyond Europe soon occurred with the introduction into India in about 1610, China in 1700 and Japan in 1766.

Scotch Irish immigrants introduced potato in North America in early 1700s. After their origin in Peru Bolivian Region in Andes, it spread to the surrounding regions of South America like Columbia. The Incas spread the growing of potato throughout their empire. The first Virginia potato to reach North America continent was indeed brought to Virginia but they did not come from South America. In 1613, potatoes were carried to Bermuda from England, they were planted and soon became a major food crop for the colonists so when two chests full of provisions were sent in 1621 to the new colony in James Town Virginia, potatoes were naturally included and were cultivated in Virginia from that time onwards. But potato growing in American colonies did not start on a large scale until 1719 when Irish immigrants brought potatoes to their settlement in Londonderry.

The potato arrived in Africa much later. A few grew in South Africa as early as 1830 but British and German colonists and missionaries did not introduce potato in East Africa until about 1880. In North and East Africa the two world wars were the main stimulus for the crop introduction. While Africa is not a major producer in terms of volume, more African countries grow potato today, than any other continent.

History of Potato Processing

Potato processing is almost as old as potato itself. Even around 200 AD natives of Peru had found a way to dehydrate Potatoes by allowing them to freeze at night and thawing during daylight. Juice was extracted from thawed potatoes by treading them with feet. This cycle was repeated several times and dehydration continued until the moisture content was reduced sufficiently to preserve the potatoes. A sample of potato flour meal was prepared in 1786 that keeps sound for “any length of time” (Fraser, 1794). In World War I, a number of dehydrated potato products were manufactured for military use. This *war* industry practically disappeared soon after the hostilities ceased, although considerable quantities of potato flour both for stock feeding and human consumption continued to be produced in Europe and to a lesser extent in England and US. Potato starch has been produced both in Europe and US for over 100 years.

Composition and Uses

Potato is considered a wholesome food. It contains water (77%), carbohydrates (20%), proteins (2%), minerals (K, P, Ca, Mg, Fe, Na and S) and vitamins (Vit. C and A). Baked potato provides 69Kcal /100 g. Potato proteins and starch are superior to cereal proteins and starch. Besides, it is a rich source of potassium and therefore, very good for patients suffering from heart ailments. Besides, chips, it is also used for production of starch and is also dehydrated.

Area Production and Productivity

India is the second largest producer of potato with an area of 19.92 lakh hectares and production of 453 lakh tonnes next only to China with 54.29 lakh hectare area and 858 lakh tonnes of production. Table 1 gives the country-wise area, production and productivity of potato in the World.

Table 1: Country-Wise Area, Production and Productivity of Potato in the World (2012-13)

Country	Area (ha)	Production (MT)	Productivity(MT/ha)
China	5429000	85860000	15.8
India	1992211	45343590	22.8
Russian Federation	2197200	29532530	13.4
Ukraine	1444100	23250200	16.1
USA	458388	19165865	41.8
Germany	238300	10665600	44.8
Poland	373000	9091900	24.4
Bangladesh	430446	8205470	19.1
Belarus	332255	6910945	20.8
Netherlands	149770	6765618	45.2
Others	6249623	120360640	19.3
World	19294293	365152358	18.9

Source: Indian Horticulture Database 2013

In India, Uttar Pradesh is the largest producer with an area of 6 lakh hectares and production of 144 lakh tonnes followed by West Bengal with an area of 3.86 lakh hectares and production of 116 lakh tonnes. The highest productivity of Potato is seen in Gujarat i.e. 30.8 tonnes per hectare. Table 2 gives state-wise area, production and productivity of Potato in India.

Table 2: State-Wise Area, Production and Productivity of Potato in India (2012-13)

State	Area ('000 ha)	Production ('000 MT)	Productivity (MT/ha)
Uttar Pradesh	603.76	14430.28	23.9
West Bengal	386.81	11591.30	30.0
Bihar	322.46	6640.55	20.6
Gujarat	81.27	2499.73	30.8
Madhya Pradesh	108.87	2299.00	21.1
Punjab	85.25	2132.31	25.0
Assam	99.77	975.27	9.8
Karnataka	44.40	698.30	15.7
Haryana	29.47	676.02	22.9
Jharkhand	47.21	659.81	14.0
Others	183.1	2741.2	15.0

Total	1992.2	45343.6	22.8

Source: Indian Horticulture Database 2013

Potato production in India has followed a constantly increasing trend. Table 4 gives year-wise trend of potato production in the country.

