

Volume 49 No. 2, 2022

ISSN 0970-8235 (Print)
ISSN 0973-5909 (Online)

Potato Journal

An international journal for potato R&D especially in the sub-tropics
Available online: <http://epubs.icar.org.in/ejournal/index.php/PotatoJ>



**Official Journal of
The Indian Potato Association**

Potato Journal (ISSN Print: 0970-8235, Online: 0973-5909)

It is the official journal of the Indian Potato Association (IPA). The journal covers all areas of potato research including Genetics, Breeding, Biotechnology, Agronomy, Soil Science, Seed Technology, Plant Pathology, Entomology, Storage, Physiology, Biochemistry, Post Harvest Technology, Agricultural Economics, Marketing, Statistics, Extension and Farm Machinery. The journal is published in two issues to form one volume per year. Information for authors can be found at the end of each issue. Acknowledgments to reviewers are published in the December issue. The IPA was founded in 1974 with the objectives to advance the cause of potato research and development. Besides publishing Potato Journal (Formerly Journal of Indian Potato Association), the IPA also holds conferences, symposia and workshops to provide opportunities for personal contacts among potato workers to promote and exchange scientific and other information and to develop means of interaction among potato researchers, industry, farmers and consumers.

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Volume 49 No. 2, 2022

ISSN 0970-8235 (Print)
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Indian Potato Association,
ICAR-Central Potato Research Institute,
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Abstracted in : CAB International, UK
Biosis, Philadelphia
AGRICOLA, USA
SCOPUS, Elsevier, The Netherlands
Indian Science Abstracts, NISCAIR, India
Indian Citation Index, India
Cosmos Foundation Germany

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DEVELOPMENT OF QUALITY POTATO SEED PRODUCTION SYSTEM IN RUSSIA

Boris V. Anisimov*, Evgeny A. Simakov, Alexey V. Mityushkin,
Alexey A. Zhuravlev and Sergey N. Zebrin

ABSTRACT: The modern system of seed potato production and commercial quality control was developed by Russian Research Centre of Potatoes and approved further by Interstate Council for Standardization, Metrology and Certification. The major aspects concerning the common terminology, classification, specifications and methods for determining the quality adopted in Russia and unified with international systems and UNECE-Standard. In the present study minimum requirements for early generation seed production (original seed), further multiplication (elite seeds) and for end-use ware potato production (reproductive seed) is presented. Which includes: varietal identity and purity, diseases and pests, external tuber quality, sizing and labeling. The modern system of seed potato quality control includes field surveys during crop growth, post-harvest control (tuber analysis) and comparative field trial of seed potato samples. The major objective of comparative field trial in 2020-2021 crop seasons with the normative tolerances of the standard requirements related to varietal identity and purity and the level of viral and bacterial diseases transmitted through seed material. 288 samples of original seed potatoes were evaluated on the test-plot of the experimental base located at «Korenevo» of the Russian Research Centre of Potatoes (Moscow region) to determine their varietal identity, the presence or absence of other variants and plants affected by virus and bacterial diseases. Results of comparative field trial of original seed potato samples are considered in this article.

KEYWORDS: seed potato, quality requirements, varietal samples, comparative trial.

INTRODUCTION

The potato is one of the main food stuff product in Russia. The average potato yield 17-18 t/ha is below than that of many potato producing countries. Requirement of good quality seed is universally considered for high productivity in all potato production systems (Forbes *et al.*, 2020; Singh and Sharma, 2018; Haverkort and Anisimov, 2007). One of the main factors determining the low level of potato yields in Russia is production and usage of low quality seeds. The total demand of potato planting material is therefore evaluated at more than 3 million tons (15% above than the total volume of potato production), but the volume of certified seed potato is not sufficient now. As a result many potato producers including agricultural enterprises, peasant farms and especially small private family farms use non-

certified seed potato which is badly affected by virus, bacteria and fungus infections. That is why one of the most important factors of yield increase and efficiency of potato production is to form the best seed growing system and improved quality of seed potato in Russia (Simakov *et al.*, 2008; Anisimov *et al.*, 2018).

Global potato trade is increasingly developing; therefore, it is necessary to unify and harmonize the Russian Potato seed quality control system with the international one, which is adopted by United Nations Economic Commission for Europe (Anonymous, 2017; UNECE Standard S-1, 2017).

MATERIALS AND METHODS

The field trial was conducted by taking basic clones selected from the bank of healthy potato varieties with optimized norms and

minimum requirements of diseases, and defects in crop and lots for three categories of seed potatoes: Original seed material (OS), Elite seed classes (ES) and Reproductive seeds (RS). Classes/generations of OS can be represented by following: healthy mother potato plants selected in the field or obtained through techniques of tissue culture; mini-tubers which are grown in the greenhouses, aeroponic and hydroponic facilities; 1st field generation from mini-tubers and super-super-elite class. ES is derived from original seed material. The super-elite and elite seed classes are included in this group. RS is the next field generation derived from the elite seed. The seed material of 3rd and following field generations after elite cannot be certified.

In 2020-2021 crop season, at the Russian Research Centre of Potatoes (Moscow region), the comparative field trial of original seed potato samples was carried out. The Comparative test material, of 288 samples, were obtained from original seed potato growers and were planted on the test plot in sequential order according to categories and classes (generations) of seed, starting with mini-tuber samples, then the first field generation and super-super-elite. Plots with samples of the same generation within each cultivar were placed side by side, so that the samples with the presence of atypical plants or with external symptoms of diseases were clearly visible during observations and convenient for their detailed comparative analysis with reference samples obtained directly from the originator of the cultivar.

During the growing season, the samples on the plots were examined to identify signs that deviated from the official description of the variety, as well as external symptoms of the diseases transmitted through the seed material. Since many varietal traits can appear in different phases of plant growth and development, at least 3 assessments were

carried out immediately before and after the flowering. Viral diseases were controlled by external symptoms of moderate and severe mosaic (PVM and PVY), as well as by the method of immunodiagnostics of leaf samples taken at the emergence of full shoots. Finally a joint survey of the samples was carried out during the flowering period of plants on the test plot, and the results of the observations were discussed with the participation of the originators of the varieties and producers who had submitted their samples for comparative verification tests.

RESULTS AND DISCUSSION

Sequential potato seed production process in Russia is represented by three structure blocks, which include production of original, elite, and reproductive seeds. The original potato seed production block includes the production of virus-free seed from sterile *in vitro* crop (microplants and microtubers), growing minitubers in a controlled environment protected from vectors of infection, as well as growing the first field generation seed from minitubers and super-superelite potato under the conditions of pure phyto-hygiene and spatial isolation from lower classes/generations of potato seed and commercial potato.

Elite seed categories includes production of classes of superelite and elite potato by sequential propagation of original potato seed while preserving and maintaining its high purity of a variety, productivity and sowing qualities.

Lots of elite potato varieties which comply with standards in terms of their sowing and varietal properties enters the trade turnover and are sold to agro-enterprises producing commercial potato, private farms, as well as farms of individual entrepreneurs and individual farms for variety transformation and variety change.

The general view of the innovative flow chart of the potato seed production process developed based on research of the Russian Research Centre of Potatoes is presented in Fig. 1.

Production of reproductive seeds includes seed produced from the first and second field generations intended for sale to farms producing commercial potato, farmers and common people. The third generations is the last stage in potato seed propagation and the yield is used for food, technical and feed purposes.

Based on the comparison of classification systems adopted in Russia and EU countries, the category of original potato seed may be conditionally made equivalent to the category of prebase (PB) potato seed. Accordingly, the category of elite potato seed is equivalent to the category of base potato seed (classes SE and E) and the category of reproductive potato seed is equivalent to the category of certified potato seed (classes A 1-2).

According to standards the maximum number of field generations should not

exceed 6, including 2 generations each for OS, ES and RS categories. In the EU countries, as recommended by the European Seed Association (ESA), up to a maximum of 9 generations are allowed, including in the category of prebase seeds – 4, base seeds – 3 and certified seeds – 2 field generations.

Experiences gained over the previous years has shown that the use of the innovative flow chart (Fig. 1) of the original seed production opens the potential for the expansion of time frames and more productive use of growing houses/ net houses/ poly houses and production equipment in the process of producing microtubers in *in vitro* crop plant during the fall-winter season (September-January) and clonal propagation of microplants during the winter-spring season (January-May). This makes it possible to substantially increase the volume of growing minitubers and the total quantitative yield of seed stock when growing the first field generation seed from minitubers and super-superelite potato varieties, which ensures 25-30% increase in profitability of production.

The modern system of seed potato quality control includes the following elements:

- Field inspection Haulm killing dates on the basis of aphid monitoring
- Visual and laboratory postharvest control (PCR and ELISA laboratory test)
- Lot inspection
- Comparative field trial of original seed potato samples for detailed check of the varietal identity and purity.

The tolerances established by the standard take into account the possible reduction of individual quality indicators during the production of OS, ES and RS categories. The tolerances for different categories of seed potato are reflected and also had - made



Fig. 1 The modern potato seed production system developed by Russian Research Center of Potatoes

changes in seed production and further marketing, with development of new methods for defection of harmful organisms.

The standard specifies minimum tolerance acceptable limits for the proportion of growing plants not true to the variety, affected by blackleg and showing symptoms of virus diseases. For example, the percentage of growing plants affected by PVY and PLRV should not exceed: 0 per cent for tissue culture and mini-tubers, 0.4 per cent for original field generation, 1 per cent for elite classes and 2 per cent for reproductive seed. Plants affected by Black leg should not exceed: 0 per cent for OS and ES categories and 1 per cent for RS crops.

For lots of seed potato tubers affected by wet rot are tolerated up to 1 per cent for class ES and RS only. Dry rot is tolerated up to 0.5 per cent for OS and 1 per cent for ES and RS categories. No rots are allowed in TC and mini-tubers. Common and netted scabs are allowed in all categories and classes except TC and mini-tubers no more than 5

per cent of tubers may exceed. Powdery scab is allowed in OS, ES and RS categories except TC and mini-tubers; no more than 1 and 3 per cent of tubers may exceed. Rhizoctonia is allowed OS, ES and RS categories except TC and mini-tubers no more than 1,3 and 5 per cent of tubers may exceed respectively. External defects (e.g. misshapen or damaged tubers) are tolerated up to 5 per cent in OS, ES and RS categories. Shriveled tubers are tolerated up to 1 per cent in OS, ES and RS categories. Shriveled tubers are not allowed in TC and mini-tubers(table1).

The seed potatoes shall be free from *Globodera rostochiensis* and *Globodera pallida*, *Synchytrium endobioticum*, *Clavibacter michiganensis* spp. *sepedonicus*, *Ralstonia solanacearum*, Potato spindle tuber viroid and *Ditylenchus destructor*.

The results of comparative field trial of original seed potato samples conducted at Russian Research Centre of Potatoes during the 2020-2021 growing season are presented in table 2.

Table 1. Tolerances for different categories of seed potato

	Tissue culture (TC)	Mini-tubers	OS	ES	RS ₁₋₂
Crop tolerances(per cent of plants)					
Other varieties and of types	0	0	0	0	0.5
Viral diseases*	0	0	0.4	1	2
Black leg (<i>Dickeya</i> and <i>Pectobacterium</i>)	0	0	0	0	1
Lot tolerances (per cent of tubers)					
Wet rot (<i>if not caused by Ralstonia s.</i>)	0	0	0	1	1
Dry rot	0	0	0.5	1	1
Common and netted scab**	0	0.5	5	5	5
Powdery scab**	0	0	1	3	3
Rhizoctonia**	0	0	1	3	5
External defects (misshapen and damaged tubers)	0	0	5	5	5
Shriveled tubers	0	0	1	1	1
Damaged tubers by pests	0	0	2	2	2

*Only severe mosaic (PVY) and potato leaf roll (PLRV) symptoms are considered.

**The tuber is considered as diseased in that case, if the proportion of the affected surface scab (common and netted)=33.3%; Surface powdery scab = 10%; Rhizoctomia = 10%.

Table 2. Results of comparative field trial of original seed potato samples (2020-2021)

Parameters	Mini-tubers	1st generation from mini-tubers	Super-super Elite	Total
Samples evaluated	91	106	91	288
Conforms to standard tolerances:				
- by true to type	90 (98.9%)	100 (94.3%)	89 (97.8%)	279 (96.8%)
- for viral diseases (PVY) and PLRV	81	82	67	230
- for bacteriosis (black leg)	91	106	87	284
Exceeded standard tolerances:				
- true to type	1	6	2	9
viral diseases (PVY) and PLRV	10	24	24	58
- bacteriosis (black leg)	0	0	4	4

Based on the observations and assessments on the totality of the varietal distinctive characteristics of the plant, stem, leaf, inflorescence, the presence of plants with deviations in the typicality of varietal characteristics plant height and tuber shape was revealed on 6 samples of 1st generation and 2 samples of super-super elite. 6 samples of the first field generation, were identified as an admixture of another variety. Exceeding the established tolerances Symptoms of viral diseases (PVY) was found on 10 samples of mini-tubers, 24 samples of the first field generation and 24 samples of super-super-elite. External signs of bacterial diseases of plants (black leg) were found only in 4 samples.

The indicators of plant productivity and the structure of the yield differed depending on the conditions of the season, maturation period of the varieties and mainly corresponded to their varietal characteristics.

CONCLUSION

The development of Russian systems of seed potato and quality control facilitates the conditions to improve the quality of potato seed material, to increase potato production and to integrate the Russia into the international potato market. Unification and harmonization with international

requirements of Russian system of seed potato, quality control as well as transfer of modern potato technology is very important for the development of potato production in Russia. Now It is expected that Russia will lead with an overall improvement of potato yields on farms to a level of 25-30 tones/ha, reduction of losses from diseases and pests and improvement in economic parameters of potato production. That will enable us to attract investments from various sources (venture capital, entrepreneurs, interested breeding and seed potato company) for the development of the infrastructure, renovation and modernization of technical and technological levels of potato production.

CONFLICT OF INTEREST

The authors confirm that this manuscript has no conflict of interest

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MS Received: August 10, 2022; Accepted: December 09, 2022

EFFECT OF ORGANIC FERTILIZERS ON NUTRITIONAL AND PROCESSING QUALITY OF POTATOES (*SOLANUM TUBEROSUM* L.)

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ABSTRACT: The aim of this study was to determine the effect of different organic fertilizers on the nutritional and processing quality of potatoes. Composting of different materials was done using 12 formulations and it lasted 6 months. These compost formulations were used to grow potatoes, Kinigi variety, at the rate of 10 tonnes per hectare and control was used as well. Parameters analysed were moisture content, crude protein, crude ash, crude fibers, reducing sugars and total sugars using standard methods. There was a significant difference in parameters analysed for different treatments at $P < 0.05$. Moisture content ranged from 73.05 to 80.44%, protein from 1.22 to 3.64%, ash from 0.17 to 2.12%, fiber from 3.04 to 4.08%. Analysis of sugars showed that reducing sugars ranged from 1.29 to 2.28% and total sugars from 2.22 to 2.94%. These potatoes are suitable for boiled and mashed products. However, due to high sugar content, they are not suitable for dehydrated and fried products. Controlling maturity and handling should be emphasized in order to reduce the amount of reducing sugars.

KEYWORDS: Compost fertilizers, Nutritional quality, processing quality, potatoes, reducing sugars

INTRODUCTION

Potato (*Solanum tuberosum* L.) is an edible tuber which belongs to the family of Solanaceae and genus Solanum. It is an annual, herbaceous, dicotyledonous and vegetatively propagated plant that can grow as a perennial in selected environments and propagate through botanical seeds commonly known as true potato seed (CIP, 2022). It is the fourth most important in terms of human consumption after maize, wheat and rice. Potato consumption in Rwanda is at 145kg per capita (Rukundo, 2019). It grows well in Northwest part of the country. A good quality of potato is characterized by low moisture content around 80%, uniform shape and size with low reducing sugars. It has become a

routine to use fertilizers in order to enrich soils with lacking nutrients which leads to the increase in productivity.

To meet the food requirements of the growing population, the increase of food productivity for arable land is crucial. Nutrition of the plant is an important factor to control the productivity. Continuous use of agricultural land depletes nutrients in soil which leads to poor productivity (Savci, 2012). To mitigate this, people have adopted the use of fertilizers to increase productivity. Fertilizers are added to the soil to improve its physical, biological, and chemical properties. A physical property is related to soil friability, porosity and absorption (Sharma and Chetani, 2017). Biological properties are related to the

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microorganisms living in the soil (Sharma and Chetani, 2017). The chemical properties encompasses the soil pH (acidity level) and the availability of nutrients to the plants for absorption (Sharma and Chetani, 2017). Fertilizers contribute to rapid growth of the plant with bigger and healthy crops which leads to more food production. Use of mineral fertilizers has contributed to food security in many nations though it has left other many unsolved problems.

During industrial revolution which was followed by green revolution, the world adopted the use of inorganic fertilizers to increase production per unit area. Inorganic fertilizers comprise nitrogen fertilizer, potash fertilizer, phosphorus fertilizer, and compound fertilizers (Sharma and Chetani, 2017). Some of the minerals which are used in food production accumulate in the environment and lead to the environmental pollution. Excessive use of nitrogen in inorganic fertilizer leads to the leaching and accumulation of nitrate in drinking water and rivers (Savci, 2012). It was reported that around one third to one fourth of applied nitrogen fertilizer is lost as ammonium and nitrous oxide gases to the atmosphere or as nitrates to the surface or ground waters and they are associated with the environmental and health problems (Bahar *et al.*, 2019). Use of inorganic fertilizers was also reported to negatively affect the soil. Fertilizers containing sodium and potassium deteriorate soil structure and increase its acidity (Savci, 2012). Inappropriate application of inorganic fertilizer can lead to the emission of different gases which threaten the environment. These gases include carbon dioxide, methane, hydrogen sulfide with chloro-fluoro hydrocarbons like halon gases (Savci, 2012). Inorganic fertilizers contribute to the deterioration of the ecosystem.

Accumulation of chemical wastes in soil, water and air imparts a continuous toxicity

to the marine and land ceatures. Chemical wastes accumulates in the water bodies and when it is used in soil during irrigation, its continuous use degrades the soil health and quality hence causing the soil pollution. As a results environment and ecosystem are greatly destroyed. Accumulation of nitrogen in water leads to eutrophication which threatens marine life, while nitrosamines resulting from nitrates was reported to be carcinogenic (Bahar *et al.*, 2019). The adverse effect of these synthetic chemicals on human health and environment can only be reduced or eliminated by adopting new agricultural technological practices such as shifting from chemical intensive agriculture to organic agriculture which include the use of organic inputs such as manure, bio fertilizers and nanofertilizers that would improve the human health as well as environmental and ecosystem protection. Opting to organic farming will create a healthy natural environment and ecosystem for the present as well as future generation.

Organic fertilizer which consists of use of compost has been found to be more useful. Compost is a soil amendment produced through the metabolism of an organic substrate by aerobic microbes under controlled conditions. It is an ancient agricultural technology with important applications in modern cropping systems. In organic cropping systems, compost provides a primary source of nutrients to the crops (Seyedbagheri, 2010). It is an organic fertilizer that can be made at farm level and it consists of decomposed organic matter, such as crop residues or animal manure, most of these ingredients can be easily found around the farm (Seyedbagheri, 2010; Sharma and Chetani, 2017). A good compost is made up with five main components such as greens, browns, water, air and soil (Seyedbagheri, 2010). It can also be a mixture of organic

residues like manure, animal carcasses, straw, etc, that have been piled, mixed and moistened to undergo thermophilic process where microorganisms can feed on the organic components and convert the piled organic material to fairly stable nutrients rich soil amendment

Organic farming tends to be better for the environment by reducing pollution, conserving water and water health, reducing soil erosion, increasing soil fertility and health, and using less energy (Sharma and Chetani, 2017). Organic farming also creates healthy soil that does not need much water which results in growing healthy food. On the other hand, treating soil with harmful chemicals makes the soil dependent on these unnatural substances. Inorganic fertilizer is loosing popularity for both environmentalists and consumers.

Due to the increasing perception of consumers on the negative effects of synthetic fertilisers which have dominated agriculture of potatoes in Rwanda, and due to the high consumption rate of potatoes in Rwanda, it is worthwhile to increase potato production while using agricultural inputs which will protect environment with less or no health threatening effects. Therefore, the current research was conducted to evaluate the contribution of different organic fertilizers on chemical composition of potatoes.

MATERIALS AND METHODS

Area of study and composting

The experiment was conducted in Northern province, Musanze district, Busogo sector, UR-CAVM farm and laboratories. It is geographically located at 1°33'26" S and 29°32'39" E with altitude of 2221.00 m. The site is characterized by Andosol due to volcanic soil. The average temperature is 17.9°C with average annual rainfall of 1420 mm (Climate-

Data.Org, 2021). different composts were utilised for potato cultivation in the period of May to October 2021 and Kinigi variety was used. Each composting treatment had 3 m for length, 2 m for width and 1.7 m of height. The composting lasted 6 months. Mixing was done every month while 40 liters of cow urine or 40 liters of pig urine were applied every two weeks in case it did not rain in that period. Fertilizer application was at the rate of 10 tonnes of compost fertilizer per hectare. Details of compost fertilizers used are described below.

T1: Eucalyptus (fresh+ dry) + cow manure +cow dung+ soil

T2: Cyprus (fresh+ dry) + cow manure +cow dung+ soil

T3: Alnus (fresh+ dry) + cow manure +cow dung+ soil

T4: Eucalyptus (fresh) + Cyprus(fresh) + Alnus (fresh+ dry) + cow manure +cow dung+ soil

T5: Eucalyptus (dry) + Green plant + cow manure +cow dung+ soil

T6: Cyprus (dry) + Green plant+ cow manure +cow dung+ soil

T7: Alnus (dry) + Green plant+ cow manure +cow dung+ soil

T8: Eucalyptus (dry) + Cyprus (dry) + Alnus (dry) + Green plant+ cow manure +cow dung+ soil

T9: Eucalyptus (dry) + Cyprus (dry) + Alnus (dry) + Human hair+ Green plant+ cow manure +cow dung+ soil

T10: Human hair + Green plant+ soil + cow dung

T11: Cyprus (dry) + Green plant + pig manure + soil + pig dung

T12: Human hair + Green plant + soil from Alnus + cow dung

T13: No compost fertilizer was used

Proportions used:

- Layer of 30 cm of fresh mulch (when used alone)
- Layer of 20 cm of fresh mulch (when used with dry mulch)
- Layer of 10 cm of dry mulch (where it was applied)
- 45 kg of the cow manure compost
- 60 kg of the topsoil
- 20 liters of cow urine or pig urine
- One basin of human hair

Sample preparation

From each treatment 1 kg of potato of processing size was taken. Selected potatoes were fresh, free from disease and damage. They were transported carefully to UR-CAVM laboratory for further preparation and analysis. Selected potatoes were washed in tap water and spread at room temperature to dry off adhering water. They were thereafter sliced, dried in oven at 45°C until dried. They were then ground into flour and kept in refrigerator at 4°C for further analysis.

Determination of moisture content

Moisture content was determined using standard method (AOAC 2000). About 2 g of potato powder were weighed into a crucible dish and placed in heating oven at 105°C for 2 hours. The moisture content was computed as follows:

$$\text{Moisture content \%} = \frac{\text{Weight of wet sample} - \text{weight of dried sample} \times 100}{\text{Weight of wet sample}} \dots\dots\dots 1$$

Determination of crude protein

Crude protein was determined using kadjeldhal standard method (AOAC, 2000). About 2 g of finely ground flour were used. conversion factor (CF) used was 6.25

$$\text{N \%} = \frac{\text{ml acid for sample} - \text{ml acid for blank} \times \text{morality HCl} \times \text{DF} \times 14 \times 100}{\text{Weight of sample in mg}} \dots\dots\dots 2$$

$$\text{Crude protein \%} = \text{\%N} \times \text{CF} \dots\dots\dots 3$$

Determination of ash content

Crude ash was determined using(AOAC, 2000) method. About 2 g of sample of potato powder were weighed and added into the crucibles and placed in muffle furnace at 550°C for 4 hours. The ash content was computed as follows:

$$\text{Crude ash \%} = \frac{\text{Weight after ashing} \times 100}{\text{Weight of the sample}} \dots\dots\dots 4$$

Determination of crude fiber content

The method used by (AOAC, 1995) was adopted. The reagents consisted of 1.25% of sulfuric acid and 1.25% of sodium hydroxide. About 5 g of finely ground flour were weighed into a graduated glass beaker and 100 ml of hot water was added before adding 25 ml of sulfuric acid. The volume was increased to 200 ml with hot water and the contents were boiled for 30 minutes. Timing started onset of boiling and the volume was kept at 200 ml by constantly adding hot water with gentle boiling. After 30 minutes, they were vacuum filtered using the filter sticks packed with glass wool and washing was done three times with hot water. Thereafter, about 100 ml of hot water was added before adding 25 ml of 1.25% sodium hydroxide and the volume was increased to 200 ml with hot water and kept constant during boiling by adding hot water. The filter sticks were allowed to remain in the solutions with residue and boiled for 30 minutes. After they were removed, filtered, and washed three times with hot water. Residues and glass wool were transferred in 75 ml porcelain dish. The beaker of all residues were washed using hot water into the dish while filtering. Further washing was done and filtrates were collected in clean and dry crucible. The crucible with contents were dried in oven set at 105°C overnight, cooled in desiccator and weighed accurately. They were thereafter placed in the furnace set at 550°C for 4 hours to ash and then allowed to cool

to about 100°C and then continue cooling in a desiccator to room temperature and weighed.

$$\text{Crude fiber \%} = \frac{(\text{Weight of oven dried sample} - \text{weight of ashed sample}) \times 100}{\text{Weight of fresh sample}} \dots\dots\dots 5$$

Determination of reducing sugars

The Lane and Eynon titration method using Fehling's solution was used for determination of reducing sugars (RS) and total sugars (TS) (AOAC, 2000) no 925.35. About 10 g of sample were homogenized in 100 ml distilled water to dissolve all suspended particles followed by filtration with Whatman filter paper in a 250 ml volumetric flask. From filtrate, 10 ml of diluted HCl was added and boiled for 5 min. The obtained solution was allowed to cool at room temperature and neutralized with 10% NaOH using 3 drops of phenolphthalein as an indicator. It was there after made up to volume in a 250 ml volumetric flask with distilled water. The solution was titrated with Fehling's solution using 3 drops of methylene blue as an indicator and readings were recorded at the brick red end point and calculation used the formula below:

$$\text{Reducing sugars \%} = \frac{4.95 (\text{factor}) \times 250 (\text{Dilution}) \times 100}{\text{Weight of the sample} \times \text{Titre} \times 1000} \dots\dots\dots 6$$

$$\text{Total sugars \%} = \frac{4.95 (\text{factor}) \times 250 (\text{Dilution}) \times 2.5 \times 100}{\text{Weight of the sample} \times \text{Titre} \times 1000} \dots\dots\dots 7$$

Data analysis

Analysis of Variance was done using Minitab17 statistical software at 5% level of significance. Means separation was done using Tukey's HSD.

RESULTS AND DISCUSSION

Moisture content of potato

Moisture content of analysed potatoes was significantly different at ($p < 0.05$). The moisture content ranged from 73.05 (T8) to 80.44% (T12) as presented in Table 1. Norell *et al.* (2016) reported moisture content of 75 to 85% which aligns with this study. Moreover, these results agree with a study done on eleven cultivars in India showing a range from 78.10% to 84.85% of moisture content for fresh potatoes and from 77.2% to 83.7% after cold storage of six months (Pal *et al.*, 2008). Based on this study the moisture content for treatment (T12) was the highest,

Table 1 Nutritional composition of potatoes in percentage of fresh weight

Treatment	Moisture%	Protein%	Ash%	Fiber%
T1	75.18±0.014 ^b	2.27±0 ^{cd}	0.32±0.11 ^{fg}	3.15±0.02 ⁱ
T2	73.70±0.015 ^j	2.68±0.2 ^b	0.23±0 ^g	3.67±0.02 ^g
T3	80.34±0 ^b	2.56±0.2 ^{bc}	0.45±0 ^{defg}	3.56±0.13 ^f
T4	78.77±0.012 ^d	1.92±0.02 ^{de}	0.4±0.01 ^{efg}	3.29±0.04 ^h
T5	76.3±0.013 ^g	3.61±0.1 ^a	0.17±0.06 ^g	3.81±0 ^d
T6	77.44±0.012 ^e	2.15±0.1 ^d	0.4±0.01 ^{efg}	3.36±0.02 ^g
T7	74.57±0.014 ⁱ	1.28±0.1 ^{gh}	2.12±0.01 ^a	3.56±0.01 ^f
T8	73.05±0.015 ^m	1.69±0.1 ^{3f}	0.77±0.05 ^{cde}	4.08±0.01 ^b
T9	73.11±0.014 ^l	1.51±0.1 ^{fgh}	0.94±0.11 ^{bcd}	3.24±0.01 ^h
T10	73.31±0.015 ^k	1.57±0.3 ^{efg}	1.26±0.12 ^b	3.93±0.01 ^c
T11	76.7±0.013 ^f	1.22±0 ^h	0.92±0.04 ^{bcd}	3.04±0.03 ^j
T12	80.44±0.001 ^a	2.74±0.1 ^b	1.1±0.06 ^{bc}	3.42±0.02 ^e
T13	78.92±0.015 ^c	1.75±0.14 ^e	0.762±0.18 ^{cdef}	3.49±0.03 ^f

Means followed by the same letter in the column do not differ by Tukey's test at 5%

while treatment (T8) was the lowest and many treatments performed better than the control. Potatoes are classified based on their moisture content. Potatoes for dehydrated products, French fries and crisps should have moisture content of 80% and below, while the ones for canning should have moisture content above 82% (Marwaha *et al.*, 2010). T3 and T12 are slight higher in moisture content and the remaining are suitable for processing of fried and dehydried potato products and compost used can be adopted in potato production for different purposes.

Protein content of potato

Protein content of analyzed potatoes was significantly different among 13 treatments at ($p < 0.05$). Protein content ranged from 1.22 (T11) to 3.64% (T5) as shown in Table 1. The potato protein was reported to range from 1 to 5% (Rodriguez, 2011). Based on this study the protein content for treatment (T5) was the highest, while treatment (T11) was the lowest. The average protein content of potato was reported to be 2.57% (Liu, 2013). Protein content of some potatoes is above average. Potato protein is rich in essential amino acids with high biological value. Potatoes with high protein content are of paramount important due to their high biological value. Compost T5, T3, T2 and T1 can be recommended where high amount of protein is needed. However, free amino acids should be low as their contribute to browning and acrylamide formation in fried potatoes.

