Volume 51 No. 1, 2024

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*

POTATO
INDIAN
ASSOC.
ESTD. 1974

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.

Available online : http://epubs.icar.org.in/ejournal/index.php/PotatoJ

Editorial Office:

Potato Journal, Indian Potato Association, ICAR-Central Potato Research Institute, Shimla 171 001, (HP) India
Phone: 91 177 2625073; Fax : 91 177 2624460; E-mail: potatojournal@ipashimla.org; potatojournal@gmail.com

IPA Membership:

Annual membership : ₹ 944 or US$ 71 (for foreign members)
Life membership : ₹ 7,080 or US$ 472 (for foreign members)

Subscription (Annual):

Printed copy or online access : ₹ 1,260 (in India) or US$ 126 or equivalent (other countries)
Printed copy + online access : ₹ 1,890 (in India) or US$ 189 or equivalent (other countries)

The membership/subscription dues should be sent through bank draft or money order in favour of the Indian Potato Association, ICAR-Central Potato Research Institute, Shimla 171 001, (HP) India. OR

Payment can also be made online/ digitally using following details:
Name of Bank: **State Bank of India**; *Branch Name*: **Shimla Main Branch**; *Branch Code*: **718**;
Beneficiaries/ Organization name & Bank Account Number: **Indian Potato Association (IPA)**;
A/c No. 10836122130; *IFSC Code*: **SBIN0000718**; *PAN No*: **AAAAI2001C**.

The members are entitled to all issues of the journal published by the IPA.

Volume 51 No. 1, 2024

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*

POTATO
INDIAN ASSOC.
ESTD. 1974

Official Journal of

The Indian Potato Association

Potato Journal

being published since **1974;**
is the official Journal of the
Indian Potato Association,
ICAR-Central Potato Research Institute,
Shimla 171 001 (Himachal Pradesh)
India

Phone : 91 177 2625073 Fax : 91 177 2624460
E-mail: potatojournal@gmail.com

Available online : http://epubs.icar.org.in/ejournal/index.php/PotatoJ

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

ISSN Print : 0970-8235
ISSN Online : 0973-5909

Potato Journal

51(1) January - June, 2024

Contents

Research Papers

Review Papers

Potato J (2024) 51 (1): 1-8

ANALYSIS OF POTATO FARMING PRODUCTION FACTORS

A. Amrullah[1*], Ahmad Dewangga Haerul[2] and Muslim Salam[1]

ABSTRACT: There have been many research results that show that production factors affect agricultural production. However, a thorough analysis of production factors has not been carried out much. In addition, there has been no comprehensive analysis of the efficiency of potato production factors in Indonesia. Therefore, this study was conducted to determine the production factors that significantly affect potato production and the efficiency of the use of production factors. A Cobb-Douglas production function analysis was carried out to determine the influence of production factors on potato production. Furthermore, an allocative efficiency analysis was carried out to determine the efficiency of using production factors. The study results showed that the production factors of land area, seed, urea fertilizer, NPK fertilizer, fungicide, land cultivation labor, and harvest labor positively and significantly affected potato production. This study also found that only the input factor of planting labor had a significant adverse effect on potato production. In the allocative efficiency analysis, it was found that the use of production factors of seed, urea fertilizer, NPK fertilizer, fungicide, land cultivation labor, and harvest labor is inefficient, so these production factors must be increased in their use. On the other hand, the production factor of the land area shows inefficient results, so the land area must be reduced to achieve optimal efficiency.

KEYWORDS: Production Factors; Potato Production; Production Efficiency

INTRODUCTION

Despite the increase in potato production in Indonesia, it has not yet met market demand. However, the potential for further growth is promising, supported by the availability of various resources for potato cultivation development. Potatoes, as a horticultural commodity, hold great promise for food diversification, and with the right strategies, potato production can be increased to meet the high demand (Salsabila *et al.*, 2022).

The use of production factors in potato farming management highly determines potato production. These production factors, or inputs, are resources used to produce something. They play a vital role because of their significant influence on crop size. Understanding and effectively managing these factors is crucial for increasing the production of potatoes (Kilo *et al.*, 2018). Agriculture's production factors generally used are land area, seed, fertilizer, pesticides, and labor. The optimal use of production factors is vital to get the desired amount of production.

Potato crop production tends to fluctuate due to various production factors. Each production factor plays a unique role and influences production results. Farmers can guarantee the desired production results by using effective and efficient production factors. On the other hand, inefficient use of production factors can cause production to be less than optimal (Adiyoga, 2016; Mardani & Salarpour, 2015; Van Evert *et al.*, 2017). This study shows the importance of analyzing the use of production factors in potato farming.

---

*Corresponding author; email: amrullahma@unhas.ac.id

[1] Laboratory of Farm Management and Agricultural Marketing, Department of Socio-economics of Agriculture, Faculty of Agriculture, Hasanuddin University, Jl. Perintis Kemerdekaan Km.10 Makassar 90245, Indonesia.

[2] Agribusiness Study Program, Bachelor Degree of Graduate School of Hasanuddin University, Jl. Perintis Kemerdekaan Km.10 Makassar 90245, Indonesia.

The analysis of potato production factors is vital to find out the production factors that have a significant influence on potato production. Furthermore, an allocative efficiency analysis was carried out to determine the use of inefficient production factors. The analysis results can show the use of production factors that need to be added or subtracted. The potato production factors analyzed in this study are land area, number of seedlings, fertilizer use, pesticide use, fungicide and herbicide, and labor (**Fig. 1**).

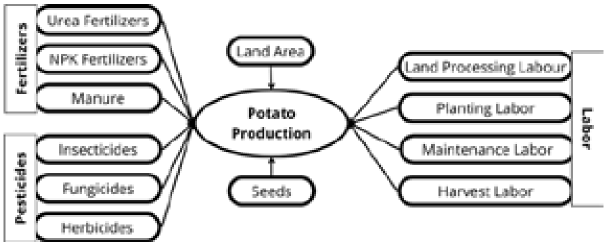


Fig.1. Conceptual Framework for the Influence of the Use of Production Factors

MATERIALS AND METHODS

Research Location, Data Collection, and Research Samples

Our research was conducted in Uluere District, Bantaeng Regency, South Sulawesi, a region known for its high potato production. This location was chosen purposively because the area has the highest potato production in Bantaeng Regency. The data collection technique used is a structured interview using a questionnaire that has been prepared. Respondents were sampled using a simple random sampling method from the farmer population. The *Cochran* formula is used to determine the minimum number of farmers to be sampled. The error tolerance limit has been set at 5%, so the number of samples selected for interview is 186 respondent farmers.

Data Analysis

The Cobb-Douglas function is a quantitative analysis tool used to determine the correlation between production and the production factors that affect it (Giang *et al.*, 2023; Zhang *et al.*, 2020). Therefore, this study's Cobb-Douglas Production Function Analysis determines the influence of production factors on potato farming. Cobb Douglas production function is a function or equation involving two or more variables, where the dependent variable is given the symbol Y and the independent variable is given the symbol X. The relationship between variables Y and X can be solved by regression, where the variation of Y will be affected by the variation of X (Nurprihatin & Tannady, 2017).

Specification of the Cobb-Douglas Equation Model

This study has an independent variable tested for its effect on the potato production as dependent variable. The independent variables including land area, seed, urea fertilizer, NPK fertilizer, manure, insecticide, fungicide, herbicide, land cultivation labor, planting labor, maintenance labor, and harvest labor. The specifications of the Cobb-Douglas Production Function Analysis model are presented in Equation 1.

$$\log Prod = \alpha + b1\log LL + b2\log B + b3\log Pa + b4\log Pb + b5\log Pc + b6\log Insek + b7\log Fungi + b8\log Herb + b9\log TKa + b10\log TKb + b11\log TKc + b12\log TKd + e \quad \text{.............................} \; 1)$$

where: Prod = Potato production (kg), LL = Land area (ha), B = Seed (kg), Pa = Urea fertilizer (kg), Pb = NPK fertilizer (kg), Pc = Manure fertilizer (kg), Insek = Insecticide (L), Fungi = Fungicide (L), Herb = Herbicide (L), TKa = Land Cultivation Labor (man-days), TKb = Planting labor (man-days), TKc = Maintenance labor (man-days), TKd = harvest labor (man-days), α = Regression Equation Intercept Coefficient, B1-B12 = Independent Variable Regression Coefficient, e = error terms

Allocative Efficiency Analysis

The allocative efficiency analysis was carried out by looking at the ratio between the Marginal Product Value (NPM) and its input price (P_x) (Cordanis *et al.*, 2020), where efficiency allocates if NPM/P_x is equal to one, as presented in Equations 2 and 3.

$$\frac{NPMXi}{Pxi} = 1 \quad \text{.........} \quad (2)$$

or

$$\frac{Py.bi.Yi}{Xi.Pxi} = 1 \quad \text{.........} \quad (3)$$

where: NPMxi = Marginal production value of the ith input, Pxi = Price per ith unit (Rp/unit), Py = Price per output unit (Rp/unit), Yi = Average production (kg), Xi = Average usage of the ith input (unit), Bi = Regression Coefficient,

To find out whether an input needs to be increased or decreased, its use can be done by comparing the marginal product value (NPMxi) with the marginal input price (Pxi), i.e. if:

NPMxi/Pxi > 1 means that the use of inputs is not yet efficient, so the use of inputs needs to be increased.

NPMxi/Pxi = 1, meaning that the use of inputs is already at an efficient level

NPMxi/Pxi < 1, meaning that the use of inputs is inefficient, so the use of inputs needs to be reduced

Model Testing

Model testing is used to determine the influence of significant variables jointly and partially. In this study, two tests were used, namely F-Test and t-Test, whose objectives and decision criteria were explained as follows:

The F-test is used to determine the significant influence between independent variables on dependent variables. If the value of F-count < F-table, then H0 is accepted, which means there is no significant influence between the independent and dependent variables. Then, if the value of F-count > F-table, H0 is rejected, which means that there is a significant influence between the independent variable and the dependent variable (Kadir, 2016).

The t-test determines how much influence each independent variable has on the dependent variable. If the t-calculated value > t-table, the individual independent variables significantly affect the dependent variables. Meanwhile, if the t-count is < t-table, then the independent variable partially does not significantly affect the dependent variable (Sarwono, 2018) .

RESULTS AND DISCUSSION

Research Results

The value of the determination coefficient (R2) is 0.750, so it can be concluded that 75% of the influencing factors of potato production are explained by the variables studied. This study obtained the F-table value of 1.808 from the 5% alpha table. The significance level obtained was <0.001, and the F-count value was 47.284, then a significant value of <0.001 <0.05 (alpha: 5%) and an F-count value (47.284) > F-table (1.808) was obtained, so it can be concluded that the independent variable has a simultaneous influence on the dependent variable. The t-test results showed independent variables that partially affected the dependent variables: land area, seed, urea fertilizer, NPK fertilizer, fungicide, land cultivation labor, and harvest labor. Meanwhile, other variables, namely manure fertilizer, insecticide, herbicide, planting labor, and maintenance labor have no partial effect on production. *Results of Cobb-Douglas Production Function Analysis*

Cobb-Douglas production function analysis was used to analyze the influence of production factors on potato production. The results of the study of the Cobb-Douglas production function can be seen in **Table 1**.

In **Table 1**, it can be seen that there are two types of regression coefficients, namely Unstandardized Coefficients and Standardized Coefficients. To make it easier to prepare the interpretation, the regression coefficients used are Standardized

Table 1. The results of the Cobb-Douglas function analysis of the influence of input use on potato production.

Coefficients[a]

Type		Unstandardized Coefficient		Standardized Coefficient	t-value	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.627	.942		3.852	.000
	ln LL (Land Area)	.419	.172	.223	2.430	.016*
	ln B (Seed)	.409	.066	.328	6.225	.000**
	ln Pa (Urea fertilizer)	.310	.075	.209	4.135	.000**
	ln Pb (NPK fertilizer)	.259	.093	.165	2.777	.006**
	ln Pc (Manure fertilizer)	-.058	.120	-.022	-.483	.629
	ln Insek (Insecticide)	.025	.071	.019	.352	.725
	ln Fungi (Fungicide)	.137	.068	.099	2.011	.046*
	ln Herb (Herbicide)	-.092	.064	-.060	-1.421	.157
	ln TKa (Land Cultivation Labor)	.237	.036	.457	6.562	.000**
	ln TKb (Planting Labor)	-.429	.110	-.367	-3.888	.000**
	ln TKc (Maintenance labor)	-.176	.120	-.136	-1.466	.145
	ln TKd (Harvest Labor)	.237	.097	.168	2.434	.016*
Dependent Variable: ln Prod						

Information: *Significant at a 95% confidence level, and **Significant at a 99% confidence level.

Coefficients, which are presented in the following equation:

$$\ln Prod = \alpha + 0.223 \ln LL + 0.328 \ln B + 0.209 \ln Pa + 0.165 \ln Pb - 0.022 \ln Pc + 0.019 \ln Insek + 0.099 \ln Fungi - 0.60 \ln Herb + 0.457 \ln TKa - 0.367 \ln TKb - 0.136 \ln TKc + 0.168 \ln TKd + e$$

Results of Allocative Efficiency Analysis

Farming can be considered efficient if a production factor's marginal product value (NPM) is equal to its price. (Kune *et al.*, 2016). If the marginal product value of an input is equal to one (NPMx/Px=1), then it can be interpreted that the use of the input is efficient. Meanwhile, if the marginal product value of an input is more than one (NPMx/Px>1), it means that the input is not efficient and needs to be added to achieve the level of efficiency. The use of inputs is said to be inefficient if (NPMx/Px<1), so to achieve a level of efficiency in the use of inputs needs to be reduced (Puryantoro & Wardiyanto, 2022). The results of the allocative efficiency analysis can be seen in **Table 2**.

The independent variables of seed, urea fertilizer, NPK fertilizer, fungiside, land cultivation labor, and harvest labor are not yet efficient, so it is necessary to add inputs to achieve an efficient level (**Table 2**). On the other hand, using inputs for land area and planting labor is inefficient, so it is necessary to reduce inputs.

Discussion

1. Land Area

The land area variable positively and significantly affected potato production, with a regression coefficient value of 0.223 and a significance level of 0.016. In addition, the t-test results showed a t-count value of 2.43 > t-table 2.00. Every 1% increase in land area will increase potato production by 0.223% if other variables are constant. The ratio between NPM from the input of land area to the land rental price per season per hectare is less than one (0.20), so it can be interpreted

Table 2. Results of allocative efficiency analysis of input use on potato production.