Table 4: Historical Trend of Area, Production and Productivity of Potato in India

Year	Area ('000 ha)	% of Total Veg. Area	Production ('000 MT)	% of Total Veg. Production	Productivity (MT/ha)
1991-92	1135.1	20.3	18195.0	31.1	16.0
2001-02	1259.5	20.5	24456.1	26.1	19.4
2002-03	1337.2	22.0	23161.4	27.3	17.3
2003-04	1484.7	23.5	27925.8	30.0	18.8
2004-05	1523.9	22.6	28787.7	28.4	18.9
2005-06	1569.2	21.9	29174.6	26.4	18.6
2006-07	1743.0	23.0	28600.0	24.9	16.4
2007-08	1795.0	22.9	34658.0	27.0	19.3
2008-09	1828.0	22.9	34391.0	26.6	18.8
2009-10	1835.3	23.0	36577.3	27.3	19.9
2010-11	1863.0	21.9	42339.0	28.9	22.7
2011-12	1907.0	21.2	41482.8	26.5	21.8
2012-13	1992.2	21.6	45343.6	28.0	22.8

Source: Indian Horticulture Database 2013

Soil and Climate

Potato is basically a *Rabi* season crop but also grown in the *kharif* season in hilly regions. Optimum temperature for growth and development is 15-25^{0}C with a maximum of 30-32^{0}C and a minimum of 10-20^{0}C in the plains and a maximum of 20-22^{0}C and a minimum of 12-15^{0}C in the hills. Maximum tuberization takes place at 20^{0}C. Sandy loams to silt clay soils with a pH range of 5.5 to 7.5 without hard pan up-to one meter depth are considered best for Potato cultivation.

Cultivation Aspects

Potato is traditionally grown using **tubers. Tissue culture** technique (mini-tubers, micro-tubers) holds promise. True Potato Seed (TPS) technique could not take off in India because of heavy management required. **Aeroponics** is a new innovation in potato husbandry. An acre of potato cultivation requires around 1500-1800 kg of tuber seeds. The land is ploughed at a depth of 24-25 cm and exposed to the sun. The soil should have a higher pore space and offer least resistance to tuber development. Well decomposed FYM (25-30 t/ha) is mixed with the soil during last ploughing. In India, the crop geometry is **18*5 inch**. Potato seed tuber of any weight is cut into two to three parts to reduce the cost of seed (seed is the costliest input in potato cultivation) and sown in ridges and furrows. Potato requires light but shallow **irrigation** as the root system is shallow. First irrigation should be light and given 5-7 days after planting and subsequent irrigation are given at 7-15 days interval depending upon the climatic condition and soil type. The drip system of irrigation is most economical giving highest productivity and saving almost 50% water. It also enables application of fertilizers through irrigation water (fertigation).

Earthing up is an important operation as tubers should not be exposed to air; otherwise they will turn green and lose market value. It also keeps the soil loose and destroys the weeds. Two or three earthing ups should be done at an interval of 15-20 days. The first earthing-up should be done when the plants are about 15-25 cm high. The second earthing up is often done to cover up the tubers properly. Use of double mould board plough ridger or 3 and 5 row tractor drawn culti-ridger can accomplish the earthing up operation very well. **Weeds** are a menace in potato particularly in early stages (upto four weeks) Weeding can be done manually however it is expensive due to labor shortage. Hence, animal drawn three-time cultivator is used which can cover one hectare per day. Alternatively pre-emergence spraying of weedicides such as Flucholralin (0.70-1.0 kg a.i/ha) or Pendimethalin (0.50 kg/ha) is recommended for controlling annual grassy weeds and broad leaf weeds.

Varieties

Broadly the potato growing zones in India could be classified into the northern hills, the northern plains, the eastern hills, the plateau region and the southern hills. The growing season in the northern hills is the kharif season with long days. The crop experiences water stress during the emergence and initial growth phase while during the maximum bulking phase it is invariably exposed to late blight infection. Therefore varieties for this region requires resistance to late blight, should be able to withstand water stress, be able to yield well under long day conditions and the crop duration can be between 120 – 150 days. Presently **Kufri Jyoti and Kufri Giriraj** are the main varieties for this region.

The northwestern plains comprises of the Indo Gangetic plains extending from Punjab in the West to West Bengal in the East. Here, autumn is the main potato season. The crop duration is short about 100-120 days in the West but a short spring crop can also be raised. In the central and eastern Indo Gangetic plains, the winter season is short and spring crop is invariably not possible. The potato varieties adapted to the Indo Gangetic plains should be short to medium duration, having moderate resistance to late blight. At present **Kufri Jawahar, Kufri Chandramukhi, Kufri Sutlej** are recommended for the western plains while **Kufri Bahar, Kufri Anand and Kufri Ashoka** have been recommended for the central plains while **Kufri Pukhraj, Kufri Sindhuri and Kufri Ashoka** have been recommended for the eastern plains.