Ash content of potato

Ash content of analyzed potatoes were significantly different among 13 treatments at ($p < 0.05$). Ash content ranged from 0.17 (T5) to 2.12% (T7) as shown in Table 1. Stone *et al.* (2011) reported total ash of four potato varieties from four different areas of Japan to range from 0.88 to 1.03%. Based on this

study the ash content for treatment (T7) was the highest, while treatment (T 5) was the lowest. The high amount of ash content means the presence of high amount of minerals. Minerals play vital role in humans due to their contributions to the human metabolism. Therefore, Treatment T7, T10 and T12 can be recommend due to their high ash content.

Fiber content of potato

Crude fibers content of analyzed potatoes were significantly different at ($p < 0.05$). Fiber content ranged from 3.04 (T11) to 4.08% (T8) as presented in Table 1. Fiber content of potato was reported to range from 0.17 to 3.48% (Lister and Munro, 2000). The average of fiber content was reported to be 2.5% Liu (2013). Fiber content was influenced by organic fertilizer application and some potatoes had fiber content above the average. It is recommended to consume 14 g of fibers for every 1000 calories (Madhu *et al.*, 2017). Fibers contribute to the bulk of feces, bind undesirable materials such as mutagenesis, carcinogen, and helps in digestion by creating a conducive environment for valuable microflora in the intestine (Visvanathan *et al.*, 2016; Madhu *et al.*, 2017). Compost used increased fiber content of potatoes which in return have healthy effect on consumers. High fiber content is desired in our routine diet and potatoes in this study are highly recommended due to their high fiber content.

Reducing sugars and total sugars of potato

Reducing sugars and total sugars are important for determination of the processing quality of potatoes. The experiment showed that the results of reducing sugars and total sugars were statistically significantly different at ($p < 0.05$). Reducing sugars ranged from 1.29 to 2.28% and total sugars

from 2.25% to 2.94% as presented in Table 2. Reducing sugars were reported to range from 0.10 to 0.20% and total sugar from 0.26 to 0.55% of fresh weight (Bhattacharjee *et al.* 2014). Moreover, Leonel reported reducing sugar content to range from 0 to 2%. Sugar content is linked to the variety and maturity of potatoes. It was suggested that reducing sugars should be 0.25% for dehydrated products, 0.15% for French fries, less than 0.1% for crisps and 0.5% for canned potatoes (Marwaha *et al.*, 2010). Due to high amount of reducing sugars and total sugars, these potatoes should not be used for dehydrated and fried products. However, they can be boiled or mashed. It is very important to allow potatoes to mature to the level where haulms become fully dried which allows translocation of nutrients to the tubers and conversion of simple sugars into starch.

CONCLUSION

The world is facing unprecedented challenge related to the reluctancy of consumers on some food. Use of inorganic

fertilizers has gained momentum but nowadays people are concerned with their use in food production and environment. The emphasis is being shifted to the use of organic fertilizer which seems to have less effect on the ecosystem. The use of compost to grow potatoes revealed that dry matter of potatoes produced was within acceptable range of potato for processing. However, both reducing and total sugars were high. Produced potatoes are not suitable for production of dehydrated and fried products due to high content of reducing sugars. However, they can be used for boiled and mashed potato products. High amount of these sugars might have been caused by early harvesting time. Haulm should be allowed to dry naturally which might diminish reducing sugars content and improve processing quality of potato.

CONFLICT OF INTEREST

The authors confirm that this manuscript has no conflict of interest.

LITERATURE CITED

Table 2 Reducing sugars and total sugars in percentage of fresh weight of potato

Treatments	Reducing sugars %	Total sugars %
T1	1.29±0.4 ^{ef}	2.27±0.53 ^{ab}
T2	1.60±0.31 ^{cde}	2.61±0.51 ^{ab}
T3	1.93±0.52 ^{cb}	2.94±0.16 ^a
T4	1.69±0.02 ^{cde}	2.67±0.17 ^{ab}
T5	1.82±0.45 ^{bcd}	2.8±0.93 ^{ab}
T6	2.04±0.31 ^b	2.59±0.1 ^{ab}
T7	1.64±0.6 ^{cde}	2.65±0.83 ^{ab}
T8	1.98±0.16 ^{bc}	2.62±0.13 ^{ab}
T9	1.36±0.17 ^{def}	2.36±0.18 ^{ab}
T10	2.28±0.41 ^a	2.38±0.03 ^{ab}
T11	1.74±0.31 ^{cd}	2.34±0.25 ^{ab}
T12	1.51±0.8 ^{def}	2.25±0.24 ^{ab}
T13	1.42±0.3 ^{def}	2.16±0.28 ^b

Means followed by the same letter in the column do not differ by Tukey's test at 5%

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MS Received: November 22, 2022; Accepted: January 03, 2023

EVALUATION OF POTATO VARIETIES FOR EXPORT POTENTIAL IN EARLY SEASON

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ABSTRACT: Uttar Pradesh, particularly its western region, has better export potential for the premium early potato segment as leading Indian exporters demand export-grade tubers (>55mm) during January to tap the deficit period of fresh potatoes in the global market. With this background, a field experiment was conducted during 2020-22 in the early crop season with five promising varieties/ advanced hybrid viz., Kufri Sangam, Kufri Kiran, Kufri Neelkanth, Kufri Chipsona-4 and WS/07-113. The crop was planted in September end and harvested in mid-January. Advanced hybrid WS/07-113 recorded the highest export-grade tuber yield (4.95 t/ha), followed by Kufri Kiran (4.63 t/ha). Maximum tuber dry matter content was attained by cv. Kufri Chipsona-4 (21.3%) followed by Kufri Kiran (20.1%) and Kufri Sangam (19.3%). As a specialty segment, exporters showed keen interest in cv. Kufri Neelkanth which has 4.32 t/ha export-grade tuber yield and 18.6% specific gravity. As exporters require potatoes in January, crop duration may easily be increased to 85-90 days to achieve higher yields. Performance of varieties and exporters' feedback indicates that western UP can lead to export-grade potato production during the early-season.

KEYWORDS: Potato, export, early season, fresh potato, GlobalGAP

INTRODUCTION

The impact of extensive potato research and development in India during the last seven decades has been phenomenal. Area, yield and production of the country were 0.23 mha, 6.59 t/ha and 1.54 mt, respectively, in 1949-50, whereas the third advance estimate for the year 2020-21 by the Ministry of Agriculture and Farmers' Welfare has projected potato production of 54.23 mt from 2.25 mha area with a productivity level of 24.12 t/ha. Today, India is the world's second-largest potato-producing country, contributing around 14.3% of global production (Anonymous, 2022). However, the importance of the Indian potato has not been felt in the international market as the quantum of potato export is less than 1% of total production. Around 90% of fresh potatoes are harvested in March-April in the Indo-Gangetic plains, where frequent glut has

been observed during the peak harvesting time, leading to price crashes and monetary loss to potato growers. Lack of proper marketing avenues, insufficient/expensive cold storage facilities, poor condition of the supply chain and lower domestic utilization than production are some factors that precipitate a glut situation. As a result, potato export is neither steady in quantum nor governed by any concrete commitment (Luthra *et al.*, 2004, Khurana, 2013). Rigorous policy intervention has long been felt for a semi-perishable and bulky agri-commodity like potato.

Action by the Government of India in launching Agri-export Policy 2018 for a stable trade regime has come at the right point of time with a mission of doubling agricultural exports to around US\$ 60b by 2022 and reaching US\$ 100b in the next few years. In this, potato has been identified as

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a potential exportable crop and districts of Agra and Farrukabad in Uttar Pradesh, Indore and Gwalior in Madhya Pradesh, Jalandhar, Hoshiarpur, Kapurthala and Navashehar in Punjab and Banaskantha and Sabarkantha in Gujarat have been selected initially for potato export promotion (Anonymous, 2018). These districts have been identified based on their production, contribution to export, exporters' operation, the potential for upscaling operations, awareness about certification requirements and capacity to achieve export targets in the short term. Such export-oriented cluster development will ensure potato production compliance with standard physical and quality parameters for establishing a brand in the export market (Pandey *et al.*, 2000, CPRI, 2019). In addition, efforts are on at the institute level to identify potential varieties suitable for specific international market destinations and develop agro-technologies complying with the GlobalGAP (Chakrabarti *et al.*, 2019 and; Anonymous, 2019).

Uttar Pradesh produces around 28% of total potatoes within the country, and its western region has latent export potential, particularly early-season potatoes. January harvest can tap the deficit period of the international market with better remuneration. The exporters demand suitable varieties producing export-grade quality tubers of more than 55 mm in size, oval-oblong shape and lower losses during transport. Tuber qualities like flesh color, skin color, taste, flavor and dry matter content (>17-18%) *etc.*, are also crucial for export. With this motivation, a field experiment was conducted to screen promising cultivars, including one water stress tolerant hybrid suitable for early potato export from the western region of Uttar Pradesh (Luthra *et al.*, 2020 and Gupta *et al.*, 2021).

MATERIALS AND METHODS

Experimental site: Field trials were conducted during 2020-22 at ICAR-Central Potato Research Institute Regional Station Modipuram, Meerut, UP, India (29° 05'19" N, 77° 41'50" E, 237 m asl). The soil of the experimental site was sandy loam in texture with neutral pH, low in soil organic carbon content and available nitrogen, while medium in available phosphorous and available potassium (Table 1). The research station is located under semi-arid and sub-tropical agroecology, where mean maximum weekly temperatures ranged between 19.4-32.5°C and 13.3-34.8°C during the crop season of 2020-21 and 2021-22, respectively. While mean minimum weekly temperatures during the crop period ranged between 3.7-21.6°C in 2020-21 and 6.1-27.3°C in 2021-22, respectively. Cumulative rainfall was negligible in the crop season of 2020-21, but 16 mm rainfall was recorded during the season of 2021-22 (Fig. 1 & 2).

Experimental details: The study was conducted in a randomized block design with

Table 1: Soil status of the experimental site

Soil physico-chemical properties	Values
Mechanical analysis	
Sand (%)	57.9
Silt (%)	25.8
Clay (%)	16.3
Texture	Sandy loam
Physical analysis	
Bulk density (g cm ⁻³)	1.54
Chemical analysis	
Soil pH	7.19
Electrical conductivity (dS m ⁻¹ at 25°C)	0.12
Organic carbon (%)	0.32
Available N (kg ha ⁻¹)	160.4
Available P (kg ha ⁻¹)	39.1
Available K (kg ha ⁻¹)	183.2

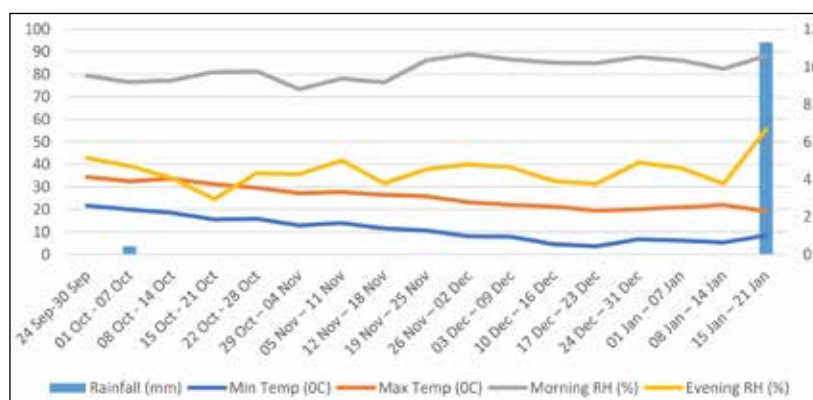


Fig. 1. Weekly weather during potato crop season of 2020-21

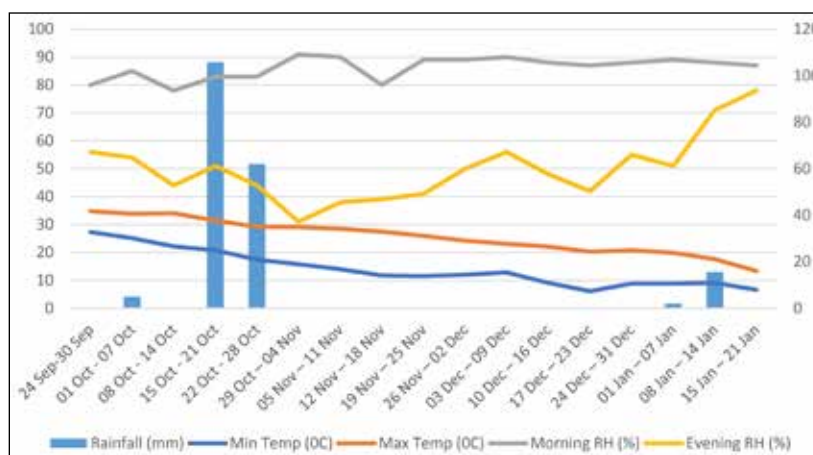


Fig. 2. Weekly weather during potato crop season of 2021-22

three replications. Five advanced hybrid or varieties, *viz.*, Kufri (K) Sangam, Kufri Kiran, Kufri Neelkanth, Kufri Chipsona-4, and WS/07-113, were selected for field evaluation due to their tuber quality, storage behavior and specialty attributes (**Table 2**). Green manuring (*Sesbania aculeata*) was followed in preceding crop season and approximately 25-30 t/ha of it was *in situ* incorporated. Further, FYM (10 t/ha) and gypsum (500 kg/ha) was incorporated into the soil 15 days before seedbed preparation. Sprouted seed tubers of 40-45 mm size were planted in the last week of September at a 66 cm × 20 cm distance in a plot size of 26.4 m². Uniform fertilizer doses of 110, 34.4 and 104 kg/ha of Nitrogen, Phosphorous and Potassium

respectively, were applied at planting, and 110 kg/ha of nitrogen was applied 20-25 days after planting (DAP) at the time of inter-cultivation and earthing. Approximately 50 mm of water (50 l/m³) was applied during each irrigation through the conventional ridge and furrow method. Water application started 10-12 DAP and continued at the same interval up to 10 days before haulm cutting. The recommended schedule of herbicide, fungicide and insecticide application for potato crop was followed to maintain proper crop growth. The crop was dehaulmed at 60 and 75 DAP to understand tuber bulking and harvested 15 days after tuber skin maturity.

Table 2: Tuber quality of selected potato varieties and advanced hybrid

Varieties/ Advanced hybrid	Tuber characters	Storability	Special feature
Kufri Chipsona-4	White-cream, round-ovoid, shallow, white, 20-21% tuber dry matter, floury texture	Very good	Suitable for chips, field resistant to late blight
Kufri Sangam	White-cream, ovoid, shallow, cream, 18-20% tuber dry matter, mealy texture	Very good	Dual purpose, table (northern plains) and processing (central plains), field resistant to late blight
Kufri Neelkanth	Purple, ovoid, shallow, yellow, 18% tuber dry matter, mealy texture	Very good	Antioxidant (anthocyanin & carotenoids) rich potato variety, field resistant to late blight
Kufri Kiran	White-cream, ovoid, shallow, white, 18% tuber dry matter, mealy texture	Excellent	Tolerant to heat, hopper and mite, suitable for growing early-season crop
WS/07-113	White-cream, ovoid, shallow, white, dry matter >19%, floury texture	Good	Water stress tolerant, moderately resistant to late blight

Observations and analysis: Growth parameters were recorded at scheduled intervals, while grading of tubers at harvest time was done in conformity with export requirements (>55mm), while the rest of the tubers were graded as marketable (55-30mm) and non-marketable (<30mm) for recording tuber number and yield. Tuber dry matter content (TDMC) was estimated by drying a representative sample (50g) of chopped tuber pieces drawn from three export grade tubers from each treatment at 80°C until a constant weight was achieved in a forced hot air draft oven. Specific gravity was also measured by the method described by Kumar *et al.* (2005). Haulms were also dried similarly, where the sample size was 100g. Data from two years of field trials were pooled, and statistical analysis was done using the statistical software IRRISTAT (IRRI, 1999).

RESULTS AND DISCUSSION

Plant population and growth

The ANOVA of the pooled analysis revealed that plant emergence was normal and uniform (>95%) for all five varieties/hybrid under study without showing any statistical significance (Table 3). However, parameters of plant growth *viz.*, plant height (cm), number of shoots per plant and number of compound leaves per plant varied significantly among the genotypes. Maximum plant height (49.5) was observed in cv. Kufri Chipsona-4 remains comparable to advanced hybrid WS/07-113 (48.7) and Kufri Neelkanth (47.2), while Kufri Sangam (38.4) recorded the lowest of it, followed by Kufri Kiran (39.7). Shoot number per plant was highest in cv. Kufri Neelkanth (4.09) and these were comparable to Kufri Chipsona-4 (4.08) and Kufri Sangam (3.91). Kufri Kiran had a

Table 3: Plant emergence and growth parameters of potato genotypes (pooled mean)

Genotypes	Emergence (%)	Plant height (cm)	Shoot no./ plant	Leaf no./ plant
Kufri Chipsona-4	97.0	49.5	4.08	55.2
WS/07-113	96.8	48.7	3.22	40.9
Kufri Sangam	97.0	38.4	3.91	48.4
Kufri Neelkanth	97.8	47.2	4.09	54.2
Kufri Kiran	97.5	39.7	2.53	32.5
CD _{0.05}	NS	2.68	0.64	3.47
SEM±	0.41	0.87	0.21	1.12

minimum shoot number (2.53), while 3.22 shoots per plant were observed in advanced hybrid WS/07-113. Variety Kufri Chipsona-4 attained highest compound leaf number per plant (55.2), followed by statistically similar leaf number in cv. Kufri Neelkanth (54.2). The minimum of this parameter was found in cv. Kufri Kiran (32.5). Kufri Sangam and advanced hybrid WS/07-113 had 48.4 and 40.9 compound leaf numbers. Overall, Kufri Chipsona-4, Kufri Neelkanth, Kufri Sangam and advanced hybrid WS/07-113 recorded better plant growth. Plant growth depends upon the genetic response of a genotype to the provided environmental conditions (Kumar and Minhas, 2013).

Performance of genotypes at 60 days

Tuber number and yield

Graded and total tuber number (000/ha) varied significantly among different genotypes except for the export grade tubers of more than 55mm. However, differences in graded and total tuber yield (t/ha) were statistically distinct (**Table 4**). Variety Kufri Neelkanth (34) recorded maximum export-grade tuber number closely followed by advanced hybrid WS/07-113 (33). Minimum export-grade tuber was observed in cv. Kufri Chipsona-4 (27) equivalent to cv. Kufri Sangam (29) and Kufri Kiran (29). Conversion of tuber number into a greater

proportion of export grade at 60 days was pertinent to assess the earliness of the genotypes; however, percent of export grade tuber number at this stage was found to be similar among them the genotypes evaluated. Varieties Kufri Chipsona-4, Kufri Sangam, Kufri Neelkanth, Kufri Kiran and hybrid WS/07-113 attained 5.0, 7.1, 7.2, 6.7 and 5.9% of export grade tubers out of total tuber number in the respective varieties (**Fig 3**). The highest marketable size tuber number ('000/ha) was observed in cv. Kufri Chipsona-4 (209) at par with hybrid WS/07-113 (208), while Kufri Kiran had the lowest marketable tubers (169). The maximum and minimum small-sized tuber numbers were observed in hybrid WS/07-113 (319) and cv. Kufri Sangam (208), respectively. In the case of total tuber number, the highest tubers were found in hybrid WS/07-113 (560), closely followed by Kufri Chipsona-4 (544), while the lowest total tuber number was observed in cv. Kufri Sangam (409) which were at par with Kufri Kiran (435) and cv. Kufri Neelkanth had 473 thousand total tuber numbers at 60 days. Variation in tuber number among different genotypes in potato crop is a genetic trait and has also been reported by Philipp *et al.* (2019) under *in vitro* and *in vivo* crop growth environments.

Regarding graded and total tuber yield (t/ha), marked variations were observed at

Table 4: Graded tuber number and yield of potato genotypes at 60 days (pooled mean)

Genotypes	Graded tuber number (000/ha)				Graded tuber yield (t/ha)			
	>55mm	30-55mm	<30mm	Total	>55mm	30-55mm	<30mm	Total
Kufri Chipsona-4	27	209	308	544	2.79	7.36	3.65	13.8
WS/07-113	33	208	319	560	3.36	6.42	5.22	15.0
Kufri Sangam	29	172	208	409	3.33	5.37	2.30	11.0
Kufri Neelkanth	34	181	258	473	3.98	5.47	4.85	14.3
Kufri Kiran	29	169	237	435	4.32	8.47	2.71	15.5
CD _{0.05}	NS	14.9	18.4	32.8	0.64	0.85	0.58	1.11
SEM±	4.12	4.86	5.97	10.6	0.21	0.27	0.19	0.36

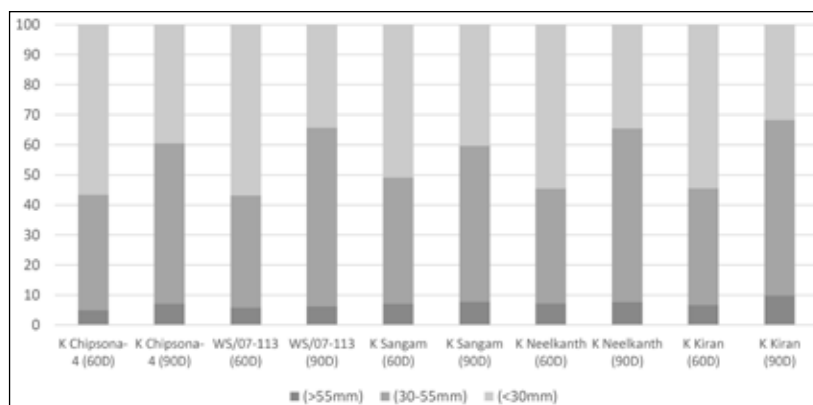


Fig. 3. Percent distribution of graded tubers in total tuber number at 60 and 90 days

60 days. Variety Kufri Kiran significantly achieved the highest export-grade tuber yield (4.32 t/ha) among all genotypes which shows their earliness in tuberisation under heat stress. Hybrid WS/07-113 and Kufri Sangam were comparable in performance as both recorded similar export-grade tuber yields of 3.36 and 3.33 t/ha, respectively. The proportion of export-grade tuber yield in total yield was 27.9, 30.3, 27.8, 22.4 and 20.2%, respectively, in cvs. Kufri Kiran, Kufri Sangam, Kufri Neelkanth, hybrid WS/07-113 and Kufri Chipsona-4 (Fig 4). Highest and statistically superior marketable tuber yield (8.47 t/ha) was recorded in cv. Kufri Kiran. Other potential genotypes for marketable tuber yield were Kufri Chipsona-4 (7.36) and hybrid WS/07-113 (6.42). The lowest

marketable tuber yield was observed in cv. Kufri Sangam (5.37). Small size tuber yield also varied distinctly where maximum (5.22) and minimum (2.30) yield was reported in hybrid WS/07-113 and Kufri Sangam, respectively. Overall, for total tuber yield Kufri Kiran (15.5) was the best performer variety and it remained statistically comparable to hybrid WS/07-113 (15.0) and Kufri Neelkanth (14.3). Variety Kufri Sangam attained the lowest total tuber yield (11.0). Genotypic variations in yield level and their performance for this trait under different kinds of stress is governed by several factors like the ability of the crop to maintain growth and canopy cover, and finally, efficient translocation of photosynthates from source to sink (Schafleitner *et al.*, 2007).

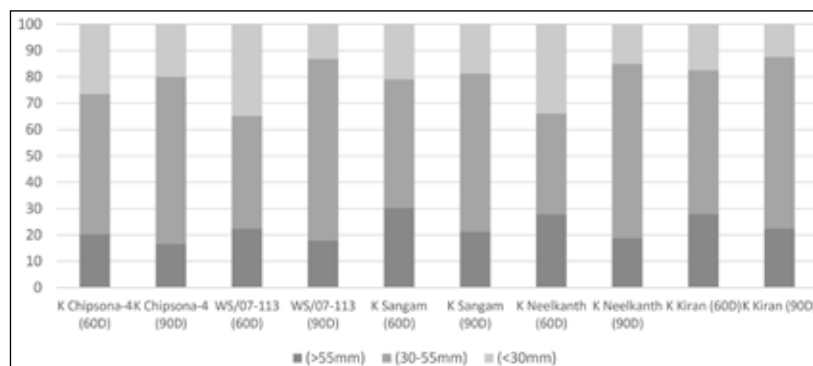


Fig. 4. Percent distribution of graded tubers in total tuber yield at 60 and 90 days

Tuber dry matter content and yield

Tuber dry matter content (%) and yield (t/ha) showed significant differences among the varieties and advance hybrid evaluated under this field study (**Table 5**). The highest tuber dry matter content was accumulated by cv. Kufri Chipsona-4 (20.1) which remained statistically superior over all the genotypes evaluated. Variety Kufri Sangam (18.4) and Kufri Kiran (18.0) had comparable tuber dry matter content. Alike, Kufri Neelkanth (17.5) and hybrid WS/07-113 (17.3) were also statistically at par. Tuber dry matter content is an essential parameter for considering the suitability of potatoes for export purposes. Further, it affects tuber dry matter yield and fresh tuber yield (Philipp *et al.*, (2019). There is also a relationship between tuber dry matter content and the storage behaviour of tubers. Better storability is important in export as tubers pass through different phases and modes of transit. Tuber dry matter yield varied markedly and was found highest in Kufri Kiran (2.78), remaining at par with Kufri Chipsona-4 (2.77) and hybrid WS/07-113 (2.58). Variety Kufri Neelkanth (2.50) and Kufri Sangam (2.03) attained lower tuber dry matter yield at 60 days.

Biomass yield and harvest index

Biomass yield and harvest index (HI) was calculated based upon tuber and haulms dry matter yield. Like tuber dry

matter yield, another component of biomass yield, haulms fresh and dry weight, varied significantly (**Table 5**). The highest biomass yield recorded by cv. Kufri Chipsona-4 (5.36) was statistically better among all the genotypes evaluated. The next best performer was Kufri Kiran (4.75) which also remained significantly higher over hybrid WS/07-113 (4.44), Kufri Neelkanth (4.24) and Kufri Sangam (3.95). HI, an efficiency in converting more photosynthates into economic yield also differed statistically and heat tolerant cv. Kufri Kiran (0.61) exhibited its trait while remaining comparable to Kufri Neelkanth (0.58) and hybrid WS/07-113 (0.58). Medium duration varieties Kufri Sangam (0.54) and Kufri Chipsona-4 (0.51) attained lower HI at 60 days.

Performance of genotypes at 90 days

Tuber number and yield

Significant variations were found in graded as well as total tuber number (000/ha) and yield (t/ha) at 90 days among the evaluated genotypes (**Table 6**). The highest export grade tubers were observed in cv. Kufri Kiran (43) which were comparable to Chipsona-4 (39). Kufri Neelkanth (37) and hybrid WS/07-113 (36) also had at par tubers of this grade, while Kufri Sangam (32) recorded the lowest export grade tubers. Percent of export grade tuber number varied

Table 5: Biomass yield and harvest index at 60 days (pooled mean)

Genotypes	Tuber dry matter content (%)	Tuber dry matter yield (t/ha)	Haulms fresh yield (t/ha)	Haulms dry yield (t/ha)	Biomass yield (t/ha)	Harvest index
Kufri Chipsona-4	20.1	2.77	20.1	2.59	5.36	0.51
WS/07-113	17.3	2.58	18.4	1.86	4.44	0.58
Kufri Sangam	18.4	2.03	14.1	1.92	3.95	0.54
Kufri Neelkanth	17.5	2.50	15.0	1.74	4.24	0.58
Kufri Kiran	18.0	2.78	14.3	1.97	4.75	0.61
CD _{0.05}	0.52	0.25	1.60	0.22	0.25	0.04
SEM±	0.17	0.08	0.52	0.07	0.08	0.01

Table 6: Graded tuber number and yield of potato genotypes at 90 days (pooled mean)

Genotypes	Graded tuber number (000/ha)				Graded tuber yield (t/ha)			
	>55mm	30-55mm	<30mm	Total	>55mm	30-55mm	<30mm	Total
Kufri Chipsona-4	39	292	216	547	3.62	13.9	4.38	21.9
WS/07-113	36	341	197	574	4.95	19.1	3.66	27.7
Kufri Sangam	32	217	168	417	3.55	10.1	3.18	16.8
Kufri Neelkanth	37	280	167	484	4.32	15.2	3.47	23.0
Kufri Kiran	43	256	139	438	4.63	13.4	2.62	20.6
CD _{0.05}	4.73	23.9	16.8	33.4	1.10	1.29	0.52	2.20
SEM±	1.53	7.75	5.47	10.8	0.35	0.42	0.17	0.72

between 6.3% in hybrid WS/07-113 to 9.8% in Kufri Kiran and rest of three cultivars had 7.1-7.7% of export grade tubers at 90 DAP (**Fig 3**). Advanced hybrid WS/07-113 (341) attained maximum marketable tuber number which were statistically distinct from other genotypes. Kufri Chipsona-4 (292) and Kufri Neelkanth (280) had comparable marketable grade tubers, followed by Kufri Kiran (256) and Kufri Sangam (217). Variety Kufri Kiran recorded lowest (139) under-size tubers, while the highest small tubers were found in Kufri Chipsona-4 (216). Total tuber numbers were maximum in hybrid WS/07-113 (574), which were at par with Kufri Chipsona-4 (547), and the lowest total tubers were recorded in Kufri Sangam (417).

Alike tuber number, significant variations were observed in graded and total tube yield (t/ha) at 90 days, and the highest export grade tuber yield was observed in hybrid WS/07-113 (4.95), which was statistically comparable to Kufri Kiran (4.63) and Kufri Neelkanth (4.32). Variety Kufri Chipsona-4 (3.62) and Kufri Sangam (3.55) attained lower export grade tuber yield. The proportion of export-grade tuber yield to total yield was 22.5, 21.1, 18.8, 17.9 and 16.5%, respectively, in cvs. Kufri Kiran, Kufri Sangam, Kufri Neelkanth, hybrid WS/07-113 and Kufri Chipsona-4 (**Fig 4**). Marketable tuber yield was also maximum in hybrid WS/07-113

(19.1) which was significantly better than other genotypes. The second best performer w.r.t. marketable yield was Kufri Neelkanth (15.2) which was at par with Kufri Chipsona-4 (13.9). Variety Kufri Kiran and Kufri Sangam recorded 13.4 and 10.1 t/ha marketable tuber yields, respectively. Non-marketable tuber yield was significantly higher in cv. Kufri Chipsona-4 (4.38) than other genotypes *viz.*, hybrid WS/07-113 (3.66), Kufri Neelkanth (3.47), Kufri Sangam (3.18) and Kufri Kiran (2.62). Overall, hybrid WS/07-113 (27.7) recorded maximum and statistically superior total tuber yield among all genotypes, followed by Kufri Neelkanth (23.0), Kufri Chipsona-4 (21.9) Kufri Kiran (20.6) and Kufri Sangam (16.8). Luthra *et al.* (2020) reported the yield performance of Kufri Neelkanth on similar lines to this study. Tuber yield and its stability under any stress are crucial in screening genetic material. As far as the performance of a genotype under varied stress like soil moisture or temperature is concerned, it may differ due to variation in metabolic activities and rate of transfer of metabolites to tubers during tuberisation, which is ultimately governed by some genes (Schafleitner *et al.*, 2007).