Variable	Bi	Average Y	PY	Xi	Pxi	PMxi	NPMxi	NPMxi/Pxi	Optimum^{a}
Land Area*	0.223	3,370.86	12,316.67	0.46	100,000,000	1624.45	20,007,827.56	0.20^{te}	2.31
Seed*	0.328	3,370.86	12,316.67	373.71	18,050	2.96	36,439.59	2.02^{be}	754.45
Urea fertilizer*	0.209	3,370.86	12,316.67	130.85	2,400	5.38	66,311.74	27.63^{be}	3,615.51
NPK fertilizer*	0.165	3,370.86	12,316.67	117.60	2,900	4.73	58,253.26	20.09^{be}	2,362.22
Manure fertilizer	-0.022	3,370.86	12,316.67	398.52	500	-0.19	-2,291.95	-4.58	-86.94
Insecticide	0.019	3,370.86	12,316.67	1.83	250,000	34.91	429,959.76	1.72	3.16
Fungicide*	0.099	3,370.86	12,316.67	2.94	170,000	113.65	1,399,813.33	8.23^{be}	24.18
Herbicide	-0.060	3,370.86	12,316.67	2.12	130,000	-95.36	-1,174,494.85	-9.03	-0.23
Land Cultivation Labor*	0.457	3,370.86	12,316.67	10.37	100,000	148.53	1,829,373.54	18.29^{be}	189.74
Planting Labor	-0.367	3,370.86	12,316.67	2.91	100,000	-425.43	-5,239,852.01	-52.40^{te}	-0.06
Maintenance Labor	-0.136	3,370.86	12,316.67	25.26	100,000	-18.15	-223,495.66	-2.23	-11.30
Harvest Labor*	0.168	3,370.86	12,316.67	9.64	100,000	58.76	723,701.93	7.24^{be}	69.75
Allocative Efficiency Average								1.43	

Information: *positively and significantly affects the 95% confidence level, a = Optimum use value per hectare, be = not yet efficient, te = inefficient

that the use of land area is not efficient. These results are in line with the results of the research Sufa (2023) and Andrias *et al.* (2017), which says that the variable land area influences production, which means that the more land is used, the higher the production produced. Research on potato production across various countries indicates that land area generally positively impacts production, though its effect on yield can vary. In Indonesia, larger land areas (š1 hectare) were associated with higher technical efficiency in potato farming (Utami & Mamilianti, 2021). Similarly, in Ethiopia, land allocated for potato production positively and significantly affected output (Bukul, 2018)

2. *Seed*

This study showed that the seed variable had a positive and significant effect on potato production with the t-test results, namely a t-count value of 6.22 > a t-table of 2.00. The regression coefficient value is 0.328 with a significance level of less than 0.001, so it can be interpreted that every additional seedinput of 1% will increase potato production by 0.328% if other variables are constant. In line with several previous studies, it was also found that seed had a significant effect on agricultural production (Paul, 2017, Agatha & Wulandari, 2018 and Nugraheni *et al.*, 2022). Research has shown that using high-quality seed potato can significantly improve potato production and food security. Certified seed potato (CSP) has been found to increase yields and food security among smallholder farmers in Kenya (Okello *et al.*, 2017). Similarly, true potato seed (TPS) offers potential benefits for small-scale farmers in developing countries (KH Ababaker & Benyamin Esho, 2022). Positive selection, a method of choosing healthy plants for seed, has demonstrated yield increases averaging 12% compared to farmers' traditional selection methods in Uganda (Priegnitz *et al.*, 2020) The ratio between the NPM of seed and the price of seed is 2.02, so it can be interpreted that the use of seed is inefficient economically.

3. *Urea Fertilizer*

The urea fertilizer variable showed a positive and significant relationship with the amount of potato production. The regression results showed a regression coefficient value of 0.209 with a significance level of <0.001. It can be interpreted that every 1% addition of urea fertilizer input will increase potato production by 0.209% if other variables are constant. On the other hand, the ratio value between NPM from urea fertilizer input and the fertilizer price in question is 27.63. This value indicates that the use of urea fertilizer by respondent farmers is not efficient. This is in line with the findings of Rohman *et al.* (2021) and Rohi *et al.* (2018), which found that urea fertilizer can increase production by accelerating and optimizing plant growth.

NPK Fertilizer

The use of NPK fertilizer can positively and significantly influence potato production, with a regression coefficient value of 0.165 and a significance level of 0.006. Meanwhile, the t-test results show a t-count value of 2.77 > t-table 2.00. It can be interpreted that every 1% increase in NPK fertilizer input will increase potato production by 0.165% if other variables are constant. The ratio between NPM from NPK fertilizer and the fertilizer price is more significant than one (20.09). Based on the value of this ratio, it can be concluded that the use of NPK fertilizer is inefficient.

The results of research by Anggraesi *et al.* (2020) and Ruskandar *et al.* (2019) also found that NPK fertilizer affect production to a significant extent. The use of NPK fertilizer can spur plant generative growth and encourage the synthesis process to increase growth and production. (Quraisyin *et al.*, 2020). According to Tulung *et al.* (2021), the use of NPK fertilizer at the correct dosage can be the fresh weight of potato plants, the diameter of the tubers, and the productivity of the plants.

Fungicide

Using fungicide showed a positive and significant influence on potato production, with a regression coefficient value of 0.099 and a significance level of 0.046. It can be interpreted that every 1% increase in manure fertilizer input will increase potato production by 0.099% if other variables are constant. The t-test results showed a t-count value of 2.011 > t-table 2.00. Meanwhile, the ratio between NPM from fungicide and the price of the fungicide in question is 8.23, so it can be concluded that fungicide application is economically inefficient. The influence of fungicide that can support production is caused by the application of fungicide in the proper doses, which can inhibit the growth of diseases caused by fungi so that plants can grow better (Fitria & Diding, 2019).

Land Cultivation Labor

Land Cultivation Labor has a positive and significant effect on potato production, with a regression coefficient value of 0.457 and a significance level of less than 0.001. It can be interpreted that every 1% increase in planting labor will increase potato production by 0.457% if other variables are constant. The study also obtained similar results. (Lama & Kune, 2016) and Laksmayni (2022), which says that labor has a real effect on production. Meanwhile, the NPM ratio of the input of Land Cultivation Labor to the amount of wages provided is 18.29. A ratio value of more than one indicates that Land Cultivation Labor allocation is inefficient.

Planting Labor

The planting labor variable had a negative and significant effect on potato production with a regression coefficient value of -0.367 with a significance level of <0.001. **Table 1** shows every 1% increase in land cultivation labor will reduce potato production by 0.367%

if other variables are constant. This can be caused by the number of workers above the optimal number, so the division of labor becomes unclear, and the results of the work are ineffective. In addition, each farmer has his way of using labor inputs according to his experience and habits (Rahmasita *et al.*, 2022).

Harvest Labor

Harvest labor has a positive and significant effect on potato production, with a regression coefficient value of 0.168 and a significance level of 0.016. The t-test results also obtained a t-count value of 2.43 > a t-table 2.00. **Table 1** shows every 1% increase in harvest labor will increase potato production by 0.168% if other variables are constant. The addition of labor can optimize the implementation of potato harvesting activities so that the number of potatoes to be harvested will be more significant. This is in line with the results of the study Neonbota & Kune (2016) and Suripto & Safitri (2021), i.e., labor can positively affect production to a significant extent. The NPM ratio of harvest labor to the number of wages given is more than one (7.24), so it can be interpreted that the allocation of harvest labor is not economically efficient.

CONCLUSION

The results of this study can conclude that the variables of land area, seed, urea fertilizer, NPK fertilizer, fungicide, land cultivation labor, and harvest labor have a positive and significant effect on potato production. The Insecticide variable had a positive but insignificant effect on potato production. On the other hand, the variables of manure fertilizer, herbicide, and maintenance labor have a negative but insignificant effect. In contrast, the variable of planting labor has a negative and significant effect on potato production. Based on the allocative efficiency analysis results, the variables of seed, urea fertilizer, NPK fertilizer, fungicide, land cultivation labor, and harvest labor showed inefficient results, so these production factors must be increased in their use. Meanwhile, the land area variable shows the results of inefficient allocative efficiency, so land use must be reduced in area to achieve optimum efficiency.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

ETHICAL STATEMENT

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

LITERATURE CITED

Adiyoga, W. (2016). Faktor-faktor yang Memengaruhi Perilaku dan Keputusan Konsumen untuk Membeli Kentang, Bawang Merah, dan Cabai Merah. *Jurnal Hortikultura*, *21*(3), 280. https://doi.org/10.21082/jhort.v21n3.2011.p280-294

Andrias, A. A., Darusman, Y., & Rahman, M. (2017). Pengaruh Luas Lahan Terhadap Produksi dan Pendapatan Usahatani Padi Sawah. *Jurnal Ilmiah Mahasiswa AGROINFO GALUH*, *4*(1), 521–529.

Bukul, B. B. (2018). Factors Affecting Smallholder Farmers Potato Production in Shashemene District, West Arsi Zone, Oromia National Regional State, Ethiopia. *Food Science and Quality Management*, *76*, 66–72. www.iiste.org

Cordanis, A. P., Sudirman, P. E., & Piran, R. D. (2020). Efisiensi Usaha Tani Jagung di Kecamatan Amabi Oefeto Timur Kabupaten Kupang. *CIWAL (Jurnal Ilmu Pertanian Dan Lingkungan)*, *1*(1), 23–26.

Fitria, R. U., & Diding, R. (2019). Efektivitas Fungisida Bahan Aktif Mankozeb Untuk Mengendalikan Hawar Daun Kentang (Phytopthora infestans). *Agrika*, *13*(2), 90. https://doi.org/10.31328/ja.v13i2.1192

Giang, P. Q., Thi, V., & Huong, T. (2023). *Comparison of the Impact of Production Factors on the Ecological and Economic Efficiency of the Potato Land-Use Type in Vietnam and Russia Based on the Cobb-Douglas Production Function*. *24*(9), 272–281.

Kadir. (2016). Statistika Terapan: Konsep, Contoh, dan Analisis Data dengan Program SPSS/Lisrel dalam Penelitian. *Edisi Kedua. Jakarta: RajaGrafindo Persada.*

KH Ababaker, S., & Benyamin Esho, K. (2022). Producing Potato from True Seed, Review. *Acta Scientific Agriculture*, *6*(3), 51–63. https://doi.org/10.31080/asag.2022.06.1111

Kilo, I., Halid, A., Rauf, A., & Soekartawi. (2018). Analisis Faktor-Faktor yang Mempengaruhi Produksi pada Usahatani Jagung Hibrida di Kecamatan Tibawa Kabupaten Gorontalo. *Agrinesia: Jurnal Ilmiah Agribisnis*, *2*(2), 105–110.

Kune, S. J., Muhaimin, A. W., & Setiawan, B. (2016). Analisis Efisiensi Teknis dan Alokatif Usahatani Jagung (Studi Kasus di Desa Bitefa Kecamatan Miomafo Timur Kabupaten Timor Tengah Utara). *Agrimor*, *1*(01), 3–6. https://doi.org/10.32938/ag.v1i01.23

Laksmayni, M. K. (2022). Analisis Efisiensi Penggunaan Input Produksi Pada Usahatani Padi Sawah Di Desa Kotaraya Timur Kecamatan Mepanga Kabupaten Parigi Moutong. *Agrotekbis*, *10*(3), 270–277.

Lama, M., & Kune, S. J. (2016). Faktor-Faktor yang Mempengaruhi Produksi Usaha Tani Sayur Sawi di Kelurahan Bensone Kecamatan Kota Kefamenanu Kabupaten Timor Tengah Utara. *Agrimor*, *1*(02), 27–29. https://doi.org/10.32938/ag.v1i02.102

Mardani, M., & Salarpour, M. (2015). Measuring technical efficiency of potato production in Iran using robust data envelopment analysis. *Information Processing in Agriculture*, *2*(1), 6–14. https://doi.org/10.1016/j.inpa.2015.01.002

Neonbota, S. L., & Kune, S. J. (2016). Faktor-Faktor yang Mempengaruhi Usahatani Padi Sawah di Desa Haekto, Kecamatan Noemuti Timur. *Agrimor*, *1*(03), 32–35. https://doi.org/10.32938/ag.v1i03.104

Nurprihatin, F., & Tannady, H. (2017). Pengukuran Produktivitas Menggunakan Fungsi Cobb-Douglas Berdasarkan Jam Kerja Efektif. *JIEMS (Journal of Industrial Engineering and Management Systems)*, *10*(1), 34–45. https://doi.org/10.30813/jiems.v10i1.36

Okello, J. J., Zhou, Y., Kwikiriza, N., Ogutu, S., Barker, I., Schulte-Geldermann, E., Atieno, E., & Ahmed, J. T. (2017). Productivity and food security effects of using of certified seed potato: The case of Kenya's potato farmers. *Agriculture and Food Security*, *6*(1), 1–9. https://doi.org/10.1186/s40066-017-0101-0

Paulus, J. (2017). Analisis Faktor Yang Mempengaruhi Faktor Padi Sawah Pasang Surut Di Desa Kuala Dua Kecamatan Sungai Raya Kabupaten Kubu Raya. *Universitas Tanjungpura*, 1–12.

Priegnitz, U., Lommen, W. J. M., van der Vlugt, R. A. A., & Struik, P. C. (2020). Potato Yield and Yield Components as Affected by Positive Selection During Several Generations of Seed Multiplication in Southwestern Uganda. *Potato Research*, *63*(4), 507–543. https://doi.org/10.1007/s11540-020-09455-z

Quraisyin, D. N., Sugiarto, S., & Nurhidayati, N. (2020). Respon Dua Varietas Tanaman Kentang (Solanum tuerosum L.) Terhadap Aplikasi Pupuk Majemuk NPK. *Folium: Jurnal Ilmu Pertanian*, *4*(1), 75–82.

Rahmasita, Alam, M. N., & Christoporus. (2022). Analisis Penggunaan Input Produksi Padi Sawah Di Desa Toribulu Kecamatan Toribulu Kabupaten Parigi Moutong. *Agrotekbis*, *10*(6), 951–958.

Salsabila, H., Hanani, N., & Asmara, R. (2022). Analisis Kinerja Produksi Usahatani Kentang (Kasus di Desa Sumberbrantas, Kecamatan Bumiaji, Kota Batu). *Jurnal Ekonomi Pertanian Dan Agribisnis*, *6*(2), 551. https://doi.org/10.21776/ub.jepa.2022.006.02.19

Sarwono, J. (2018). Statistik untuk riset skripsi. *Yogyakarta: Andi Offset*.

Sufa, B. (2023). *Analisis Usaha Tani Padi Sawah di Desa Komba-Komba Kecamatan*. *2*(1), 13–19.

Suripto, & Safitri, O. L. (2021). Analisis Efisiensi Penggunaan Faktor Produksi Usahatani Bawang Merah di Desa Parangtritis, Kecamatan Kretek, Kabupaten Bantul. *Triangle*, *02*(04), 537–542.