In the eastern hills, two crop viz summer and kharif crops are taken. Both the crops are relatively short and the kharf crop is prone to late blight. Resistance to late blight is a must. Presently **Kufri Jyoti** and **Kufri Megha** are the varieties recommended for the region. In the plateau region two crops viz kharif and Rabi are taken in many places. The kharif crop encounters long days, erratic rainfall, warm temperatures, high incidence of early blight and mites. **Kufri Jyoti** and **Kufri Lauvkar** are recommended for this season. The Rabi crop is of very short duration and early bulking variety like **Kufri Lauvkar** is successful in this season. **Kufri Jyoti** is also grown in this season.

In the southern hills, potato is grown in the Nilgiri hills. Three crops are taken. Potato cyst nematode and late blight are the problems of the region. **Kufri Jyoti** and **Kufri Swarna** are the varieties recommended for the region (CPRI, 2009).

Very few of the Indian varieties are suitable for processing because of high reducing sugar content. Foreign varieties suitable for processing are Russet series (mainly Russet Burbank), Shepody, Sierra Gold, Snowden, Lady Blanca etc.

Nutrient Management in Potato

Field experiments jointly conducted by International Potash Institute (IPI), Potash Research Institute of India (PRII) and Central Potato Research Institute (CPRI) at Shimla and Jalandhar show that a balanced N x K fertilization increased tuber yield. Increasing K doses decreased the yield of small grade tubers and increased the proportion of large marketable tubers. Potassium application also dramatically decreased the incidence of late blight. In 1998, a maximum yield of 40.8 t ha^{-1} was obtained at Kufri (Shimla) when applied 180 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1} and 150 kg K_2O ha^{-1}, against a tuber yield of only 14.6 t ha^{-1} at the control plots (Patricia and Bansal, 1999).

It is concluded that high yields and enhanced quality tubers can only be sustained through the application of optimal nutrient doses in balanced proportion.

Plant Protection

Numbers of pests are prevalent on potato. Prominent among these are cut worms (*Agrotis ipsilon*), tuber moth (*Phthorimaea operculella),* white grubs *(Holotricha sp.),* Tobacco caterpillar *(Spodoptera littura),* green leaf hopper *(Empoasca Kerri),* green peach aphid *(Myzus persicae) and* white fly *(Bemecia tabaci).* Few pests attack potato in storage also. Table 5 below gives the control measures for potato pests

Table 5: Pests of Potato and Their Control Measures

S. No.	Name of the Pest	Damage	Control Measures
1	Cut worms	Young larvae feed on the epidermis of the leaves. Older larvae come out at night and feed young plants by cutting their stems. They also damage the tubers by eating away part of them.	Chlorpyriphos 20EC @ 1 lit/ha
2	Tuber moth	Larva tunnels into foliage, stem and tubers. Galleries are formed near tuber eyes	Quinalphos 25 EC @ 2ml/lit
3	White grubs	Grubs feed on roots and tubers	Quinalphos 5% Dust @ 25 kg/ ha – 10 days after first summer rain
4	Tobacco caterpillar	The young larvae first feed gregariously and scrape the leaves. Older larvae spread out and may completely devour the leaves resulting in poor growth of plants.	Chlorpyriphos 20 EC @ 2lit/ha or Dichlorovos 76 WSC 1 lit/ha
5	Green leaf hopper	Tips of affected leaves become brown, turn upwards and get dried up	Dimethoate 30EC or Phosphomidon (Dimecron) @ 2ml/lit
6	Aphids	Aphids suck sap of plants, as a result of which leaves turn pale and dry up. This pest also transmits various viral to potato plants.	Dimethoate @ 0.3%
7	White fly	Nymphs suck sap from the leaves and lower their vitality. Yellowing and curling of leaf. Sooty mould develops on affected leaves.	Dimethoate @ 0.3%

Source: http://agritech.tnau.ac.in/crop_protection/potato/potato_1.html

Potato is attacked by a number of **diseases.** Major ones among them are late blight (*Phytopthora infestans*), early blight (*Alternaria solani*), wart (*Synchytrium endobioticum*), soft rot (*Erwinia carotovora* ssp *carotovora*), bacterial wilt or brown rot (*Pseudomonas solanaceraum*), black scurf and stem canker (*Rhizoctonia solani*), common scab (*Streptomyces spp.*), dry rot (Fusarium spp.), and potato leaf roll virus and potato mosaics. Most of these are spread through seed tubers. Seed (tuber) treatment with mancozeb is used to control dry rot and late blight while carboxin (including its sulphone analogue oxycarboxin) seed tuber treatment is used to control black scurf and stem canker which is a soil borne disease. Table 5 below highlights the major diseases of potato and their control measures.