Tuber dry matter content, specific gravity and yield

Tuber dry matter content (%), specific gravity and yield (t/ha) differed statistically

for the varieties and advanced hybrid evaluated under this trial (**Table 7**). The highest tuber dry matter content (21.3) and specific gravity (1.087) found in cv. Kufri Chipsona-4 was significantly better than all other genotypes. Variety Kufri Kiran also accumulated statistically higher tuber dry matter content (20.1) and specific gravity (1.083) over the rest of the genotypes. Similar was the case of Kufri Sangam as it attained 19.3% tuber dry matter and had 1.078 specific gravity. Hybrid WS/07-113 (18.7) and Kufri Neelkanth (18.6) had comparable tuber dry matter content and specific gravity. Hybrid WS/07-113 had maximum and significantly marked (5.15) tuber dry matter yield over the varieties evaluated at 90 days. Kufri Chipsona-4, Kufri Neelkanth, Kufri Kiran and Kufri Sangam recorded 4.68, 4.26, 4.13 and 3.24 t/ha tuber dry matter yield, respectively.

Biomass yield and harvest index

Biomass yield and HI were calculated based upon tuber and haulms dry matter yield. Components of biomass yield *viz.*, tuber dry matter yield, haulms fresh and dry weight varied significantly (**Table 7**) among the genotypes evaluated. The highest biomass yield was obtained in hybrid WS/07-113 (6.12), which was at par with cv. Kufri Chipsona-4 (5.66). Variety Kufri Kiran, Kufri Neelkanth

and Kufri Sangam recorded 4.75, 4.59 and 3.70 t/ha of dry matter yield, respectively. Harvest index improved considerably at 90 days among all the genotypes compared to 60 days crop duration. Better and comparable HI was observed in heat tolerant cv. Kufri Kiran (0.89), Kufri Neelkanth (0.89) and Kufri Sangam (0.87). In comparison, HI was lower in hybrid WS/07-113 (0.84) and Kufri Chipsona-4 (0.82).

Feedback of exporters

Representatives of two leading potato exporters from Gujarat and progressive potato growers from the western zone of Uttar Pradesh observed produce at harvest time after ninety days. In addition, tuber samples of all varieties and the hybrid were provided to the exporters for further taking initial feedback from associates of importing destinations. In the second year, exporters positively responded to promoting the export of indigenous potato varieties, particularly Kufri Neelkanth in the specialty segment and Kufri Kiran and Kufri Sangam as table potato due to their overall performance for different parameters, including better storability.

CONCLUSION

Potato export is a demand and quality-driven segment as it is crucial to cater to the specific demand of an importing nation in

Table 7: Biomass yield and harvest index at 90 days (pooled mean)

Genotypes	Tuber dry matter content (%)	Specific gravity	Tuber dry matter yield (t/ha)	Haulms fresh yield (t/ha)	Haulms dry yield (t/ha)	Biomass yield (t/ha)	Harvest index
Kufri Chipsona-4	21.3	1.087	4.68	6.64	0.98	5.66	0.82
WS/07-113	18.7	1.078	5.15	8.89	0.97	6.12	0.84
Kufri Sangam	19.3	1.078	3.24	3.73	0.46	3.70	0.87
Kufri Neelkanth	18.6	1.077	4.26	4.18	0.49	4.75	0.89
Kufri Kiran	20.1	1.083	4.13	4.04	0.46	4.59	0.89
CD _{0.05}	0.49	0.001	0.45	0.66	0.09	0.48	0.02
SEM±	0.16	0.0003	0.14	0.21	0.03	0.15	0.001

a particular period. It is essential to match the standards and preferences of destination countries along with better storability for lower losses in transit. As there is a deficit in the supply of fresh potatoes in the early season and the western region of Uttar Pradesh has the potential to tap this opportunity. Variety Kufri Kiran and Kufri Neelkanth and advanced hybrid WS/07-113 can potentially maintain the supply chain for early season export.

CONFLICT OF INTEREST

The authors confirm that this manuscript has no conflict of interest

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MS Received: August 09, 2022; Accepted: December 26, 2022

RETURNS TO POTATO RESEARCH IN INDIA: A CASE OF KUFRI PUKHRAJ

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ABSTRACT: This study has estimated returns accrued from a potato variety called Kufri Pukhraj developed by ICAR-CPRI in 1998. This variety is most popular in North Indian Plains and covers about 33 % of total potato area in India. Time-series data collated from published records have been used to assess benefits during the period 1978-2021. The economic surplus model is employed to measure benefits in a closed economy framework at all-India level. Results have shown that adoption of Kufri Pukhraj provided gross returns of Rs 1,03,585 crore during the period 1978-2021, and large benefits have gone to consumers (73 %) and remaining to producers. The average annual return was assessed as Rs 2,354 crore. The NPV from spending in potato research was observed Rs 20,073 crore, and Rs 7,975 crore at 5 % and 8 %, respectively, during the study period. The IRR from monetary benefits was 49 %, a good rate of returns. Sensitivity analyses have provided substantial returns, and IRR between 46-51 %. The study infers that spending on R&D on potato has proved financially beneficial and suggests that other major technologies (varieties/ production practices/ others) having special traits may be studied for justifying past funding and make the strong case for future funding.

KEYWORDS: Potato, Kufri Pukhraj, Economic Surplus, IRR, NPV

INTRODUCTION

The role of agricultural research in transforming India's food security situation brining the country attaining top position among countries of the globe in production of few commodities is well known. Realizing the role of agricultural research in improving yield and increasing production, the governments and other agencies have given substantial funding for building research and development (R&D) infrastructure in past decades. However, the lack of funding for any economic activities like R&D is a global issue including India. The governments and other agencies are now interested in evidences of past achievements on people and regions to make the basis for funding future projects. Because, investment in agricultural research has helped in improving the welfare of farmers and consumers by reducing costs and providing food at cheaper rate, increasing production and product quality, or

introducing new products (Araji *et al.* 1995). Studies assessing the impacts of investment in agricultural research have reported high social payoffs (Joshi *et al.*, 2015; Chand *et al.*, 2012; Ruttan 1982; Arndt *et al.*, 1977; Akino and Hayami 1975; Evenson and Jha 1973). Most of these studies were confined to estimation of aggregate benefits from agricultural research. Measuring research benefits at an aggregate level has limitations in terms of relevance to decision making at the micro-level. Evenson (1967) argued that a more useful approach is to measure research productivity for a particular commodity or a particular agricultural experiment station.

The past studies have assessed the impact of research for a wide range of commodities (Punia *et al.* 2017). Although, the aspects like climate change on potato yield is studied (Pradel *et al.* 2019; Dua *et al.* 2013), the monetary benefits from a potato variety/ technology is less studied in India.

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Dahiya (2005) in a study tried to justify the impact of potato research, by comparing both area and value of production (VOP) with rice and wheat. Study noted that potato has performed better than rice and wheat. Potato is grown on 1 % of gross cropped area (GCA) and contributes about 3 % of the VOP from agriculture (crop), i.e. thrice the area under cultivation. As against this, rice occupied 22 % of GCA but contributed only 14 % to the VOP from agriculture. The corresponding figures for wheat were 15 % and 9.6 % during triennium ending (TE) 2018-19.

The VOP from potato was Rs. 29,310 crore (at 2011-12 prices) during TE 2018-19 (MoSPI 2021). Moreover, funding agencies are now skeptical of spending to various sectors/ programs/ commodities having alternatives uses. Presently, funding agencies are more interested in investing resources for targeted people and areas for better results. Keeping in view, the present study attempts to assess the monetary benefits of popular potato variety Kufri Pukhraj at all-India. *Firstly*, paper provides profile of potato production and about variety. *Secondly*, it describes data, methodology and framework adopted for analysis. *Finally*, monetary benefits from Kufri Pukhraj under various scenarios have been discussed.

PROGRESS OF POTATO IN INDIA

Production Profile

Potato is an important food crop in India. It is grown in almost all states under diverse agro-climatic conditions, except coastal areas. This crop is grown during short-winter days from October to February/ March. Therefore, availability of sunshine is the main factor for deciding yield of potato in India (Kumar *et al.* 2015). During TE 2020-21, India produced about 53 million tonne (Mt) of potato from 2.1 million hectare (Mha) area with a yield level of 24 t/ ha (Fig. 1). However, substantial

area under potato lies in eight major states of India viz., Uttar Pradesh, West Bengal, Bihar, Gujarat, Madhya Pradesh, Punjab, Karnataka and Assam. These states together accounted for about 87 % of area and 92 % of production in the country during TE 2020-21 (Table 1).

State-wise performance of potato has shown that, Uttar Pradesh accounted for about 30% of total production in India, followed by West Bengal (24%), and Bihar (16%) in 2020-21. The yield level in Gujarat and West Bengal (about 30 t/ha, each) was highest among the major states of India. It was 6 t/ha higher than the national average

Table 1. Share of area and production and yield of potato in major states, TE 2020-21

State	Per cent share		Average yield (t/ha)
	Area	Production	
Assam	4.7	1.4	7.3
Bihar	14.7	16.5	27.2
Gujarat	5.9	7.3	29.9
Karnataka	1.5	1.0	15.7
Madhya Pradesh	6.9	6.3	22.8
Punjab	4.8	5.3	26.4
Uttar Pradesh	28.4	30.2	25.8
West Bengal	20.1	24.3	29.3
Other states	12.9	7.4	14.1
All-India	100.0	100.0	24.2

Source: NHB (2021)



Fig. 1. Trends in area, production and yield of potato in India

(24.2 t/ha). By increasing the yield of potato in major states to the level of Gujarat and West Bengal, about 8 Mt additional potato can be added to total production. Apart from bio-physical factors like fluctuation in temperature; assured irrigation, timely and adequate availability of inputs, especially of seeds and fertilizers, and low seed replacement rate are the main factors responsible for poor yield in major states. Adopting micro-irrigation in place of furrow method and good agricultural practices can make this attainable (Kumar *et al.* 2009, Kumari 2012; Singh 2013).

Varietal Progress in India

Till date, more than 80 varieties of potatoes have been introduced for production in India, wherein 66 varieties (82%) have been developed by ICAR-Central Potato Research Institute (CPRI), Shimla. This public funded Institute is responsible for coordinating, managing, and guiding the potato sector in India. The potato varieties developed by CPRI are classified into early, medium and late categories based on maturity period¹ (Kumar *et al.* 2014). In depth scrutiny has revealed that majority of varieties of CPRI are of medium maturity (73%), followed by long maturity (15%) and remaining are early maturity (12%). Since, potato is used mainly as vegetable throughout year in India, early to medium maturity varieties offering better yield, tolerant to multi-stresses and better storability are preferred over others in the development process. Need of desired variety seeds and their availability are key parameters of adoption of varieties.

Among the potato varieties, Kufri Pukhraj is most popular in India in terms of area

coverage. This variety covered about 521.38 thousand hectares (i.e. 33% of potato area) in 2015 and grown in Bihar, Gujarat and Punjab, Uttar Pradesh and West Bengal. It is preferred by the farmers due to early-maturity and high-yielding. The second most dominant variety in India is Kufri Jyoti (1968) covered an area of 325.67 thousand hectares (21% of potato area). It is most dominating variety in Karnataka and West Bengal. Despite prone to late blight and lower yield over to Kufri Pukhraj, this variety is still preferred by farmers due to good shape and storability, tuber size, and a slow degeneration rate. The third most popular potato variety is Kufri Bahar (1980) covered 272.64 thousand hectares (17% of potato area) in Uttar Pradesh. Besides, some notable varieties being used for industrial purposes include Kufri Chipsona 1, Kufri Chipsona 3, including foreign varieties namely Atlantic, Kennebec and Lady Rosetta. Released in 1998, Kufri Chipsona 1 is cultivated mainly in Uttar Pradesh for industrial use. It has low sugar content, high dry matter, and good tuber size and shape.

Kufri Pukhraj

Released by ICAR-CPRI in 1998, Kufri Pukhraj is an early maturing and most popular among the potato varieties and gives yield between 35-40 t/ha. It has medium storability and resistance to early blight and moderate resistance to late blight. This variety is not suited to early sowing due to heat sensitive and limited yield (Rana *et al.* 2013). It has a waxy texture, mild flavor, and free from discoloration after-cooking and coloration on exposure to light. This variety is grown mainly in North Indian plains and Plateau regions wherein above 80% of total potato area lies. Tubers of Kufri Pukhraj are an excellent source of vitamin C, potassium, and fibre. As this variety is the most popular among all varieties, evidence on monetary benefits from investment in research seems

¹Note: varieties mature between 70-90 days are classified as early, varieties mature between 100-110 days are classified as medium, and varieties require more than 110 days to mature, are classified as late.

pertinent for researchers, policymakers, government and other stakeholders.

MATERIALS AND METHODS

Data

The present study has used secondary data collated from published records and other sources. Data on production and prices of potato was obtained from Indian Horticulture Database, while demand and supply elasticities are taken from published record (CPRI 2009). The maximum adoption level for Kufri Pukhraj has taken from Pradel *et al.* (2019), and data on yield gain, reduction in cost, lag to first adoption (years) are collected from frontline demonstrations and published sources (Kang *et al.*, 2000). The data on research cost was built in from records of ICAR-CPRI and covered items like scientists' salary (including personnel from All India Coordinated Research Project), operational expenses, overhead cost and cost of extension. The benefits accrued from the variety was assessed for the period 1978-2021. The discounted stream of benefits and costs have been arrived at using World Bank Gross Domestic Product (GDP) deflator for India². The summary data used for assessing economic surplus are provided in Table 2.

Theoretical Framework and Concept of Economic Surplus Model

This study has applied economic surplus model (ESM) in *ex-post* framework to estimate the potential monetary returns to research and extension investment on Kufri Pukhraj in India. The model assumes that with the adoption of Kufri Pukhraj, the supply curve will shift downward from S_0 to S_1 , and the domestic demand curve of potato, and demand curve D is to remain unchanged (Fig. 2).

As a result of shift in supply curve, consumer will be benefited from reduction in price (P_0 to P_1) as consumer surplus changes, equal to the area P_0abP_1 , and the change in producer surplus is equal to the area $P_1bI_1 - P_0aI_0$. The area beneath the demand curve and between the two supply curves i.e., area I_0abI_1 represents the total surplus from the research induced supply shift (Alston *et al.* 1995).

The analysis has been done in closed economy framework, since the export of potato and its products from India is very limited. A total period of 44-years (1978-2021) have been considered for developing the streams of costs and benefits. The research for breeding Kufri Pukhraj was initiated in 1978 and the variety was released after 20 years in 1998 (Kang *et al.*, 2000) Following Alston *et al.* (1995), the changes in producer, consumer, and total surplus in the closed economy are estimated using following formula:

$$\Delta CS_t = P_0 Q_0 Z_t (1 + 0.5 Z_t \eta) \quad (1)$$

$$\Delta PS_t = P_0 Q_0 (K_t - Z_t) (1 + 0.5 Z_t \eta) \quad (2)$$

$$\Delta TS_t = \Delta CS + \Delta PS = P_0 Q_0 K_t (1 + 0.5 Z_t \eta) \quad (3)$$

$$Z_t = K_t \varepsilon / (\varepsilon + \eta) \quad (4)$$

where, ΔCS_t is the change in consumer surplus in year t, ΔPS_t is the change in

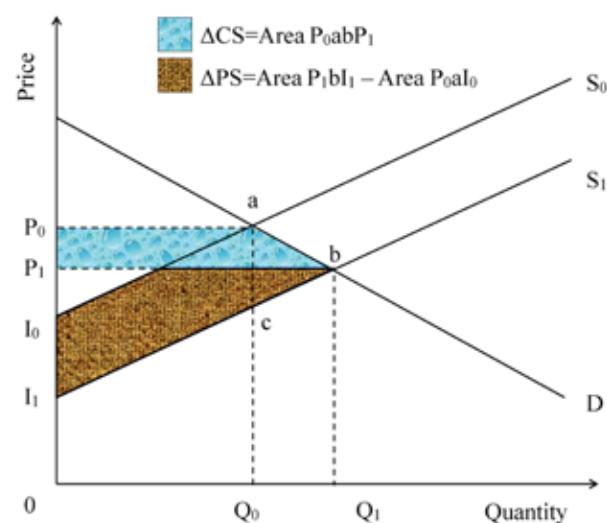


Fig. 2: Changes in economic surplus (closed economy) from the adoption of Kufri Pukhraj

²World GDP Deflator for India at 2019-20 prices has been used for deflating stream of costs and benefits. <https://data.worldbank.org/indicator/NY.GDP.DEFL.ZS?end>

Table 2. Parameters and assumptions used for analysis of returns from Kufri Pukhraj

Base Parameter	Value	Source
Average price level for TE 2019-20	Rs 13.6/ kg	Monthly Potato Report, MoAFW, GoI 2020
Production quantity (1999-00 to 2020-21)	Thousand tonnes	Indian Horticulture Database various years
Supply elasticity (ϵ)	0.8	CPRI Annual Report (2008-09)
Demand elasticity (η)	0.3	CPRI Annual Report (2008-09)
Proportionate yield gain [E(Y)]	15 %	Scientists' opinions, field survey, FLD data
Proportionate reduction in cost [E(C)]	15 %	Scientists' opinions, field survey, FLD data
Maximum adoption level	33 %	Pradel <i>et al.</i> (2019), CPRI reports
Lag to first adoption (years)	20 year (1978-98)	Kang <i>et al.</i> , (2000), review of literature
Year to full adoption	11 years	Scientists' opinions
Depreciation	5%	Scientists' opinions
Research Period	1978-1998	Kang <i>et al.</i> , (2000), review of literature

producer surplus in year t , ΔTS_t is the change in total surplus, P_0 is the initial price, Q_0 is the initial level of production, Z_t is the reduction in price as a result of an increase in supply due to adoption of Kufri Pukhraj, η is absolute value of demand elasticity, ϵ is the supply elasticity and K_t is the proportionate supply shift in the year t due to adoption of the variety. The value of K_t can be obtained as:

$$K_t = \{[E(Y)] / \epsilon - [E(C)] / [1 + E(Y)]\} p A_t (1 - \delta_t) \quad (5)$$

where, $E(Y)$ is the proportionate change in yield per ha, $E(C)$ is the proportionate change in variable input costs per ha, p is the success rate, A_t is the adoption rate in year t and δ_t is the rate of annual depreciation in year t . Once change in economic surplus is projected over time, the net present value at the rates of 5 and 8 per cent, and internal rates of return are calculated along with sensitivity analyses. The estimates of returns and costs were deflated in real terms using a World Bank GDP deflator for India at 2019-20 price level.

RESULTS AND DISCUSSION

Adoption of Kufri Pukhraj at farmers' fields with 33% adoption level accrued gross returns / surplus of Rs 1,03,585 crore (at 2019-20 prices) to the country's economy

during 1978-2021, with average annual return of Rs 2,354 crore (Table 3). Of gross returns, large share of 73 % (Rs 75,335 crore) have gone to consumers, and remaining 27 % (Rs 28,250 crore) to potato producers. The NPV of research spending is estimated as Rs 20,073 crore and Rs 7,975 crore at discount rates of 5% and 8%, respectively. The IRR from research investment is estimated as 49%, which is a good rate of returns. Past studies have also reported similar rates of returns from investment in agricultural research (Rada and Schimmelpfenning 2018; Punia *et al.* 2017; Chand *et al.* 2012). Due to the uncertainties in parameters used for estimating gains, the

Table 3. Returns to investment in research in Kufri Pukhraj, 1978-2021

(Amount Rs crore)	
Particulars	Returns to research
Consumer surplus	75, 334.8
Producer surplus	28, 250.5
Total surplus	1, 03, 585.3
Annual average gross return	2,354
NPV at 5% discount rate	20, 072.7
NPV at 8% discount rate	7, 975.0
Annual net benefit	2, 143.4
IRR (%)	49

Source: Authors' estimate

sensitivity analyses have also been made. The various levels of adoption, yield gains, change in cost and others details are provided in Appendix Table 1. Sensitivity analysis shows that gross returns ranges from Rs 57,051 crore to Rs 1,54,318 crore, and IRR between 46-51%.

The results of base model and sensitivity analyses have shown that spending in development of Kufri Pukhraj has benefitted immensely to the society and Indian economy. Growing of early variety, which mature between 70 and 90 days, provide more flexibility in harvesting of crop and potentially provides additional income if cultivated in between two rice cycles (Bardhan *et al.*, 2007). This variety is preferred by farmers because of its short-maturity, drought tolerant, low inputs need, suitable for many potato-based cropping systems and can be harvested early for getting premium price. It benefits producers because of early-maturity and produces sizeable yields, even if harvested pre-maturely after 60 days.

Studies have noted that suitable growing window of potato gradually been shortened in the Indo-Gangetic Plains due to rise in

temperature and event of drought have become frequent, resulting negative impact on yield (Kang *et al.*, 2000). These pose enormous challenge to scientists, extension agents and farmers, who are targeting to achieve average yield of about 35 t/ha in India by 2050 to meet the future demand of growing population. In order to cope up with these challenges, the ICAR-CPRI need to put emphasis on development of varieties which are early maturing, and resistant to drought and heat (Kumar *et al.*, 2015). Although, the Potato Institute has developed cultivars like Kufri Khyati and Kufri Mohan on the lines of Kufri Pukhraj which perform very well in the farmers' fields and offering better yield than Kufri Pukhraj. However, these varieties are less popular among farmers. There could be several reasons for this like poor information about these varieties, high seed cost, and non-availability of quality seeds at sowing time. The farmers should be made aware of these varieties by organizing extension activities like training, frontline demonstrations, and advisory services. The private sectors should also be encouraged to take up production of quality seeds of

Appendix Table 1. Sensitivity analysis for gross returns and net present value from adoption of Kufri Pukhraj, 1978-2021

(Rs Crore)

Particulars	Net present value		IRR (%)	Gross returns			
	5%	8%		Consumer surplus	Producer surplus	Total surplus	Annual average
Base level scenario							
(i) Adoption level (33%)	20,072.7	7,975.0	49	75,334.7	28,250.5	1,03,580.3	2,354.2
(ii) Yield increase (15%)							
(iii) Cost reduction (15%)							
Moderate scenario							
(i) Adoption level (25%)	11,286.3	4,539.9	46	41,491.3	15,559.3	57,050.6	1,296.6
(ii) Yield increase (10%)							
(iii) Cost reduction (10%)							
Optimistic scenario							
(i) Adoption level (40%)	29,407.0	11,570.0	51	1,12,231.0	42,086.6	1,54,317.7	3,507.2
(ii) Yield increase (20%)							
(iii) Cost reduction (20%)							

Source: Authors' estimate

improved varieties and supply to farmers at reasonable prices. Other adaptation strategies like micro-irrigation using drip and fertigation should be popularized to reduce production cost and sustained increase in yield.

CONCLUSION AND IMPLICATIONS

Systematic analysis of improved production technology including varieties are key to provide concrete evidence on returns to past funding and generate more funding for R&D in future. The analysis has shown that Kufri Pukhraj is the most popular among all the cultivars and covers about 33 % of total potato area at all-India. This variety is widely grown in states of Bihar, Gujarat and Punjab, including Uttar Pradesh and West Bengal. The gross returns/economic surplus from Kufri Pukhraj is estimated as Rs 1,03,585 crore (at 2019-20 prices) for the period 1978-2021. The IRR from investment was 49 %. The sensitivity analyses have shown that the variety have potential to give substantial returns between Rs 57,051 to Rs 1,54,318 crore and IRR ranging 46-51 % at varying level of adoption. Study noted that addressing supply side constraints and irrigation practices, significant increase in potato yield and production can be achieved. The results of analysis infer that other major technologies (consisting varieties, production practices and others) having special traits may be targeted for development process to address the negative impacts of emerging climate change and other problems. Also, the location specific improved varieties need to be popularized among farmers through effective and efficient extension activities for harnessing the potential. Efforts should be also made to promote micro-irrigation technologies among the potato farmers to avoid depletion of groundwater and hardness of soil, which otherwise limit yield. Quality seed production programme should be taken up on a large scale by the stakeholders so that farmers can get quality seeds of desired

varieties at cheaper price rate and at right time. Regular seed replacement plays a major role in increasing yield. A study by Kant *et al.* (2020) in Bihar showed 53.28 % increase in yield when farmers replaced local existing varieties with improved seeds of Kufri Pukhraj.

ACKNOWLEDGEMENT

The authors are grateful to ICAR-National Institute of Agricultural Economics and Policy Research, New Delhi, for providing support to write this paper.

CONFLICT OF INTEREST

The authors confirm that this manuscript has no conflict of interest

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ORGANIC POTATO PRODUCTION: A STEP TOWARDS SUSTAINABLE AGRICULTURE (LIFE CYCLE ASSESSMENT BASED STUDY)

Rohit Kumar, Arvind Bhardwaj*, Lakhwinder Pal Singh and Gurraj Singh

ABSTRACT: Potato as staple vegetable has a significant influence towards the global target of food security. However, its production is also correlated to environmental burden via the processes like fertilization, crop protection and the production of electricity for irrigation. Although organic production is known to reduce the impacts of fertilizer as well as other agro-chemicals due to their non-usage, there is a need to assess its overall impact in the light of its related processes with respect to transportation of manure and higher water requirements. Therefore, a cradle to farm gate type Life cycle assessment (LCA) methodology has been used to quantify its impacts in terms of the chosen indicators. Taking one hectare of land under potato cultivation as the functional unit, the Sima Pro version 9.0.0 along with CML 2 baseline 2000 approach have been used. The results highlight sowing and irrigation as the most critical processes that harm the environment. The findings of normalization results revealed that the marine aquatic ecotoxicity category was the greatest contributor to overall environmental impact. The results were further strengthened by substance contribution analysis which shows that carbon dioxide followed by nitrate emissions to air, water and soil was the most significant substances, accounting for 65.36% and 54.01% respectively.

KEYWORDS: Organic Potato Production; Sustainable Agriculture; Life Cycle Assessment; Agriculture Practices.

INTRODUCTION

Potato (*Solanum tuberosum*) is the fourth most important food crop after rice, wheat, and maize in the world. India holds world's second rank for largest producer of potatoes, with a total output of around 54 million tons. Rapidly expanding potato production has played a significant role in improving both the agricultural revenue as well as country's carbohydrate need. However, this increased output is heavily reliant on high inputs of materials/resources during agriculture production, notably agrochemicals. Excessive use of fertilizers and pesticides not only wastes resources, but also contaminates water, increases greenhouse gas emissions (Singh, 2022) and affects soil quality (Fantin *et al.*, 2017). All of these issues are inherently linked to food safety concerns, creating substantial societal debate over how to address these

concerns in India (Pérez-Escamilla, 2017). One alternative solution is to use organic farming rather than inorganic production, which not only improves food safety aspects but also includes better nutritional advantages (Meier *et al.*, 2015). However, there are a lot of undesirable impacts on the environment that are associated with the organic growth of potatoes. This is mainly due to the resource and energy involvement in producing the farm yard manure, its transportation as well as application apart from the higher quantities of irrigation water requirements (Pishgar-Komleh *et al.*, 2012). So, in order to determine the environmental status of organically cultivated potatoes, a sustainability assessment is required which can systematically analyze the potential environmental impacts of products or services during their entire life cycle of organic potato

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production. Among the range of evaluation methodologies, Life cycle assessment (LCA) is regarded as one of the widely accepted tool for analyzing the environmental consequences of agriculture products (Selvaraj *et al.*, 2021). LCA is a method for assessing the potential ecological consequences of a chosen process or product throughout the course of its whole life in order to assist the decision-making process related to production and consumption (Fig 1). It has seen extensive application in agricultural contexts, particularly associated with agricultural production and the allied industries (Khanali *et al.*, 2020; Meier *et al.*, 2015; Selvaraj *et al.*, 2021). Fig 2 shows the main phases involved in LCA framework along with the interconnected flows.

Moreover, in a recent review article by Selvaraj *et al.*, (2021) compared more than twenty crops grown in India including cereals, fruits, oilseeds, vegetables and cash crops from different farming systems by means of the LCA methodology and pointed out the need for a more comprehensive assessment of environment sustainability of agricultural products using LCA. There are a large number of comparison studies between organic and conventional cultivation

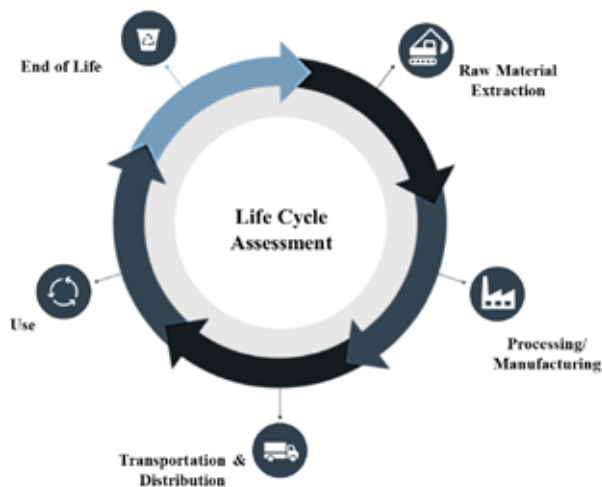


Fig. 1. Schematic of product life cycle of product

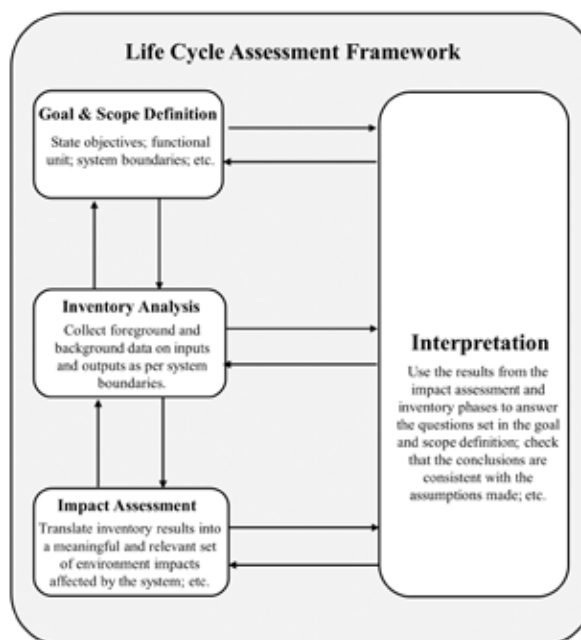


Fig. 2. Main phases in the Life cycle assessment framework adopted from ISO 14044: 2006 (ISO, 2006)

systems which have been conducted on a variety of other crop as well (Foteinis and Chatzisyneon, 2016; Kowalczyk and Cupiał, 2020; Longo *et al.*, 2017 and Tricase *et al.*, 2018). As per most findings, organic cultivation is more ecological friendly than conventional cultivation due to its lower consumption of fossil fuels and greenhouse gas emissions, which contribute less to environment (Reganold and Wachter, 2016).