Tulung, L. E. A., Pinaria, A. G., & Husain, J. (2021). Respons Pertumbuhan dan Produksi Kentang Medians terhadap Pemupukan NPK di Kelurahan Rurukan Propinsi Sulawesi Utara. *Jurnal Trandisiplin Pertanian*, *17*(2), 561–568.

Utami, D. C., & Mamilianti, W. (2021). Efisiensi teknis usahatani kentang pada luas lahan yang berbeda di kabupaten Pasuruan. *Agromix*, *12*(2), 102–110. https://doi.org/10.35891/agx.v12i2.2577

van Evert, F. K., Gaitán-Cremaschi, D., Fountas, S., & Kempenaar, C. (2017). Can precision agriculture increase the profitability and sustainability of the production of potatoes and olives? *Sustainability (Switzerland)*, *9*(10). https://doi.org/10.3390/su9101863

Zhang, Q., Dong, W., Wen, C., & Li, T. (2020). Study on factors affecting corn yield based on the Cobb-Douglas production function. *Agricultural Water Management*, *228*(2519), 105869. https://doi.org/10.1016/j.agwat.2019.105869

MS Received : June 06, 2024; Accepted : July 31, 2024

Potato J (2024) 51 (1): 9-18

KUFRI DAKSH: A NEW WATER-USE EFFICIENT TABLE POTATO VARIETY WITH CROSS TOLERANCE TO HIGH TEMPERATURE STRESS

Devendra Kumar[1*], Sanjay Rawal[1], Name Singh[1], VK Gupta[1], Vinay Bhardwaj[2], Brajesh Singh[2], JS Minhas[2], SK Luthra[1], Som Dutt[2], Mehi Lal[1], Pooja Mankar[1] and Vikas Mangal[2*]

ABSTRACT: Kufri (K) Daksh is a main season, medium maturing, high yielding, water-use-efficient table potato variety that can be grown in regions with limited water availability. It is a clonal selection from the cross between CP1748, having high water use efficiency and LT-1 tolerating high temperature stress. Its plants are tall and vigorous with field resistance to late blight. Its tubers are white-cream (light yellow), ovoid with shallow to medium eyes and cream flesh with good keeping quality. It is fertilizer responsive and can yield 30-35 t/ha under low water (≤ 20%) availability in middle Gangetic plains. K Daksh has better trade-off for high CO_2 gain and low water loss through optimization in plant canopy leaf area and plant height components. K Daksh can be an excellent choice to tolerate high temperature and water stress regimes in changing climatic scenarios.

KEYWORDS: Potato, variety, water use efficiency, tolerance, drought, high temperature stress

INTRODUCTION

Potato (*Solanum tuberosum* L.) is the world's fourth most important food crop and yields more food calories per unit water than cereals. Compared to other leading food crops, potato grows more rapidly, require less land, and can withstand harsher climates. These qualities enable this crop to potentially attain the position of third most staple food globally (Wang *et al.* 2023).

Notwithstanding the plant's extensive distribution and capacity to thrive in diverse environmental and climatic circumstances, environmental issues impact potato growth (Handayani *et al.* 2019). Nevertheless, due to its sparse root system and inadequate capacity to recover from water stress, potato is susceptible to drought conditions, which in turn restricts their yield. That is why traditional potato varieties are susceptible to water stress and likely have a limited genetic base for drought tolerance (Sprenger *et al.* 2015). Consequently, it is predicted that worldwide drought will reduce the potential potato yield by 18–32% between 2040 and 2069 (Obidiegwu *et al.* 2015).

It is generally known that several field crops, including potato, respond differently to water stress in terms of growth characteristics and production. Agronomic traits (plant height, leaf number and total above-ground biomass) and physiological traits (chlorophyll content, rate of photosynthesis, stomatal conductance, transpiration, relative water content (RWC)) are useful indicators of drought tolerance (Mthembu *et al.* 2022). To achieve successful breeding, precise knowledge of effective drought tolerance traits, their heritability, the interaction between genotype and environment, and appropriate selection strategies for the desired traits are necessary (Muthoni *et al.* 2016).

---

[1]ICAR-Central Potato Research Institute, Regional Station, Modipuram, Meerut - 250110, Uttar Pradesh, India
[2]ICAR-Central Potato Research Institute, Shimla - 171 001, Himachal Pradesh, India
*Corresponding author; email: devkmalik@gmail.com; vikas90bharatpur@gmail.com

From an agronomic perspective, the concept of drought tolerance is associated with the ability of crops to produce higher yields in conditions of limited water availability (Minhas *et al.* 2003).

The expansion of potato cultivation in water-scarce environments poses significant research challenges (Qin *et al.* 2019), and elite cultivars with improved drought resistance and wide adaptation are needed in India and other countries that are facing water scarcity problems. So far, ICAR-CPRI has released three water-use efficient varieties, i.e. Kufri Thar-1 (Kumar *et al*. 2021), Kufri Thar-2 (Luthra *et al.* 2020) and Kufri Thar-3 (Kumar *et al.* 2020) for different agroclimatic zones. Apart from water stress, high-temperature stress during crop growth and tuberization restricts the adoption of this crop in early planting conditions of northwestern plains and peninsular India (Luthra *et al.* 2013; 2018). Therefore, a water-use efficient variety having tolerance to high temperature stress shall be adopted more in different agro-ecologies of the country and shall prove more remunerative to the potato growers. Keeping changing climate scenario and increasing food and nutrition demand in view, water stress tolerant variety K Daksh (WS/07-113) has been developed and released to extend potato cultivation in non-traditional and drought prone areas for sustainable productivity and to ensure farmers' income.

BACKGROUND

Female (♀) parent (CP1748) was selected, having high water use efficiency ($\Delta^{13}C$), high transpiration rate and better water mining capacity ($\Delta^{18}O$) using isotope ratio mass spectrophotometer (IRMS) at UAS Bangalore. Male (♂) parent (LT-1) potato accession is known worldwide for heat tolerance.. These parents were selected to combine these characteristics to impart water and high temperature stress tolerance in the offspring. These parents were used in hybridization at Kufri (32°N, 77°E, 2501 AMSL) in Shimla hills in 2007. Seedlings were raised at the ICAR-Central Potato Research Institute, Regional Station, Modipuram (29°N, 76°E, 222AMSL). The initial selection of genotypes was based on tuber characteristics *viz*., shape, eye depth, skin colour etc. In subsequent generations, selections were made based on tuber yield under water deficit conditions attained through delayed irrigations. Several promising clones were identified and finally, advanced clone WS/07-113 was evaluated under normal and reduced water regime at Modipuram during 2015-18. The clone was introduced in 2018 in the All-India Co-ordinated Research Project on Potato (AICRP-Potato) for systematic multi-location evaluation in different potato growing agro-climatic regions of the country. After these three-year multilocation trials during 2019-22, this advanced clone was recommended for release as a new variety in 40th AICRP (Potato) Group Meeting during 07-09 October 2022 at SKUAST Srinagar. It was recommended as medium maturing (90 days), water & heat stress tolerant, high-yielding clone (32 t/ha) having substantial yield advantage over the check varieties and moderately resistant to late blight. The advanced clone WS/07-113 was recommended for the central and eastern plains of India. Subsequently, advanced clone WS/07-113, christened as 'Kufri Daksh' was released by the "Central Sub-committee on Crop Standards, Notification and Release of Varieties for Horticultural Crops", Ministry of Agriculture and Co-operation, Government of India, New Delhi in June 2023. The variety Kufri Daksh is recommended as a water use efficient variety suitable for planting in central plains (Gujrat, Madhya Pradesh and Chhattisgarh) and eastern plains (Orissa and Uttar Pradesh).

Varietal Description

Plant**:** Medium, plant canopy semi-compact, stem medium hollow, predominantly green, wings highly developed and wavy.

Foliage**:** Green, leaves open, leaflet width medium, leaflets ovate, leaflet waviness of margins medium, rachis green, midrib colouration absent (**Fig.1**).

Flower**:** Flowering medium, inflorescence medium, floral stalk green, floral stalk-pedicle articulation clearly visible and located above the middle, calyx green, corolla white, corolla medium in size, anther yellow, anther cone normally developed, stylar length longer than stamen column and stigma bilobed (**Fig.1**).

Tubers**:** Whitish cream (light yellow), ovoid tubers with shallow to medium eyes and cream flesh (**Fig.1**).

Sprout**:** Sprout red purple, shape cylindrical, pubescence at sprout base is strong (**Fig.1**).

Evaluation in Station Trials at Modipuram (at 90 days)

In field trials at Modipuram, WS/07-113 consistently out yielded the control (K Bahar), both in well-watered control and water deficit stress at 90 days in three successive replicated yield trials during 2015-16 to 2017-18 except 2016-17 (well-watered control) (**Table 1**). Under mild stress conditions, clone WS/07-113 (32.4 t/ha) recorded distinctly higher (>14.5%) mean tuber yield over K Bahar (28.3 t/ha). Similarly, clone WS/07-113 (36.7 t/ha) under well-watered conditions had a higher mean tuber yield than Kufri Bahar (35.2 t/ha).

Water use efficiency (WUE) in clone WS/07-113 at Modipuram

Adaptation to water deficit stress may involve several morphological and physiological characteristics of the plant like WUE, leaf water loss, chlorophyll fluorescence and proline accumulation in the leaves of potatoes. WUE is a crucial trait for developing varieties with resilience to drought. In agronomic trials, WUE was calculated with the following formula-

WUE = Tuber yield (q ha^{-1})/ water applied through irrigation (mm)

Mean water use efficiency (WUE) was highest in WS/07-113 (1.501 q/ha-mm) and far superior to Kufri Bahar (1.432 q/ha-mm) during 2016-17 ~~of~~ evaluation under semi-dry moisture (0.60-0.65 bars) regime (**Table 2**).

Drought tolerance in clone WS/07-113 at Modipuram

To assess the resilience to water stress conditions, the drought susceptibility index (DSI) and drought tolerance index (DTI) were calculated as suggested by Hassanpanah (2010). Analysis revealed that clone WS/07-

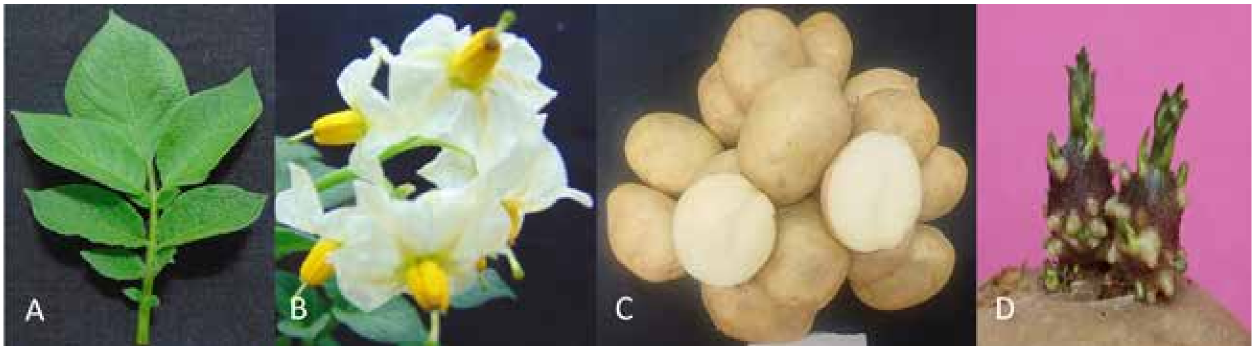


Fig. 1. WS/07-113 (K Daksh): (A) Leaflet (B) Inflorescence (C) Tubers and (D) Sprout

Table 1. Mean performance of clone WS/07-113 during 2015-18 under well-watered (control) and reduced moisture level at Modipuram.

Genotype	2015-16		2016-17		2017-18		Mean	
	Control	Stress	Control	Stress	Control	Stress	Control	Stress
				Total tuber yield (t/ha)				
WS/07-113	29.5	24.0	42.3	38.8	38.2	34.3	36.7	32.4
Kufri Bahar	27.6	22.8	42.8	30.2	35.2	31.9	35.2	28.3
CD (0.05)	1.26		2.29		3.54			
				Marketable tuber yield (t/ha)				
WS/07-113	26.9	22.0	38.1	34.8	32.4	29.8	32.5	28.8
Kufri Bahar	26.2	21.4	39.9	26.0	30.0	27.4	32.0	25.0
CD (0.05)	1.11		2.56		3.67			
*No. of Rep	3		3		3			
*No. of Geno	6		7		4			

*Indicate composition of evaluation trial in the respective year

Table 2. Mean performance of advanced drought tolerant clone WS/07-113 during 2016-17 under different irrigation levels at Modipuram.

Genotype (G)	TY (t/ha) and Irrigation* (I)			Mean	WUE (q/ha-mm)			Mean
	Wet	Moist	Semi-dry		Wet	Moist	Semi-dry	
WS/07-113	37.2	31.7	29.5	32.8	1.255	1.284	1.501	1.35
Kufri Bahar	33.1	30.2	28.2	30.5	1.115	1.224	1.432	1.26
LSD (0.05)	I: 2.4	G: 3.9	I x G: NS		I: 0.101	G: 0.164	I x G: NS	
	Marketable tuber yield (t/ha)				Total tuber number ('000'/ha)			
WS/07-113	35.0	29.5	27.9	30.8	671	557	505	578
Kufri Bahar	31.2	28.4	26.4	28.7	537	425	544	502
LSD (0.05)	I: 2.5	G: 3.1	I x G: NS		I: NS	G: NS	I x G: NS	

*Wet (0.20-0.25 bars), Moist (0.40-0.45 bars) and Semi-dry (0.60-0.65 bars)
Total water (including rains) appl. was 297, 247 & 197 mm in wet, moist & semi-dry regime, resp.

113 had the lowest DSI (1.11) and lowest yield reduction under stress, compared to K Bahar, having comparatively higher DSI (1.15) and yield reduction. Besides, clone WS/07-113 recorded the highest DTI (1.05) as compared to K Bahar (0.89) under water stress (**Fig.2**). All these parameters resulted in an improved trade-off for carbon assimilation and yield formation in the clone WS/07-113. Evaluation of drought associated traits showed a higher Pn rate (25.6 µ mol CO_2 $m^{-2}s^{-1}$) as compared to K Bahar (12.5 µ mol CO_2 $m^{-2}s^{-1}$), resulting into higher WUE (5.83 Pn/ mol H_2O) against K Bahar (5.11 Pn/ mol H_2O) (**Table 3**).