Table 6: Major Diseases of Potato and Their Control

S. No.	Disease	Symptom	Control Measures
1	Late blight	Small pale green spots, which enlarge into large water soaked lesions. A white mildew (cottony growth) ring forms around the dead areas on the lower side of leaves. In dry weather, water soaked areas turn necrotic brown. On stems, light brown elongated lesions are formed which may encircle the stem. Tubers develop reddish brown, shallow to deep, dry rot lesions. The affected tuber flesh becomes 'caramalised' with a sugary texture. Frequently metallic tinge develops on the margins of the affected tissue	Mancozeb @ 0.2% (preventive sprays) Metalxyl @ 0.25%
2	Early blight	Small (1-2 mm) circular to oval brown spots on lower and older leaves. These lesions have the tendency to become large and angular at later stage. Mature lesions on foliage look dry and papery, and often have the concentric rings, looking like bulls eye. The symptoms on the tuber comprise of brown, circular to irregular and depressed lesions with underneath flesh turning dry, brown and corky. Lesions tend to enlarge during storage and affected tubers later become shriveled	Copper Oxychloride @ 0.30% and Bordeaux mixture @ 1.0%
3	Soft rot	Under low humidity, the initial soft rot lesions become dark and sunken. Under high humidity, the lesion may enlarge and spread to larger area. Tubers in advanced stages of decay are usually invaded by other organisms and the decaying tissue becomes slimy with foul smell and brown liquid ooze. The tuber skin remains intact and sometimes the rotted tubers are swollen due to gas formation. At harvest, many small rotted tubers with intact skin can be seen. The infected seed tubers rot before emergence resulting in gaps. The symptoms appear as water soaked lesions on the stem, leaves and petioles. The affected parts turn black and rot leading to toppling of the stem and leaves.	Treating the tubers with 3% boric acid for 30 min and drying them under shade minimizes infection in the storage
4	Bacterial wilt/brown rot	Slight wilting of the top, which is soon followed, by total wilting. In advanced stage, if the base of the stem of the affected plants is cut transversely and squeezed, the bacterial mass is seen to ooze out as a dull white slimy mass on the cut surface. Two types of symptoms are produced in tubers, viz. vascular rot and pitted lesions. In vascular rot, the vascular tissues look like a water soaked circle, which subsequently may turn brown. The lesions on tuber are produced due to infection through lenticels (skin pores). Initially water soaked spots develop which enlarge forming pitted lesions.	Bleaching powder @ 12kg/ha mixed with fertilizer in furrows while planting reduces wilt incidence by 80%.
5	Black scurf & stem canker	Dark brown to black irregular lumps sticking on the surface of tubers. These irregular lumps are closely adhered to the tuber surface and do not wash off easily. Other symptoms on the tuber include skin cracks, crater like depressions, pitting, stem-end necrosis and shape deformity	Seed treatment with Thiabendazole, TBZ + 8 HQC, Acetic acid + Zinc Sulphate, Carbendazim & Boric Acid effectively controls the disease
6	Common scab	abrasion of skin (russetting); corky lesions around lenticels which may be star shaped or irregularly circular; irregular concentric corky rings around lenticels; raised rough corky pustules and 3-4 mm deep	Phenyl Mercuric Acetate @

		pits surrounded by hard corky tissues including disfiguring of tubers.	
7	Dry rot	The skin of the dry rot infected tubers first becomes brown then turns darker and develops wrinkles. These wrinkles are often arranged in irregular concentric circles. In the later stage of infection, a hole may be observed in the center of the concentric ring with whitish or pinkish growth of fungal mycelium. On cutting these affected tubers, whitish or brownish tissues are seen with one or more cavities. Eventually the infected tubers loose water and become dry, hard and shriveled.	Seed treatment with Mancozeb (1 Kg in 450 liters of water)
8	Leaf roll virus	Top young leaves, usually stand upright, roll and turn slightly pale. The secondary symptoms of PLRV develop when plants are grown from infected seed tubers. Such symptoms are rather prominent in older leaves. Infected plants have characteristic pale, stunted and upright appearance with rolling of lower leaves that turn yellow, brittle and are leathery in texture.	Acephate for controlling aphid vector
9	Mosaics (Potato Virus A, X, M, S)	Inter-veinal and veinal chlorosis, mild mottling and slight crinkling of leaves. Top necrosis occurs in immune varieties while others express light yellowing of the leaf margins or shiny yellow mottle of the entire leaf lamina.	Use certified seeds

Physiological Disorders in Potato

Potato suffers many physiological disorders both in field as well as storage. **Internal brown spot** occurs due to improper irrigation. Small, round or irregularly shaped, light tan, reddish brown, or rust colored spots or blotches are found scattered throughout the tuber flesh. The brown spots consist of groups of dead suberised cells that are free of fungi and bacteria. The spots can be anywhere but are more commonly found inside the vascular ring and towards the apical end. There are no external symptoms except that larger and deformed tubers show a higher incidence of Internal Brown Spot. It can develop just after tuber initiation or during bulking in periods of rapid or uneven growth of tubers. Re-absorption of water or other constituents from tubers to support vegetative development cause tuber cells to die. This can occur during periods of plant stress normally on coarse textured soils with hot dry weather, high soil temperatures and low or fluctuating soil moisture. Calcium deficiency can also lead to Internal Brown Spot.