In terms of potato cultivation, a growing number of LCA studies on potato farming have been presented in recent decades, the majority of which were primarily concerned with the conventional production systems (Kowalczyk, 2019; Kumar *et al.*, 2022 and Rööös *et al.*, 2010), meanwhile few of the studies compared conventional and organic potato cultivation crop production using the LCA method (Selvaraj *et al.*, 2021 and Timpanaro *et al.*, 2021). However, only a few studies have covered organic production so far, such as (Mattsson and Wallén, 2003;

Pacifico and Paris, 2016 and Singh, 2022). The majority of investigations have been conducted in European nations, and their findings demonstrated that the emissions that caused eutrophication, acidification and global warming were mostly caused by agricultural production, manufacturing of packing materials, and household activities. However, there is a lack of comprehensive research on the environmental performance of organic potato production, particularly in relation to Indian climatic conditions, which may reveal different results due to differences in farming practices, weather conditions, transportation requirements, energy sources, waste management practices, socioeconomic factors, mechanization techniques, and so on. Therefore, it is essential to perform an LCA study specific to the Indian scenario using first hand data. This study seeks to document the Environmental Impacts of organic potato production at Jalandhar district, Punjab, India. The core goals of the study are to: (1) develop an inventory for environment impact analysis of organic potato production, (2) identify major hotspots in life cycle of the crop and (3) analyze each agricultural activity that most influence the natural environment.

MATERIALS AND METHODS

Description of the system

The study evaluates the environmental implications of organically grown potatoes in

northern India. The analysis was carried out with foreground data collection from potato fields in the State of Punjab, India. A total of 20 small sized potato fields (less than 5 hectare) were chosen around the district of Jalandhar, Punjab. All chosen farmers were members of the Jalandhar Potato Growers Association (JPGA), which assured accurate data gathering and the same crop variety sown by all farmers. The district has largest share in state's total potato production (Rana *et al.*, 2020). The surveys were conducted through direct interviews using a questionnaire administered to 15 organic potato growers. LCA tool is considered as the main approach to find environment burden associated with potato cultivation (Table 1).

System Boundary

Environment burden of crop production arises not only from agricultural' activities, but also from the extraction, manufacturing, and shipping of essential resources like manure, fuel, and seed. All of these factors must be taken into account in order to perform a thorough evaluation. The LCA boundary consist all input and outputs for a selected production system (Fig 3).

Life Cycle Inventory

The life cycle inventory is important part of the study as the subsequent processes depend on this phase. The information was

Table 1 System description for selected cultivation system

Classification	Description
Goal	- Evaluation of environment impacts of organic production supply chain - Identification of environment hotspots linked with different agricultural practices
Scope	Cradle-to-farm gate
Functional Unit	One hectare of Potato Production (1 ha)
System boundary	- Include all agricultural practices from field preparation to harvesting - Environment impacts of farm used capital (infrastructure and machinery depreciation) were not taken in this study but long-term emission has been included. - Unavailable data were taken from Ecoinvent database (Indian average)

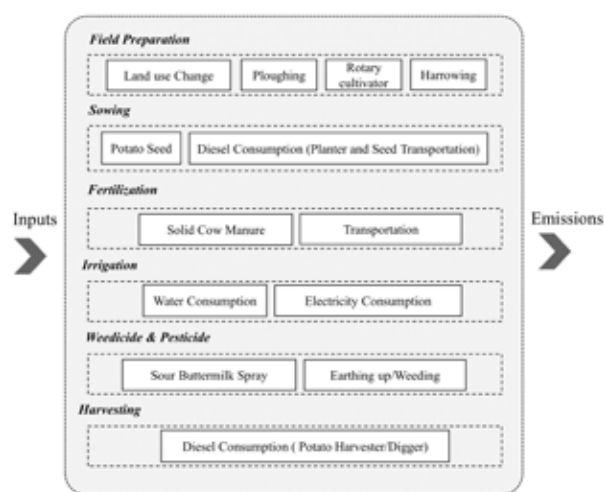


Fig. 3. System Boundary of selected one hectare organic potato production

collected via field survey and a standardized questionnaire at the farm level during the crop season 2021-22. In order to prevent any errors, data was further examined by agricultural experts and each field operation and input for each system was recorded in terms of resource use and consumption (Table 2).

In the starting of September, primary tillage operation was carried and the field

was allowed for sun drying (4–5 days). Afterward, the second operation was carried out, and it facilitated the soil by destroying weeds, pests and their breeding places in order to prepare the land for sowing practice. In the sowing process an average seed rate used by farmer in the study area was 2.5 tonne per hectare. All the selected farmer used conventional potatoes as seed potatoes to cultivate crop in order to avoid the problem of seed-borne disease. Whole seed tubers were planted without cutting and tuber damage is as little as 1%. The consumption of diesel used in agricultural machinery has been taken in this study. For organic crop, the field preparation practices are performed mechanically, whereas sowing and crop management practices (earthing, weeding, organic fertilizing, and pesticide spraying) are carried out either manually or mechanically depending upon the farmer's decision and the infrastructure available. The relevant data has been taken from world leading database Ecoinvent version 3.7. Furthermore, in the fertilizer application solid cow manure is most commonly used

Table 2 Selected Life cycle Inventory for one hectare potato production

Farming Practices	Activity	Org.	Unit	Source
Land Preparation	Transformation, from agriculture	10000	m ²	Ecoinvent database
	Transformation, to agriculture	10000	m ²	Ecoinvent database
	Tillage, ploughing	1	Times/ha	Ecoinvent database
	Tillage, rotary cultivator	1	Times/ha	Ecoinvent database
	Diesel	30	Ltr	Field Survey
Sowing	Potato seed	2500	kg	Ecoinvent database
	Diesel	16.5	Ltr	Field Survey
	Manure, solid, cattle	21000	kg	Field Survey
	Transport (by tractor and trailer)	1889.8	tkm	Field Survey
Irrigation	Water, fresh	1150.6	m ³	Field Survey
	Electricity, low voltage (IN-Northern grid)	142.2	kWh	Field Survey
Crop Protection	Water	250	Ltr	Field Survey
	Buttermilk, from cow milk	7.5	kg	Field Survey
Harvesting	Diesel	30	Ltr	Field Survey

fertilizers in the respective region (Amritpal and Sidhu, 2015 and Rana *et al.*, 2020). The well-decomposed solid cattle manure, which was mixed with the soil during the last ploughing. The use of organic fertilizer not only prevent the outflow of pollutants into water bodies, but also provides a supply of rich nutrients to potato fields and resources recycling for livestock farming (Manickam *et al.*, 2012). A mean value of 20 tons per hectare along with a mean distance of 50 km to transport this manure to potato farms has been taken in this study. Coming to crop protection, a 10 Ltr of sour buttermilk per hectare was used as a pesticide in this region. Additionally, diesel consumption during earthing up/weeding activities has been also taken in the life cycle inventory.

Water consumption for field activities and to hydrate the cultivation system were recorded according to irrigation type (i.e., groundwater) and water intake. Potatoes need irrigation at frequent interval, depending on the soil and climatic circumstances. In organic cultivation of potatoes generally, three to five irrigations are sufficient, including 1-2 mild irrigations following pre-sowing irrigation. All the selected farmers used electricity as a resource to run the water pumps which was operated on an average for ten hours for doing one irrigation and there were total of four irrigations has been recorded in 1 hectare of field. So, a mean electricity consumption has been taken in the study from all the selected farms. The consumption of diesel by potato harvester (digger) has been also taken in this study. In order to record precise data collection, it was also ensured that all the selected farms used same powered tractor and implement machinery.

Assumptions

- Since the life cycle inventory data was taken from twenty organic potato farms

so an average value of the inventory data has been taken.

- The geographic location is Jalandhar, Punjab.
- Water which is used for irrigation is 10% rainwater and 90% groundwater.
- The diesel consumption which is used in the inventory is the total diesel burnt in the machinery used in agriculture.
- The mean distance of transportation is taken to be 50 kms for carrying manure to the farm from its source.

Life Cycle Impact Assessment

One of the most popular software used for LCA is SimaPro because of its reliability and close integration with authoritative and trustworthy data sources like Ecoinvent Agribalyse, and Agri-footprint, encompass with several datasets related to agriculture and allied industries (Iswara *et al.*, 2020) So Sima pro version 9.0.0 was used in this study to model the LCA of one hectare organic potato production. A life cycle assessment was conducted at midpoint characterization level by employing CML 2000 baseline V2.05, which is one of the most commonly used indicator method in LCA analysis (Abeliotis *et al.*, 2016). The study mainly focused on the characterization and normalized results to present the relevant findings. The findings of the results help us to make practical judgements about how emissions influence the ecosystem, health and resources.

RESULTS AND DISCUSSION

The results and discussion section covers three sub-sections where the first one highlights the Characterization results, the next one presents the Normalization results with respect to involved farming practices and the last section covers the substance contribution to key impact categories.

Characterization results and discussion

It is apparent from Fig. 4 that the sowing practice followed by irrigation practice carry the highest impact out of all chosen farming practices across 10 impact categories. When the most influential impact indicators are considered, sowing, irrigation, field preparation, and organic fertilization contribute 33.97 %, 20.42 %, 17.67 %, and 16.95 %, respectively, to the 'global warming' impact.

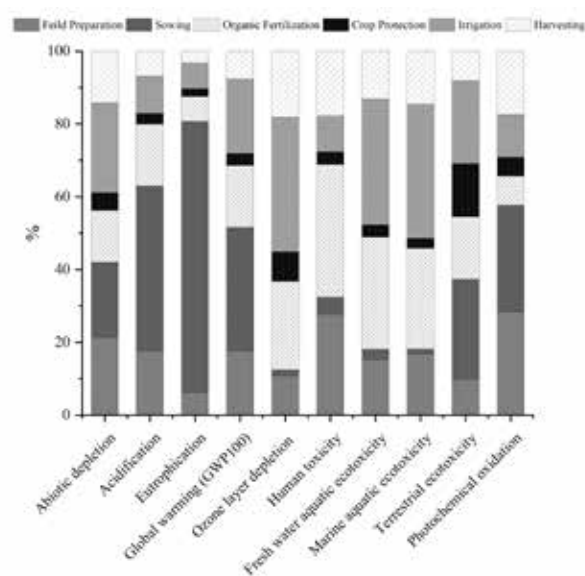


Fig. 4 Characterization results w.r.t to different farming practices of organic potato cultivation

Based on the characterization results, all the impact indicators have been discussed (Table 3). The Global Warming Potential (GWP 100) was established; this primarily denotes the amount of energy absorbed upon the emissions of a certain gas in relation to the amount of energy absorbed following the emission of one tonne of CO₂ gas (Masset *et al.*, 2014). In the current study, the largest source of greenhouse gases is showing, which accounts for 423.42 kg CO₂ eq (Table 3). In a similar study conducted by Pishgar-Komleh *et al.*, (2012) the amount of GHG emission was reported as 992.88 CO₂ eq. per ha. The dominant contribution attributes to resource utilized in seed material and consumption of diesel during planting. Moreover, the use of seed potato for the current study was from conventional production, hence, the seed related emissions can further be reduced by selected organically grown potato seed (which was currently unavailable to us). By adopting General precautions against pests and diseases, such as crop rotation, use of tolerant or resistant varieties, use of healthy and certified organic seed tubers (Goffart *et al.*, 2022) as well by cultivate with sufficient distance from other potato plots to avoid viral infection and blight (Kreuze *et al.*, 2020) can reduce the problems arising with

Table 3. Characterization values w.r.t to farming practices of organic potato cultivation

Impact category	Unit	Total	Field Preparation	Sowing	Organic Fertilization	Crop Protection	Irrigation	Harvesting
Abiotic depletion	kg Sb eq	8.492	1.805	1.766	1.207	0.416	2.096	1.203
Acidification	kg SO ₂ eq	8.572	1.519	3.881	1.455	0.250	0.883	0.585
Eutrophication	kg PO ₄ eq	6.225	0.390	4.636	0.422	0.133	0.443	0.200
Global warming (GWP100)	kg CO ₂ eq	1246.548	220.273	423.427	211.400	41.749	254.635	95.063
Ozone layer depletion (ODP)	kg CFC-11 eq	1.330E-04	1.426E-05	2.320E-06	3.230E-05	1.081E-05	4.922E-05	2.409E-05
Human toxicity	kg 1,4-DB eq	976.636	270.989	45.763	355.755	33.870	96.666	173.593
Fresh water aquatic ecotoxicity	kg 1,4-DB eq	309.950	47.404	8.754	95.440	10.539	107.253	40.561
Marine aquatic ecotoxicity	kg 1,4-DB eq	500136.222	84569.501	6406.827	138502.376	13502.118	184465.674	72689.726
Terrestrial ecotoxicity	kg 1,4-DB eq	5.161	0.507	1.421	0.886	0.753	1.178	0.416
Photochemical oxidation	kg C ₂ H ₄ eq	0.282	0.080	0.083	0.023	0.015	0.033	0.049

organic seed which further lead to weakens environment burden.

Additionally, the practice of sowing adds to acidification, eutrophication, terrestrial ecotoxicity, and photochemical oxidation with a share of 74.47%, 45.27%, 27.53%, and 29.34% respectively. The influence of these impact categories might be due to usage of Cow dung manure during the time of sowing. The cattle manure application can significantly increase CH₄ emissions in soil which leads to toxicity in soil as well as the water bodies (Kim *et al.*, 2014).

Next major contributor is irrigation practice with a share of more than twenty five percent in abiotic depletion (25.56%), Ozone layer depletion (37%), freshwater aquatic ecotoxicity (34.60%) and marine aquatic ecotoxicity (36.88%). This can be attribute to high usage of groundwater consumption and electricity consumption to run the water pump (Timpanaro *et al.*, 2021). The use of drip irrigation can reduce this particular impact by a noticeable amount however, it is still not in much practice in the region under study.

The other phases include organic fertilization, field preparation, harvesting and crop protection are generally proportionate to resource usage (Kumar *et al.*, 2022); for example, organic fertilization impact was shown to be greater due to high amount of organic manure usage and diesel consumption involved in their transportation to farm. Overall, it would be fair to state that the sowing & irrigation phase lends a major portion of contribution to the environmental.

Normalization result and discussion

It was also important to normalize the results in order to have a better understanding of the severity of the environment consequences related with the potato cultivation (Prasara and Gheewala,

2016). After normalization the impact category indicators all have the same unit, which makes it easier to compare them. The Fig 5 shows that 'marine aquatic ecotoxicity' contributed the largest to the overall environment; the fresh water aquatic ecotoxicity, eutrophication, and acidification also holds substantial contributions, but the impact of other categories on the ecosystem were almost negligible. The higher contribution by marine aquatic ecotoxicity is primarily attributed to the irrigation, organic fertilization and field preparation stages, due to the soil toxicants leaching into the groundwater or getting transferred with sediments by runoff, thus polluting freshwater aquatic ecosystems, and promoting eutrophication (Tuomisto *et al.*, 2012). The categories namely acidification and eutrophication were caused by sowing process due to fossil fuel usage in mechanical agitation i.e., tractor ploughing, and rotary cultivator etc. of soil (Khanali *et al.*, 2020). Nevertheless, such percentage can be brought down by adopting more efficient sowing mechanisms or by further optimizing the

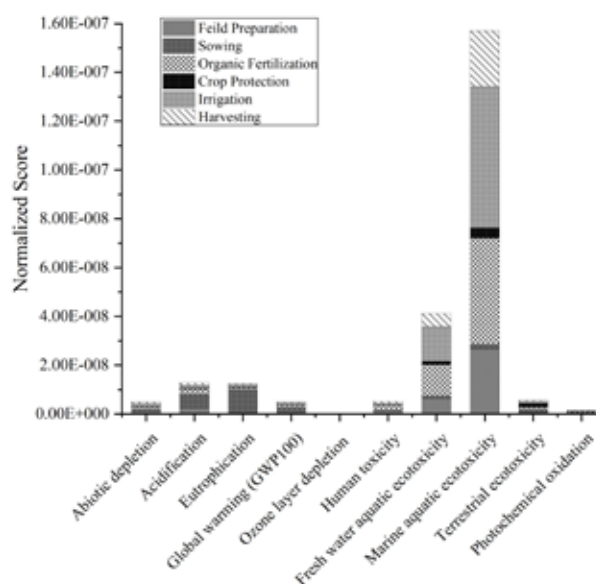


Fig. 5 Normalized results at various farming practices involved in organic potato production

design parameters of the planting equipment for reduced load on the tractor. However, such an analysis is beyond the scope of the current study.

Substance contribution analysis

The normalized findings of one-hectare organic potato production (Fig 5) revealed that the 'marine aquatic ecotoxicity', 'fresh water aquatic ecotoxicity', 'eutrophication', and 'acidification' were the most notable indicators of the overall ecological impact.

Additionally, a fifth key impact category namely 'GWP 100' has also been included among the previously mentioned four categories in light of its criticality towards the environment as per recent study by Singh (2022). To defined individual roles on these key categories, substance contribution analysis was performed within the system boundary, the results were presented in Fig 6. The dominant contributor to 'global warming' were carbon dioxide (65.53%), which is mainly released from diesel combustion to air

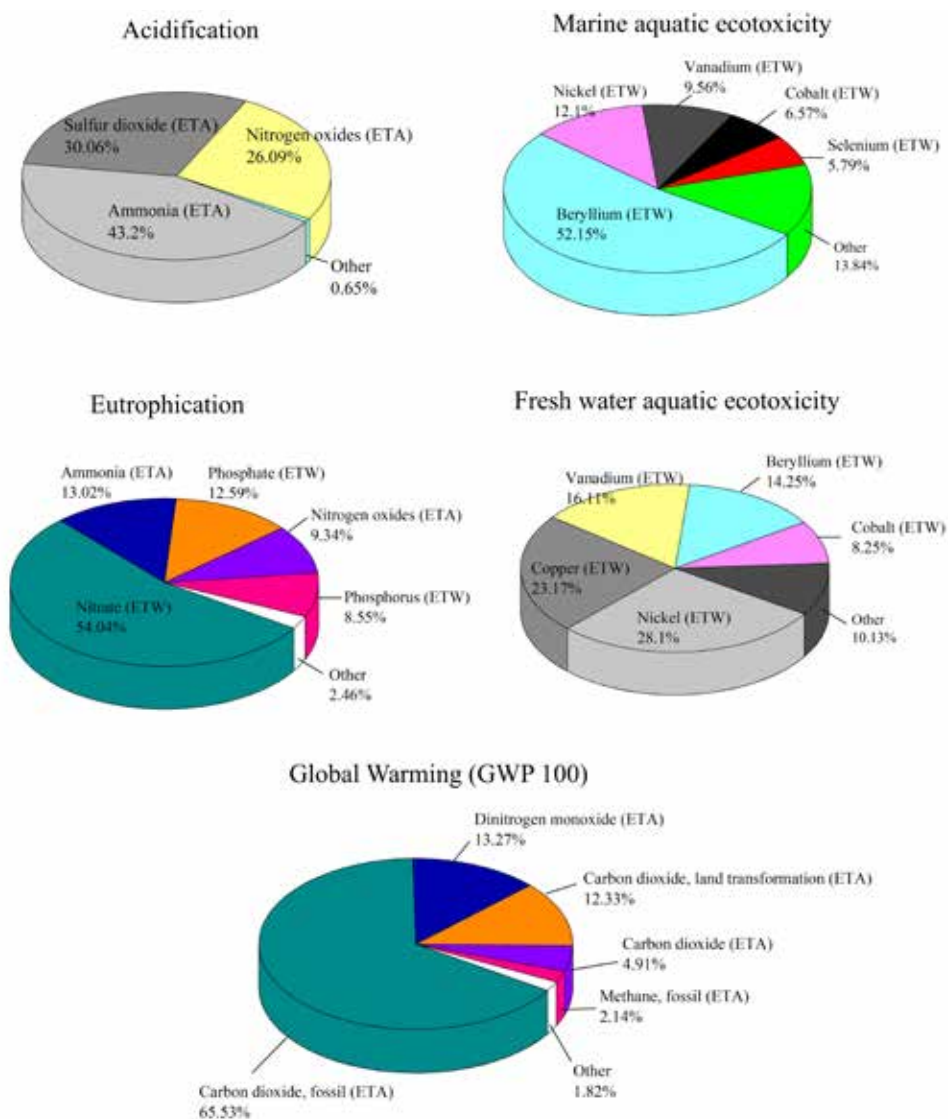


Fig. 6 Substance contributors to key categories. Note: ETA denotes emissions to air; ETW denotes emission to water

(Timpanaro et al., 2021). The most significant contribution to the impact of "freshwater ecotoxicity" and "marine ecotoxicity" was beryllium emission, followed by nickel, copper, vanadium and cobalt emission to water bodies. The contribution of ammonia to air is the highest for 'acidification' category while for eutrophication, nitrate emissions to air, water and soil was the most significant factor, accounting 54.01%. In summary, the above substance was identified as specific pollutants that should be strictly controlled by reducing on-site emissions specifically fossil fuel consumption and resource use.

CONCLUSION

The current study enlists the most crucial environment impact indicators and also evaluates their contribution towards the ecological footprint in the production of one hectare of organic potatoes. It is found that the sowing practice followed by irrigation practice emit the highest impact out of all chosen agricultural practices across all the major impact categories. Furthermore, it is suggested that at the farmers end, adoption of efficient sowing mechanism using advanced irrigation technologies like drip irrigation and developing infrastructure for organic manure production can effectively reduce the impact of there of hotspots. Also, at the govt's end, the development of renewable energy sources can counter act the negative impacts of conventional agriculture.

CONFLICT OF INTEREST

The authors confirm that this manuscript has no conflict of interest

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MS Received: October 06, 2022; Accepted: January 05, 2023

EFFECT OF CLIMATE VARIABILITY ON POTATO YIELD UNDER DIFFERENT AGROCLIMATIC ZONES OF PUNJAB

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ABSTRACT: A study was conducted to determine the role of meteorological parameters on year to year variability in potato yield in two different agroclimatic zones of Punjab viz. Central Zone (Ludhiana) and Western Zone (Bathinda) using last 17 years (2003-04 to 2019-20) data. The meteorological data of different months from October to January was used to conduct this study. The meteorological data of October and November month did not show any significance for locations. Whereas, meteorological data of December and January month significantly influenced potato yield at both locations. Potato yield showed highly significant positive correlation with minimum temperature and evening relative humidity for both locations whereas yield showed significant negative correlation with sunshine hours at Ludhiana. After studying the deviation of meteorological parameters from respective normals during highest and lowest yield years and the correlation of meteorological parameters with potato yield it can be concluded that in the Punjab minimum temperature along with sunshine hours play a major role in determining the potato yield. Regression model based on maximum and minimum temperature, morning relative humidity and sunshine hours gave good results. Validation of the regression models for prediction of potato yield proved the efficiency of the targeted predictions at both locations.

KEYWORDS: Potato, Agroclimatic Zones, Meteorological Parameters, Regression Models, Validation

INTRODUCTION

Potato (*Solanum tuberosum* L.) was originated in the Andean hills of South America. It belongs to the genus *Solanum* of the *Solanaceae* family. It was first introduced in the Europe by the Spanish conquerors in the end of 16th century. In India, it was introduced in early 17th century by Portuguese traders. At world level, potato is the third-largest food crop after wheat and rice and is cultivated in numerous countries, including China, India and Iran (Arab *et al.*, 2012). Total area under potato in India is ~2.16 million ha (m ha) with the production of 51.3 million tonnes (mt) and average productivity of 23.8 t ha⁻¹ far behind China (Choudhary *et al.*, 2021). The Indo-Gangetic plains (IGP) are the main potato growing region accounting for almost 85 per cent of the area under the crop in India, where it is grown as an irrigated crop during the winter season and

contributes more than 80 per cent to the total potato production of the country (Pandey and Kang, 2003). In Punjab, during 2020-21, 1.07 thousand ha area was under potato with production of 2.95 mt (Anonymous, 2021).

Potato requires long days and low temperature for its flowering and is restricted to its temperature requirement for tuber formation. Optimum tuber formation takes place at 20°C. Increase in temperature above 21°C cause sharp reduction in the tuber yield and at 30°C complete inhibition of tuber formation occurs. Temperature dependent planting time is major factor in determining growth and yield in the major potato growing regions of IGP (Haris *et al.*, 2015). The entire phase from emergence to tuber initiation is photosensitive. Short photoperiods favour early tuber initiation. However, under drought stress conditions tuber initiation and maturity is hastened (Beukema and Van

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der Zaag, 1990; Paul *et al.*, 2016). Various studies have projected a 10-40 per cent loss in potato production in India by 2080-2100 due to climate change unless farmers adapt to climate change (IPCC, 2007). Its growing duration in the IGP is projected to decrease due to climate change. The effect of climate change on potato production in India has been studied by Singh *et al.* (2009) and they revealed that under the warming scenarios, potato productivity is expected to decline in all potato growing states of India. The radiation use efficiency (RUE) is suppressed under high temperatures (Allen and Scott, 1992; Rajpoot *et al.*, 2021). It requires cool night temperature to induce tuberization (Ewing, 1997). Potato is very sensitive to frost. Severe damage of foliage occurs when temperature falls below 0°C (Hijmans *et al.*, 2003). Temperature less than 1°C for more than 4-5 hours can cause 50 per cent loss of foliage even in one night. Frost causes burning and leaf withering. Prolonged cold can cause a purplish discolouration of edges of leaflets. The frozen part of tuber become soft and blackens from inside. Frost can cause high reduction in yield. However, the reduction of yield depends on stage of crop when frost occurs. If frost occurs at 80-90 days after planting then 10-15 per cent yield loss occur while at 50-60 days after planting then 30-40 per cent yield loss occur. In Punjab, frost is the very dangerous for potato growth and yield. When planting is delayed beyond third week of October then severe damage can occur due to frost. This can be avoided by timely planting of crop. Frost can cause reduction of leaf area and can cause decrease in photosynthesis and yield. Potato is well known for its specific temperature and day length requirement for tuber formation as well as flowering, so it becomes the most vulnerable crop for climate change. As potato is the major food crop at global scale, thus

evaluating the effect of climate change on its productivity is the need of hour, so keeping this in view, the effect of climate variability on potato yield under two agro-climatic zones of Punjab have been analyzed and discussed in this paper.

MATERIALS AND METHODS

The impact of meteorological parameters on potato yield was analysed by conducting analysis of historical data. The historical data (2003-04 to 2019-20) of potato yield was collected for Ludhiana and Bathinda from "Statistical Abstracts of Punjab". The data of different meteorological parameters *viz.* temperature, relative humidity, rainfall, rainy days, sunshine hours for both locations was collected from Department of Climate Change and Agricultural Meteorology. The normal weekly meteorological data of Ludhiana was calculated by using data of 1970-2017 and for Bathinda was calculated by using data of 1977-2015. The potato yield data was analyzed and year with highest and lowest yield were identified. The deviations of different parameters were calculated for Ludhiana and Bathinda for highest and lowest yield year. Correlation and regression analysis was conducted to study the relation between potato yield and different meteorological parameters. The validation of developed regression models for Ludhiana and Bathinda was done by using data of 2004-05 and 2009-10 and 2005-06 and 2018-19 (that was not used in development of model) respectively. These years' data was used for predicting the potato yield.

RESULTS AND DISCUSSION

Meteorological parameters and potato yield at Ludhiana

The perusal of weekly maximum and minimum temperature during highest (2019-20) and lowest (2005-06) potato yield

year at Ludhiana revealed that maximum temperature was mostly below normal during highest yield year. The deviations of temperatures were calculated for both highest and lowest yield year and it was observed that during 2019-20 i.e. highest yield year, deviation of maximum temperature was in range of -7.9°C to 0.0°C as shown in Table 1. This data showed that during crop duration period in 2019-20, maximum temperature was not above normal even for a single week. Whereas, for lowest yield year deviation of maximum temperature was in range of -0.2°C to $+3.7^{\circ}\text{C}$. Out of 18 weeks, 14 weeks recorded above normal maximum temperature and resulted in lower potato yield. Comparison of weekly minimum temperature, during these two years indicate that during highest yield year only 3 weeks out of 18 weeks observed below normal minimum temperature and

on the other hand during lowest potato yield year 11 weeks recorded below normal temperature during crop duration period. Similarly, Singh *et al.*, (2010) revealed that lower yield is most common problem in areas where night temperatures fall below optimum during winter season.

The analysis of rainfall and sunshine hours prevailed during highest and lowest potato yield year is presented in Table 2. The highest yield year recorded 68.7 mm above normal rainfall whereas lowest yield year recorded 36.3 mm below normal rainfall. The comparison of sunshine hours indicate that lower sunshine hours favoured potato yield as more sunshine hours lead to more frost days. So, it was observed that, highest yield year recorded very low sunshine hours than normal as compared to lowest yield year which recorded more sunshine hours than highest

Table 1. Weekly maximum and minimum temperature deviation from normal during highest and lowest potato yield year at Ludhiana

Month	SMW	Normal $T_{\max}$	2019-20 (H)	2005-06 (L)	Normal $T_{\min}$	2019-20 (H)	2005-06 (L)
October	40	33.3	-3.1	+0.7	19.7	+0.8	+1.1
	41	32.8	-1.6	+0.7	18.2	+1.0	+0.7
	42	31.6	-1.1	+0.2	16.1	+2.4	0.0
	43	30.5	0.0	+0.6	14.6	+1.2	-0.9
November	44	29.3	-0.3	-0.4	13.5	+2.7	+0.2
	45	28.1	-0.7	-0.2	12.2	+1.4	-1.4
	46	26.8	-1.7	+0.6	10.8	+2.8	-1.4
	47	25.3	-0.5	+2.0	9.5	+1.7	-1.3
December	48	23.8	-1.4	-0.9	8.1	+3.9	-0.7
	49	22.9	-0.5	+0.1	7.3	-0.1	-2.5
	50	20.8	-4.6	+0.5	6.9	+2.5	-3.3
	51	19.6	-6.0	+0.1	6.2	+1.9	-2.3
January	52	18.2	-7.9	+1.5	5.6	-0.2	-0.2
	1	17.6	-1.3	-0.8	5.4	+0.3	+0.3
	2	17.9	-2.8	+1.8	5.4	+1.7	-2.3
	3	17.7	-1.6	+1.8	5.8	+1.6	+4.5
	4	18.5	-0.2	+0.3	5.8	+0.4	-1.5
	5	19.4	-1.9	+3.7	6.3	-0.6	+1.5

Where, $T_{\max}$: Maximum Temperature $T_{\min}$: Minimum Temperature H: Highest yield year L: Lowest yield year

Table 2. Weekly rainfall and sunshine hour's deviation from normal during highest and lowest potato yield year at Ludhiana

Month	SMW	Normal Rainfall	2019-20 (H)	2005-06 (L)	Normal Sunshine hours	2019-20 (H)	2005-06 (L)
October	40	3.1	-3.1	-3.1	9.2	-2.0	1.2
	41	1.8	-1.8	-1.8	8.9	0.1	0.1
	42	4.6	-4.6	-4.6	8.6	-3.1	-0.8
	43	0.5	-0.5	-0.5	8.4	-2.1	-0.7
November	44	2.4	-2.4	-2.4	7.4	-6.2	-1.4
	45	0.6	-0.6	-0.6	9.1	-3.2	-0.7
	46	0.6	-0.6	-0.6	9.0	-4.9	0.9
	47	1.7	-1.7	-1.7	8.8	-3.7	0
December	48	1.1	+34.1	-1.1	8.5	-3.5	-1.7
	49	2.9	-2.9	-2.9	8.2	-2.0	0.2
	50	3.0	+43.8	-3.0	7.6	-5.3	0.4
	51	4.7	-4.7	-4.7	7.0	-6.1	-3.5
	52	3.8	-3.8	-3.8	6.9	-6.0	-2.4
January	1	4.3	+9.1	1.9	7.3	-4.5	-1.6
	2	4.3	+15.7	-4.3	6.8	-2.7	0.7
	3	5.5	-5.5	5.1	7.1	-3.3	-2.8
	4	8.2	-1.8	-8.2	6.8	-0.5	2.4
	5	3.1	-3.1	-3.1	7.5	-0.3	0
Total		53.1	+68.7	-36.3	143.1	-59.3	-9.7

yield year. Comparison of the number of frost days between highest and lowest potato yield years at Ludhiana is shown in Fig. 1. In the year 2005-06, highest number of frost days (17 and 12 days) was recorded in month of December and January respectively, whereas in 2019-20 very few days (1 and 4) observed frost during December and January. Hijmans *et al.*, (2003) also revealed that potato is highly sensitive to frost and severe damage may occur when temperature drops below 0°C.