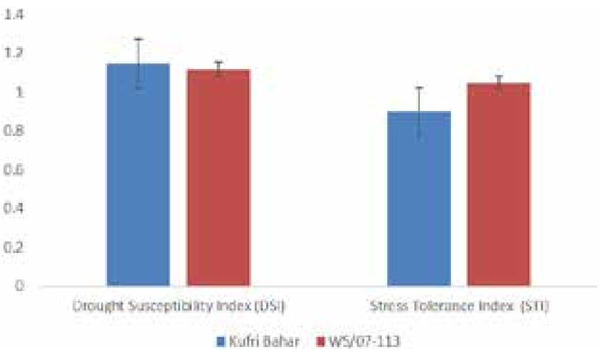


Fig.2. Drought Susceptibility Index (DSI) and Stress Tolerance Index (STI) in WS/07-113.

[DSI= (1-Yst/Ypt) /DI and DI=1-Ys/Yp, STI= k{(Ypt*Yst)/(Yp)2}, where: $k=(Yst)^2/(Ys)^2$,Y_{st} -yield stress, Y_{pt} -yield cont, Y_s -mean yield of all cvs in stress and Y_p- mean yield of all cvs in cont.]

Table 3. Physiological traits associated with drought stress in clone *WS/07-113*

Genotype	Pn rate (µmol $CO_2m^{-2}s^{-1}$)		Stomatal conductance (mmol CO_2 $m^{-2}s^{-1}$)		Transpiration (mmol $H_2Om^{-2}s^{-1}$)		WUE (Pn/mol H_2O)	
	Control	Stress	Control	Stress	Control	Stress	Control	Stress
WS/07-113	26.7	25.6	0.588	0.446	4.14	4.39	6.47	5.83
K Bahar	23.2	12.5	0.444	0.118	4.40	2.45	5.28	5.11
	CD (0.05)				CD (0.05)			
T	1.45		0.043		0.339		-	
G	2.29		0.068		0.537		-	
V × T	3.23		0.097		0.759		-	

Fertilizer requirement trials

Advanced potato clone WS/07-113 responded to optimum doses of 180 kg/ha N and 80 kg/ha P_2O_5 and 100 kg/ha K_2O to attain optimum marketable (23.3 t/ha) and total tuber yield (24.5 t/ha) under water deficit stress, i.e., 33% less irrigation water (**Table 4**).

Evaluation under AICRP-Potato Trials

Replicated yield trials with local controls (**Table 5a**) were conducted during 2019-20 to 2021-22 at 5 locations (Bhubaneswar, Faizabad, Deesa, Gwalior and Hisar) in the first year, and at 6 locations (Bhubaneswar, Faizabad, Deesa, Gwalior, Raipur and Hisar) in subsequent two years under AICRP (Potato). Since advanced clone was evaluated for specific traits i.e. less water regime. Therefore, watering/irrigations were executed either following IW: CPE or mm CPE values uniformly at all locations (**Table 5b**). In all the locations, uniformly two irrigations were saved compared to six irrigations in well-watered control.

Performance in Eastern plains

***Middle Gangetic plains (Faizabad)*: ** Under targeted environment having water deficit stress treatment (I_2) at 90 days, WS/07-113 (30.6 t/ha) recorded 4.8% and 29.7% higher total tuber yield than K Thar-2 (29.2 t/ha) and K Sindhuri (23.6 t/ha), respectively (**Table 6**).

***East coast plains and hills (Bhubaneswar)*:** Under the targeted environment having water deficit stress treatment (I_2) at 90 days, WS/07-113 (19.6 t/ha) yielded 8.9% and 21.7% higher total tuber yield than K Thar-1 (18.0 t/ha) and K Jyoti (16.1 t/ha), respectively (**Table 6**).

Performance in Central Plains

***Deesa*:** Clone WS/07-113 (34.5 t/ha) yielded 19.8% and 3.6% higher total tuber yield than

Table 4. Influence of N-P-K nutrition on marketable and total tuber yield in *clone* WS/07-113 (Pooled mean of 2015-16 and 2016-17).

Nutrition* (kg/ha)	Marketable tuber yield (t/ha)				Total tuber yield (t/ha)			
	WS/07-113		Kufri Bahar		WS/07-113		Kufri Bahar	
	Normal	Stress	Normal	Stress	Normal	Stress	Normal	Stress
75%N-P-K	25.4	22.0	20.6	16.0	26.6	23.7	22.7	17.7
100%N-P-K	24.8	23.3	21.9	16.8	25.9	24.5	23.8	18.9
125%N-P-K	25.1	24.6	23.5	17.7	27.8	26.3	25.8	19.1
CD 0.05	Nutrition: NS				Nutrition: NS			

*Recommended dose: 180-80-100 N-P-K kg/ha

Table 5a. Details of control used at AICRP locations during 2019-20, 2020-21 and 2021-22.

Variety	BHN	DES	FZB	GWL	HIS	RPR*	KOTA	MDP
V_1	WS/07-113	WS/07-113	WS/07-113	WS/07-113	WS/07-113	WS/07-113	WS/07-113	WS/07-113
V_2	K Thar-1	K Thar-2	K Thar-2	K Thar-1	K Thar-3	K Thar-2	K Thar-2	K Thar-3
V_3	K Jyoti	K Pukhraj	K Sindhuri	K Jyoti	K Bahar	K Sindhuri	K Sindhuri	K Pukhraj

*Raipur included in 2020-21

Table 5b. Details of irrigation/watering treatments executed in multi-location trials during 2019-20, 2020-21 and 2021-22 under AICRP.

Treatment	Gwalior, Hisar, Modipuram, Kota		Bhuvneshwar, Deesa, Faizabad, Raipur	
	IW: CPE	Irrigations	CPE (mm)	Irrigations
I_1	2.5	6	20	6
I_2	1.5	4	30	4

Table 6. Performance of clone WS/07-113 under AICRP in Eastern plains at 90 days.

Location	Irrigation	WS/07-113	Kufri Thar-2	Kufri Sindhuri
Faizabad	I_1	32.9	31.4	27.4
Bhubaneswar*	I_1	21.2	19.2	16.9
Overall mean		27.1	25.3	22.1
% Yield increase ±		-	7.1	22.6
Faizabad	I_2	30.6	29.2	23.6
Bhubaneswar*	I_2	19.6	18.0	16.1
Overall mean		25.1	23.6	19.8
% Yield increase ±		-	6.4	26.8

*Bhubaneswar: K Thar-1 and K Jyoti

Table 7. Performance of clone WS/07-113 under AICRP in Central Plains at 90 days.

Location	Irrigation	WS/07-113	Kufri Thar-2	Kufri Pukhraj
Deesa	I_1	45.7	42.6	44.8
Gwalior*	I_1	31.8	31.7	29.2
Raipur**	I_1	18.5	20.4	20.4
Overall mean		32.0	31.6	31.5
% Yield increase ±		-	1.3	1.6
Deesa	I_2	34.5	28.8	33.3
Gwalior*	I_2	28.9	29.6	25.0
Raipur**	I_2	16.7	13.5	16.8
Overall mean		26.7	24.0	25.0
% Yield increase ±		-	11.2	6.8

*Gwalior: K Thar-1, and K Jyoti; **Raipur: K Thar-2, K Sindhuri

K Thar-2 (28.8 t/ha) and K Pukhraj (33.3 t/ha), respectively at 90 days (**Table 7**).

Gwalior: Clone WS/07-113 (28.9 t/ha) yielded 15.6% higher total tuber yield than Kufri Jyoti (25.0 t/ha) and at par with Kufri Thar-1 (29.6 t/ha) at 90 days (**Table 7**).

Raipur: WS/07-113 (16.7 t/ha) yielded 23.7% higher total tuber yield than Kufri Thar-2/ Kufri Pukhraj (13.5 t/ha) and at par with Kufri Sindhuri (16.8 t/ha) at 90 days (**Table 7**).

Performance in north Indian plains in replicated yield trials (2019-20 to 2021-22)

Hisar: At 90 days, clone WS/07-113 yielded (30.6 t/ha) at par with K Bahar (29.8 t/ha) (**Table 8**).

Yield performance of clone WS/07-113 over all locations in AICRP trials

The results on a pooled mean basis reflected that clone WS/07-113 with a total tuber yield

Table 8. Performance of clone WS/07-113 under AICRP at Hisar (Northern Plains) at 90 days.

Year	Irrigation	WS/07-113	Kufri Thar-3	Kufri Bahar	CD (0.05)
2019-20	I_1	26.3	29.3	30.0	5.39
2020-21	I_1	39.8	40.8	35.0	3.88
2021-22	I_1	32.1	35.3	40.1	0.97
Overall mean		32.7	35.1	35.0	-
% Yield increase ±		-	-6.8	-6.6	-
2019-20	I_2	29.9	31.9	21.4	5.39
2020-21	I_2	37.3	39.5	32.0	3.88
2021-22	I_2	24.5	31.7	36.1	0.97
Overall mean		30.6	34.4	29.8	-
% Yield increase ±		-	-11.0	2.7	-

of 27.6 t/ha showed a yield increase by 7% and 15% over K Thar-1, 2 or 3 and local checks, respectively, at 90 days (**Table 9**).

***Tuber dry matter content* (%):** Clone WS/07-113 (18.8%) possessed at par tuber dry matter content with K Thar 1/2/3 and local check (18.3) at 90 days crop duration under AICRP evaluation (**Table 10**).

Disease resistance

Advanced clone WS/07-113 possessed field resistance to late blight (**Table 11**), and therefore, it is likely to replace the late blight susceptible varieties like K Bahar. It showed a lesion area of 5.23 cm^2 as compared to K Bahar, which exhibited 8.34 cm^2. For AUDPC also proposed that it showed less AUDPC in comparison to the variety K Bahar.

Table 9. Total tuber yield (t/ha) of clone WS/07-113 under AICRP at 90 days.

Year	Irrigation	WS/07-113	Kufri Thar-1/2/3	Local check	Mean
2019-20	I_1	26.7	28.2	26.3	27.1
2020-21	I_1	31.0	30.2	28.5	29.9
2021-22	I_1	35.7	32.8	30.2	32.9
	Mean	31.1	30.4	28.3	29.9
% Yield increase ±		-	2.3	9.9	-
2019-20	I_2	23.2	22.9	21.8	22.6
2020-21	I_2	28.4	25.9	22.5	25.6
2021-22	I_2	31.1	29.0	27.4	29.2
	Mean	27.6	25.9	23.9	25.8
% Yield increase ±		-	6.6	15.5	-

2019-20: Bhubneshwar, Faizabad, Deesa, Gwalior and Hisar
2020-21: Bhubneshwar, Faizabad, Deesa, Gwalior, Raipur and Hisar
2021-22: Bhubneshwar, Faizabad, Deesa, Gwalior, Raipur and Hisar

Table 10. Tuber dry matter content in WS/07-113 at 90 days.

Year	Irrigation	WS/07-113	K Thar-1/2/3	Local check	Mean
2019-20	I_1	18.9	19.3	18.0	18.7
2020-21	I_1	19.0	19.9	18.5	19.2
2021-22	I_1	18.7	20.1	16.5	18.4
	Mean	18.9	19.8	**17.7**	**18.8**
2019-20	I_2	19.0	18.4	18.4	18.5
2020-21	I_2	19.2	19.6	18.5	19.1
2021-22	I_2	18.3	19.9	18.1	18.8
	Mean	18.8	19.3	18.3	18.8

Keeping Quality

Advanced clone WS/07-113 possessed medium (6-8 weeks) dormancy. Physiological weight loss, rottage, total weight loss and firm tuber appearance were comparable to K Bahar after 90 days of storage at room temperature. After 90 days, sprouting was 46%, rottage was 0%, sprout weight was 4.9 g/5kg fresh weight, and weight loss was 12.8% in clone WS/07-113, whereas, K Bahar recorded higher sprouting (74%), and comparable rottage (0.7%), sprout weight (4.2 g/5kg fresh weight) and weight loss 12.9% (**Table12**).

Evaluation of clone WS/07-113 for heat tolerance

This advanced clone was also evaluated for heat tolerance at Modipuram (75 days)

Table 11. Reaction to late blight in foliage and tuber at Modipuram.

Hybrid/ variety	Lesion area (cm^2)	Remarks/ result
	Tuber slice test	
WS/07-113	5.23	Moderately resistant
Kufri Bahar	8.34	Susceptible

Hybrid/variety	AUDPC	rAUDPC	Remarks/ result
	Field Evaluation		
WS/07-113	728.8	0.347	Moderately resistant
Kufri Bahar	1350.7	0.643	Susceptible

Table 12. Keeping quality traits after 90 days of storage at room temperature.

Variety	Sprouting (%)	Rottage (%)	Sprout weight (g/5kg Fr. Wt.)	Weight loss (%)
WS/07-113	46	0.0	4.9	12.8
K Bahar	74	0.7	4.2	12.9
K Pukhraj	100	1.3	16.6	16.3
Mean	80	0.6	8.3	13.6

and Raipur (90 days). At Modipuram, clone WS/07-113 performed well and yielded (24.8 t/ha) more over K Surya (23.0 t/ha) and was comparable to K Kiran (24.7 t/ha). At Raipur, advanced clone WS/07-113 (42.56 t/ha) yielded more over K Kiran (39.31 t/ha) and K Surya (37.54 t/ha), as depicted in **Tables 13 &14**.

Package of practices for cultivation of potato variety Kufri Daksh (WS/07-113)

***Selection of field and land preparation*:** Sandy loam soil with 6.5-7.5 pH is most suitable for potato cultivation. Summer cultivation of the field is necessary to control diseases and pests. Green manuring is recommended to improve soil organic carbon and control of soil and tuber-borne diseases. Field should be levelled and well drained. The field is prepared by 1-2 ploughing with mould board plough or disc harrow followed by 2 cross harrowing and 2-3 tilling with tiller. Afterwards, cross planking is done for better soil moisture conservation.

Table 13. Evaluation under high-temperature stress at Modipuram (75 days).

Hybrid/ variety	Emergence (%)	Marketable tuber yield (t/ha)	Total tuber yield (t/ha)	TDMC (%)	Foliage senescence (%)
WS/07-113	83.3	22.6	24.8	18.9	50
K Bahar	90.0	16.0	16.8	17.9	75
K Kiran	72.2	22.9	24.7	17.2	50
K Surya	80.0	22.4	23.0	18.7	50
CD (0.05)	7.70	3.23	3.25	-	-
CV (%)	21.3	8.96	8.53	-	-

Table 14. Evaluation for heat tolerance at Raipur (90 days).