Hollow Heart

Develops during tuber initiation called stem-end Hollow Heart and or later in the season called apical Hollow Heart. Star shaped or lens shaped, cork lined cavity in the pith of the tuber is seen. Cavities can range from tiny openings to pockets nearly the size of the entire pith tissue. Possible causes include splitting of the central tissue during excessively rapid tuber growth. Breakdown of tissue in the centre of the tuber during early stages of growth due to potassium deficiency followed by rapid tuber growth is another reason for occurrence of hollow heart. Stresses during or shortly after tuber initiation cause potato plants to take water, minerals and carbohydrates from the young growing tubers, resulting in the death of some cells. When the stresses are relieved on return of favorable growing conditions, it results in rapid tuber enlargement, causing the injured cells to separate thus forming the Hollow Heart cavity.

Black Heart

Is due to high storage temperature and low oxygen supply. Due to high temperature the tissues break down, resulting in high respiration and failure of gas-exchange. The net result is that the tubers are spoiled. If the affected tubers are cut to examine the cut surface turns pink, then dark brown to black. Providing sufficient aeration and storing the tubers in thin layers on racks help to avoid the damage.

Chilling Injury

At low temperature (around 0 to 1 degree Celsius) potatoes suffer chilling injury. In studies conducted by Howard *et al* (1969) it was concluded that when Potato tubers held continuously 19 weeks at 32^0 F developed chilling injury symptoms early during storage and the symptoms worsened with time in storage. Early symptoms included browning and surface mold on skinned areas. By 11 weeks mahogany browning, blackheart, and hollow heart, bluish skin discoloration and sinking of intact skin were visible in daylight. And under ultraviolet light, yellow fluorescence was visible in halos, washes, or spots around or near internal tuber tissues discolored by other chilling-injury symptoms. Some damage at 32 F became visible after subsequent holding of tubers for 1 week at 60 F. Tubers accumulated high amounts of reducing and total sugar at 32 F and respiration, measured at 60 F as CO_2 evolved, was progressively stimulated by time at 32 F. Sugar build-up, respiration-rate increase, and chilling injury seemed to show no cause-and-effect relationship but appeared as separate phenomena each caused by the stress of holding tubers at too low a temperature.

Freezing Injury

At subzero temperatures, potato suffers freezing injury. According to Wright (1927), freezing injury is the term usually applied to injury caused by freezing after potatoes have been dug and removed from the field. It occurs while they are in storage or in transit. A study of the development of freezing injury in potatoes shows that freezing progresses somewhat rapidly in comparison with the rate at which it takes place in some of the fruits or other vegetables. Numerous observations on potatoes with thermocouples inserted have shown that freezing begins almost the instant under-cooling terminates. When the tubers are inoculated by being struck sharply with a pencil or by quickly withdrawing and again inserting the thermocouple, freezing is indicated by a quick rise in temperature from the under-cooled point to the freezing point.

Potato Greening

The role of a potato tuber for the potato plant is to produce the next generation of potatoes. It therefore contains nutrients in the form of starches, sugars, proteins and minerals for the new potato plant. When a potato tuber is exposed to light it turns green by producing chlorophyll and then can make extra energy for the new plant through photosynthesis. The green patches act in the same way as leaves do. The potato plant also has the interesting ability to produce its own protective chemicals which can make it lethal to insects, animals and fungi which attack it. These protective chemicals (glycoalkaloids) are at high levels in the leaves, stems and sprouts of the potato plant and are normally at very low levels in potato tubers. Upon exposure to light, however, the potato tuber will produce elevated levels of these protective glycoalkaloids, with the highest levels being in the sprouts as they emerge from the tuber. Potatoes will also produce high levels of glycoalkaloids (such as solanine) in response to bruising, cutting and other forms of physical damage, as well as to rotting caused by fungi or bacteria. In these instances high levels of glycoalkaloids are present in the potato. However, in non-damaged potatoes, greening is a warning sign.

Green potatoes may cause food poisoning (CSIRO, 2009) and since some of the symptoms are similar to gastroenteritis it is possible that some undiagnosed cases of gastroenteritis have been caused by eating green potatoes. Human and livestock deaths have been recorded as a result of the consumption of greened or damaged potatoes with very high glycoalkaloid levels. It should be noted that glycoalkaloids are not destroyed by cooking processes, even by frying in hot oil. Consequently potatoes with pronounced greening or with signs of damage should not be eaten. It is advisable that green or damaged potatoes are avoided by pregnant women or women who are likely to become pregnant, as there is some evidence of possible foetal damage or loss of the foetus from glycoalkaloid poisoning in animals.