Meteorological parameters and potato yield at Bathinda

The analysis of weekly maximum and minimum temperature during highest (2003-04) and lowest (2007-08) potato yield year at Bathinda showed that maximum temperature was mostly below normal during highest yield year. The deviations of temperatures

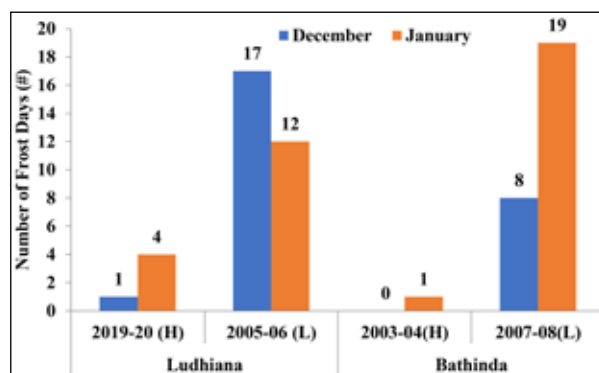


Fig. 1. Frost days variability during highest and lowest potato yield year

revealed that during highest yield year (2003-04), deviation of maximum temperature was in range of -5.5°C to +1.3°C as shown in Table 3. Whereas, for lowest yield year deviation of maximum temperature was in range of -0.2°C to +1.4°C. The comparison of weekly minimum temperature, during these

Table 3. Weekly maximum and minimum temperature deviation from normal during highest and lowest potato yield year at Bathinda

Month	SMW	Normal T _{max}	2003-04 (H)	2007-08 (L)	Normal T _{min}	2003-04 (H)	2007-08 (L)
October	40	34.6	-2.8	+0.7	19.7	-0.5	-0.9
	41	34.0	-2.7	+0.4	18.5	-0.1	+0.2
	42	32.7	-1.1	+0.6	16.4	+1.0	-0.8
	43	31.8	-1.4	+0.9	14.8	+0.2	+0.2
November	44	30.9	-2.3	+0.5	13.4	+1.3	-0.3
	45	29.7	+1.3	-0.2	12.0	+0.8	-1.9
	46	28.5	-0.9	-3.1	10.9	+1.4	+1.4
	47	26.8	-2.7	-3.9	9.3	-0.2	-2.9
December	48	25.2	-2.0	-2.0	7.7	-1.6	-2.9
	49	24.3	-4.8	-1.2	6.9	-1.2	+2.8
	50	22.6	-1.8	-1.6	6.5	-0.7	+3.6
	51	21.1	+1.3	-3.4	5.7	+0.8	-0.4
	52	19.5	-0.6	-2.8	4.9	-0.1	-1.3
January	1	18.3	+0.1	-3.7	4.5	-1.5	+0.3
	2	18.6	-1.3	+1.4	4.5	+2.1	+1.8
	3	18.5	-1.1	-1.1	4.9	-0.5	+2.5
	4	20.1	-5.5	-3.1	5.5	-6.6	+1.1
	5	20.6	-4.9	-4.5	5.8	-4.5	-0.8

two years indicate that during highest yield year deviation of minimum temperature was in range of -6.6°C to +2.1°C and on the other hand during lowest potato yield year, range of deviation was -2.9°C to +2.5°C. Dua *et al.* (2018) revealed that increase in temperature can lower potato yield by 10-11.4 per cent.

The analysis of rainfall received during highest and lowest potato yield year is presented in Table 4. The highest yield year recorded 1.1 mm below normal rainfall whereas lowest yield year recorded 22.2 mm below normal rainfall. The Comparison of the number of frost days between highest and lowest potato yield years at Bathinda is shown in Fig. 1. In the year 2007-08 highest number of frost days (8 and 19 days) was recorded in month of December and January respectively, whereas in 2003-04 very few days (0 and 1) observed frost during December and January.

Correlation Analysis

The pooled correlation coefficients between potato yield and different meteorological parameters were calculated for Ludhiana and Bathinda on the basis of potato yield and monthly data of different meteorological parameters prevailed during crop duration period as presented in Table 1. For Ludhiana, potato yield and meteorological parameters data of 2004-05 and 2009-10 years was not used for correlation and regression analysis as these years data was used for model validation.

Similarly, for Bathinda, potato yield and meteorological parameters data of 2005-06 and 2018-19 years were not used for correlation and regression analysis as these years' data was used for model validation. Among this correlation coefficient analysis, meteorological data of October month did not show any significance for both locations.

Table 4. Weekly rainfall deviation from normal during highest and lowest potato yield year at Bathinda

Month	SMW	Normal Rainfall	2003-04 (H)	2007-08 (L)
October	40	4.4	-4.4	-4.4
	41	2.8	-2.8	-2.8
	42	6.6	7.8	-6.6
	43	1.2	-1.2	-1.2
November	44	1.7	-1.7	-1.7
	45	1	-1.0	-1.0
	46	0	0.0	0.0
	47	2	7.8	-2.0
December	48	0	0.0	0.0
	49	1	5.4	-1.0
	50	1	-1.0	-1.0
	51	2	-2.0	-2.0
January	52	4	1.8	-4.0
	1	4	-4.0	-4.0
	2	2	1.4	-2.0
	3	2	-1.0	-2.0
	4	6	-6.0	-1.0
	5	3	-0.2	14.5
Total		44.7	-1.1	-22.2

Whereas, meteorological data of December and January month significantly influenced potato yield at both locations. Potato yield showed highly significant positive correlation with minimum temperature and evening relative humidity whereas yield showed significant negative correlation with sunshine hours at Ludhiana.

Development of a regression model

On the basis of different correlation coefficients and relationships of potato yield with different meteorological parameters most influencing meteorological parameters were identified from different months. These meteorological parameters were from crop duration period. After analyzing number of regression equations best fit equation with significant R^2 -value was selected as a model

for forewarning potato yield at Ludhiana and Bathinda. For Ludhiana, selected regression model includes maximum and minimum temperature, morning and evening relative humidity, rainfall and sunshine hours as independent variables and potato yield as dependent variable as dependent variable. The regression models for Ludhiana and Bathinda are as follows:

For Ludhiana:

$$Y = 50784.3 + 691.4T_{\max} - 268.9T_{\min} - 386.8RH_m + 88.1RHe + 53.8RF - 1094.0SSh$$

($R^2 = 0.54$)

For Bathinda:

$$Y = 10474.4 + 354.8T_{\max} + 1186.1T_{\min} - 104.7RH_m + 183.7RHe - 23.7RF$$

($R^2 = 0.64$)

Where,

Y= Potato Yield (Kg/ha)

$T_{\max}$: Maximum Temperature ($^{\circ}\text{C}$) $T_{\min}$: Minimum Temperature ($^{\circ}\text{C}$)

RH_m : Morning Relative Humidity (%) RHe : Evening Relative Humidity(%)

RF: Rainfall (mm) SSh: Sunshine Hours (hrs)

R^2 : Coefficient of Determination

This model indicates that potato yield at Ludhiana as well as Bathinda is highly influenced by meteorological parameters. The significant R^2 -value of 0.54 indicates that 54 per cent variability in potato yield at Ludhiana was due to different meteorological parameters. Similarly, for Bathinda district, R^2 -value of 0.64 indicates that 64 per cent variability in potato yield at Bathinda was due to different meteorological parameters (Table 5).

Validation of model

Validation of regression models for Ludhiana as well as Bathinda was done by calculating the predicted yield of two years data (2004-05 and 2009-10 for Ludhiana and 2005-06 and 2018-19 for Bathinda)

Table 5: Correlation coefficients between meteorological parameters and potato yield at Ludhiana and Bathinda (pooled over 15 years)

Meteorological Parameter	Ludhiana				Bathinda			
	Oct	Nov	Dec	Jan	Oct	Nov	Dec	Jan
Maximum Temperature (°C)	-0.40	-0.22	-0.11	-0.28	0.26	-0.20	-0.11	-0.29
Minimum Temperature (°C)	0.54	0.46	0.48	0.58	0.18	0.13	0.10	0.76
Morning Relative humidity (%)	-0.03	-0.21	-0.57	-0.26	0.32	-0.21	-0.14	0.41
Evening relative humidity (%)	0.08	0.42	0.16	0.42	0.35	0.15	0.36	0.71
Rainfall (mm)	0.22	0.41	0.26	0.24	0.07	0.16	-0.18	0.29
Sunshine hours (Hrs/day)	-0.52	-0.37	-0.53	-0.65	Data not available			

*significant at 5 per cent level of significance

*bold values were used for development of regression models

which was not used in development of the regression model. This validation indicated that developed regression model predicted yield very near to the observed yield (Fig.2).

CONCLUSION

The analysis of meteorological data for both locations indicated that deviations were comparatively less during high yield year as compared to lowest yield years. Number of frost days was significantly higher during lowest yield years. Correlation coefficients between different meteorological parameters and potato yield showed that minimum temperature, morning relative humidity and sunshine hours during December and January period significantly influenced potato yield at Ludhiana and Bathinda. Regression equation between different meteorological parameters and potato yield indicated that potato yield

is highly dependent on weather conditions of December and January. Significant R^2 values explained that more than 54 and 64 per cent variability in potato yield at Ludhiana and Bathinda respectively, was due to different meteorological parameters.

CONFLICT OF INTEREST

The authors confirm that this manuscript has no conflict of interest

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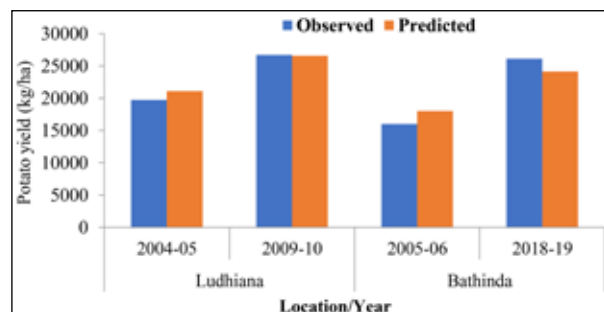


Fig. 2. Observed and predicted potato yield for Ludhiana and Bathinda

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MS Received: October 20, 2022; Accepted: January 03, 2023

FORECASTING OF POTATO PRODUCTION IN HIMACHAL PRADESH USING ARIMA MODEL

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ABSTRACT: This study focuses on the application of the ARIMA time series model to forecast the future potato production in Himachal Pradesh based on past data from 1991-92 to 2019-20. The stationarity of the data has been checked using the augmented dickey Fuller test which showed that the data was non-stationary. Therefore, differencing up to the first order has been done to make it stationary. Based on various model selection criteria, the best-fitted model was ARIMA (0, 1, 1) which has been used for the forecast of the next five years i.e., from 2020-2024. From the forecasted figure, potato production will go from 29612.36 tons to 22543.08 tons in 2024 showing an increasing trend.

KEYWORDS: ARIMA, Stationarity, Forecasting, Time Series data, Potato production

INTRODUCTION

Potato plays a vital role in the agricultural economy. India is the 2nd largest producer of potato in the world after China, accounting for ~12% of global potato production (Choudhary *et al.*, 2021). It is economically important not only for its contribution to the livelihood of farmers but also for its dominance in the agricultural consumption basket of households (Paul *et al.*, 2016). China is the biggest producer of potatoes worldwide, with about 1/3rd of the world's potatoes produced in China and India. According to FAO estimates, in 2020, over 359 million tons (mt) of potatoes were produced worldwide, an increase from a production volume of 333.6 mt in 2010. Potato (*Solanum tuberosum*) is the 3rd top most consumed crop worldwide after rice and wheat (International Potato Center, 2013).

In Indian agricultural GDP, the contribution of potatoes from the unit area of cultivable land is about 3.7 times higher than rice and 5.4 times higher than wheat

(Indian Horticulture, 2019). Some popular potato varieties have been developed by ICAR-Central Potato Research Institute for farmers which cover almost 95 % of the total area under potatoes. India produced approximately 45.87 mt of potato annually during the triennium 2014-17 and contributed ~57,512 crores annually to the Gross Value Added (GVA) at current prices (Indian Horticulture, 2019). The economy of Himachal Pradesh is largely dependent on agriculture. About 12.73 % of the total gross state domestic product (GSDP) is generated through agricultural and allied sectors (Economics Survey of Himachal Pradesh, 2019-20). So, it is an essential sector for the sustained growth of the state economy. Although rice, wheat, and maize are major agricultural crops grown in the state yet, the potato is also one of the important commercial crops. Out of total vegetable production in the country, the major share goes to potatoes (28.9 %). Out of the total 17.22 lakh tons production of vegetables in the state, potato accounts for 1.87 lakh

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tons i.e. 10.85 % which is the largest among all other vegetables (Economics Survey of Himachal Pradesh, 2019-20).

In this research paper, forecasting of potato production has been done for the next five years (2020 to 2024) for Himachal Pradesh. In recent times, forecasting methods have been increasingly applied by researchers. Some popular forecasting analysis methods are exponential smoothing methods, the Box-Jenkins ARIMA model, the Grey forecasting model, and others (Şahinli, 2020). Time series analysis for forecasting may be regarded as a useful practice to develop an appropriate econometric model for estimating future behavior based on previously observed behaviour (Ray and Bhattacharyya, 2020).

ARIMA (p, d, q) models are created by first taking the differences of the data from d degree for the stabilization process and then adding the ARMA (p, q) model. Hossain and Faruq (2016) used a time series model to find out the patterns in the past and utilize that information to forecast the future values of potato production in Bangladesh. They selected Box-Jenkins ARIMA (0,2,1) model for forecasting the potato production for the whole of Bangladesh. Jubair *et al.* (2019) carried out horizontal variability of some soil properties in Wasit governorate Iraq by using time series analysis. Mishra *et al.* (2021) did an estimation of fish production in India using ARIMA, Holt's Linear, BATS, and TBATS Models. Jamuna *et al.* (2021) analyzed the price of potatoes through the time series analysis using a price forecasting system that is implemented based on ARIMA Model. The potato price at one main market for each state was examined using the ARIMA model based on monthly average data obtained from Karnataka, Madhya Pradesh, Gujarat, Rajasthan, and Maharashtra. Kumar

and Baishya (2020) worked on forecasting of potato prices in India through the ARIMA model. Kumar *et al.* (2019) also used time series modeling to forecast the oilseed production in India.

ARIMA is also called as Box-Jenkins model because it was proposed by George Box and Gwilym Jenkins in 1976. Since, the ARIMA model employs non-zero autocorrelation between the subsequent values of the time series data, it was chosen for predicting in the current study. The present work has been taken with the following objectives:

- (i) To investigate the past trend in potato production in Himachal Pradesh.
- (ii) To develop an ARIMA model for potato production in Himachal Pradesh.
- (iii) To forecast the future potato production for the next 5 years i.e. from 2019 to 2020.

MATERIALS AND METHODS

Time series data on potato production in Himachal Pradesh for the last 30 years, i.e., from 1991-92 to 2019-20 were used for the present study. Data were procured from Statistical Yearbooks of Himachal Pradesh published by the Government of H.P.

Autoregressive Integrated Moving Average Model:

Three elements make up an ARIMA model: Moving Average (MA), Integration (I), and Autoregression (AR). The variable of interest is regressed on its own lagged values to create the AR model. I display how many times the series has been made stationary by differencing. A stochastic term's current value as well as several previous values are linearly reliant on the output variable that MA represents. A basic ARIMA model is expressed as (p, d, q), where p signifies the

order of the moving average process, d the number of times the series has undergone differencing to make it stationary, and q the order of the autoregressive process.

A time series must be stationary in order to be used for forecasting. In the event that the series is not stationary, it must be made stationary by taking the differencing up to the appropriate order. A time series generating process's statistical characteristic that doesn't change over time is called stationarity. If the mean, variance, autocorrelation, etc. remain constant across time, a series is said to be stationary. If the conditions listed below are true for every t , a time series Y_t is stationary.

$$E(Y_t) = \mu < \infty, V(Y_t) = E(Y_t - \mu)^2 = \sigma_0 < \infty \text{ and } Cov(Y_t, Y_{t-k}) = E\{(Y_t - \mu)(Y_{t-k} - \mu)\} = \sigma_k$$

To test whether a series is stationary or not, one may apply the unit root test. The unit root test checks whether the given time series has a unit root or not. Augmented Dickey-Fuller (1979) test is prominently used which assumes that the error term in the model is correlated.

Correlogram: It is a visualisation of a time series' time lag against partial and autocorrelation correlations. The underlying behaviour of a time series is examined using the patterns displayed in a correlogram. The basic connection between X_t and, let's say, X_{t+h} is shown by autocorrelation; this correlation between series has a lag. The autocorrelation function is expressed mathematically as:

$$\rho = \frac{Cov(y_t, y_{t-p \text{ or } q})}{var(y_t)}$$

Partial autocorrelation is the relationship between two observations after eliminating the linear relationship of every observation that comes between those two observations. Mathematically, it is given as:

$$\varphi(p) = \frac{\rho_p - \sum_{j=1}^{p-1} (\varphi_{p-2,j} - \varphi_{pp}\varphi_{p-2,p-j})\rho_{p-j}}{1 - \sum_{j=1}^{p-1} (\varphi_{p-2,j} - \varphi_{pp}\varphi_{p-2,p-j})\rho_j}, p \geq 3$$

The autocorrelation plot in the correlogram helps to decide the order of MA (q) whereas the partial autocorrelation plot helps to identify the order of AR (p).

Ljung-Box Q statistic: It is used to assess whether the observations are independent and arbitrary over time. It is a way to test for the *absence* of serial autocorrelation, up to a specified lag k . The test determines whether or not the autocorrelations for the errors or residuals are non-zero. The null hypothesis of the Ljung-Box Test is that H_0 : the model *does not* show a lack of fit. The alternative hypothesis is that H_1 : the model *does* show a lack of fit. A significant p-value in this test rejects the null hypothesis that the time series *data are not* autocorrelated. Ljung-Box Q statistic has an asymptotic chi-square distribution.

$$Q(p) = T(T+2) \sum_{i=1}^p \frac{\rho_i^2}{T-1} \sim \chi_p^2$$

A Box Jenkins methodology can be applied in three main steps viz., Identification, estimation and model checking, and forecasting.

Identification: To determine if the provided time series is stationary or not, model identification is used. If a stationary model is discovered, forecasting can be done using it. If it isn't, the series must be differentiated in order to make it stationary. An ARIMA model is then given for the differences series after the original series has been substituted by a series of differencing.

Estimation and Model Checking: Diagnostic testing, which is a stage in ARIMA modelling, entails looking at autocorrelation and partial autocorrelation functions for the estimation of residual behaviour. This aids

in determining the situations in which the model is inappropriate. At this point, the estimated models are tested to see if they meet the requirements for single-variable time series.

Forecasting: In this step, the estimated model is used to predict the future values of the time series.

RESULTS AND DISCUSSION

Figure 1 shows the behavior of the data on the annual production of potatoes. The scenario of potato production has shown an overall increasing trend except for steep low production in 2010.

Augmented Dickey-Fuller (ADF) test for checking stationarity of the data: ADF test is the most widely used test for determining the stationarity of data. The ADF test has the hypothesis that H_0 : the non-stationarity of the data against H_1 : the data are stationary. The critical value for the rejection of the null hypothesis of the unit root test was not significant as the p-value is (>0.05) at 5 % level of significance. The results showed that the data regarding potato production were non-stationary and could be used for forecasting purposes.

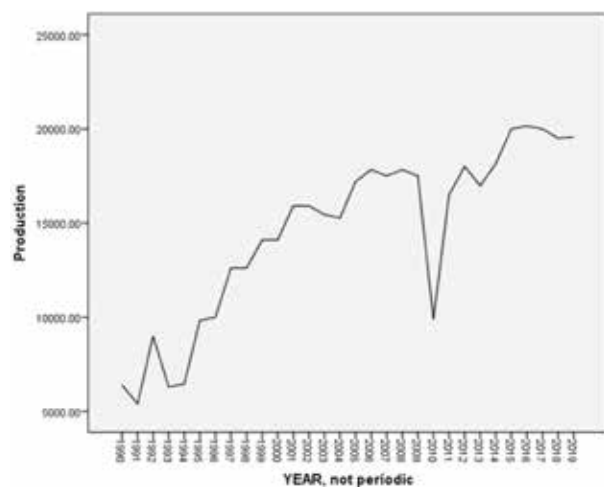


Fig. 1: Behaviour of the potato production in Himachal Pradesh for the period from 1999 to 2019

Since Table 1 reveals that the data were non-stationary, therefore, differencing up to order one is to be done to make it stationary.

It can be seen from above figure 2 that the mean and variance appeared to be normalized which indicates that data are now made stationary. ADF test statistics value is -5.65 and is highly significant which shows that the model is good and can be used further for forecasting purposes (Table 2).

The next step is to find out the values of p and q . For this, the autocorrelation and partial autocorrelation coefficients of various orders of X_t are computed. The ACF and PACF (Fig. 3, 4) show that the order of p is zero and q can be at the most one.

Table 1: Unit root test for checking the stationarity of the data

	Test - statistics	Significant value
ADF Test at 5 % level of significance	-1.79	0.38

Table 2: Unit root test for checking the stationarity of the data after the first difference

	test - statistics	Significant value
ADF Test at 5 % level of significance	-5.65	0.00

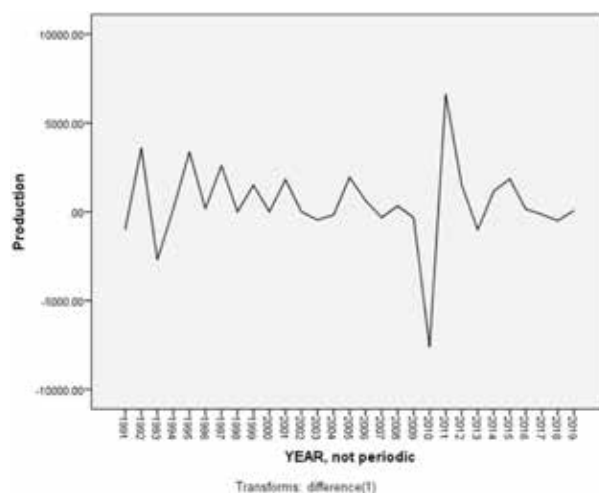


Fig. 2: Time-series plot of stationary Potato production data

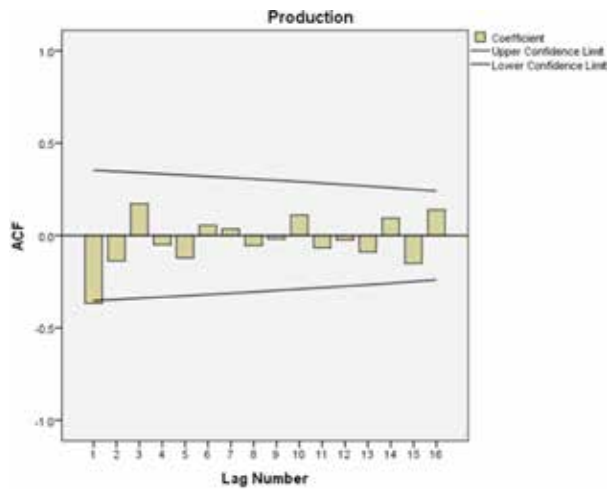


Fig. 3: Sample autocorrelation function

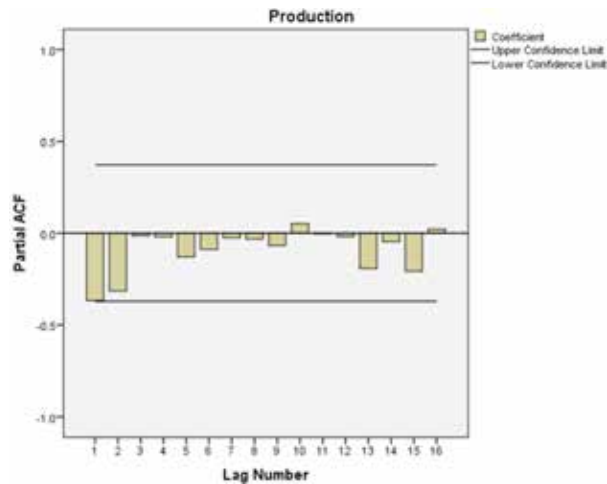


Fig. 4: Sample partial autocorrelation function

After trying all the possible ARIMA models, we chose the model ARIMA (0, 1, 1) and depicted it based on certain model selection criteria as:

ARIMA (p, d, q)	Stationary R-squared	Normalized BIC	MAPE
(0, 1, 1)	0.20	15.55	12.29

Table 3: Estimation of parameters

ARIMA Model Parameters	Estimate	SE	t	Significant
Constant	482.70	190.36	2.53	0.01
MA	0.53	0.16	3.21	0.00

Ljung-Box Q-statistics = 11.13 (p value = 0.85)

Model Estimation and Verification

Table 3 depicts the results of the estimation of parameters. The value of Ljung-Box Q-statistics shows that model does not show a lack of fit. MA estimates are highly significant at 1 per cent level which indicates that model is best fitted and good for forecasting.

The ACF and PACF of the residuals (Fig. 5) also indicate a 'good fit of the model and indicate that there is no correlation between sample errors.

Residuals of models are needed to be checked to see if they have any systematic pattern which will lead to the selection of a much better ARIMA model. This is done by examining the autocorrelations and partial autocorrelations of the residuals of various orders. For this purpose, the various correlations up to 25 lags are computed and the same along with their significance

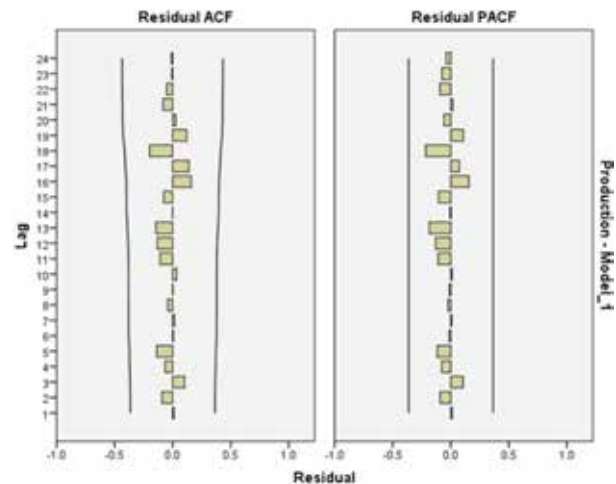


Fig. 5: ACF and PACF of residuals of fitted ARIMA (0, 1, 1) model.

Table 4: Forecasted values for the next five years

Year	Estimated Production	LCL	UCL
2020	20612.26	16263.18	24961.34
2021	21094.97	16301.95	25887.99
2022	21577.67	16378.48	26776.86
2023	22060.38	16484.53	27636.23
2024	22543.08	16614.45	28471.71

are tested by the Box-Ljung test. As the results indicate, none of these correlations is significantly different from zero at 5% level. This proves that the selected ARIMA model is appropriate.

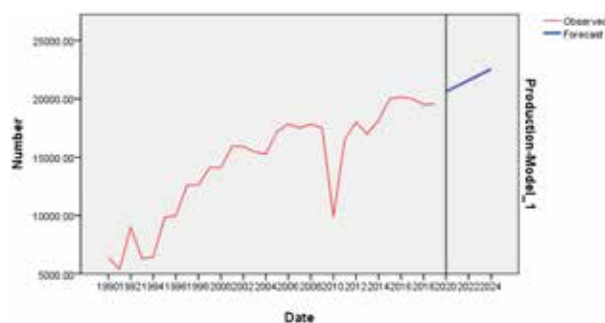
Forecasting with ARIMA model

Table 4 showed that for 2020, a forecast of maize area was 20612.26 mt with the lower and upper limit of 16263.18 and 24961.34 mt respectively. The forecasting of potato production in Himachal Pradesh in 2024 would be 22543.08 mt with the lower and upper limit of 16614.45 and 28471.71 mt respectively..

It can be seen from the fig.6 that potato production will increase in the upcoming five years according to the forecasted model.

CONCLUSION

In this study, ARIMA (0, 1, 1) model was developed and the validity of the forecasted values can be checked when the data for the lead periods become available. The correctness of the anticipated values may be verified once the data for the lead periods are available since an ARIMA (0, 1, 1) model was used in this study. Analysis of the performance of potato production from preceding 1991-92 to 2019-20 gives us the ARIMA (0, 1, 1) model which helps us in forecasting the future values of potato production. ARIMA (0, 1, 1) was chosen from different model parameters as it provides the best model which satisfies all the criteria of

**Fig 6: Forecasted graph for 2020 -2024**

fit statistics. For forecasting potato production in Himachal Pradesh, the model can be preferred by the researchers but it should be updated time and again with the inclusion of contemporary data.

CONFLICT OF INTEREST

The authors confirm that this manuscript has no conflict of interest.