Hybrid/ variety	Emergence (%)	Foliage senescence (%)	Tuber yield (t/ha)		TDMC (%)
			Total	Marketable	
WS/07-113	98.6	35.0	42.6	40.5	18.54
K Kiran	97.2	22.3	39.3	37.3	19.28
K Surya	98.6	21.7	37.5	36.4	19.09
S.Ed	1.61	3.29	1.75	1.91	0.24
CD (0.05)	NS	7.04	3.75	4.09	0.52
CV (%)	2.04	17.18	5.18	6.02	1.57

***Seed treatment*:** After harvesting, wash the seed tubers in clean water and treat them (dip or spray) with 3% boric acid for 15-20 minutes. Dry tubers in shaded places and keep them in cold storage. The boric acid solution, once prepared, can be used 20 times in dipping. This is effective in management of black scurf and common scab.

***Sowing/planting time*:** In *Rabi* season, the optimum planting time is are Last week of October to the first fortnight of November (for Gujrat and Orissa) and the last week of October to the first week of November (for Madhya Pradesh, Chhattisgarh and Uttar Pradesh).

***Seed and planting*:** Take out seed tubers from cold store at least 10 days before planting. Do not bring out seed bags in direct sunlight, as tubers may rot due to sudden exposure to high temperatures. Spread the tubers in thin layer under shade, preferably in diffused light for sprouting and allow sprouts to become 0.5-1.0 cm long, thick and green. Carry sprouted tubers to the fields in seed trays or baskets for planting to avoid sprout damage. Remove white, pale, thin sprouted, diseased and rotten tubers. Seed size tubers should have a diameter of 30 to 55 mm (40-60 g), and seed rate may vary from 35-40 q/ha. Whole tuber is recommended for disease free quality seed production. For optimum plant population, crop geometry of 60 cm as inter-row and 20 cm intra-row spacing is desirable. Planting depth of 10-12 cm is better for achieving uniform emergence.

***Nutrient management*:** Apply 10-15 t/ha well rotten FYM before planting. This, along with green manuring, reduces half the dose of phosphorus and potassium. For seed crop, generally 90 kg nitrogen, 80 kg phosphorous and 100 kg potash per hectare at the time of planting and 90 kg nitrogen per hectare at the time of earthing-up is recommended. For ware crops, at Modipuram, optimum nitrogen, phosphorous and potassium levels are 180, 80 and 100 kg/ha, under mild water stress conditions (33% less irrigation water). Nutrient management in other agro-ecologies may differ and regional recommendations may be adopted to obtain optimum productivity for variety.

Weed control measures: Herbicides can be used to control weeds if their intensity is high. Pre-plant incorporation of fluchloralin (0.70-1.0 kg/ha) or pre-emergence application of metribuzin (0.50-0.75 kg/ha) or post-emergence application of paraquat (0.40- 0.50 kg/ha) at about 5% emergence of potato crop controls annual grasses and broad leaf weeds effectively. Inter-culture and earthing operations are recommended to provide aeration in root zone, improving nitrogen use and controlling second flush of weeds. This is done after 22-25 days of planting when the crop is 8-12 cm tall. The remaining nitrogen dose is also applied at this stage.

Irrigation: If sufficient soil moisture is unavailable, then pre-planting irrigation is done to ensure uniform emergence. First irrigation should be applied 12-14 day after planting. Second irrigation is applied after earthing at 25-27 days. Subsequently, 1-3 irrigations at 12-15 days interval are sufficient as the variety has tolerance for water deficit stress. However, it also yields very well under normal irrigation. Light irrigation should be applied, and the ridges should not submerge under water in any case.

Disease and Pest Management

Late Blight: Prophylactic spray (just at the time of canopy closure) with mancozeb or propineb or chlorothalonil @ 0.2% (2 g/l of water) followed by need based application of cymoxanil + mancozeb or dimethomorph + mancozeb or fenamidone + mancozeb @ 0.3% (3 g/l of water) for effective management of late blight.

White flies and aphid: For seed crops, Seed treatment with imidacloprid (200 SL) @ 0.04% (4 ml/10 l) for 10 minutes before planting. Place yellow sticky traps (size 15 × 30 cm^2) just above the canopy height @60 traps per hectare at equidistance from each other for mass trapping of white flies/aphids. First spray with imidacloprid (200 SL) @ 0.03% (3 ml/10 l of water) at 85% crop emergence. Second spray with thiamethoxam (25 WG) @ 0.05% (5 gm/10 l of water) after 10-15 days of first spray.

Other Insect and Pests:

In early planted crop, against leaf hoppers and mites, foliar spray of imidacloprid (200 SL) @ 0.03% (3 ml/10 l of water) or dicofol 18.5 EC @ 2 l/ha at 30-35 days after planting should be given. In main crop, for the management of cutworms, white grubs, beetles and leaf eating caterpillars spray chlorpyriphos 20EC @ 2.5 l/ha.

Harvesting: Stop irrigation 10-15 days before haulm cutting. Harvest crop after 15-20 days of haulm cutting and at proper soil moisture. After harvest, dry the produce in shade and keep tubers in heaps for 10-15 days for skin curing. Remove all damaged and rotten tubers. To get good returns, grade the produce, pack in gunny bags and label them. Store them immediately in cold storage, if meant for selling later in the season.

Expected yield of variety: Expected yield of the variety under deficit water (20% less) conditions is around 28 t/ha and under normal irrigation conditions is around 31 t/ha.

CONCLUSIONS

Advanced potato clone WS/07-113 released as variety Kufri Daksh for central and eastern plains of India is a main season, medium maturing, high yielding, water-use-efficient table potato variety that can be grown in regions with limited water availability and high-temperature stress. Its plants are tall and vigorous, with field resistance to late blight. Its tubers are white-cream (light yellow), ovoid with shallow to medium eyes and cream flesh with good keeping quality. It is fertilizer responsive and capable of yielding 30-35 t/ha under low water (≤ 20%) availability in middle Gangetic plains. Kufri Daksh could be an excellent choice to tolerate high temperature and water stress regimes in changing climatic scenarios.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

ETHICAL STATEMENT

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

LITERATURE CITED

Handayani T, Gilani SA and Watanabe KN (2019) Climatic changes and potatoes: How can we cope with the abiotic stresses? *Breeding Science* **69**(4): 545-63

Hassanpanah D (2010) Evaluation of advanced potato cultivars against water deficit stress under in vitro and in vivo conditions. *Biotechnology* **9**: 164–169

Kumar D, Minhas JS, Gupta VK, Rawal S, Singh B, Malik K and Singh BP (2021) Kufri Thar-1: A new water-use efficient potato variety for low water availability areas in middle Gangetic plains, east coast plains and hills region in India. *Potato Journal* **47**(2):116-125

Kumar R, Kang GS, Singh N and Kumar M (2020) Kufri Thar-3: A water use efficient medium maturing potato variety for north Indian plains. *Potato Journal* **47**(1):30-40

Luthra SK, Rawal S, Gupta VK, Bandana, Kumar V, Bhardwaj V, Singh BP, Sharma N, Kadian MS, Arya S and Bonierbale M (2020) Kufri Thar-2: A new drought tolerant table potato variety. *Potato Journal* **47**(1):22-29

Luthra SK, Malik K, Gupta VK and Singh BP (2013) Evaluation of potato genotypes under high-temperature stress conditions. *Crop Improv* **40**(1): 74-80

Luthra SK, Rawal S, Gupta VK and Malik K (2018) Performance of potato (*Solanum tuberosum*) advanced hybrid MS/6-1947 under high-temperature stress and water deficit conditions. *Indian Journal of Agricultural Sciences* **88**(7): 1070-76

Minhas JS, Khurana SP, Sheshshayee MS and Kumar MU (2003) Potato varieties show genetic variability in water use efficiency based on carbon isotope discrimination. *Journal of the Indian potato association* **30**(1-2): 193-94

Mthembu SG, Magwaza LS, Mashilo J, Mditshwa A and Odindo A (2022) Drought tolerance assessment of potato (*Solanum tuberosum* L.) genotypes at different growth stages, based on morphological and physiological traits. *Agricultural Water Management* **261**: 107361. https://doi.org/10.1016/j.agwat.2021.107361

Muthoni J and Kabira JN (2016) Potato production under drought conditions: Identification of adaptive traits. *International Journal of Horticulture*, 6 (12): 1-10.

Obidiegwu JE, Bryan GJ, Jones HG and Prashar A (2015) Coping with drought: stress and adaptive responses in potato and perspectives for improvement. *Frontiers in plant science* **6**: 151023. https://doi.org/10.3389/fpls.2015.00542

Qin J, Bian C, Liu J, Zhang J and Jin L (2019) An efficient greenhouse method to screen potato genotypes for drought tolerance. *Scientia horticulturae* **253**: 61-69

Sprenger H, Rudack K, Schudoma C, Neumann A, Seddig S, Peters R, Zuther E, Kopka J, Hincha DK, Walther D and Köhl K (2015) Assessment of drought tolerance and its potential yield penalty in potato. *Functional Plant Biology* **42**(7): 655-667

Wang ZJ, Liu H, Zeng FK, Yang YC, Xu D, Zhao YC, Liu XF, Kaur L, Liu G and Singh J (2023) Potato processing industry in China: Current scenario, future trends and global impact. *Potato research* **66**(2): 543-62

MS Received : May 05, 2024; Accepted : July 18, 2024

Potato J (2024) 51 (1): 19-27

SCREENING OF POTENTIAL INDIAN POTATO VARIETIES FOR EXPORT PROMOTION FROM WESTERN UTTAR PRADESH AND GUJARAT

Pooja Mankar[1*], Sanjay Rawal[1], Satish Kumar Luthra[1], Vijay Kumar Gupta[1], Sanjeev Sharma[2], Mehi Lal[1], Subhash S[1], Devendra Kumar[1] and Manoj Kumar[1]

ABSTRACT: Indian potato production potential (54 million tonnes) strengthens the cause of export of this crop from the country. Government of India has identified districts of Agra and Farrukhabad in Uttar Pradesh, and Sabarkantha and Banaskantha in Gujarat for potato export promotion in the Agri- export policy-2018. However, issues like suitable varieties, sustainable production and protection technologies, and efficient marketing channel are challenges for acceleration of potato export in a significant way. One of the critical gaps, suitable export potential varieties was taken up in current study. Eight potato varieties were evaluated in replicated field trials at farmer's fields in district Agra and Gandhinagar. Based upon yield performance and feedback from exporters, potato varieties Kufri (K) Frysona (35.3), K Ganga (31.8), K Chipsona-3 (28.2), K Sangam (28.0) and K Bahar (24.0) have better export-grade (>55mm) tuber production potential (tha^{-1}) in western Uttar Pradesh. Variety K Chipsona-3 (30.7), K Sangam (29.6), K Ganga (27.2) and K Frysona (24.9) are exhibiting prospects of export from Gujarat. Newly released specialty potato cv. K Neelkanth has also attracted the attention of exporters. Suitable potato varieties acceptable for importing destinations and Good Agricultural Practices (GAP) developed by ICAR- CPRI holds a better future for Indian potato export.

KEYWORDS: Potato, export, main season, variety, GAP

INTRODUCTION

India is the second largest potato-producer contributing around 14.3% in global production. Despite the remarkable annual potato production of 54.2 million tonnes (MT), the quantum of export was only 0.41 MT, valued at around US$ 82.53 m in 2021-22, which was less than 1% of total production (APEDA, 2022). Indian potato export is dynamic and influenced by domestic production, market price, situation of glut *etc*. (Khurana, 2013; Chakrabarti *et al*., 2019). Major export destinations during 2021-22 were Nepal (47.5%), Indonesia (10.3%), Oman (9.4%), Malaysia (6.1%), Mauritius (5.2%), Sri Lanka (4.2%), Saudi Arab (3.1%), Kuwait (2.8%) and Maldives (2.3%).

Among Indian states, Uttar Pradesh produces approximately 30% of the country's total potato production (16. 2 MT) roughly from acreage of 0.62 m ha. Agra, Kannuj, Firozabad, Hathras, Farrukhabad, Aligarh and Kanpur are the main potato-producing districts. Well-established cold storage facilities and good infrastructure make western Uttar Pradesh a suitable destination for potato export promotion. On the other hand, Gujarat is one of the promising states producing about 3.7 MT of potatoes from an area of 0.13 m ha with higher productivity level of 29 tonnes per ha and is going on fast track in potato export despite short crop growing window (Anonymous, 2022). It is happening due to the adoption of advanced agro-technologies, viz., drip irrigation, raised bed cultivation, use of suitable varieties; adequate cold storage facilities, proximity to ports, and favourable business environment. Hence, in the Agri-

---

[1]ICAR-Central Potato Research Institute, Regional Station, Modipuram, Meerut - 250110, Uttar Pradesh, India
[2]ICAR-Central Potato Research Institute, Shimla - 171 001, Himachal Pradesh, India
*Corresponding author; email: mail: Pooja.Mankar@icar.gov.in

export policy-2018 of Government of India, the clusters of Agra and Farrukhabad from Uttar Pradesh, and Sabarkantha, Banaskantha from Gujarat have been selected for potato export promotion.

Key constraints of potato export from the country are lack of knowledge of suitable varieties, optimum use of agrochemicals, pesticide residues, and post-harvest handling standards preferred by the importers, sometimes resulting in rejection of consignments (Pandey *et al*., 2000; CPRI, 2019). Hence, field trials were conducted at farmers' fields at village Banguri, Agra (Uttar Pradesh) and Dehgram, Gandhinagar (Gujarat) near the Sabarkantha district to screen suitable potato varieties for export from both the states.

MATERIAL AND METHODS

Experimental site**:** Field trials were conducted consecutively for two years during 2020-22 at farmer's fields in the main season during October-March at village Banguri, Agra district (29^{o} 05'19" N, 77^{o} 41' 50" E, 237 m asl) and at Dehgram, Gandhinagar, Gujarat (23^{o} 12′ 94″ N, 72^{o} 78′ 88″ E, none m asl). The soil of experimental sites at both locations was sandy loam soil in nature with low organic carbon level (<0.5%) and neutral in pH (7.6-7.9). The climate of district Agra (UP) is semi- arid tropics with average annual rainfall of 750 mm, majority of which is received during July- September and potato growing winter season is generally dry receiving low precipitation occasionally. Atmospheric temperature varies from minimum of 4^{0}C during December-January to 48^{0}C in May-June, respectively. Climate of district Gandhinagar is also semi- arid tropics and receives rainfall through the southwest monsoon, which normally starts from the middle of June till August. Average rainfall is 665mm, wherein winters are generally dry; however, scanty and uneven rainfall patterns are common now. Atmospheric temperature varies from minimum of 7°C during December- January to 45°C in the month of April- May.