Potato Sprouting (In Storage)

High moisture and temperature favour sprouting in Potatoes. During sprouting starch converts to sugar. Sprouted Potatoes are not recommended for consumption. At least the sprouted part should be removed before consumption. Seed Potatoes when stored are applied with CIPC (Chloropham) an anti sprouting agent. It is applied as an aerosol or emulsifiable concentrate. Internal sprouting is a malformation in which a lateral sprout grows inward into the tuber or outward into an adjacent tuber. This tuber defect mainly occurs in long term storage, and then only occasionally. The causes of this disorder are not well understood but appear to be related to a lack of CIPC on or around tightly packed Potatoes.

Harvesting

For most commercial varieties, yellowing of the potato plant's leaves and easy separation of tubers from stolons indicates that the potato crop has reached maturity. If the potatoes are to be stored rather than consumed immediately, they are left in the soil to allow their skin to harden – hard skin also help seed potatoes to resist storage diseases. However, leaving tubers for too long in the ground increases their exposure to the fungal disease black scurf and increases the risk of losing quality and marketable yield. To facilitate harvesting and stop tuber growth, potato vines should be removed two weeks before the potatoes are dug up. Depending on the scale of the production, potatoes are harvested using a spading fork, a plough or commercial potato harvesters that unearth the plant and shake or blow the soil from the tubers. During harvesting, especially if it is done mechanically, it is important to avoid bruising or other injuries, which provide entry points for storage diseases and reduce the commercial, processing quality and storability of the tubers. In suitable environments and where growing conditions are adequate, commercial yields are in the range of 40–60 tonnes per hectare. In many developing countries, however, they are far below this figure, with national averages of about 10- 20 tonnes per hectare (FAO, 2009).

Storage

Potatoes are semi perishable because they contain about 80% water and 20% dry matter (Woolfe,1987).The optimum temperature for storing ware potatoes is $4\text{-}7^0$ C and for seed potatoes $2\text{-}5^0$C (Hesen,1987). In the Indian cold storage industry, the two most important problems are: higher energy consumption and storage losses beyond the permissible limits. The annual electrical power consumption in the commercial potato cold storages varies from 4 – 6.5 units per quintal. Also, the storage losses account for 3 – 10 % of the stored product in the form of rotting, cold injury, weight loss, sprouting, nutritive value degradation, etc (Chourasia and Goswami, 2001). However, the potato losses may increase up to 38 – 45 % due to defective design, poor storage management and inefficient operations (Bhatnagar and Gupta, 1979).

SECTION 3

HARMFUL EFFECTS OF CHEMICAL PESTICIDES

Potato pesticides pose serious health hazards. For example, 14 of 41 commonly-used potato pesticides are classified as carcinogens by the U.S. Environmental Protection Agency. These include chlorothalonil, mancozeb and iprodione, as well as the fumigants dichloropropene and metam-sodium. Pesticide residues on potatoes are common; 83 percent of potatoes sampled recently by the U.S. Department of Agriculture were contaminated with pesticides. In addition, these chemicals are showing up in water and in our food. Thirty-three of the 41 pesticides have been linked to impacts on the endocrine system, reproductive system, and male fertility. The endocrine system is the collection of glands and hormones (chemical messengers) that regulate growth, development, behavior and sexuality. Certain chemicals, including widely-used pesticides, can disrupt the functioning of the endocrine system.

A small dose of an endocrine-disrupting chemical at a critical point in development could have lifelong impacts. The kinds of impacts that are being attributed to endocrine disruption include abnormal sexual organs, behavioral abnormalities, and population declines in wildlife, birth defects, and cancer. Farmers and farm-workers have the highest exposures to these chemicals because they work with the chemicals and live in the area where the applications occur. Additionally, farmers, farm-workers, and consumers are also exposed to these chemicals through the water they drink and the food they eat.

Twenty out of the 41 pesticides used on Potato have been detected in groundwater or surface water. Four out of these 20 are most commonly used on Potato. In another study of groundwater in central Washington, researchers found that 67 percent of the well samples were contaminated with pesticides. In addition, 23 compounds (pesticides, pesticide degradation products, or impurities) were found in groundwater under irrigated crop land. The U.S. Department of Agriculture's pesticide monitoring program found pesticides on 32 percent of the potatoes sampled. When post harvest treatments were included (the sprout inhibitors chlorpropham and thiabendazole) the percentage of detections increased to 83 percent. Up to 18 different pesticides were found on potatoes.