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- MS Received: November 29, 2022; Accepted: December 19, 2022

BIODIVERSITY AND IDENTIFICATION OF POTATO WHITE GRUBS IN HIGH HILLS OF HIMACHAL PRADESH

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ABSTRACT: The most challenging insect-pests of the potato crop in Himachal Pradesh are white grubs. Their diversity tends to fluctuate, depending on altitude, geography, ecosystems, and other environmental variables. The survey on white grubs of potato was carried out in 19 locations from five districts of Himachal Pradesh during 2021-22. The altitude of these locations varied from 1378-3279m amsl. In total, 13 species of white grubs were collected feeding on roots and tubers of potato crop. Out of 13 species, 8 species have been identified as *Brahmina crinicornis* Burmeister, *Brahmina coriacea* (Hope), *Brahmina flavosericea* Brenske, *Holotrichia longipennis* Blanchard, *Anomala rufiventris* Redtenbacher, *Melolontha fuscicauda* Ancey, *Melolontha cuprescens* Blanchard and *Polyphylla sikkimensis* Brenseke. We couldn't rear four species till adult emergence and hence this species remained unidentified. The raster patterns of all 13 species have been described with suitable pictures.

KEYWORDS: Potato, white grub, raster pattern, distribution

INTRODUCTION

Potato is cultivated in almost all states of India under diverse agro-climatic conditions and has wider adaptability. It is a high-volume crop and yields substantially more edible energy, protein and dry matter per unit area and time because of a short vegetative cycle than many other crops (Dhiman *et al.*, 2007). India produces about 7.72 per cent of the world's potato from 7.57 per cent of the total global potato growing area, with productivity levels higher than the world's average (Rana 2011). In Himachal Pradesh, potato occupies an area of 14407 hectares with production of about 1.97 lakh MT (Anonymous 2021).

Insect-pests cause variable and complex problems for potato farmers. India has a great diversity of insect-pests that attack potato. The significance of various insect-pests in potato production varies from region to region. According to Simpson (1977), potato

crop is attacked by more than 100 arthropod pests, and out of these 80 pests have been reported from India (Saxena and Misra 1983). Among different insect-pests, white grubs are more destructive and troublesome insects, impeding potato production especially in hilly states of India (Chandel *et al.*, 2015). White grubs are immature stages of scarab beetles popularly known as chaffer beetles or May-June beetles.

This is a polyphagous pest both in adult and grub stage and inflicts heavy damage on various fruit/forest trees, their nurseries, vegetables, lawns and field crops (Chandel *et al.*, 2010). Being polyphagous they feed on a wide variety of cultivated as well as uncultivated plants (Mehta *et al.*, 2010).

In India, no record exists of any white grub damage to potato tubers until the 1960s. The first record of white grubs causing damage to potato in India is from Himachal Pradesh by Sharma and Bhalla

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(1964). They mentioned two species viz., *Brahmina coriacea* (Hope) and *Lachnosterna* (= *Holotrichia*) *longipennis* Blanchard causing damage to several crops including potato in Himachal Pradesh. The problem of white grubs is quite serious in the entire north-western Himalaya, where potatoes are grown during summer season as a rainfed crop under long day conditions (Misra and Chandel 2003). In Himachal Pradesh, potato cultivation is done on sloppy lands with light and loose-textured soils and high rainfall. The potato fields are normally situated in the vicinity of fruit orchards in entire north-western Himalaya, and the adults of white grubs prefer to feed on fruit trees during night (Chandel *et al.*, 1997), and enter into nearby potato fields where they lay eggs in the soil during May-June (Chandel *et al.*, 1995). These conditions are conducive for development and multiplication of white grubs (Singh *et al.*, 2002). In India, 24 species of white grubs have been recorded to damage potato from the states of Himachal Pradesh, Uttarakhand, Jammu & Kashmir, Tamil Nadu, Karnataka and north-eastern hill states. The most widespread and destructive species are *B. coriacea*, *Brahmina flavosericea* Brenske, *Melolontha indica* Hope, *Anomala dimidiata* (Hope), *H. longipennis*, *Holotrichia sikkimensis* (Brenske), *Holotrichia seticollis* Moser, *Phyllognathus dionysius* (Fabricius) and *Lepidiota mansueta* Burmeister (Chandel *et al.*, 2013, Bhattacharyya *et al.*, 2011).

MATERIALS AND METHODS

Field survey for collection of white grubs from potato

The survey on potato white grubs was carried out in 19 locations from five districts, mainly in high hills areas of Himachal Pradesh (Table 1). The survey work continued for about one year, the sampling sites in a field were selected randomly by throwing

a 1 feet² quadrant over one's shoulder with no two sampling pits overlapping, the data on grub population were recorded by using pit sampling method with each pit consisting of 1 cubic feet area. At each location, at least 20 samples were taken. At each location sampling of soil was done by carefully digging field by shovel and different larval, pupal and adult stages were carefully collected. The collected white grubs were brought to the laboratory in polythene bags along with moist soil. The observations on raster pattern were taken under the stereo zoom microscope model LEICA S9i. The rearing of grubs was done in the white grub laboratory, Department of Entomology, CSK HPKV, Palampur for adult emergence, and their further identification from the relevant sources. In the laboratory, the grubs were sorted out species wise on the basis of their raster pattern. Some of the white grubs were preserved in 70 per cent alcohol and data on their length and breadth were also recorded. After through sorting of larvae, grubs were transferred to individual paper cups/glass jars having soil and FYM mixture (1:1). Potato tubers were given as food for developing larvae, and observations were recorded on their development up to May, 2022. After adult emergence, beetles were killed and sent to NBAIR, Bengaluru for identification.

RESULTS AND DISCUSSION

The survey on potato white grubs was carried out at 19 different locations in Himachal Pradesh, and 13 species of white grubs were collected as shown in table 1.

In Chamba district, *Brahmina crinicolis* was found to be the predominant species comprising 100 per cent population at Salooni and 68.18 per cent at Mani. At Shillaroo, Chidgaon, Matiana, Kufri and Fagu in Shimla district, only *Brahmina coriacea* grubs were

Table 1. Location-wise species distribution of white grubs in Himachal Pradesh

Sr. No.	Location	Altitude (m amsl)	Species	Relative abundance (%)
1.	Salooni	1734	<i>Brahmina crinicolis</i> Burmeister	100.00
2.	Mani	1514	<i>Brahmina crinicolis</i> Burmeister	68.18
			Unidentified sp. I	31.82
3.	Rohru	1965	<i>Brahmina coriacea</i> (Hope)	77.38
			Unidentified sp. II	17.26
			<i>Anomala rufiventris</i> Redtenbacher	4.17
			<i>Melolontha furcicauda</i> Ancey	1.19
4.	Chidgaon	1767	<i>Brahmina coriacea</i> (Hope)	100.00
5.	Khadrala	2603	<i>Melolontha cuprescens</i> Blanchard	100.00
6.	Tikkar	2244	<i>Brahmina Coriacea</i> (Hope)	56.20
			Unidentified sp. III	43.80
7.	Shillaroo	2479	<i>Brahmina coriacea</i> (Hope)	65.07
			<i>Holotrichia longipennis</i> Blanchard	34.93
8.	Matiana	2394	<i>Brahmina coriacea</i> (Hope)	100.00
9.	Kufri	2561	<i>Brahmina coriacea</i> (Hope)	100.00
10.	Fagu	2519	<i>Brahmina coriacea</i> (Hope)	100.00
11.	Nihri	2114	Unidentified sp. V	65.49
			<i>Brahmina coriacea</i> (Hope)	26.55
			<i>Anomala rufiventris</i> Redtenbacher	7.96
12.	Bagsiad	1849	<i>Brahmina crinicolis</i> Burmeister	100.00
13.	Janjheli	2095	<i>Brahmina crinicolis</i> Burmeister	62.50
			<i>Polyphyllasikkimensis</i> Brenske	32.24
			<i>Anomala rufiventris</i> Redtenbacher	5.26
14.	Barot	1807	<i>Polyphylla sikkimensis</i> Brenske	61.19
			<i>Brahmina crinicolis</i> Burmeister	38.81
15.	Karsog	1378	<i>Brahmina flavosericea</i> Brenske	100.00
16.	Benchi	1501	<i>Brahmina flavosericea</i> Brenske	57.75
			Unidentified sp. I	37.32
			Unidentified sp. IV	4.93
17.	Banjaar	1876	Unidentified sp. V	100.00
18.	Anni	2006	Unidentified sp. V	60.95
			Unidentified sp. III	39.05

found to cause damage to potato tubers. Maximum population of white grubs was recorded at Shillaroo with a mean of 11.45 ± 1.05 grubs/ft². At Rohru and Tikkar, *B. coriacea* comprised 77.38 and 56.20 per cent of total grub count, respectively.

The observations recorded on morphometrics and development of different species is discussed here under.

***Brahmina coriacea* (Hope):** The grubs caused heavy damage to potato ranging from 8.20 to 45.90 per cent in high hills of Shimla, Mandi

and Kullu districts of Himachal Pradesh. In Shimla district, *B. coriacea* grubs comprised 56.06 to 100.00 per cent at Tikkar, Rohru, Chidgaon, Shillaroo, Matiana, Kufri and Fagu. Chandel *et al.* (2003) also found *B. coriacea* to be a common species in Shimla hills of Himachal Pradesh, constituting about 90 per cent of the population. In Thanedhar, Kotgarh, Matiana and Jubbal areas, 100.00 per cent beetles of *B. coriacea* have been taken in different collections by various workers (Singh and Dogra 1984). In the present study, observations were recorded on grubs and pupae of *B. coriacea* under laboratory conditions at Palampur. The first instar grubs of *B. coriacea* were collected during July 2021 from potato fields located in Shillaroo, Matiana, Fagu and Kufri areas. The collected grubs were greyish white in colour, and their body length ranged from 6.2 to 7.3 mm. Mean head capsule width was recorded to be 1.64 ± 0.09 mm (range: 1.59-1.74 mm). The identity of grubs was confirmed based on their raster pattern as described by Pathania *et al.*, (2017). The raster pattern is given in fig. 1, and it is ornamented with two rows of palidia. There are 13 pali in each row. The pali of one side are crossing the corresponding pali from other side in the middle of septula. There is gradual narrowing of septula from posterior to anterior direction. The hemate setae are bold and short. The palidium was broad at the base, tapered gradually, with pointed tip. The hemate setae seems to be fitted in round socket like structure, comparatively less tapered, and terminal end is slightly curved to right side. Chandel *et al.* (1995) reported body length of fully fed first instar grubs of *B. coriacea* ranging from 11.0-12.7mm with an average head capsule width of 1.5 ± 0.03 mm, and these values are in the same range as recorded in the present study. The first instar grubs occupied 12.0-14.0 days under laboratory conditions at Palampur. Chandla *et*

al. (1988) reported somewhat higher duration of the first instar grubs of *B. coriacea* in Shimla hills. However, Chandel *et al.* (1995) reported first instar ranging from 11-20 days with an average of 14.4 ± 0.6 days at Nauni located in mid hill region of Himachal Pradesh.

To complete post eclosion development, the grubs of *B. coriacea* moulted twice having three distinct instars. The body length of second instar grubs was observed to range from 14.0-16.20 mm for fully fed second instar grubs. The width of head capsule varied from 2.30-2.44 mm. The second and third instar grubs did not show much difference in morphological characters, except that there was considerable increase in larval size in third instar. During this final instar, the grubs turned slightly yellowish to creamish white in colour, but the colour of the head capsule remained dark brown. The third instar grubs (Fig. 1) measured from 22.87-26.12 mm in body length, and 3.87-4.19mm in head capsule width. The head capsule width as reported by Chandel *et al.*, (1995) is 2.4 and 4.3 for instars II and III, and the grubs in successive instars were on an average 14.95 and 24.13mm long, respectively. Contrary to our findings, Chandla *et al.*, (1988) reported third instar grubs of *B. coriacea* ranging from 35-38mm in body length. Duration of the second instar was recorded to be 23-27 days (mean $\pm$ SE: 24.50 ± 0.89 days). The third instar was recorded to be the overwintering stage, thus required 184-214 days for maturity. Although the duration of the third instar was about six months (October 2021-March 2022), but the duration of active feeding of third instar grubs was for about 60-70 days through October-November.

The fully fed third instar grubs stopped feeding by November, and formed hard earthen cells for overwintering and subsequent development as pupa and adults. Contrary

to this, average duration of third instar at Shimla was found to be 74.4 ± 2.80 days (Chandla *et al.*, 1988). Possibly they have recorded observations only on active third instar grubs before formation of earthen cells. These observations are in line with those of Veeresh (1977) for *H. serrata*. The total larval period was found to be 219-255 days with an average of 244 ± 10.12 days. Gupta (2012) reported total larval period of 214-267 days under laboratory conditions at Palampur. The prepupal period in laboratory was short, ranging from 11-12 days. The pupation in laboratory was observed as early as fourth week of March 2022 in hard earthen cells. The pupa (Fig. 1) measured on an average 16.61 ± 0.38 mm long and 7.07 ± 0.31 mm wide. The average pupal period was 15.95 ± 0.82 days, the minimum and maximum being 14 and 18 days, respectively. The pupal duration as reported by earlier workers was 12-20 days at

Nauni and 19-24 days at Palampur (Chandel *et al.*, 1995; Gupta 2012). Adult formation in earthen cells was noticed in second week of April 2016 under laboratory conditions at Palampur.

The adult beetles are black in colour (Fig. 1). The body length of beetles ranged from 12.45-16.60 mm with a mean of 14.6 ± 0.40 mm, while the width ranged from 7.47-7.98 mm with a mean of 7.54 ± 0.35 mm as shown in table 2. The body length width of *B. coriacea* beetles as reported by earlier workers was in the range of 12-17.55 5.94-7.85 mm (Gupta 2012; Chandel *et al.*, 1995). Thus, our findings are in complete agreement with their results.

***Brahmina flavosericea* Brenske:** In the present study, maximum abundance of *B. flavosericea* was recorded in Karsog area at an altitude of 1492 amsl. Pathania (2014)

Table 2. Duration and morphometrics of different development stages of *B. coriacea*

Stage	Duration (Days)		Body Length (mm)		Width (mm)	
	Range	Mean $\pm$ SE	Range	Mean $\pm$ SE	Range	Mean $\pm$ SE
Grub I	12-14	13.15 ± 0.80	6.2-7.3	6.33 ± 0.35	1.59-1.74	$1.64 \pm 0.09^*$
II	23-27	24.50 ± 0.89	14.0-16.20	14.90 ± 0.55	2.30-2.44	$2.47 \pm 0.14^*$
III	184-214	207 ± 4.9	22.87-26.12	24.13 ± 0.15	3.87-4.19	$4.02 \pm 0.13^*$
Total larval period	219-255	244 ± 10.12	-	-	-	-
Prepupa	11-12	11.8 ± 0.87	-	-	-	-
Pupa	14-18	15.95 ± 0.82	16.12-17.07	16.61 ± 0.38	6.75-7.20	7.07 ± 0.31
Adult	-	-	12.45-16.60	14.6 ± 0.40	7.47-7.98	7.54 ± 0.35

*Refers to head capsule width.

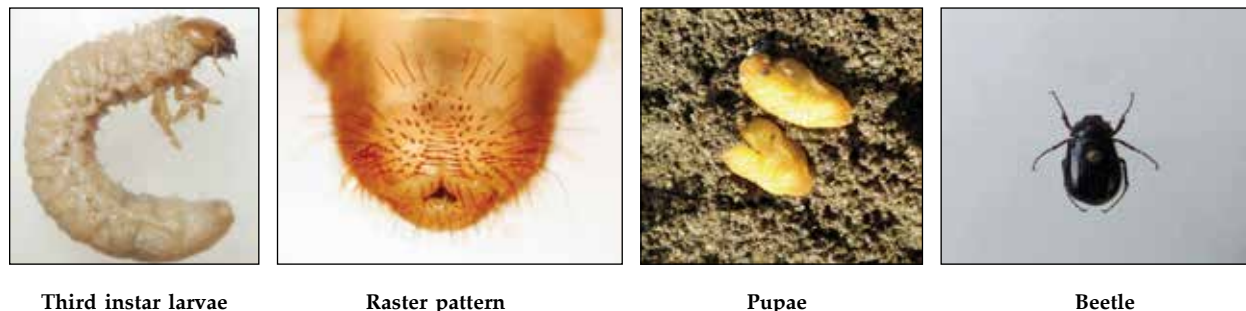


Fig. 1 Development stages and raster pattern of *B. coriacea*

has recorded this species in low to moderate numbers from Shillaroo, Bharmour, Nauni, Sangla and Kalpa areas. Chandel *et al.* (2010) reported that it is one of the leading species in Janjheli area of Mandi district. The young grubs were pearly white with a dark head. The fully fed first instar grubs were about 5.13 ± 0.04 mm long (range: 4.94 to 5.32 mm). The average head capsule width was recorded to be 1.16 ± 0.02 mm. The period of first instar larvae averaged 20.0 ± 2.13 days with extremes of 16 and 24 days. The average body length of second instar was noted to be 20.0 ± 0.83 mm (range: 19.20-22.10 mm). The second instar had extremes of 29 and 35 days with an average of 30.2 ± 0.12 days. The duration of third instar was found to be varying between 185 to 215 days, with an average of 203.50 ± 5.82 days. The length of fully grown third instar larvae ranged from 23.10 to 29.0 mm (mean: 27.38 ± 0.21 mm). Mehta *et al.* (2008) reported larval length of 22-24 mm in fully fed grubs of *B. flavosericea*. The average head capsule width was recorded to be 2.14 ± 0.02 and 3.29 ± 0.05 mm for second and third instar grubs, respectively. Pathania (2014) found head capsule width for first, second and third instar grubs of *B. flavosericea* as 1.16 ± 0.01 , 2.13 ± 0.03 and 3.30 ± 0.04 mm, respectively. These reports are well within the range observed from this species in the present study. The raster pattern is shown in fig.2. The septula is elongate, and palidia are arranged in two parallel rows. The number

of pali varied from 12 to 14, which are arranged in two parallel rows. The base of pali is spherical and the tip is pointed. The hemate setae had a circular flat base, more or less of same thickness from base to terminal end. The tip of hemate setae looks globular and is curved to right side.

The fully fed larva created a small earthen cell in the upper layer of soil in the month of November, and remained in the cell till adult emergence in next summer (Fig.2). Pupation occurred in earthen cells, and was observed as early as 17th April, 2022 in laboratory. The pupa measured from 15.74 to 17.46 mm with an average of 16.94 ± 0.52 mm. When freshly formed they were creamy white in colour, and darkened before emergence. There was a single generation in a year. Adult formation commenced on 3rd May, 2022, and newly transformed adults remained in earthen cells for a period of about 20 days. The adults are medium sized elongate beetles. The elytra are yellowish in colour. The head and legs are dark brown in colour (Fig. 2). The length of beetles ranged from 14.44 to 16.65 mm with a mean of 15.99 ± 0.21 mm, while the width ranged from 6.79 to 7.18 mm, with a mean of 7.05 ± 0.04 mm as shown in table 3. Mehta *et al.* (2008) recorded length as 13-14 mm, and breadth of 7-8 mm for beetles of *B. flavosericea*.

***Brahmina crinicornis* Burmeister:** The grubs of this species were collected in the month

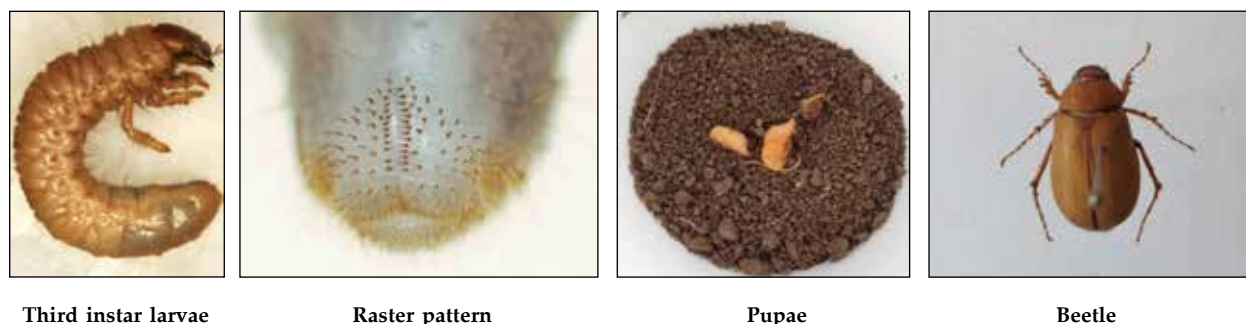


Fig. 2 Development stages and raster pattern of *B. flavosericea*

Table 3. Duration and morphometrics of different development stages of *B. flavosericea*

Stage	Duration (Days)		Length (mm)		Width (mm)	
	Range	Mean $\pm$ SE	Range	Mean $\pm$ SE	Range	Mean $\pm$ SE
Grub I	16-24	20.0 $\pm$ 0.83	4.94-5.32	5.13 $\pm$ 0.04	1.09-1.1.19	1.16 $\pm$ 0.02*
II	29-35	30.20 $\pm$ 0.12	19.20-22.10	20.0 $\pm$ 0.83	2.08-2.19	2.14 $\pm$ 0.02*
III	185-215	203.50 $\pm$ 5.82	23.10-29.0	27.38 $\pm$ 0.21	3.24-3.48	3.29 $\pm$ 0.05*
Total larval period	230-274	241 $\pm$ 11.20	-	-	-	-
Pupa	18-22	19.45 $\pm$ 0.64	15.74-17.46	16.94 $\pm$ 0.52	6.64-7.31	7.08 $\pm$ 0.42
Adult	-	-	14.44-16.65	15.99 $\pm$ 0.21	6.79-7.18	7.05 $\pm$ 0.04

*Refers to head capsule width.

of July at Salooni, Mani, Bagsiad and Janjheli in the present study. The head capsule width for third instar grubs ranged from 2.99 to 3.47 mm with an average of 3.25 $\pm$ 0.06mm. The fully fed third instar grubs measured on an average 26.24 $\pm$ 1.03mm in length (range: 23.51 to 29.8mm). The grubs continued feeding on potato tubers throughout August to October. The raster pattern (fig. 3) can be identified by two rows of palidia, each consisting of 18-20 pali. Each palidium runs parallel to each other from anterior to posterior direction upto 12 pali, but after 12 pali, each palidium diverge in opposite direction in a typical semi-circle forming J-shaped pattern as shown in fig.3. During November, fully fed third instar grubs constructed earthen cells and overwintering occurred in quiescent larval stage in these earthen cells from November to March. In the first week of April, grubs transformed into pupae inside the earthen cells. The pupation in laboratory

was observed as early as 4th April, 2022. The pupa measured on an average 16.53 $\pm$ 0.41mm long, and 7.08 $\pm$ 0.42mm wide. The average pupal period was 17.95 $\pm$ 0.74 days under laboratory condition, the minimum and maximum being 16 and 20 days, respectively. Total duration of third instar was calculated to 190 to 220 days (mean: 205.60 $\pm$ 5.7 days), and there was one generation per year.

Adult formation inside earthen cells was noticed as early as 18th April. Adult beetles are shiny black in colour, but the head and thorax are covered distinctly with brown hairs showing clear cut distinction from the rest of the body. The beetles measured 14.68 to 16.98mm in length, and 6.76 to 7.46mm (range: 6.76-7.46mm) in width.

***Holotrichia longipennis* Blanchard:** The grubs of *H. longipennis* were collected at Shimla in potato fields. According to Thakur (2000), this species usually occurs in northern India

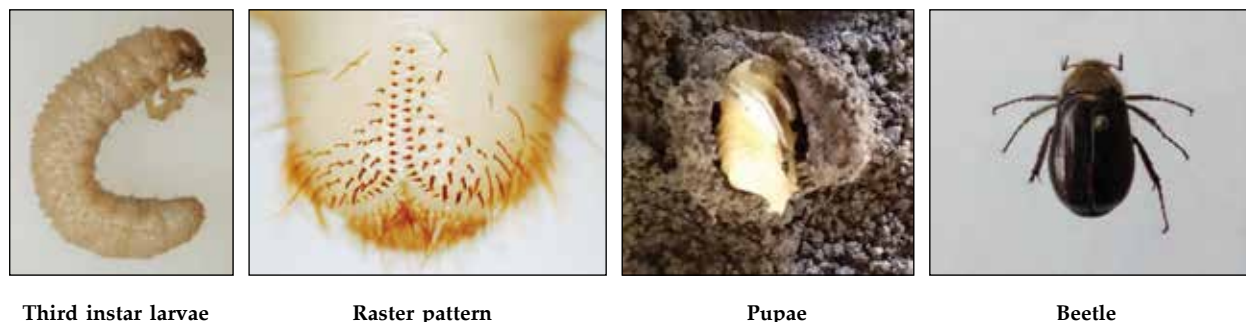


Fig. 3 Development stages and raster pattern of *B. crinicollis*

and Pakistan at altitude varying from 700-2500 amsl. The average density in potato fields was recorded to be 4.15 ± 0.17 grubs/ ft^2 (range: 2 to 6 grubs/ ft^2). The collected grubs were in first instar, and were further reared in laboratory till adult emergence. The field collected first instar grubs were creamy white in colour with light brown head which was prominently broader from rest of the body. The head capsule width of first instar averaged 1.73 ± 0.03 mm. Mean body length of fully fed first instar was recorded to be 8.88 ± 0.14 mm (range: 8.28 to 9.14 mm). Shah and Shah (1990) reported body length of early first instar grubs of *H. longipennis* as 6.92 ± 1.64 mm, and 1.97 ± 0.28 mm as width from first thoracic segment. Pathania et al. (2016) found body length of first instar larvae of *H. longipennis* to vary from 8.35 to 9.1 mm; and the average head capsule width has been reported to be 1.74 ± 0.01 mm. These reports are well within the range observed for this species in the present study. Under laboratory condition, the duration of first instar was recorded to be 14 to 18 days. Pathania et al. (2016) reported first instar of *H. longipennis* ranging from 21 to 26 days in Himachal Pradesh. However, in Uttarakhand, earlier workers have indicated higher duration ranging from 40.08-41.8 days for first instar grubs of *H. longipennis*.

The first instar grubs moulted into second instar by the end of August. The body colour of grubs in second instar was dirty white with dark brown head capsule. The body length ranged from 18.9 to 20.14 mm for fully fed second instar grubs. The head capsule width varied from 3.32 to 3.67 mm. Mishra et al. (1998) reported body length of second instar of *H. longipennis* ranging from 23.5 to 25 mm in Uttarakhand. The head capsule width reported by Pathania et al. (2016) is 3.15 ± 0.04 mm. These reports clearly substantiate our results. The duration

of second instar lasted for 26 to 32 days with an average of 29.20 ± 0.81 days. The second instar grubs of *H. longipennis* occurred from August to October. The second instar grubs constructed earthen cells and moulted inside these cells to the third instar. According to Kalpana (2015), the average duration for second instar of *H. longipennis* was 35.06 ± 0.52 days for this species at Palampur. During the final instar, the grubs turned greyish white in colour, measured from 32.88 to 34.31 mm in body length, and 5.03 to 5.13 mm in head capsule width. Shah and Shah (1990) reported that third instar of *H. longipennis* are 31.69 mm long indicating almost similar size of final instar grubs, whereas head capsule width reported by them is on higher side (8.91 mm). The raster pattern is given in fig. 4. Raster is equipped with two widely separated prominent palidia. The palidia (comb like structure) and hemate setae (lateral to palidia on each side -Tegillum) covered nearly half of the last ventral abdominal segment. Each palidium possessed long, sharp 13-14 pali. The septula (space between two palidia) is wide, linear and appears to be narrow 'V' shaped. Tegilla occupied nearly caudal half of the area between lower anal lip and the anterior margin of the last abdominal segment. The description of raster pattern matches with that of Kalpana (2015) and Pathania et al. (2016).

The duration of third instar ranges from 207-228 days with an average of 218 ± 3.12

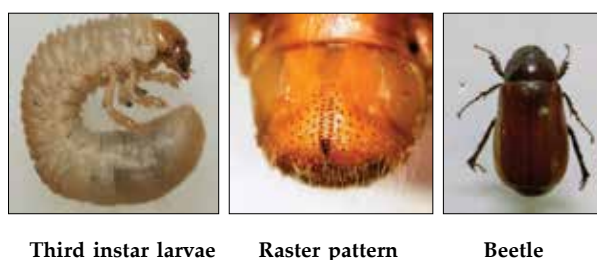


Fig. 4 Development stages and raster pattern of *H. longipennis*

days. The third instar grubs occurred from September to April. The average period of third instar of *H. longipennis* at Ranichauri was found to be 211.6 ± 3.14 days (Mishra *et al.* 1998). Haq (1962) reported that the duration of third instar grubs of *H. longipennis* in Uttarakhand ranges from 160-191 days with a mean value of 175.4 days. The fully fed third instar grubs moved downward, stopped feeding and constructed earthen cells. The formation of earthen cells by third instar grubs was noticed in the month of November. Third instar grubs produced large irregular cavities deep into the potato tubers, and such tubers are rendered totally unfit for marketing. Total larval period ranged from 247-303 days. The pupation in laboratory was observed as early as 14 April, 2022. The average pupal period was recorded to be 14.0 ± 0.86 days under laboratory condition. The minimum and maximum being 12 and 16 days. According to Shah and Shah (1990), the pupal period was of 22 to 28 days at Nainital for this species. It was of 15 to 23 days at Ranichauri (Mishra *et al.* 1998). In laboratory, the adult formation was noticed in the first week of May. Pathania *et al.* (2016) also noticed adult formation of *H. longipennis* inside earthen cells as early as 7th May at Palampur. The adult beetles of *H. longipennis* are shining light chestnut brown in colour with light brown abdomen and dark brown legs. The average body length x width of beetle was recorded to be $21.61 \pm 0.34 \times 9.08 \pm 0.05$ mm. Kalpana (2015) recorded length of 21.29 to 21.49 mm and breadth of 8.94 to 9.27 mm for beetles of *H. longipennis* in Himachal Pradesh. There was one generation in year.

***Anomala rufiventris* Redtenbacher:** The grubs of *A. rufiventris* were collected at Janjheli and Nihri in Mandi district, and Rohru in Shimla district of Himachal Pradesh. *A. rufiventris* has been recorded on light trap in Sirmour district by Chandra (2005). Kumar *et al.* (2007)

collected *A. rufiventris* on light trap in Kullu valley. In Kumaon hills of Uttarakhand, *A. rufiventris* comprised 0.18-0.31 per cent of total beetle catch on light trap (Sushil *et al.* 2006). The grubs were further reared in laboratory at Palampur. The fully fed third instar grubs averaged 42.06 ± 1.93 mm in their body length with a range of 40.13 to 43.98 mm. The head capsule width of third instar grubs averaged 4.29 ± 0.12 mm (range: 4.17 to 4.4 mm). The raster pattern is given in fig.5. The raster is characterised by very long and thin pali. The pali of each side overlap corresponding pali of other side in the centre, and pali are arranged in a clustered manner. The grubs did not inflict much damage, but superficial scrapping was seen on potato tubers. The fully-fed larvae made a small earthen cell in deep layer of soil (about 6 to 8 cm deep) on first November, and remained in the cell till adult emergence in next summer. The grubs remained active for about 90 days before constructing earthen cells. They spent about 180 days in earthen cells before transforming into pupae. Pupa was observed as early as 2 May, 2002 in laboratory. The length of pupal stage was found to vary from 24 to 27 days with an average of 25.33 ± 0.88 days. The adult formation commenced on 26 May, 2022. There was single generation per year, and the total average duration of the third instar and pupa was observed to be 288 ± 2.13 days. The adults are medium sized, elongate beetles. Their body is smooth, shining, very dark bronzy-green, sternum and legs greenish black and



Third instar larvae

Raster pattern

Beetle

Fig. 5 Development stages and raster pattern of *A. rufiventris*

ventral abdominal segments mahogany red. Pronotum thinly and very minutely punctate. The length of beetles ranged from 16.10 to 22.00 mm, while the width varied from 10 to 11mm. Rai and Joshi (1988) has reported *A. rufiventris* causing damage to potato in Uttarakhand. According to Chandra and Uniyal (2007), *A. rufiventris* distributed in Himachal Pradesh, Uttar Pradesh, West Bengal, Manipur, Meghalaya, Sikkim and Bhutan.