Experimental details**:** Field evaluation of eight potato varieties *viz*., Kufri (K) Bahar, K Chipsona-3, K Chipsona-4, K Frysona, K Ganga, K Mohan, K Neelkanth and K Sangam was carried out in a randomized block design consisting three replications (Mankar *et al*., 2023). These were selected due to their tuber quality, storage behavior and specialty attributes **(Table 1)**. In Agra, well-sprouted 40-45 mm size whole seed tubers were planted during the second fortnight of October following crop geometry of 66 cm 20 cm in conventional ridge- furrow system. Recommended fertilizer dose of 180 N-80 P_2O_5 -100 K_2O kg ha $^{-1}$ for table purpose and 270 N-80 P_2O_5 -150 K_2O kg ha $^{-1}$ for processing purpose varieties was applied during whole crop growth period. Flood irrigation method was followed and first water application was done at 10-12 days after planting (DAP) and continued at the same interval up to 10 days before haulm cutting. The recommended herbicide, fungicide and insecticide application schedule was followed to maintain proper and uniform crop growth. The crop was dehaulmed as per varietal maturity ranging from 90 to 120 days, and harvested 15 days after haulm cutting for having tuber skin maturity. While in Gandhinagar, cut pieces of seed tubers consisting at least two eyes and treated with 0.25% mancozeb were planted in two row raised beds of 132 cm width, and method of drip irrigation was followed. Regional recommendation of fertilizer level of 220 N-110 P_2O_5 -220 K_2O kg ha $^{-1}$ and package of practices adopted to raise the successful crop. Alike Agra, the crop was dehaulmed as per varietal maturity ranging from 90 to 120 days, and harvested one week after haulm cutting.

Table 1. Important features of potato varieties evaluated for export purpose.

Variety	Duration	Tuber characters	Storability	Special features
K Bahar	90-100	White-cream skin, ovoid tubers, medium deep eyes, white flesh	Very good	Suitable for long-distance transportation
K Chipsona-3	100-120	White-cream skin, ovoid tubers, shallow eyes, white flesh	Good	Suitable for making chips and French fries
K Chipsona-4	100-110	White-cream skin, round-ovoid tubers, shallow eyes, white flesh	Very good	Suitable for making chips, field resistance for late blight
K Frysona	110-120	White-cream skin, long-oblong tubers, shallow eyes, white flesh	Good	Suitable for making French Fries
K Ganga	90-100	White-cream skin, ovoid tubers, shallow eyes cream flesh	Good	Tolerant to moderate water stress conditions
K Mohan	90-100	White-cream skin, ovoid tubers, shallow eyes, white flesh	Good	Early bulker
K Neelkanth	90-100	Purple skin, ovoid tubers, shallow eyes, yellow flesh	Very good	Antioxidant-rich potato variety, field resistance for late blight
K Sangam	100-110	White-cream skin, ovoid tubers, shallow eyes, cream flesh	Very good	Dual purpose (table and processing), field resistance for late blight

(Catalogue of Indian Potato Varieties for Export, ICAR-CPRI, Shimla, Mankar *et al.*, 2023)

***Observations and analysis*:** Crop emergence was recorded at 30 DAP, while growth parameters *viz.*, plant height, number of stem and compound leaves per plant were recorded at prime growth stage of 55-60 DAP. At harvest, tubers were graded in compliance with desired export requirements of size, shape and tuber quality. Tubers were graded for export grade (>55mm) and non-export grade but suitable for the domestic market (35-55 mm) for recording the tuber number and yield. Tuber dry matter content (TDMC) was estimated by drying a representative sample (50 g) 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 measured by the method described by Kumar *et al*. (2005). Data from two years of field trials were pooled, and statistical analysis was done using the statistical software IRRISTAT (IRRI, 1999).

RESULTS AND DISCUSSION

Growth parameters

***Agra*:** Under field evaluation, plant emergence was normal and uniform (>96%) for all eight varieties at Agra (Location-1) and the parameter did not vary statistically (**Table 2**). Highest plant emergence was recorded in K Ganga (98.8) followed by cv. K Chipsona-3 (98.6), K Chipsona-4 (98.5), K Sangam (98.4), K Mohan (98.2), K Neelkanth (97.5) and K Bahar (97.4). French fry variety K Frysona (96.9%) attained the lowest plant emergence. Growth parameters *viz.*, plant height (cm) and compound leaves per plant exhibited significantly marked differences among the varieties, while number of shoots per plant remained statistically at par. Maximum plant height (70.8 cm) was observed in cv. K Frysona, while lowest was in K Bahar (53.4). Cultivars K Ganga (69.3), K Sangam (65.8), K Neelkanth (62.6) and K Chispsona-3 (62.3) had comparable plant height to K Frysona. Shoot number per plant were highest in cv. K Neelkanth (4.00), while the lowest shoot number were observed in cv. K Mohan (3.08). Variety K Chipsona- 3 (54.4) attained the highest compound leaf number per plant, which was statistically at par with K Ganga (47.1) and K Frysona (46.8), while the lowest of it was found in cv. K Neelkanth (42.1).

Table 2. Plant emergence and growth parameters of potato varieties.

Variety	Location-1 (Agra)				Location-2 (Gandhinagar)			
	Emergence (%)	Plant height (cm)	Shoot no./ plant	Leaf no./ plant	Emergence (%)	Plant height (cm)	Shoot no./ plant	Leaf no./ plant
K Bahar	97.4	53.4	3.33	44.4	98.7	68.2	4.26	47.7
K Chipsona-3	98.6	62.3	3.41	54.4	97.3	78.8	5.08	49.3
K Chipsona-4	98.5	58.5	3.41	45.7	98.0	64.5	3.71	51.7
K Frysona	96.9	70.8	3.16	46.8	98.2	75.8	3.83	51.3
K Ganga	98.8	69.3	3.40	47.1	97.0	71.3	4.23	52.8
K Mohan	98.2	60.1	3.08	44.0	97.2	69.5	4.04	53.3
K Neelkanth	97.5	62.6	4.00	42.1	98.2	70.0	4.33	44.7
K Sangam	98.4	65.8	3.66	42.3	97.6	70.8	3.50	47.2
$CD_{0.05}$	NS	9.26	NS	7.68	NS	4.49	NS	NS
SEM±	0.53	3.24	0.97	2.53	0.74	1.48	1.60	3.77

Gandhinagar: Similar to Location-1, plant emergence was normal and uniform (>97%) for all eight varieties without exhibiting any significant variations (**Table 2**) and growth traits like number of shoots and compound leaves per plant also followed similar trend. Whereas, plant height (cm) varied markedly and it ranged between 64.5 cm (K Chispsona-4) to 78.8 cm (K Chipsona-3). Maximum shoot number per plant were recorded in cv. K Chipsoan- 3 (5.08), while the lowest were in cv. K Sangam (3.50). Although, compound leaf number per plant did not differ significantly, but variety K Mohan (53.3) attained the highest leaf number, while the minimum of this parameter was found in cv. K Neelkanth (44.7). Overall, eight evaluated cultivars recorded better plant growth which depends upon the genetic response of a genotype to the provided environmental conditions (Kumar and Minhas, 2013).

Yield performance

Agra: Exportable, marketable and total tuber numbers (000 ha^{-1}) varied significantly among all the potential genotypes during field evaluation at Location-1(**Table 3**). Variety K Frysona and K Neelkanth (194) recorded

Table 3. Tuber number and yield of potato varieties at location-1 (District Agra).

Variety	Graded tuber number (000 ha^{-1})			Graded tuber yield (t ha^{-1})		
	Exportable	Marketable	Total	Exportable	Marketable	Total
K Bahar	84	567	651	24.0	19.2	43.2
K Chipsona-3	83	491	574	28.2	27.9	56.1
K Chipsona-4	150	533	683	28.4	19.6	48.0
K Frysona	194	449	644	35.3	28.0	63.4
K Ganga	167	548	715	31.8	25.0	56.7
K Mohan	133	485	618	24.8	19.2	44.0
K Neelkanth	194	522	717	32.0	33.6	65.6
K Sangam	97	489	585	28.0	17.4	45.5
$CD_{0.05}$	35.9	47.6	70.4	2.69	2.11	3.77
SEM±	11.85	15.69	23.21	0.89	0.69	1.24

maximum export-grade tuber number remaining at par with K Ganga (167), while the lowest found in K Chipsona-3 (83). Variety K Frysona, K Neelkanth, K Ganga, K Chipsona-4 and K Mohan attained 30, 27, 23, 22 and 22% of this grade out of total tuber number in the respective varieties (**Fig. 1**). Highest marketable size tuber number were observed in cv. K Bahar (567) which were comparable to K Ganga (548), K Chipsona-4 (533) and K Neelkanth (522) and K Frysona (449) attained the lowest marketable tuber number. Cultivar K Bahar, K Chipsona-3 and K Sangam had 87, 86 and 84% marketable tuber numbers out of their total tuber numbers, wheras lowest were in K Frysona (70). Total tuber number were highest in cv. K Neelkanth (717) remaining at par with K Ganga (715), K Chipsona-4 (684) and K Bahar (651), while the lowest were seen in cv. K Chipsona-3 (574). Variation in graded and total tuber number is a genetic trait of different genotypes of potato crop and has also been reported by Philipp *et al*. (2019) under *in vitro* and *in vivo* crop growth environments. However, agronomic interventions may help in increasing the proportion of export and marketable grade tuber number to improve their percentage to a significant level (Mankar *et al*., 2022).

Similar to tuber number, all eight varieties showed marked variation in graded tuber yield during field evaluation (**Table 3 & Fig. 2**). French fry variety K Frysona recorded highest and significantly superior export-grade tuber yield (35.3 t ha^{-1}), 56% of its total tuber yield. Cv. K Neelkanth and K Ganga recorded 32.0 and 31.8 t ha^{-1}, respectively export-grade yield, which was 49 and 56% of their total tuber yield. Lowest export-grade tuber yield (24.0 t ha^{-1}), 56% of its total tuber yield was observed in K Bahar. Processing variety K Chipsona-4 produced (28.4 t ha^{-1}) the highest proportion of export-grade (59%) of its total tuber yield (48.0). While considering export, the domestic market demand is equally important; hence, marketable tuber yields were also recorded for all the varieties and cv. K Neelkanth attained the significantly highest marketable tuber yield (33.6) among all the varieties with a proportion of 51% to its total tuber yield (65.6). Cv. K Frysona (28.0) and K Chipsona-3 (27.9) also performed fairly well, although marketable yields were markedly lower in comparison to K Neelkanth. Lowest marketable tuber yield (17.4) was observed in cv. K Sangam with a proportion of 38% to its total tuber yield (45.5). Total tuber yield was maximum in cv. K Neelkanth (65.6) and it remained statistically comparable to K Frysona (63.4). On the other hand, K Bahar attained the lowest total tuber yield (43.2). Genotypic potential and performance of a variety under a set of environmental conditions govern overall growth, translocation of photosynthates from source to sink, yield attributes and ultimately, the yield (Schafleitner *et al*., 2007).

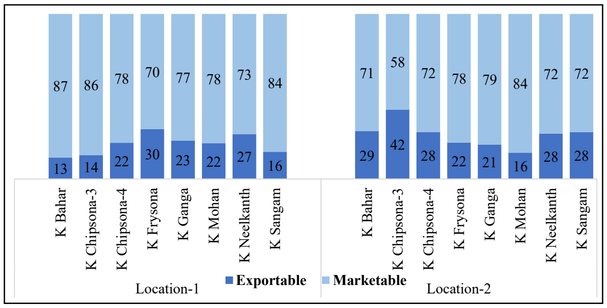


Fig.1. Percent distribution of exportable and marketable tuber number in total tuber number

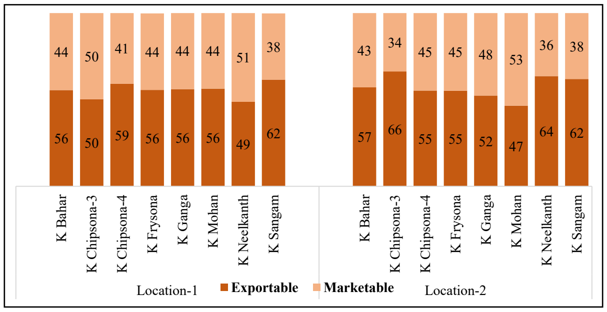


Fig.2. Percent distribution of exportable and marketable tuber yield in total tuber yield

Gandhinagar: Significant variations were found in exportable, marketable and total tuber number (000 ha^{-1}) and yield (t ha^{-1}) among all the field-evaluated export potential Indian potato varieties at this location, too (**Table 5**). Variety K Chipsona-3 (237) recorded significantly highest export grade tuber number, which was comparable to K Bahar (207), K Neelkanth (193) and K Sangam (187), while the lowest of this trait was observed in K Mohan (111). The percentage of export-grade tuber number in K Chipsona-3, K Bahar, K Neelkanth and K Sangam were 42, 29, 28 and 28%, respectively (**Fig. 1**). Lowest proportion was found in K Mohan (16%). Cv. K Ganga (615) attained maximum marketable tuber number remaining statistically similar to K Frysona (589) and K Mohan (587), whereas, K Chipsona-3 (329) recorded the lowest one. All seven varieties produced marketable size tubers above 70% of the total number except for cv. K Chipsona-3 (58%). This indicates the scope for agronomic interventions in these varieties for improvement in export-grade size. It is established that managing macro-nutrients in potatoes affects their tuber size (Amarananjundeswara *et al.*, 2020). Total tuber numbers were significantly highest in K Ganga (775) remaining comparable to K Frysona (756), K Bahar (715), K Neelkanth (701) and K Mohan (698). The lowest total tubers were exhibited in K Chipsona-4 (537).

During field assessment in Gujarat, K Chipsona-3 (30.7 t ha^{-1}) recorded the maximum exportable tuber yield and it was statistically at par with K Sangam (29.6 t ha^{-1}) and K Neelkanth (28.9 t ha^{-1}), while cv. K Mohan (21.5 t ha^{-1}) had the lowest export grade yield (**Table 5**). Variety K Chipsona-3 also attained the highest per cent of exportable tuber yield (66%) followed by K Neelkanth (64) and K Sangam (62) and cv. K Mohan (47) had the lowest proportion in total tuber productivity (**Fig. 2**). In case of marketable tuber yield, cv. K Mohan (24.7 t ha^{-1}) and K Ganga (24.7 t ha^{-1}) recorded significantly highest marketable yield as compared to other cultivars, whereas, K Chipsona-3 had lowest yield (15.6 t ha^{-1}). Similar trend was observed in proportion of marketable productivity to total tuber yield as cv. K Mohan (53) attained maximum of this trait followed by K Ganga (48) and lowest in K Chipsona-3 (34). In terms of total tuber yield, K Ganga (51.9 t ha^{-1}) recorded a significant and maximum yield followed by K Sangam (47.8 t ha^{-1}), K Bahar (46.9 t ha^{-1}) and K Chipsona-3 (46.3 t ha^{-1}). Variety K Neelkanth attained 45.4 t ha^{-1} of total tuber yield, while K Chipsona-4 (44.7 t ha^{-1}) had the lowest productivity. Similar productivity trends were also reported by Mankar *et al.* (2022) in their evaluation of potential varieties for export in the early season. Islam *et al.* (2022) conducted a similar field study in Bangladesh and screened sixty two potato varieties for selecting suitable one having export potential. They concluded that a genotype with higher productivity & percentage of export-grade tubers having uniform size and high tuber dry matter content could be selected for export from the country.