Seed treatment fungicides are an important Agri input to maintain good plant health in Potato. At the same time they constitute a major input cost for potato farmers. Mancozeb (DM-45) which is used to control Late blight and dry rot, along with its degradate, Ethylene Thio Urea (ETU) has many adverse effects on environment, soil and a number of life forms. As observed by (Zbigniew *et al*, 2009), that when soil micro-arthropods were exposed to the pesticide mancozeb (240 mg per 1 m2) over a six month period, there was significant reduction in their population. Another study conducted by Pallavi Srivastava and Anjay Singh in 2009 indicated that when fresh water fish, *Clarius batrachus* were exposed to Mancozeb at 80% of LC 50 (22.87mg/l) for 24 hours, protein, amino acids, glycogen, nucleic acids and enzyme succinic dehydrogenase decreased in liver and muscles, but lactic dehydrogenase levels, protease, GOT and GPT increased in the both tissues. Literature by Armenian Women for Health and Healthy Environment (AWHHE)- a non-profit, non-governmental organization in Armenia, concludes that chronic skin diseases have been observed in workers exposed to Mancozeb. It is a potential ground water contaminator, suspected endocrine disruptor, reproductively toxic. In Sweden, Mancozeb was classified as carcinogenic and severely restricted. In Norway, it was phased out by 2000.

SECTION 4

NON-CHEMICAL ALTERNATIVES TO AGROCHEMICALS IN POTATO PRODUCTION

Potatoes can be successfully grown using a variety of innovative techniques instead of pesticides. Green manure crops can reduce pest nematode populations, and corn grown in rotation with potatoes controls the disease verticillium wilt.

Specifically, there are many non chemical alternatives to mancozeb. A combination of compost tea and microbes yielded same production but significantly less diseased leaf area when treated with Mancozeb (Ridomil MZ) and Brestan 60. Serenade a bio-fungicide produced by Agra Quest Inc, is a wettable powder formulation of *Bacillus subtilis,* QST-713 strain. *B. subtilis* is applied as a preventative fungicide and works as an antagonist against many pathogens, including *P. infestans that* causes late blight. When applied to the foliage, Serenade inhibits attachment of the pathogen, stops it from growing, and induces an acquired resistance in the plant (George Kuepper and Preston Sullivan, 2004). Use of resistant varieties is a safe alternative. Varieties like A74114-4, A76260-16, and BR6316-7 are highly resistant to the two common *Fusarium* dry-rots (Dennis and Joseph, 2009). Genetically modified Potato Desiree offers some hope in future against the dreaded late blight disease.

Carboxin (vitavex) is used to control black scurf and stem canker in Potato. Carboxin was first registered as a pesticide in the U.S. in 1968. Carboxin has been shown to have low acute toxicity. Toxicity Categories, which range from I (most toxic) to IV (least toxic), were III for the oral route of exposure, IV for inhalation, and III for dermal. Carboxin is a slight eye irritant (Toxicity Category III), is not a skin irritant (Toxicity Category IV), and is negative for dermal sensitization (EPA, RED Facts, Carboxin-2004). However, Double Nickel LC (*Bacillus amyloliquifacines* Strain D747, a registered biofungicide can be effectively used to control the disease in a non chemical manner (Organic Minerals Review Institute, 2012). Another alternative is the use of *Gliocladium catenulatum* str. J1446 (Prestop) at the rate of 1.4-3.5 oz/2.5 gallons of water as a soil drench.

Chlorpyriphos is used to control soil pests like cut worms and also tobacco caterpillar. There are several organic alternatives to Chlorpyriphos. PFR-97 20% WDG *(Isaria fumosorosea Apopka str.97)* is most widely used against cut worms and tobacco caterpillar particularly in the US. It is soil applied. PyGanic EC 5.0 (Pyrethrins) can also be effectively used. Quinalphos is traditionally used to control tuber moth and white grubs. However, it can be effectively replaced by *Metarhizium anisopliae* application @ 4×10^9 conidia ha^{-1}. Dimethoate is used to control green leaf hopper, aphids and white flies. An organic alternate is garlic oil (available as Bio-repel) applied at the 1% with water.

Indian Scenario on Non Chemical Alternatives to Agrochemicals used in Potato Cultivation

In India organic potato cultivation area is almost negligible. Specifically, as such there are no exact organic alternatives available to disease control chemicals like Mancozeb and Carboxin. However, liquid biofertilizers strains like Azotobacter and Azospirillum are found to have diseases suppression activity in general. Azotobacter *chroococcum isolate KG 5* exhibited activity against *Aspergillus terrus, Alternaria alternata* and *Fusarium oxysporum* and produced IAA and Gibberellins in 53 µg/ml and 62 µg/ml amount respectively (Mali and Bodhankar, 2009). Alternaria spp. cause early blights and *Fusarium oxysporum* is responsible for causing wilt in many crop species. Use of resistant varieties like Kufri Jyoti and Kufri Badshah is also recommended in areas where late blight is prevalent.