***Melolontha cuprescens* Blanchard:** The grubs of *M. cuprescens* were collected from potato fields in Khadrula area of Shimla district. It is said by Chandra (2005) to occur from Chamba, Kinnaur and Kullu district of Himachal Pradesh. Pathania (2014) has reported *M. cuprescens* in Holi, Kheradhar, Dalash and Sangla. The average population of grubs in soil was recorded to be 7.82 ± 0.50 grubs/ft². The grubs were large in size, and measured 58.74 ± 1.28 mm (range: 51.98-68.02mm) in body length. The average head capsule width was recorded to be 6.5 ± 0.15 mm (range: 51.98-68.02 mm). The grubs were collected in the month of November and were maintained in laboratory for about two months. The grubs inflicted large holes in potato tubers during feeding. The grubs stopped feeding by the end of November and hibernated in large earthen cells. There was no pupa formation in the laboratory. The raster pattern is given in fig. 6. The raster is prominently conspicuous with two

widely separated and prominent palidia in central region. The paired palidia are nearly parallel each consisting of 28-29 pali, pointed downward especially in the lower region. The anal slit is Y shaped, depressed and hooked in the centre, slightly raised on both sides and gradually tapering laterally in a semi-circular fashion. The anal cleft is straight, touching the base of septula. Rana *et al.* (2022) also revealed similar features in his description of raster pattern of *M. cuprescens*.

***Melolontha furcicauda* Ancey:** The grubs of *M. furcicauda* were collected from potato fields at Rohru during November. The grubs were collected in very few numbers in potato fields. The head capsule width was recorded to be 6.89 mm, and the body length averaged 59.03 mm. *M. furcicauda* has been reported to be an important pest infesting oats during seedling stage in northern Kashmir (Kumar *et al.*, 2019). Gupta *et al.* (1977) has reported *M. furcicauda* as a major pest of different fruit crops including apple, apricot and cherry in different regions of north-western Himalaya. The raster pattern is given in fig. 7. The raster pattern of *M. furcicauda* has been described by Rana *et al.* (2022), and it matches with our picture. Each palidium consisted of 26 pali. The anal slit is raised in the centre and gradually tapers to both sides uniformly.

***Polyphylla sikkimensis* Brenske:** The grubs of *P. sikkimensis* were collected from Barot and Janjheli in Mandi district inflicting



Third instar larvae

Raster pattern

Fig. 6 Development stages and raster pattern of *M. cuprescens*



Third instar larvae

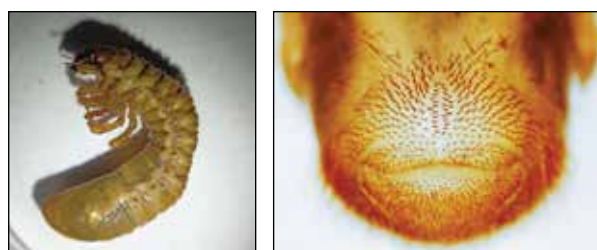
Raster pattern

Fig. 7 Development stages and raster pattern of *M. furcicauda*

considerable damage to potato tubers. The head capsule width measured 7.6 ± 0.17 mm (range: 7.32 to 7.98 mm), and body length was recorded to be varying from 58.3 to 63.12 mm (59.8 ± 1.2 mm). The grubs were collected from Janjheli in the month of July, 2021, and were reared in laboratory on potato tubers upto November. The grubs constructed earthen cells in November for hibernation. Pupa formation was not recorded under laboratory condition. The raster pattern is given in fig. 8. The palidia is short and each palidium consisted of 12 pali. The pali pointed inward and upward in the upper region with septula indistinct. Anal cleft is absent. The V shape anal slit, more or less flat in the centre, equal gradually on both side and becomes almost flat for considered end on both sides. Rana (2020) has described the raster pattern of *P. sikkimensis* in a similar manner. In *Polyphylla disoniata*, the anal opening is broadly V shape and rasterly too short, nearly parallel, longitudinal palidia each sparsely set with 7-12 cylindrical pali whose tips frequently touching those of opposite palidium (Ritcher 1966).

Unidentified Species I-V: The grubs of unidentified species I were collected at Mani, and Benchi areas. The head capsule width of grubs averaged 4.92 ± 0.14 mm (range: 4.87-5.12 mm), and body length was 33.78 mm (range: 31.98-39.53 mm). The raster pattern is given in fig. 9. The unidentified species II was collected at Rohru in the beginning of November. The head capsule width of grubs averaged 3.72 ± 0.19 mm (range: 3.50 to 4.11 mm), and mean body length measured 41.2 ± 1.2 mm (range: 39.2 to 45.10 mm). The raster pattern is given in fig. 10.

The grubs of unidentified species III were collected at Tikkar (2244 m amsl) in Shimla district and Anni (2006 m amsl) in Kullu district. The head capsule width was recorded to be 3.45 ± 0.13 mm (range: 3.29 to 3.67 mm)



Third instar larvae

Raster pattern

Fig. 8 Development stages and raster pattern of *P. sikkimensis*

Third instar larvae

Raster pattern

Fig. 9 Development stages and raster pattern of unidentified sp. I



Third instar larvae

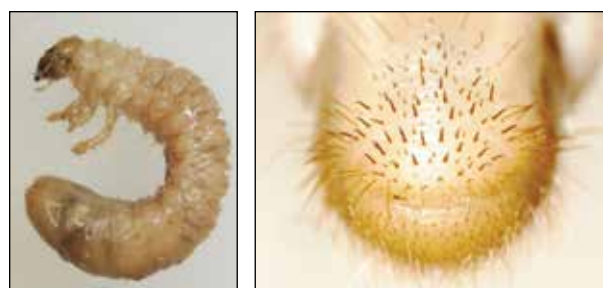
Raster pattern

Fig. 10 Development stages and raster pattern of unidentified sp. II

with body length ranging from 38.94-42.16 mm (mean: 39.74 ± 0.98 mm) (Fig. 11).

The unidentified species IV was collected at Benchi. The head capsule width of grubs was recorded to be 3.81 mm, and body length averaged 32.36 mm. The raster pattern is given in fig. 12.

The grubs of unidentified species V were collected at Nihri in Mandi district, and Banjaar and Anni in Kullu district. The fully fed third instar grubs averaged 28.98 ± 0.52 mm in their body length with a range of 27.36-31.23 mm. The head capsule width of



Third instar larvae

Raster pattern

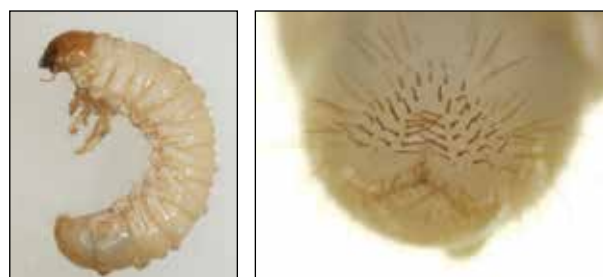
Fig. 11 Development stages and raster pattern of unidentified sp. III



Third instar larvae

Raster pattern

Fig. 12 Development stages and raster pattern of unidentified sp. IV



Third instar larvae

Raster pattern



Pupae

Beetle

Fig. 13 Development stages and raster pattern of unidentified sp. V

third instar grubs averaged 3.31 ± 0.04 mm (range: 3.22-3.48 mm). The raster pattern is given fig. 13. They spent about 125 days in earthen cells before transforming into pupae.

The adults are medium sized elongate beetles. The elytra are shining brown in colour. The head and legs are dark brown in colour (Fig.13). The length of beetles ranged from 12.49-16.7 mm with a mean of 15.05 ± 0.94 mm, while the width ranged from 7.13-7.89 mm with a mean of 7.46 ± 0.16 mm.

CONCLUSION

Lot of diversity exists in white grubs causing damage to potato which is grown under rainfed condition in high hills of Himachal Pradesh, under long day conditions. In total, 13 species were recorded from potato fields, and frequency of their occurrence is very high. *B. coriacea* is a leading species in Shimla and Mandi, whereas in Chamba area, *B. crinicollis* constituted greater percentage. Similarly in Mandi district, *P. sikkimensis* also inflicted considerable damage and warrants control measures. The existing recommendation of white grubs is based on study conducted in Shimla hills where *B. coriacea* is the only species. Therefore, there is need to develop management practices for the control of other species like *B. crinicollis* and *P. sikkimensis*, in their respective areas of occurrence. There is also need to popularize the available technology with more emphasis on biointensive management as none of sample potato growers were found to use any biopesticide to control white grubs.

CONFLICT OF INTEREST

The authors confirm that this manuscript has no conflict of interest.

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MS Received: November 05, 2022; Accepted: January 17, 2023

ABBREVIATIONS

Abbreviation/ Symbol	Meaning
amsl	Above mean sea level
et al.	Et alii (and others)
ft	feet
Fig	Figure
i.e.	Id est (that is)
m	Meter
mm	Millimeter
No.	Number
P	Page
SE	Standard error
sp.	Species (Single)
vis-à-vis	In relation to
viz.	Vi delicet (namely)
=	Equal
%	Per cent
/	Per
±	Plus or minus
*	Asterisk
&	And

RECENT CHALLENGES AND FUTURE SUSTAINABILITY OF POTATO CULTIVATION IN HUGLI DISTRICT, WEST BENGAL: A GEOGRAPHICAL APPRAISAL USING SWOT-AHP ANALYSIS

Benojir Yasmin^{1*}, Arindam Roy¹, Mehedi Hasan Mandal² and Giyasuddin Siddique¹

ABSTRACT: The prime goal of the present study is to ascertain suitable strategies regarding the sustainable and effective growth of potato cultivation in Hugli district of West Bengal by examining the Strengths (S), Weaknesses (W), Opportunities (O) and Threats (T) of the system through a combination of SWOT analysis and Analytical Hierarchy Process. The result reveals that constant year round demand of potato (S5, 0.25) and increasing expenditure costs (W3, 0.25) are the most prioritized internal strength and weakness respectively. On the contrary, large scale employment generation (O6, 0.29) for the locals as well as the migrant laborers is the most prioritized external opportunity, whereas, oscillating nature of economic profitability (T2, 0.27) is the most prioritized external threat of potato cultivation in the area. The overall priority scores of SWOT analysis exhibits that steady demand of potato throughout the year (S5) possesses the most significant (9.7%) aspect among all the internal and external factors. In conclusion, appropriate strategies have been formulated by linking the most prioritized 'strength-opportunity' and 'weakness-threat' factors for future possibilities of the potato cultivation in Hugli district of West Bengal.

KEYWORDS: Potato, SWOT Analysis, Analytic Hierarchy Process, Hugli

INTRODUCTION

Endowed with suitable agro-ecological conditions, the Hugli district has acclaimed a remarkable position in potato (*Solanum tuberosum*) cultivation since the 1970s with massive production and superior productivity in comparison to the other districts of West Bengal (Mookherjee *et al.*, 2012). Being introduced as a food crop, the potato has briskly emerged as the prime cash crop in the area on account of the substantial demand, which has persuaded the farmers to shift to potato cultivation (Ghosh, 2017). Since then potato has become the principal choice of the farmers due to higher profitability. Within a very short period of time the crop has proved its importance in the rural economy. More

than 1/3rd of the geographical area and almost 3/4th farmers of the district are engaged in potato cultivation (Ghosh, 2017). Despite significant spatio-temporal dynamicity in the area, production and yield, potato has retained its superiority in the larger part of the district, even ahead of paddy due to its capability to compensate the loss incurred by other crops (Roy *et al.*, 2019). At present, the district holds a leading position in production and export of potato to the nearby districts as well as states. Such constant expansion of market and increment in demand lead towards the escalation of production volume and greater involvement of arable land, labour and capital. Recent developments of infrastructural facilities like quality roads and cold storages, encouraging governmental

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policies have added extra impetus for success of potato cultivation in the district (Ghosh, 2017).

Despite the present flourishing state with a wider scope of future prosperity, potato cultivation in the district has experienced diverse physical, economic and policy oriented problems affecting the production, marketing and pricing of potato. The economic state of the potato growers, especially the small and marginal farmers, *bargadars* and share croppers, often encountered with uncertainty and disheartened them to grow potato. Such adverse circumstances have hindered the overall consistency of potato farming in recent days. Therefore, it is necessary to formulate suitable strategies for future sustainability through proper understanding of the functionality of potato farming in the area. In such context, the present study strives to examine the potency and flaws of the existing farming system in the area, explore the future opportunities as well as ascertain the upcoming threats and finally determine

the suitable strategy for future sustainability of potato cultivation in the district using SWOT-AHP analysis.

MATERIALS AND METHODS

The study area

The Hugli district is located in the south-central region of the state of West Bengal along the western bank of River Hooghly. The administrative boundaries extend between 23°01'20"N - 22°39'32" N and 88°30'15"E - 87°39'32"E. The district is bounded by the river Hugli in the east, Paschim Medinipur district in the west, Bankura and Purba Bardhaman districts in the north, and Howrah to the south. Located on the flat alluvial plains of lower Gangetic region, the district is served by rivers like Hugli, Damodar, Dwarakeswar, Saraswati etc. and endowed with rich, easily extractable ground water resources (Roy *et al.*, 2019). The district comes under one of the top potato producing districts in West Bengal. Therefore the district has been deliberately selected for the present

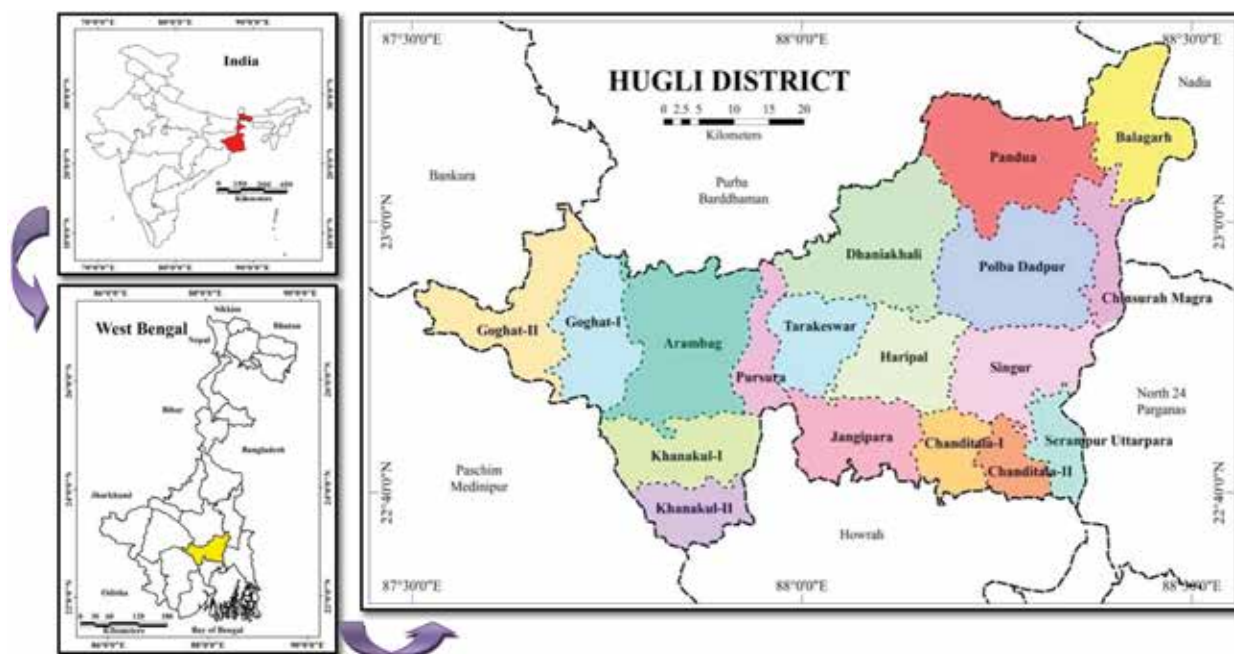


Fig. 1: Location of the Study Area

study. The district lies in the tropical humid monsoon climatic regime with oppressive hot summer, high humidity nearly all the year round and well distributed rainfall during the monsoon season. The district is characterized with three distinct seasons: hot summer, wet monsoon and cold dry winter. May is the hottest month, with the mean daily maximum temperature of 36.7°C and the mean daily minimum temperature at 24.3°C. On the contrary, January is the coldest month with the mean daily maximum temperature of about 26.6°C and the mean daily minimum temperature of about 12.1°C. The cold season starts from the middle of November and continues up to end of February. The average annual rainfall in the district is 1418.5 mm. The maximum rainfall occurs during the southwest monsoon season. Nearly 76% of the annual rainfall occurs during June to September. The relative humidity reaches above 90% in August and recedes to as low as 78% in April-May (IMD, 2008).

Sources and nature of data

The present study is based on the primary data, obtained through intensive field investigation and direct interaction with the stakeholders. Both personal interaction and focus group discussions (FGDs) were conducted to appraise individual to community perception concerning the pros and cons of the present management of potato from cultivation to marketing. For this purpose, 60 farmers, 72 *bargadars* (including share croppers and contract farmers), 80 casual labourers (engaged in harvesting, grading, sorting, packaging, preserving, transportation etc.), 40 wholesalers (or agents/ intermediaries/ middlemen), 40 retailers, 30 women workers (engaged in industries of potato chips, potato powder making) and 5 cold storage owners are interviewed with semi-structured questionnaire, containing both open ended and close ended questions. All the respondents

were selected through random sampling techniques and the interview session was conducted during the harvesting seasons of 2019-2020. Among the 60 sampled cultivators, eight farmers are large farmers (having > 4 hectares of land), 12 are medium (2-4 hectare), 14 small (1-2 hectare) and 26 marginal (< 1 hectare) farmers. Furthermore, four focus group discussions (FGDs), involving 12 stakeholders in each group (engaged in potato farming for at least 40 years) have been conducted to acquire information regarding the evolution and changing aspects of potato production system in the district.

1. SWOT-AHP Analysis

Introduced by Albert Humphrey in 1960s, the SWOT model comprises an effective decision making model by analyzing two prevailing or internal factors i.e. strengths (S) and weaknesses (W), and two upcoming or external factors i.e., opportunities (O) and threats (T) of any system (Gürel and Tat, 2017). This effective strategic tool has been used in the present study accompanying with the Analytical Hierarchy Process (AHP) to understand the determinants and their inter-connections and to formulate the strategies for future sustainability of potato cultivation. The influencing internal and external factors of potato cultivation in the study area has been highlighted in Table 1.

The Analytical Hierarchy Process (AHP) is one of the most efficient multi-criteria decision making technique (MCDM) which has widely been used to solve many real problems (Oreski, 2012). In this mathematical model, the alternatives in each category of SWOT matrix are ranked according to a certain weight based on their relative importance (Görener *et al.*, 2012). The criteria weights of each SWOT elements are assigned by using Saaty's fundamental scale (1980) which denotes the relative intensity of

Table 1: Identified internal and external factors of SWOT analysis

Strengths (S)	Weaknesses (W)
S1 Favorable agro-climatic conditions	W1 Climatic variability
S2 High cropping intensity	W2 Prevalence of biotic hazards
S3 Long experience of potato cultivation (more than 40 years)	W3 Increasing expenditure costs and decreasing profit
S4 Short duration crop that fits well within the prevailing cropping system	W4 Economically weak small and marginal farmers
S5 Continuity in demand throughout the year	W5 Irregularities in market and dominance of the middlemen (artificial crisis in the market)
S6 Availability of local labour forces	W6 Lack of infrastructural facilities (i.e. transport facilities, cold storages etc.)
S7 Farmer's willingness and massive engagement	W7 Shortage of capital and growing dependency on bank and money lenders
	W8 The absence of proper government policy and administrative control
Opportunities (O)	Threats (T)
O1 Extension of agro based and food processing industries	T1 Occurrences of crop failures
O2 Cultivation of different varieties of potato	T2 Fluctuation in economic profitability
O3 Expansion of agricultural markets and escalation in demand	T3 Over production and declining market prices
O4 Implementation of suitable policies regarding storing (like <i>Kishan Mandi</i>), marketing and trading	T4 Shifting of farmers from potato to other crops
O5 Improvement in infrastructural facilities	T5 Depletion of ground water level
O6 Large scale employment opportunities for the locals and the migrant labourers	T6 Deterioration of soil quality owing to excessive use of chemical fertilizers, pesticides etc and risk of biomagnifications
O7 Establishment and efficient management of large scale farms and participatory management system	T7 Recent changes in climate

importance between two alternative factors (Sharma *et al.* 2008).

The pair-wise comparison matrix, resembling to square and reciprocal matrix of each factor within each group, is computed by using the following equation to measure the relative priorities and find out the most influential elements (Alonso and Lamata, 2006). In this matrix, every element is a_{ij} ($i, j = 1, 2, \dots, n$) the quotient weight of the criteria where the value of w_i vary from 1 to 9.

$$A = [a_{ij}] = \begin{pmatrix} 1 & a_{12} & \dots & a_{1j} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & 1/a_{1j} & \dots & 1/a_{1n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ 1/a_{i1} & 1/a_{i2} & \dots & 1 & \dots & 1/a_{in} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ 1/a_{n1} & 1/a_{n2} & \dots & 1/a_{ni} & \dots & 1 \end{pmatrix}$$

In the next step, each matrix is normalized to compute the relative weights by multiplying

the actual eigen vector (w) with corresponding largest eigen value (λ_{max}), following the equation below (Lee and Walsh, 2011):

$$Aw = \lambda_{max}W$$

Then, the **Consistency Index (CI)** is calculated by using the following formula (Sharma *et al.*, 2008):

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

The **Consistency Ratio (CR)** helps measure the consistency of the result of pair-wise comparison in AHP where 0.1 refers to the accepted upper limit of CR. If the final Consistency Ratio exceeds this threshold value, then it indicates the inconsistency and the whole evaluation process needs to be repeated to improve the consistency

(Ergu *et al.*, 2011). The Consistency Ratio is determined from the ratio between the **Consistency Index (CI)** and **Random Index (RI)** which is as follows (Borajee and Yakchali, 2011):

$$CR = \frac{CI}{RI}$$

The overall priority of the SWOT factor have been computed by multiplying the priority of the factor within the group by the priority of the group (Kurttila *et al.*, 2000).

2. Formulation of strategic planning

A multi-criterion strategic framework has been prepared for effective decision making in futuristic developments of potato production by linking the most prioritized S-O and W-T factors. The perception based empirical approach has been followed here to link the most prioritized six positive factors and six negative factors to formulate the strategies.

- (a) **Strength-Opportunity (SO)**: SO strategy connects the most prioritized three internal strenghts with three external oppoutunities to enhance the prospect of potato production
- (b) **Weakness-Threat (WT)**: WT strategy links the most prioritized three internal weaknesses with three external threats

that suggests the alternative action planning to combat the major risks and shortcomings of potato production

The strategy having the highest recognition from respondents has been chosen as the best potential strategy for future sustainability and development of potato farming in the district. The views of the respondents have been collected by perception survey through a rating scale, classified into three categories i.e. **agree**, **disagree** and **neutral** (Chakraborty and Chakma, 2020).

RESULTS AND DISCUSSION

Analysis of the SWOT factors

The Comparison Matrix of strength factors (Table 2) reveals that permanence in demand round the year (S5, importance degree value: 0.25) is the highest strength of potato production in the studied district followed by favorable agro-climatic conditions (S1, value: 0.23), and high cropping intensity and production rate (S2, value: 0.18). The demand of potato as cheap source of starch has every prospect to sustain long rather will increase with its use as different varieties of food items. The usage of potato in traditional Bengali diet is highly appreciated due to its taste, good nutrition value and affordable price. Naturally, there is a consistent demand

Table 2: Comparison matrix of strength group

Strengths (S)	S1	S2	S3	S4	S5	S6	S7	Importance Degrees
S1 Favorable agro-climatic conditions	1.00	3.00	3.00	2.00	0.33	2.00	5.00	0.23
S2 High cropping intensity and production rate	0.33	1.00	2.00	2.00	1.00	3.00	4.00	0.18
S3 Long experience of potato cultivators (more than 40 years)	0.33	0.50	1.00	1.00	0.50	3.00	3.00	0.12
S4 Short duration crop that fits well within the prevailing cropping system	0.50	0.50	1.00	1.00	0.50	2.00	3.00	0.11
S5 Continuity in demand throughout the year	3.00	1.00	2.00	2.00	1.00	3.00	4.00	0.25
S6 Availability of local labour forces	0.50	0.33	0.33	0.50	0.33	1.00	4.00	0.08
S7 Farmer's willingness and massive engagement	0.20	0.25	0.33	0.33	0.25	0.25	1.00	0.04
C.R = 0.07								

of potato in household level for consumption in daily basis *which assumes that the internal demand is expected to be in an inflated state*. Recent rapid booming of urbanization in the eastern margin of the district along the right bank of the river Hugli and consequent increment in number of census towns during the last decade (Siddique and Mukherjee, 2017) has enhanced the demand. Besides, the increasing commercial demand in newly flourished food-processing units in and around the district has enhanced the demand side. As the area under review is located close to the Kolkata metropolitan city and Haora, the area experiences a steady demand of potato. In addition, potatoes from this belt have been exported to the neighboring states also. Such escalated demands promises greater possibility of prosperity in production in near or distant future to meet the growing demands. Concurrently, the crop has huge potentiality to cope up with the increased food demand and poverty alleviation. The need for assured food security to the ever growing population with limited availability of cultivable land has necessitated spatio-temporal intensification of cropping. As a short duration cash crop, potato has easily accustomed with the existing cropping system and shows notable capability of adjustment with the changes in the system. Moreover, the crop has revealed its greater suitability in the varied agro-climatic conditions of the district. According to the Comprehensive District Agricultural Plan (CDAP) Report (2012) and Agricultural Technology Management Agency (ATMA) Report (2005-06) the district can be divided into three distinct agro-ecological situation zones (AES), of which AES I and II, covering nearly 83.77% of the district's area, are extensively suitable for potato cultivation. Almost 65.04% area under these two zones has already been used for potato farming. Even 21.62% area in AES III where monoculture

has been practiced, is also engaged in potato cultivation (Ghosh, 2017). In a nutshell, it may be said that the physical environment of the district is not a barrier; rather it provides an extensive field for potato farming.

The Table 3 has shown the comparison matrix of weakness aspects of the system. The analysis reveals that increasing expenditure costs and decreasing profit (W3, importance degree value: 0.25) are the most dominating weaknesses of the persisting agricultural system of the area. The cost of each component of agricultural input like chemical fertilizers, pesticides, labour, HYV seeds etc. along with transportation, irrigation, cold storage facilities has conspicuously increased over the past years. Field survey has revealed that the cost of chemical fertilizers and pesticides has been increased nearly 136.45% and 41.67% respectively from 2000 to 2019. Similarly, the cost of HYV seeds is risen about 68.75%, labour cost is increased nearly 160%, and irrigation cost is enhanced up to 200% during the stipulated phase. Overall, the estimated production cost per hectare area has been incremented to 111% during past twenty years. On an average, the irrigation cost comprises almost 9.47% of the total cost in 2019-20. As a *rabi* crop, potato is generally cultivated in the district during the dry months of the winter (October-February). Naturally, potato cultivation has to depend upon irrigation water. Therefore, huge amount of ground water has been extensively extracted through deep, shallow or submersible pumps for irrigation purpose, which has alarmingly reduced the level of ground water table. The rising production expenditure naturally reduces the profit of the producers. Most notable fact is that, the economic return from the field has failed to keep pace with mounting production cost over the past years. Even in a number of cases, the farmers have failed to recover their

Table 3: Comparison matrix of weakness group

Weaknesses (W)	W1	W2	W3	W4	W5	W6	W7	W8	Importance Degree
W1 Climatic variability	1.00	2.00	0.33	0.50	1.00	4.00	3.00	3.00	0.15
W2 Prevalence of biotic hazards	0.50	1.00	0.50	1.00	0.50	3.00	2.00	3.00	0.12
W3 Increasing expenditure costs and decreasing profit	3.00	2.00	1.00	2.00	2.00	3.00	3.00	4.00	0.25
W4 Economically weak small and marginal farmers	2.00	1.00	0.50	1.00	0.33	3.00	2.00	2.00	0.13
W5 Irregularities in market and dominance of the middlemen	1.00	2.00	0.50	3.00	1.00	3.00	1.00	3.00	0.17
W6 Lack of infrastructural facilities	0.25	0.33	0.33	0.33	0.33	1.00	0.33	1.00	0.05
W7 Shortage of capital and growing dependency on bank and money lenders	0.33	0.50	0.33	0.50	1.00	3.00	1.00	2.00	0.09
W8 The absence of proper government policy and administrative control	0.33	0.33	0.25	0.50	0.33	1.00	0.50	1.00	0.05
CR = 0.05									

investments. Under such circumstances, the small and marginal farmers have become most vulnerable due to their incapability to combat the economic loss and sustain their livelihoods properly. They prefer loans from local money lenders [*Mahajans*] with high rate of interest (ranging from 10% to 15% per month during 2019-2020) to compensate for the loss and further beginning of cultivation and ultimately get trapped in debt. Thus the profit from the field of the potato growers gradually decreases which acts as a major economic constraints for potato cultivation.

Apart from this, the irregularities in market owing to the tricks of the middlemen (W5, value: 0.167), and climatic variability (W1, value: 0.15) are found to be another two most influencing internal weakness factors. The artificial crisis of potato in the market are often created by the middlemen (*forias*, *aratdars*) and the distributors for pocketing the benefit of inflated price where the economically weak small and marginal farmers are forced to sell the product at lower prices just after harvest and the middlemen multiply their profit each year. Due to the economic insolvency, the small and marginal

farmers often sell the crop from the field at a cheap cost in order to save the storage cost as the harvested products are non-preservable, easily rotten and damaged by diverse diseases.