Quality attributes

Agra: Tuber dry matter content (%), specific gravity, mean tuber weight (g) and tuber dry matter yield (t ha^{-1}) showed significant differences for the varieties evaluated in this field study **(Table 4)**. Tuber dry matter content ranged between 17.4% in cv. K Mohan to 21.6% in K Frysona. All the varieties except K Mohan attained tuber dry matter content above 18%. The specific gravity ranged between 1.050 in cv. K Mohan to 1.081 in K Sangam & K Chipsona-4. Indian potato exporters during harvest of the trials demanded a genotype having good storability and lower damages during transport to sustain the supply chain and thus a variety with 6-9 months of storability in cold storage is considered suitable. Gupta and Luthra (2020) reported a

Table 4. Tuber dry matter content (TDMC), specific gravity, mean tuber weight and tuber dry matter yield at location-1 (District Agra).

Variety	TDMC (%)	Specific gravity	Mean tuber weight (g)			Tuber dry matter yield (t ha^{-1})		
			Export grade	Market grade	Total	Export grade	Market grade	Total
K Bahar	21.2	1.064	284.0	33.9	66.3	5.10	4.10	9.2
K Chipsona-3	18.8	1.068	341.0	56.8	97.8	5.30	5.24	10.5
K Chipsona-4	20.8	1.081	189.3	36.7	70.2	5.90	4.10	10.0
K Frysona	21.6	1.079	181.5	62.4	98.5	7.62	6.04	13.7
K Ganga	19.9	1.067	190.8	45.6	79.3	6.33	5.00	11.3
K Mohan	17.4	1.050	185.9	39.6	71.2	4.32	3.34	7.7
K Neelkanth	19.7	1.065	164.5	64.3	91.5	6.30	6.62	12.9
K Sangam	19.0	1.081	290.2	35.6	77.7	5.32	3.31	8.6
CD $_{0.05}$	0.78	0.004	9.71	4.23	18.5	0.61	0.57	1.43
SEM±	0.26	0.001	3.54	2.17	5.88	0.19	0.36	0.98

Table 5. Tuber number and yield of potato varieties at location-2 (District Gandhinagar).

Variety	Graded tuber number (000 ha^{-1})			Graded tuber yield (t ha^{-1})		
	Exportable	Marketable	Total	Exportable	Marketable	Total
K Bahar	207	508	715	26.8	20.1	46.9
K Chipsona-3	237	329	567	30.7	15.6	46.3
K Chipsona-4	153	384	537	24.7	20.0	44.7
K Frysona	167	589	756	24.9	20.2	45.1
K Ganga	160	615	775	27.2	24.7	51.9
K Mohan	111	587	698	21.5	24.7	46.2
K Neelkanth	193	508	701	28.9	16.5	45.4
K Sangam	187	471	657	29.6	18.2	47.8
CD$_{0.05}$	64.9	82.5	113.0	2.75	2.18	3.50
SEM±	21.4	27.2	42.9	0.91	0.72	1.16

significant and negative correlation between the percent tuber rottage and tuber dry matter content while studying the storability of Indian and exotic potato collections. Highest mean exportable (341.0g), marketable (64.3) and total tuber weight (98.5) was observed in cvs. K Chipsona-3, K Neelkanth and K Frysona, respectively. Variety K Neelkanth (164.5g), K Bahar (33.9) and K Bahar (66.3) attained the lowest mean exportable, marketable and total tuber weight. Tuber dry matter yield varied markedly among evaluated varieties and highest of this parameter was observed in K Frysona (7.62 t ha^{-1}), K Neelkanth (6.62) and K Frysona (13.7) for exportable, marketable and total tuber dry matter yield. Whereas, lowest exportable (4.32) and total (7.70), and marketable tuber dry matter yield (3.31) was recorded by cvs. K Mohan, and K Sangam, respectively.

Gandhinagar: Similar to Location-1, tuber dry matter content (%), specific gravity, mean tuber weight (g) and tuber dry matter yield (t ha^{-1}) varied markedly among the varieties evaluated in the trial (**Table 6**). Tuber dry matter content ranged between 18.9% in cv. K Mohan to 22.8% in K Bahar. Moreover, all

Table 6. Tuber dry matter content (TDMC), specific gravity, mean tuber weight and tuber dry matter yield at location-2 (District Gandhinagar).

Variety	TDMC (%)	Specific gravity	Mean tuber weight (g)			Tuber dry matter yield (t ha^{-1})		
			Export grade	Market grade	Total	Export grade	Market grade	Total
K Bahar	22.8	1.051	129.7	39.6	65.6	6.11	4.58	10.7
K Chipsona-3	19.5	1.044	129.3	47.4	81.7	6.91	3.51	10.4
K Chipsona-4	21.5	1.076	161.8	52.0	83.2	5.31	4.29	9.6
K Frysona	21.3	1.056	149.5	34.3	59.7	5.30	4.30	9.6
K Ganga	22.5	1.073	169.6	40.2	67.0	5.14	4.70	9.8
K Mohan	18.9	1.032	193.7	42.1	66.2	3.83	4.39	8.2
K Neelkanth	21.5	1.065	149.9	32.5	64.8	6.21	3.55	9.8
K Sangam	22.6	1.052	158.6	38.7	72.7	6.69	3.99	10.6
$CD_{0.05}$	0.49	0.006	1.53	3.46	5.87	0.74	0.49	0.75
SEM±	0.18	0.003	0.70	1.59	1.76	0.24	0.18	0.52

eight varieties had above 18% tuber dry matter content, which may contribute to long-term storage and transportation. The specific gravity ranged between 1.032 in cv. K Mohan to 1.076 in K Chipsona-4. Gupta *et al*. (2015) reported a negative correlation between weight loss due to rottage and tuber dry matter content in Indian potato varieties. Highest mean exportable (193.7g), marketable (52.0) and total tuber weight (83.2) was found in cvs. K Mohan, and K Chipsona-4, respectively. Variety K Chipsona-3 (129.3g), K Neelkanth (32.5) and K Frysona (59.7) recorded the lowest mean exportable, marketable and total tuber weight. Significant differences were also observed in case of tuber dry matter yield for evaluated cultivars and maximum of this trait was attained by K Chipsona-3 (6.91 t ha^{-1}), K Ganga (4.70) and K Sangam (10.8) for exportable, marketable and total tuber dry matter yield. Whereas, lowest exportable (3.83) and total (8.20), and marketable (3.51) tuber dry matter yield was observed in cvs. K Mohan, and K Chipsona-4, respectively.

Indian potato exporter's feedback

The field study carried out at both the locations had active participation for evaluating the suitable exportable variety from the state of Uttar Pradesh and Gujarat. From Uttar Pradesh, varieties K Frysona, K Sangam, K Chispona-3, K Ganga and K Bahar were found suitable for export, while under the specialty potato segment, K Neelkanth was preferred by the exporters. Cultivars K Sangam, K Chipsona-3, K Frysona, K Ganga and K Neelaknth were found suitable for export from the state of Gujarat. Indian potato exporters faced the challenge of maintaining the supply chain in hot summer season, so, capability of a genotype to sustain in storage is an important criterion to maintain the supply chain and thus a variety with 6-9 months of storability in cold storage is considered suitable.

CONCLUSIONS

Agri-export policy-2018 has identified potato as potential commodity for export from different states of the country, particularly Uttar Pradesh and Gujarat. Apart from several other factors, a suitable genotype shall always remain on top of the priority list. Conclusion of this study says that variety K Sangam, K Ganga, K Frysona, K Bahar, K Chipsona-3 have better export potential in Uttar Pradesh. And cultivar K Sangam, K Frysona, K Ganga, K Neelaknth and K Chipsona-3 are the potential varieties for export from the state of Gujarat. In addition, the advantage of anthocyanin richness and taste makes K Neelkanth a potential variety in the specialty segment. Compilation of country-specific requirements, identifying suitable varieties, targeting the lean period of potato availability in different countries, fine-tuning & validating potato cultivation technologies, and integrating these different components into a supply chain shall provide momentum to potato export from the country.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

ETHICAL STATEMENT

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

LITERATURE CITED

Amarananjundeswara H, Vishnuvardhan PS, Anilkumar S, Sandhy GC and Shetty S (2020) Foliar application of micronutrient formulation on growth, yield and cost economics in potato. *International Journal of Current Microbiology and Applied Sciences* **9**(12): 3151-60

Anonymous (2022) Ministry of Agriculture and Farmers Welfare, GOI

APEDA (2022) Agriexchange. http://agriexchange.apeda.gov.in

Chakrabarti SK, Singh B and Shrama S (2019) Export opportunities of Indian potatoes. *Indian Horticulture* **64**(6): 67-70

CPRI (2019) Export opportunity for Indian potatoes. ICAR-Central Potato Research Institute, Shimla, HP: 8p

Gupta VK and Luthra SK (2020) Storability and organoleptic performance of indigenous and exotic potato collections. *Potato Journal* **47**(1): 80-91

Gupta VK, Luthra SK and Singh BP (2015) Storage behaviour and cooking quality of Indian potato varieties. *Journal of food Science and Technology* **52**(8): 4863-4873

IRRI (1999) IRRISTAT for Windows version 4.0. Biometrics Unit, IRRI, Los Banos, Philippines

Islam MM, Uddin MN, Naznin S, Amin M, Mondol M, Hassan R, Naznin A and Ferdous MZ and Salim M and Karim MR and Kundu BC (2022) Screening for export potential potato varieties in Bangladesh. *International Journal of Plant & Soil Science* 34(20): 623-634

Khurana SMP (2013) Indian potato exports: an overview. *Potato Journal* 33(1-2): 1-14

Kumar D and Minhas JS (2013) Evaluation of indigenous potato varieties, advanced clones and exotic genotypes against water deficit stress under sub-tropical environment. *Indian J Plant Physiol*. 18(3): 240-249

Kumar D, Ezekiel R, Singh B and Ahmed I (2005) Conversion table for specific gravity, dry matter and starch content from under water weight of potatoes grown in North-Indian plains. *Potato Journal* 32: 79–84

Mankar P, Rawal S, Kumar D, Luthra SK, Gupta VK, Sharma S, Lal M, Subhash S and Kumar M (2022) Evaluation of potential varieties for export potential in early season. *Potato Journal* 49(2):131-140

Mankar P, Luthra SK, Gupta VK, Kumar D, Rawal S, Lal M, Subhash S, Kumar M and Sharma S (2023) Catalogue of Indian Potato Varieties for Export. ICAR-CPRI, Shimla (https://cpri.icar.gov.in//WriteReadData/LINKS/Catalogue_Indian%20Potato%20varieties_Export_Final0ae8830e-118a-4190-878b-bac854a6dc31.pdf)

Pandey SK, Shekhawat GS and Sarkar D (2000) Quality attributes of Indian potatoes for export: priorities and possibilities. *Potato Journal* (*Formerly J Indian Potato Assoc.*) 27:103-11

Philipp M, Sylvia S, Ralf U, Frank O and Annegret S (2019) Assessment of yield and yield components of starch potato cultivars (*Solanum tuberosum* L.) under nitrogen deficiency and drought stress conditions. *Potato Research* 62: 193-220

Schafleitner R, Gutierrez R, Espino R, Gaudin A, Perez J, Martinez M, Dominguez A, Tincopa L, Alvarado C, Numberto G and Bonierbale M (2007) Field screening for variation of drought tolerance in *Solanum tuberosum* L. by agronomical, physiological and genetic analysis. *Potato Research* 50:71-85

MS Received : January 06, 2024; Accepted : May 31, 2024

Potato J (2024) 51 (1): 28-40

A COMPREHENSIVE STUDY ON SOCIO-ECONOMIC ANALYSIS OF POTATO GROWERS IN KANGRA DISTRICT OF HIMACHAL PRADESH

Aditi Raina[1], Pushpak Sharma[1*], Garima Gupta[2] and Arundhati Balouria[2]

ABSTRACT: This study investigated the socio-economic status of potato farmers in the Kangra district of Himachal Pradesh. This district was chosen specifically because it has a substantial area under potato cultivation. The required information was gathered from two potato-growing blocks in the district. The study revealed that the majority of household heads (57%) were in the age group of 16 and 40 years, with an average family size of five to seven members. Agriculture and livestock rearing emerged as the primary sources of income for most farms, with an average farm size of 1.76 ha, 74% of which are irrigated. During the *Kharif* season, vegetable crops were dominant, while potatoes were important during the *Rabi* season, with an average of 21.23 ha per farm. Potato productivity varied, with large farms producing 253.75 q/ha versus 246.43 q/ha on small farms. Agriculture-related earnings, or farm earnings, accounted 45.2% of total farm income, with potatoes accounting for 8%, while non-farm income accounted 26.5%. Future research topics include investigating the impact of climate change on potato farming and evaluating the effectiveness of agricultural policies in terms of income and productivity. Further research could look into the effects of modern farming techniques on sustainability and profitability, potentially providing insights into improving agricultural practices in the region.

KEYWORDS: Crop production, cropping pattern, landholdings, potato growers, socio-economic status

INTRODUCTION

The socio-economic dynamics of agricultural communities' influence farm organization, crop production, and rural livelihoods. Understanding these dynamics is critical for sustainable development in India, where agriculture continues to be the primary source of employment for a large portion of the population (Chand *et al.*, 2017). This study focuses on potato (*Solanum tuberosum* L.) growers in Himachal Pradesh's Kangra district, where potatoes are more than just a crop; it plays an important role in the agricultural economy. Potato is the world's third largest food crop in terms of consumption, after rice and wheat, with a total production of 376 million tonnes from an area of approximately 19 million ha (FAOSTAT, 2023). China leads the world in potato production with approx. 94 million tonnes, followed by India, Russia, Ukraine, and the United States (FAOSTAT, 2023). Potatoes are grown on approximately 2.16 million ha in India, with a total production of around 54 million tonnes, making it the world's second-largest producer after China (FAOSTAT, 2023). Himachal Pradesh, a hill state in northern India, is a major producer of potatoes, with 15,100 ha under cultivation and a total production of 1,95,000 tonnes. In the Kangra district alone, over 1,250 ha, or 16,030 tones, of high-quality potatoes are produced across 15 development blocks (Statistical Yearbook of Himachal Pradesh, 2022-23).