International Practices of Chemical Free/Organic Potato Production

Using disease and pest resistant varieties along with use of biofertilizers for supplying proper nutrition, is the first and foremost step to be followed for organic Potato production. Spraying fish and seaweed emulsion on the potato foliage at two week intervals makes the plants strong and keeps growth vigorous. In the United States (Cornell Region) Late blight is managed by application of *Bacillus amyloliquifaciens* Strain D 747 (Double Nickel 55/LC) at the rate of 0.25 to 3 lbs/acre as foliar spray. It can also be managed effectively by using *Bacillus subtilis* Strain QST 713 (Optiva) at the rate of 14-24 Oz per acre. Another alternative is to apply *Bacillus pumilis* (Sonata) at 2-4 q/acre while dry rot can be managed through *Streptomyces lydicus* WYEC 108 (Actino Iron) applied at 10-15 lb/acre or *Trichoderma asperellum* (Biotam) at the rate of 1.5-3 oz/1000 rows ft.

In seven European countries studies by Tamn *et al* (2004) it was revealed that organic Potato production reduced the yield by an average of 30% however the price realized was 1.5 to 4 times higher for organic potato. Since the consumer awareness on the benefits of organic Potato consumption is very high, organic potatoes find a very good market and the monetary return reduction due to yield loss is compensated by higher prices. Hence, organic Potato production in European countries like Denmark, France, Germany, Netherlands, Norway, Switzerland, United Kingdom) makes a good business sense for farmers. Accordingly area under organic Potato production in Europe increased by 11% (Denmark) to 89% (Netherlands) between 1998 and 2000. However, in India, since the consumer awareness on ill effects of chemical fungicides in tuberous vegetables is low and the majority consuming population is middle class and lower middle class which may not afford to pay for 1.5 to 4 times higher prices for organically grown potatoes, organic measures of Potato production have not gained much significance in India.

SECTION 5

PESTICIDES REGULATORY MECHANISM IN INDIA

In India, the production and use of pesticides are regulated by a few laws which mainly lay down the institutional mechanisms by which such regulation would take place – in addition to procedures for registration, licensing, quality regulation etc., these laws also try to lay down standards in the form of Maximum Residue Limits, Average Daily Intake levels etc. Through these mechanisms, chemicals are sought to be introduced into farmers' fields and agricultural crop production without jeopardizing the environment or consumer health. These legislations are governed and administered by different ministries – the regulatory regime and its enforcement have several lacunae stemming from such an arrangement. An added dimension is that administration of the legislations includes both state governments and the central government.

The Central Insecticides Act 1968 is meant to regulate the import, manufacture, storage, transport, distribution and use of pesticides with a view to prevent risk to human beings, animals and the environment. Through this Act, a Central Insecticides Board has been set up to advice the state and central governments on technical matters and for including insecticides into the Schedule of the Act. This Board, under the Chairmanship of the Director General of Health Services, consists of 29 members. Around 625 pesticides have been included in the Schedule so far. The Board is supposed to specify the classification of insecticides on the basis of their toxicity, their suitability for aerial application, to advise the tolerance limits for insecticide residues, to establish minimum intervals between applications of insecticides, specify the shelf life of various insecticides etc. Then there is a Registration Committee which registers each pesticide in the country after scrutinizing their formulae and claims made by the applicant as regards its efficacy and safety to human beings and animals. The Registration Committee is also expected to specify the precautions to be taken against poisoning through the use or handling of insecticides. This Registration Committee has five members including the Drug Controller General of India and the Plant Protection Adviser to the Government of India. Around 181 pesticides have been registered by the Committee so far in India. Then, there are other institutions like Central Insecticides Laboratory and Insecticides Inspectors to ensure that the quality of insecticides sold in the market is as per norms. The Central Insecticides Laboratory is also meant to analyze samples of materials for pesticide residues as well as to determine the efficacy and toxicity of insecticides. This laboratory is also responsible for ensuring the conditions of registration. In addition, there are other related laws like Prevention of Food Adulteration (PFA) Act, 1954 under the Ministry of Health and Family Welfare, which need to be adhered to.

SECTION 6
CONCLUSIONS

Taking all the above aspects into count, it can be concluded that chemical free potato production is possible. In India, chemical free potato production practices are not so popular because of the absence of a strict regulatory mechanism. The problem requires a three pronged strategy. First the government should, in a phased manner restrict the use of chemical pesticides and organic growers should be rewarded apart from monetary incentives in terms of higher price realizations. The government should also start pesticide residue testing laboratories in large numbers across the country. The consumer has to become more aware and alert. Public interest campaigns need to be run highlighting the ill effects of chemical pesticides on human health, environment, soil, flora and fauna. Sustainable production and clean cultivation has to be introduced as compulsory module in Agricultural courses. At the same time newer technologies need to be brought in. Early adopters of these new eco friendly technologies need to be properly recognized and incentivized. In context of the farmer, he needs to be made aware that in the long run chemical pesticides will not only change the soil chemistry will also render it infertile, apart from playing havoc with his own health.

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