The labour intensive nature of farming in the area with less use of modern machineries generates a huge demand of skilled and unskilled labourers in different stages from field preparation to marketing of potato. The greater potentialities of major agro-based industrial sector may create a wide scope of employment opportunities in near future. A bulk of poor fellow from the nearby rural areas or even from the neighboring districts migrate as agricultural labourers towards the area during harvesting season. The following comparison matrix of opportunity group (Table 4) reveal that large scale employment generations for the locals as well as for the migrant labourers from the neighboring districts (O6, importance degrees value: 0.29), expansion of agricultural markets and resulted escalation in demand (O3, value: 0.29) and extension of agro based and food processing (like potato powder, potato chips etc) industries (O1, value: 0.137) are the most

Table 4: Comparison matrix of opportunity group

Opportunities (O)	O1	O2	O3	O4	O5	O6	O7	Importance Degrees
O1 Extension of agro based and food processing industries	1.00	3.00	0.30	2.00	2.00	0.00	2.00	0.14
O2 Cultivation of different varieties of potato	3.00	1.00	0.30	0.00	0.50	0.00	2.00	0.07
O3 Expansion of agricultural markets and escalation in demand	3.00	4.00	1.00	3.00	3.00	1.00	2.00	0.23
O4 Implementation of suitable policies regarding storing (like <i>Kishan Mandi</i>), marketing and trading	0.50	3.00	0.30	1.00	3.00	0.00	0.50	0.11
O5 Improvement in infrastructural facilities	0.50	2.00	0.30	0.00	1.00	0.00	0.50	0.07
O6 Large scale employment generations for the locals and for the migrant labourers	3.00	3.00	2.00	3.00	3.00	1.00	3.00	0.29
O7 Establishment and efficient management of large scale farms and participatory management system	0.50	1.00	0.50	2.00	2.00	0.00	1.00	0.10
CR = 0.09								

prioritized opportunities among the seven opportunity factors.

Among the threat factors, the fluctuation in economic profitability (T2, importance degree value: 0.27), occurrences of crop failures (T1, value: 0.22) and depletion of ground water level (T4, value: 0.17) due to excessive irrigation in post-monsoon seasons are found to be the most alarming issues in the district (Table 5). The potato-growers of the district experience oscillation of loss and profit from potato, depending upon the production scale and profit margin, which is adjusted in the share of land under potato for the next year and control the production

volume. The year of higher production is obviously linked to increase in area under potato and resultant fall in price. The farmers experiencing loss in the economy reduce area under potato in the next year leading to reduction in production which causes rise in the price of the crop. It has been found that in every alternative year, the area under potato has shown a trend of rise and fall as in Figure 2 (District Statistical Handbook, 1990-91 - 2013-14; Ghosh, 2017).

The small and marginal farmers are most vulnerable to the frequent oscillation in economic profitability related to the fluctuation in the productivity, expenditure,

Table 5: Comparison matrix of threat group

Threats (T)	T1	T2	T3	T4	T5	T6	T7	Importance Degrees
T1 Occurrences of crop failures	1.00	0.50	2.00	3.00	4.00	3.00	2.00	0.22
T2 Fluctuation in economic profitability	2.00	1.00	3.00	2.00	4.00	4.00	2.00	0.27
T3 Over production and declining market prices	0.50	0.50	3.00	0.50	3.00	3.00	1.00	0.14
T4 Shifting of farmers from potato to other crops	0.25	0.25	0.33	0.25	1.00	0.33	0.33	0.04
T5 Depletion of ground water level	0.33	0.50	2.00	1.00	4.00	4.00	2.00	0.17
T6 Deterioration of soil quality owing to excessive use of chemical fertilizers, pesticides etc and risk of biomagnifications	0.33	0.25	0.33	0.25	3.00	1.00	0.33	0.06
T7 Recent changes in climate	0.50	0.33	1.00	0.50	3.00	3.00	0.33	0.10
CR = 0.06								

market price and profits. In addition, recent changes in climatic phenomena with decreasing length of winter period hinder the natural growth and productivity of potato in the district (Ghosh, 2017). Besides, the extreme but infrequent climatic hazards lead towards prevalence of biotic hazards (fungal, viral and bacterial diseases) and often lead towards crop failure. Such climatic irregularities (winter rains and hailstorm, humidity and temperature fluctuation etc.) put extensive effect on the production volume. For example, winter rainfall in 2005-06, hailstorm in 2006-07, and prevalence of pest diseases in 2008-09, have immensely damaged the potato cultivation across the district (Hatial and Mondal, 2015). Such climatic extremities, irregularities and the associated biotic hazards lead to massive crop failures where the small and marginal farmer are severely affected owing to poverty and lesser adaptive capacity to cope with the situation.

The overall priority scores of the SWOT factors (Table 7) have been derived by multiplying the priority score of each factor within the group with the group priority score (Table 6). The analysis has exhibited that the

incessant demands of potato over the year is the prime important factor in SWOT (S5) having highest overall priority value of 0.097. The ranks of the other considerable factors according to overall priority from each SWOT groups are as follows: large scale employment generations for the locals as well as the migrant labourers (0.10) from opportunity groups, increasing expenditure costs and decreasing profit (0.04) from weakness group, and fluctuation in economic profitability (0.03) from threat groups respectively.

The strategies: Respondents' perception

Strategy I: Strength-Opportunity (SO) strategies

The combination of most prioritized Strength-Opportunity (SO) factors has

Table 6: Pair-wise comparison of SWOT factors

SWOT Groups	S	W	O	T	Group Priority Score
Strengths (S)	1.00	3.00	1.00	4.00	0.40
Weaknesses (W)	0.33	1.00	0.33	2.00	0.15
Opportunities (O)	1.00	3.00	1.00	2.00	0.34
Threats (T)	0.25	0.50	0.50	1.00	0.11
CR = 0.04					

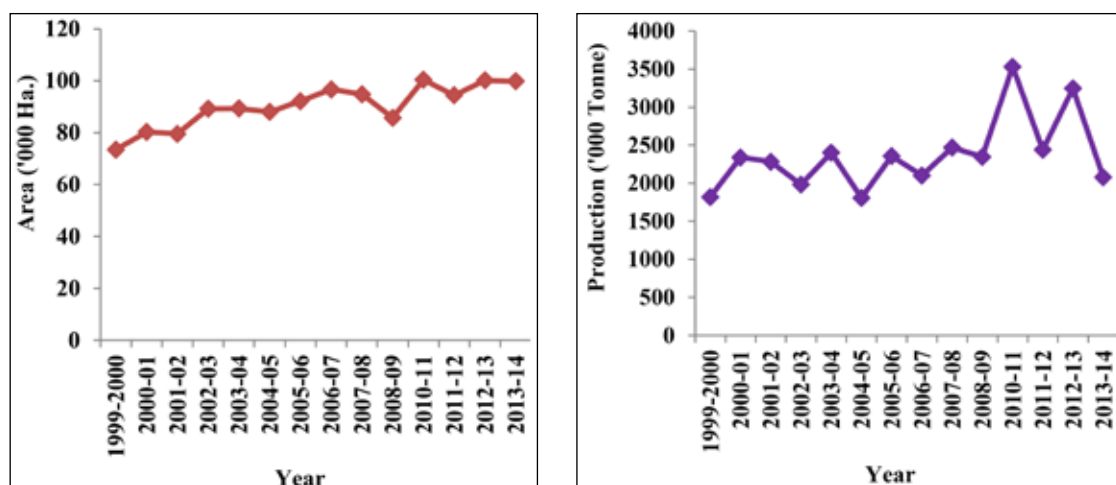


Fig 2: Temporal variation of (A) Area and (B) Production of Potato, Hugli, 1999-2000 to 2013-14

Source: District Statistical Handbook, 1990-91 - 2013-14

Table 7: Overall priority scores of SWOT factors

SWOT Group	Group Priority Score	SWOT Factors	Priority Score of the factors within the Group	Overall Priority Score of factor
Strengths (S)	0.4	S7 Farmer's willingness and massive engagement	0.04	0.02
		S6 Availability of local labour forces	0.08	0.03
		S4 Short duration crop that fits well within the prevailing cropping system	0.11	0.04
		S3 Long experience of potato cultivation (more than 40 years)	0.12	0.05
		S2 High cropping intensity	0.18	0.07
		S1 Favorable agro-climatic conditions	0.23	0.09
		S5 Continuity in demand throughout the year	0.25	0.1
Weaknesses (W)	0.15	W6 Lack of infrastructural facilities (i.e. transport facilities, cold storages etc.)	0.05	0.01
		W7 Shortage of capital and growing dependency on bank and money lenders	0.09	0.01
		W8 The absence of proper government policy and administrative control	0.05	0.01
		W1 Climatic variability	0.15	0.02
		W2 Prevalence of biotic hazards	0.12	0.02
		W4 Economically weak small and marginal farmers	0.13	0.02
		W5 Irregularities in market and dominance of the middleman (artificial crisis in the market)	0.17	0.03
Opportunities (O)	0.34	W3 Increasing expenditure costs and decreasing profit	0.25	0.04
		O2 Cultivation of different varieties of potato	0.07	0.02
		O5 Improvement in infrastructural facilities	0.07	0.02
		O7 Establishment and efficient management of large scale farms and participatory management system	0.1	0.03
		O4 Implementation of suitable policies regarding storing (like <i>Kishan Mandi</i>), marketing and trading	0.11	0.04
		O1 Extension of agro based and food processing industries	0.14	0.05
		O3 Expansion of agricultural markets and escalation in demand	0.23	0.08
Threats (T)	0.11	O6 Large scale employment opportunities for the locals and the migrant labourers	0.29	0.1
		T5 Depletion of ground water level	0.04	0
		T3 Over production and declining market prices	0.1	0.01
		T6 Deterioration of soil quality owing to excessive use of chemical fertilizers, pesticides etc and risk of biomagnifications	0.06	0.01
		T1 Occurrences of crop failures	0.22	0.02
		T4 Shifting of farmers from potato to other crops	0.17	0.02
		T7 Recent changes in climate	0.14	0.02
		T2 Fluctuation in economic profitability	0.27	0.03

pointed out the following strategies for the prosperity of potato cultivation of the district under review:

- **SO1:** The favorable agro-climatic condition (S1) leads to production of large varieties of potatoes, which helps expand the

agricultural markets and further escalation in demand (O3).

- **SO2:** Year round stability in demand (S5) will help sustain, rather expand the production scale, which will create large scale employment opportunity for the

locals as well as for the migrant labourers from the neighboring districts (O6).

- **SO3:** High cropping intensity with high production rate (S2) which will help flourish agro based and food processing industries (O1) in the area like potato powder, potato chips etc.

The analysis of the respondents' opinions has revealed that the second strategy i.e. SO2 has got the highest appreciation from the respondents (nearly 90%). The strategy number three (SO3) has been supported by 82% of the respondents, while SO1 has only 78% support from the stakeholders of the potato farming system in the study area (Fig. 3).

Strategy II: Weakness-Threat (WT) Strategies

Three WT strategies have been organized as effective measures to mitigate the relative weaknesses and threats of potato cultivation. These strategies provide alternative action plans which help to discover the most suitable strategy to combat internal weaknesses and external threats of the potato farming system of the area.

- **WT1:** The climatic variability (W1) will affect the farmers more extensively, as it leads towards greater and frequent possibilities of crop failures (T1). In this

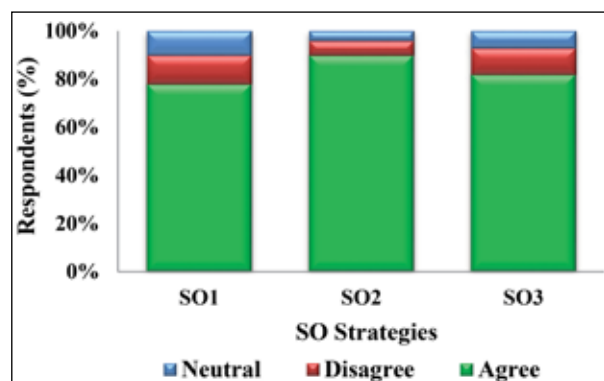


Fig 3: Perception of the respondents for SO Strategies

context, proper implementation of pre and post disaster management strategies with the establishment of infrastructural facilities and provision of financial aids are needed to alleviate the risk. Further, farmer friendly approaches of the government policies and measures (like (Minimum Support Price or MSP, crop insurance such as Restructured Weather Based Crop Insurance or RWBCIS) are also needed to cope up with the loss and damages.

- **WT2:** The artificial crisis of potato in the markets created by the middlemen (*forias, aratdars*) and the distributors (W5) is one of the inevitable and impactful weaknesses within the systems. The small and marginal farmers are most vulnerable to sustain and combat the fluctuation in economic profitability (T2). There is a serious need of proper government policy and administrative control over the middlemen, distributors and cold storage owners to rein in their dominance and tackle their unethical tricks.
- **WT3:** Increasing expenditure costs and decreasing profit (W3) is one of the major weaknesses of the existing farming system where the share of irrigation cost is not undeniable at all. The massive use of ground water during the dry post-monsoon season for irrigation purpose, leads to perceptible depletion of ground water level (T4) and also significant increment in the production expenditure. In such a situation, proper water harvesting strategies may be adopted to restore the rain water in monsoon season for the crisis periods. This will effectively mitigate the problems of excessive irrigation cost and prevent further exhaustion of ground water resources.

Respondents' opinions reveal that 95% of them has highly appreciated the WT2,

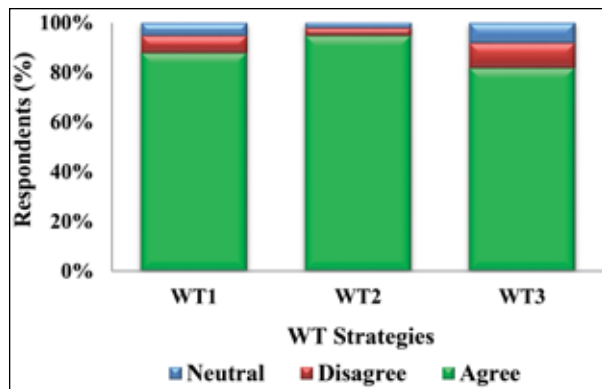


Fig 4: Perception of the respondents for WT Strategies

followed by WT1 (88%) and WT3 (82%) as indicated in Figure 4. Most of the respondents advocate in favor of implementing strong administrative control over the middlemen, distributors and cold storage owners to restrict the irregularities in markets. Controlling the artificial crisis and resulted abnormal pricing will certainly help the small and marginal farmers to get their deserved earning. It will encourage the cultivators to invest more in potato cultivation.

CONCLUSION

The present study has strived to ascertain the apt and effective strategies for future sustainability after examining the internal and external factors with the combined method of SWOT-AHP. The findings of SWOT group priority analysis has revealed that the strengths group ranked the first position with the group weight of 39.60% followed by opportunities (group weight 34.00%), weaknesses (group weight 15%) and threats (group weight 11.2%). The overall priority scores of combined SWOT-AHP have marked that unrelenting demand of potato throughout the year (S5, 0.10) plays the role of the most dominant strength factors, whereas, increasing expenditure of production (W3, 0.04) is the major weakness within the existing potato cropping system of the area. Large scale employment generation for local as well as for

the migrant workforce (O6, 0.10) is the most prioritized opportunities, while oscillation in economic profitability (T2, 0.03) has threatened the system, particularly the sustainability of the livelihood of the small and marginal farmers. The small and marginal farmers of the area have been facing severe challenges in sustaining in potato cultivation due to the rapid and notable fluctuations in the economic profitability, which have pushed them to either shift to another crop or in extreme cases to give up agricultural practices. The strategic formulation by linking the most prioritized SO and WT factors have revealed that year long continuous demand of potato (S5) in domestic as well as commercial arena, leads to escalation in production and consequent large scale employment generations has become the most appreciated SO strategy (SO2, 90%) among the stakeholders of the area. While proper implementation of administrative control over the middlemen, distributors and cold storage owners to restrict the corruption and save the small and marginal farmer from deprivation (WT2, 95%) is the most prioritized alternative WT strategy. Thus it is necessary to draw the concern over internal strengths and weaknesses and focus on external opportunities and threats for better prospect, sustainable and effective growth of potato cultivation in the area under study.

ACKNOWLEDGEMENT

The authors gratefully acknowledge help and cooperation extended by the potato cultivators, all other stakeholders and workers during the periods of primary survey.

CONFLICT OF INTEREST

The authors confirm that this manuscript has no conflict of interest.

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MS Received: December 09, 2022; Accepted: January 16, 2023

ECONOMIZED WATER VOLUME AND CONCENTRATION OF FUNGICIDE FOR MANAGEMENT OF LATE BLIGHT OF POTATO IN SUBTROPICAL PLAINS OF INDIA

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KEY WORDS: Potato, Late blight, Mancozeb, Water, Fungicide

Potato (*Solanum tuberosum* L.) belonging to the Solanaceae family, is an important vegetable and cash crop cultivated in the world. Potato is the third most important food crop in the world after rice and wheat from the point of human consumption (<https://cipotato.org>). Globally, India is the second largest producer of potato after China with about 53.40 million tons as per first advance estimate during 2021-22 (<https://agriexchange.apeda.gov.in>). Production of potato has been increased however; less productivity is still a challenge. The potato crop is affected by many biotic and abiotic stresses. Among biotic stresses, late blight of potato caused by a fungus like organism, *Phytophthora infestans* (Mont.) de Bary is one of the major causes of concern for affecting yields in the world wherever potato crop is cultivated. The managing cost of *Phytophthora* blight to the potato alone amounted to US \$6.7 billion annually (USA Blight, 2012). In India, estimated yield loss was reported up to 10-20% during 2013-14 (Lal *et al.*, 2016). The state of Uttar Pradesh alone shares about 30-32% production in the total potato production of India. Varietal resistance is the best option for managing late blight disease of potato.

However, due to complex virulence nature of *P. infestans*; the resistance of the varieties is wiped out within a decade. Therefore, the next best option leftover is use of synthetic fungicides. Several fungicides including contact, systemic and trans-laminar have been evaluated from time to time; however, the pathogen has shown a remarkable capacity for change with respect to host genotypes and fungicides. As a result, disease control requires regular application of fungicides at high rates and short intervals throughout the growing season of potato crop (Lal *et al.*, 2015). In Peru, farmers often spray fungicides more than ten times (Bustamante *et al.*, 2008; Perez *et al.*, 2009). The number of sprays depends on disease and various other factors, *viz*, nature of fungicides being used, climatic conditions, pressure, timing of the disease appearance and duration of varieties. In India, generally more number of sprays are required in hilly and plateau regions than the plain regions. It may be due to climatic conditions are more favorable in these areas than plain regions.

Water is a very crucial component for cultivation of any crop. The water table is decreasing day by day due to industrialization

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and growing of intensive cropping system. In general, for effective management of late blight of potato, it is advised that solution of fungicides must run off on the foliage of potato plants. In this process, more water volume is required (up to 1000 L/ha) along with more number of man power for spray. However, due to change in spraying technologies of equipments, water quantities can be adjusted. Many types of spraying equipments are being used for spraying of pesticides solutions viz., foot sprayer, manually operated knapsack sprayer, battery operated knapsack, tractor mounted sprayer, drone operated systems etc. These equipments require different water volume per hectare for proper coverage of potato foliage. The water volume must be economized with new spraying equipments for proper management of late blight of potato. The aim of the present study was to economize water volume and doses of fungicide per hectare for management of late blight disease on potato.

The field experiments were conducted at ICAR-Central Potato Research Institute-Regional Station, Modipuram Meerut (29.1° N, 77.92° E, 300 masl), Uttar Pradesh, India during three consecutive *Rabi* seasons of 2017-18, 2018-19 and 2019-20 years in a Randomized Block Design (RBD) with three replications. The seed tubers of cultivar Kufri Bahar (highly susceptible to late blight disease) were planted in the second week of November in a plot size of 3.0 x 3.0 m² having five rows per plot. The plant to plant distance of 20 cm and row to row distance of 60 cm was maintained. The crop was raised with the application of 180kg N, 80kg P₂O₅ and 100 kg K₂O /ha and other practices were followed as per recommendations for the region. Weedicide metribuzin 70% WP (@ 750 g/ha) was applied within five days after planting in all the years of experimentation.

Highly complex pathogenic race (mating type A1, metalaxyl resistant, race 1.2.3.4.5.6.7.8.9.10.11) of *P. infestans* was cultured on potato tuber slices and incubated at 18°C temperature with 95% relative humidity for 5-7 days in growth chamber. Inoculum was prepared by blending the freshly grown mycelia with sterile distilled water to obtain an aqueous suspension containing sporangia. For releasing the zoospores from sporangia, the suspension was incubated at 8°C temperature in BOD for 30-45 min in dark. The floating zoospores were observed under optical microscope after the set time period and the zoospores concentration was adjusted to 6x10⁴ ml⁻¹ using haemocytometer counting. The Whatman filter paper discs of size 0.3 cm² were submerged in the zoospore suspension and used for challenge inoculation. Forty-five days after planting, the leaves of potato plants in infector rows of each treatment were artificially inoculated by placing single disc on lower side of the leaf (Lal *et al.*, 2021). These rows were planted on the borders of the experimental plot to ensure proper spreading of inoculums across the treatments. The sprinkler system of irrigation was used at regular interval for maintaining the proper humidity in the experimental field.

A total of four sprays of mancozeb 75% WP in different doses with different water volumes per hectare were applied throughout the cropping season. Spraying of chemical was started before 7-8 days of initiation the disease, at appearance of disease and subsequently two other sprays at 7-10 days intervals. Terminal disease severity was recorded after 10 days of 4th spray as per the method of Henfling (1987). Percent disease control was calculated following the standard method. Tuber yield was recorded at the time of harvesting. The disease severity and yield data were subjected to standard

statistical analysis using OPSTAT software. Benefit:Cost ratio was calculated for assessing the economically effective treatment for management of late blight of potato. The 3 fungicide cost @ Rs 425.0/Kg and labour cost @ Rs 300.0/day was taken for calculation. The fixed cost was taken @ Rs 89204.0/ha. The cost of produce was taken @ Rs 8000/t.

The results presented in **Table 1** reveal that all treatments significantly reduced the average terminal disease severity (25.28 to 40.39%) over control (96.39%). Minimum average terminal disease severity (25.28, 25.78 and 26.19%) was recorded with treatment T6 (mancozeb 75%WP @ 2.5Kg/500L water), T4 (mancozeb 75%WP @ 1.5Kg/500L water) and T5 (mancozeb 75% WP @ 2.0Kg/500L water), respectively and were statistically at par with each other. Compared to these, significantly higher average terminal disease severity (40.39 and 40.0%) was recorded with treatment T1 (mancozeb 75% WP @ 2.0 Kg/1000L water) and T3 (mancozeb 75% WP @ 1.0 Kg/500L water). The average highest per cent disease control was observed in treatment T6 (73.78%) followed by T4 (72.68%) and T5 (72.51%). The least average per cent disease control was observed in the treatment T1 and T2 (58.10 and 58.5%, respectively). The average highest tuber yield was recorded in treatment T6 (34.35 t/ha) followed by T5 (33.09 t/ha) and T4 (33.07 t/ha). The treatment T6 (mancozeb 75%WP @ 2.5Kg/500L water) showed highest additional yield over control (6.21 t/ha) followed by T5 (4.95 t/ha) and T4 (4.93 t/ha). The highest gross return (Rs 49, 680.0) was recorded in T6 followed by T5 and T4 (**Table 2**). The lowest cost of treatment (Rs 5650.0) was in treatment T3, whereas highest cost of treatment (Rs 9050.0) in treatment T6. The highest net return over control (Rs 40, 630.0) and B: C (2.80) was recorded in T6 followed by treatment T4 and T5 (**Table 2**).

Mancozeb is a contact fungicide and multisite activity and widely adopted for management of late blight diseases and it was released during 1940s (Perez *et al.*, 2022). This fungicide is classified M03 FRAC code (Fungicide Resistant Action Committee) and considered as low risk group for developing resistant in fungicide. It is easily available in the farmer locality and cheaper in comparison to other contact fungicides used for managing late blight disease of potato. Determining concentration of fungicides and volume of water are essential criteria for successful management of any plant diseases. Especially, wherever technologies of spraying equipments are being changed. The foot sprayer, drum sprayer, knapsack sprayer (manual and battery operated), tractor mounted sprayer and drone based system are being used for management of plant diseases. Therefore, standardization of water volume and concentrations of fungicide as per currently spraying equipments systems are necessary for management of late blight disease. Now, Battery operated knapsack sprayer is being used by huge numbers of farmers. Because, it involved less human drudgery and spray larger area in short time with comparison to manual operated knapsack sprayer. Generally, water volume depends on the crop age and canopy of the growing cultivars. At initial stage of the crop (up to 40 Days After Planting-DAP) less water volume required than the latter stage (>40 DAP) of crop. Therefore, at present study volume of water with mancozeb fungicide was standardized using battery operated knapsack sprayer for effective management of late blight of potato. As, water level of soil is decreasing day by day due to excessive application of water for agricultural uses and other applications. Moreover, excessive application of water for fungicides application, it increases the cost of cultivation

Table 1: Evaluation of different doses of mancozeb 75 % WP in different water volumes for management of late blight of potato during the year 2017-18, 2018-19 and 2019-20

Treatments (per hectare basis)	Concentration (%)	Year 2017-18				Year 2018-19				Year 2019-20				Average	
		Terminal disease severity (%)	Disease controlled (%)	Yield (t/ha)	Terminal disease severity (%)	Terminal disease severity (%)	Disease controlled (%)	Yield (t/ha)	Terminal disease severity (%)	Terminal disease severity (%)	Disease controlled (%)	Yield (t/ha)	Terminal disease severity (%)	Disease controlled (%)	Yield (t/ha)
T1: Mancozeb 75 % WP @ 2.0 Kg/1000 L water	0.2	50.0	45.95	37.57	37.00	37.00	63.00	31.26	34.17	34.17	64.66	22.41	40.39	58.10	30.41
T2: Mancozeb 75 % WP @ 2.5 Kg/1000 L water	0.25	40.0	56.76	40.60	31.33	31.33	68.67	32.94	25.00	25.00	74.14	23.85	30.22	68.65	32.47
T3: Mancozeb 75 % WP @ 1.0 Kg/500 L water	0.2	47.50	48.65	38.05	43.33	43.33	56.67	31.49	29.17	29.17	69.83	23.41	40.00	58.50	30.98
T4: Mancozeb 75 % WP @ 1.5 Kg/500 L water	0.3	35.00	62.16	40.59	28.00	28.00	72.00	32.83	21.67	21.67	77.59	25.78	26.33	72.68	33.07
T5: Mancozeb 75 % WP @ 2.0 Kg/500 L water	0.4	31.00	66.49	40.40	25.67	25.67	74.33	32.69	20.50	20.50	78.79	26.19	26.50	72.51	33.09
T6: Mancozeb 75 % WP @ 2.5 Kg/500 L water	0.5	27.50	70.27	42.56	22.33	22.33	77.67	32.18	17.00	17.00	82.41	28.30	25.28	73.78	34.35
T7: Control		92.50	0.00	34.43	100.00	100.00	0.00	29.14	96.67	96.67	0.00	20.85	96.39	0.00	28.14
SE		1.17		1.39	0.87	0.87		0.94	1.84	1.84		1.07	0.83		0.62
CD (P 0.05)		5.52		4.32	2.72	2.72		NS	5.72	5.72		3.35	2.60		1.93
CV (%)		6.64		6.14	3.68	3.68		5.12	9.11	9.11		7.62	3.55		3.38

Table 2: Economics of different doses of mancozeb 75 % WP in different water volumes for management of late blight of potato

Treatments (per hectare basis)	Average Yield (t/ha)	Additional yield over control (t/ha)	Gross returns (Rs/ha)	Cost of treatment *(Rs/ha)	Net return over control (Rs/ha)	B:C Ratio
T1: Mancozeb 75 % WP @ 2.0 Kg/1000 L water	30.41	2.27	18160	7350	10810	2.52
T2: Mancozeb 75 % WP @ 2.5 Kg/1000 L water	32.47	4.33	34640	9050	25590	2.64
T3: Mancozeb 75 % WP @ 1.0 Kg/500 L water	30.98	2.84	22720	5650	17070	2.61
T4: Mancozeb 75 % WP @ 1.5 Kg/500 L water	33.07	4.93	39440	6500	32940	2.76
T5: Mancozeb 75 % WP @ 2.0 Kg/500 L water	33.09	4.95	39600	7350	32250	2.74
T6: Mancozeb 75 % WP @ 2.5 Kg/500 L water	34.35	6.21	49680	9050	40630	2.80
T7: Control	28.14	-	-	-	-	2.42

*It includes cost of fungicides (@ Rs. 425.0/kg), labour (@ Rs. 300.0 /labour), and potato yield (@ Rs. 8000/ton)

in the category of plant protection operation. It should be applied as per required water volume for optimum coverage of crop foliage. Concentration of mancozeb 75% WP @ 0.3-0.5% was highly effective when it was applied as 2.5 Kg/500 L (T6), 2.0 Kg/500 L (T5) and 1.5 Kg/500 L (T4). These treatments also gave higher B: C ratio with best gross returns. The alone efficacy of mancozeb fungicide and its application in combination with different systemic /contact fungicides were widely adopted for late blight management. Among them, the cymoxanil8%+mancozeb64%WP, metalaxy18%+mancozeb 64% WP, fenamidon10%+mancozeb 50% WDG were reported effective for managing late blight of potato. Mancozeb interferes with enzymes containing sulphydryl groups, disrupting many biochemical processes within the fungal cell cytoplasm and mitochondria. It is also applied in other leaf spot diseases of potato. The bio-efficacy of mancozeb under lab and field against late blight of potato reported by various researchers (Islam *et al.*, 2018 ; Lal *et al.*,2015) Moreover, this fungicide used as to develop new combination of formulation which has less chance to develop resistance against *P. infestans*.

The present study concluded that concentration of fungicides have much more

importance along with proper coverage of plant foliage. The water volume of 500 L/ha is sufficient with battery operated knapsack sprayer. If crop foliage is dense, and late blight is moderate to severe, the spray volume would be required more than 500 L/ha along with optimum concentration of fungicide (mancozeb @ 2.5 Kg/1000 L water), for the effective management of late blight of potato.

CONFLICT OF INTEREST

The authors declare no conflict of interest in this manuscript.

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MS Received: October 20, 2022; Accepted: January 03, 2023

ACKNOWLEDGEMENT TO REVIEWERS (2022)

Editorial Board of the Potato Journal thankfully acknowledge the sincere efforts of the following learned reviewers for providing valuable advice on suitability of the manuscripts for publication in the Potato Journal volume 49 (1 and 2).

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Unit	Abbreviation	Unit	Abbreviation
Centimetre	cm	Milligram	mg
Cubic centimetre	cm ³	Millilitre	ml
Gram	g	Minute	min
Hectare	ha	Nanometre	nm
Kilogram	kg	Second	s
Litre	l	Square cm	cm ²
Metre	m	Square km	km ²
Mega gram	Mg	Tonne	t

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