Farmers' socioeconomic profile includes a number of dimensions that all have an impact on their agricultural practices and overall wellbeing. Family structure and size, for example, can influence labor availability, decision-making processes, and the adoption

---

[1]University of Business School, Chandigarh University, Gharuan (Mohali), Punjab- 140413, India
[2]University Institute of Agricultural Sciences, Chandigarh University, Gharuan (Mohali), Punjab- 140413, India
*Corresponding author; email: pushpak.e13272@cumail.in

of new technologies (Kumari *et al.,* 2023; Sharma *et al.,* 2019). Farmers' receptivity to agricultural innovations, risk-taking behavior, and farm management strategies is influenced by their age and educational attainment (Rana *et al.,* 2016; Peer *et al.,* 2013), particularly among household heads. Land holdings, in terms of size and quality, are the foundation of agricultural operations. The size of landholdings is frequently associated with resource availability, mechanization levels, and the ability to invest in modern farming techniques. In areas like Kangra, where topography limits land availability, efficient land use is critical (Sharma *et al.,* 2017). Cropping patterns and crop productivity shed light on the economic significance of various crops, including potatoes, as well as how factors such as farm size may affect yields (Sharma *et al.,* 2019). Livestock rearing, which is inextricably linked to crop cultivation in Indian agriculture, provides a supplementary income source while also supporting crop production via manure and draft power (Sharma *et al.,* 2019). However, the introduction of mechanization has altered this traditional synergy, with implications for farm economics and sustainability (Kumar *et al.,* 2020). A comprehensive socioeconomic analysis looks beyond the farm gate. Off-farm and non-farm income sources, such as agricultural labor, services, and small businesses, frequently play an important role in smoothing income fluctuations and increasing household resilience (Pandit *et al.,* 2010; Sharma *et al.,* 2019). This diversification of income sources is especially important in areas prone to climatic uncertainties or market fluctuations.

Understanding the various aspects of potato growers' lives is more than just an academic exercise. It provides the foundation for evidence-based policymaking and targeted interventions. Policies based on such analyses can address specific challenges faced by different types of farmers, promote equitable growth, and encourage sustainable agricultural practices (Chand *et al.,* 2017; Rana *et al.,* 2016). The purpose of this study is to conduct a comprehensive socioeconomic analysis of potato growers in Himachal Pradesh's Kangra district. We hope to provide a comprehensive picture of these farmers' lives and livelihoods by investigating factors such as family demographics, educational status, land utilization, cropping patterns, livestock integration, and income diversification. The findings will contribute to a larger discussion about agricultural sustainability, rural development, and the well-being of farming communities in India.

MATERIALS AND METHODS

The study was conducted in Himachal Pradesh's Kangra district. Potatoes are an important cash crop for the district's farmers due to their high growth potential. A list of potato growing blocks was compiled and arranged in descending order based on the cultivation area. The first two potato growing blocks were purposively chosen. Following block selection, a two-stage stratified random sampling technique was used to select farmers (stage II) and potato-producing villages (stage I). During the initial sample phase, representatives from the revenue and agriculture departments worked together to compile a comprehensive list of all the villages in each chosen block that cultivate potatoes. The study used a sample of ten villages, five from each block. As a result, a manageable sample of 200 farmers was chosen from the selected villages, taking into account time and resource constraints. The sample farmers were arranged in ascending order according to the total area of their operational holdings. Using the square root cumulative frequency approach (Sharma *et* *al.,* 2017; Kumari *et al.,* 2020), farmers were divided into two groups: small farmers (up to two hectares) and large farmers (more than two hectares). To achieve the current study's objectives, data was collected from potato growers via in-person interviews after the schedule was prepared. Data on the socioeconomic characteristics of potato growers were also collected.

RESULTS AND DISCUSSION

Area and production

Table 1 shows a detailed comparison of potato and vegetable production in Himachal Pradesh and Kangra district. Potatoes are grown on 15,100 ha in Himachal Pradesh, yielding 1,94,500 metric tonnes, accounting for 17.3% of the state's vegetable cultivation area and 10.4% of its vegetable production. Other vegetables, on the other hand, cover 87,485 hectares and produce 1,867,413 metric tonnes, accounting for all remaining vegetable cultivation and production. In the Kangra district, potatoes are grown on 1,250 ha, yielding 16,030 metric tonnes. This accounts for 14.5% of the district's vegetable cultivation area and 10.4% of total vegetable production. Other vegetables in Kangra cover 8,612 ha and produce 1,54,834 metric tonnes, accounting for all remaining vegetable cultivation and production in the district. This comparison shows that, while potatoes are a significant crop in both Himachal Pradesh and the Kangra district, other vegetables have a larger area and production. The proportion of area and production dedicated to potatoes is slightly higher in Himachal Pradesh than in Kangra, indicating a state-level emphasis on potato cultivation. These findings are consistent with the findings of Dahal *et al.* (2023), who investigated the economic, production, and marketing aspects of potato farming in Nepal and discovered that it was a profitable endeavor for farmers. Kumari *et al.* (2023) also examined the socioeconomic characteristics of potato farmers, as well as the trend and growth rate of potato area and production in Bihar's Nalanda district, and discovered a positive growth rate in potato production, emphasizing the importance of potato cultivation in the region.

Table 1. Area and production of vegetables in Kangra district and Himachal Pradesh.

S. No.	Potato		Other Vegetables	
	Area (ha)	Production (MT)	Area (ha)	Production (MT)
1	Himachal Pradesh			
Per cent (%)	15100	194500	87485	1867413
	17.26	10.42	100	100
2	Kangra			
Per cent (%)	1250	16030	8612	154834
	14.51	10.35	100	100

Source: Statistical Year book of Himachal Pradesh, 2022-23.

Family structure and size

A family's social and economic well-being is heavily influenced by its size, which also has a significant impact on agricultural business operations. Family size influences the adoption and choice of farm operations, particularly when hired labor is limited. Table 2 shows the population distribution on sample farms based on family size and structural characteristics. According to the data, up to 1-4 family members constituted

Table 2. Sample farms distribution according to the family size and structure (No).

S.No.	Family size	Small	Large	Overall
1	1-4 members	35(33.3)	29(30.5)	64(32.0)
2	5-7 members	47(44.8)	41(43.2)	88(44.0)
3	8 and above members	23(21.9)	25(26.3)	48(24.0)
4	Total sample farms	105(100.0)	95(100.0)	200(100.0)
5	Total family members	489	463	952
6	Average size of family	4.41	5.15	4.76

Note: Figures in parentheses indicate percentage to the total in each category.

approximately 32% of the surveyed farms, indicating a sizable proportion of smaller-sized households. However, a significant proportion of the farms, approximately 24%, had eight or more family members, indicating the presence of larger households. Surprisingly, the vast majority of farms (44%) had five or seven family members. This suggests that having a large family labor force is beneficial to a sizable proportion of the sample farms. Family sizes varied from 4.41 on small farms to 5.15 on large farms, with an average of 4.76. The findings on family structure and size emphasize the significance of family labor availability for agricultural operations, particularly in areas with limited access to hired labor. Similar findings were reported by Kashyap and Guleria (2015), who discovered that the majority of apple growers in Himachal Pradesh's Mandi district had 5-8 members in their families, indicating the region's prevalence of larger families. Their research also found that larger family sizes were linked to increased apple production, as more family members could contribute to labor-intensive farm operations. However, policymakers should take into account the different needs and challenges those households of different sizes face when designing interventions to promote sustainable and equitable agricultural development.

Gender-wise distribution

Farm families' well-being is determined by both the number of family members and the gender distribution, as farming is a labor-intensive occupation. Table 3 shows the distribution of family members by gender. The table shows that there were more men than women on both types of farms. The family consisted of one child and four adults. The data also show that male children made up a higher percentage (12.4%) of all farm groups than female children (6.95%). Kushwaha *et al.* (2019) and Sharma *et al.* (2019) found similar results, indicating that male children outnumbered female children in all farm categories. These findings highlight the need for policies and interventions to promote gender equality, empower women in agriculture, and address cultural biases that perpetuate gender disparities in farm families.

Table 3. Distribution of family and sex wise of population on sample farms (No/farm).

S.No.	Particular	Small	Large	Overall
1	Male	2.68(55.60)	2.84(54.51)	2.76(54.98)
	a) Adult	2.14(44.4)	2.15(41.27)	2.15(42.83)
	b) Children*	0.54(11.2)	0.69(13.24)	0.62(12.35)
2	Female	2.14(44.40)	2.37(45.49)	2.26(45.02)
	a) Adult	1.75(36.31)	2.06(39.54)	1.91(38.05)
	b) Children*	0.39(8.09)	0.31(5.95)	0.35(6.97)
3	Total	4.82(100.00)	5.21(100.00)	5.02(100.00)
	a) Adult	3.89(80.71)	4.21(80.81)	4.06(80.88)
	b) Children*	0.93(19.29)	1.00(19.19)	0.97(19.32)

Note: Figures in parentheses indicate percentages to the total in each category
*Childern upto 15 years of age

Age–wise distribution

The age of the family head is critical for adapting to new ideas and technological advancements. Table 4 depicts the age distribution of the sample farms' heads and respondents. The age distribution of family members, with those under 15 and over 60 classified as dependents, provides insight into

Table 4. Sample farms Distribution according to the age of respondents (No).

S.No.	Age groups (Years)	Small	Large	Overall
1	Up to 40	59(56.19)	55(57.89)	114(57.00)
2	>41 to 60	32(30.48)	30(31.58)	62(31.00)
3	Above 60	14(13.33)	10(10.53)	24(12.00)
	Total	105(100.00)	95(100.00)	200(100.00)

Note: Figures in parentheses indicate percentages to the total in each category.

the family's reliance ratio. A casual glance at the table reveals that the majority of family heads were between the ages of 20 and 40, followed by 41 and 60. In the 60+ age group, the percentage of heads was significantly lower (10%). When small and large sample farms are compared, it can be seen that large farms have a slightly higher percentage of heads between the ages of 41 and 60 and up to 40 years old. In contrast, a larger proportion of heads of families over 60 lived on small farms (13.33%) than on large farms (10.53%). Rana et al. (2016) discovered that the majority of potato growers in Andhra Pradesh were between the ages of 31 and 50, with a greater proportion of younger farmers working on larger farms. Similarly, Kumari *et al.* (2023) reported that the majority of potato farmers in Bihar's Nalanda district were between the ages of 30 and 50, with a higher proportion of older farmers on small farms.

These findings indicate that larger farms are more likely to be managed by younger and middle-aged farmers, who may be more open to implementing new technologies and innovative practices. Smaller farms, on the other hand, are more likely to have older farmers who are risk-averse and resistant to change. These age dynamics have implications for agricultural extension and technology transfer programs, which must be tailored to meet the unique needs and preferences of different age groups and farm sizes.

Educational status of family

When it comes to making sound decisions on the farm to implement new technologies and innovations for the efficient allocation of limited resources and maximizing returns per unit of input, the educational background of the family's leader and members is critical. In light of this, Table 5 shows the analysis and educational status of the family head.

Table 5. Education status of the head of the family on sample farms (No).

S.No.	Level of education	Small	Large	Overall
1	Illiterate	9(8.57)	5(5.26)	14(7.00)
2	Primary	14(13.33)	10(10.53)	24(12.00)
3	Middle	21(20.00)	19(20.00)	40(20.00)
4	Matric	34(32.38)	27(28.42)	61(30.50)
5	Senior secondary	16(15.24)	20(21.05)	36(18.00)
6	Graduate and above	11(10.48)	14(14.74)	25(12.50)
	Total	105(100.00)	95(100.00)	200(100.00)
	Literacy rate (%)	91.43	94.74	93.00

Note: Figures in parentheses indicate percentages to the total in each category.

The table shows that approximately 91.4%, 94.7%, and 93% of family heads were literate. The majority of the heads were found to have completed high school or matriculation. Approximately 12.5% of household heads held degrees equivalent to or higher than those of the average farmer. Large farms, however, had a higher share than small farms. Peer *et al.* (2013) and Dahal *et al.* (2023) found similar trends in their studies, with comparable levels of education among family heads across farm sizes. These findings emphasize the importance of promoting educational opportunities and vocational training programs for farming communities, particularly for family heads, because they can have far-reaching consequences for agricultural productivity, resource efficiency, and rural development.

Occupational pattern

The occupations of the family head and other family members have a direct impact on the family's income and financial stability. Table 6 shows the occupations of the heads of families on the sample farms. A large proportion of the family heads stated that agriculture, particularly animal husbandry, was their primary source of income. The average percentage of family heads who worked in agriculture was 46.5%,

Table 6. Occupational pattern of respondents on sample farms (No).

S. No.	Occupation	Small	Large	Overall
1	Agriculture including livestock	50(47.62)	43(45.26)	93(46.5)
2	Private service	10(9.52)	12(12.63)	22(11.00)
3	Government service	15(14.29)	16(16.84)	31(15.5)
4	Business	6(5.71)	5(5.26)	11(5.50)
5	Daily paid labourer	10(9.52)	9(9.47)	19(9.50)
6	Others (artisans, craftsman, etc.)	14(13.33)	10(10.53)	24(12.00)
	Total	105(100.00)	95(100.00)	200(100.00)

Note: Figures in parentheses indicate percentages to the total in each category

indicating a strong reliance on the industry. When small farms were compared to large farms, the former had a significantly higher percentage of household heads who worked in agriculture. The service industry employed 26.5% of all heads, making it the second largest source of employment. Only 9.5% of the heads of families worked as daily wage laborers in agriculture or other fields. This is a very small percentage. Small and large farms had similar percentages of heads working in the service sector. Pandit *et al.* (2010) and Dahal *et al.* (2023) found similar trends and reported comparable findings in their studies. The high proportion of household heads involved in agriculture, particularly animal husbandry, demonstrates the sector's importance as a primary source of income for rural communities. However, the diversification of occupations, with a significant number of heads employed in service sectors and other non-farm activities, emphasizes the importance of policies that promote sustainable agriculture while also providing alternative income opportunities. This diversification could be used as a risk management strategy as well as to supplement agricultural income, improving rural households' overall financial stability.

Land holding and utilization

Agriculture is a land-based activity, so land resources are critical to farming and the foundation of the farmer's economy. The size of a farm household's holding demonstrates the fundamental strength of the farming family, as does how well they use this natural resource. Table 7 displays the distribution of holdings across the various farm categories. According to the data, the average farm holding size was 0.82 hectares, with 66% irrigated. Leasing in and out was common on both small and large farms. Approximately 2% of the total land holding

Table 7. Land inventory and its utilization on sample farms (ha /farm).

Sr. No.	Particulars	Small			Large			Overall		
		UIR	IR	Total	UIR	IR	Total	UIR	IR	Total
1	Owned land	0.32 (96.97)	0.75 (89.29)	1.07 (91.45)	0.55 (94.83)	1.67 (95.98)	2.22 (95.69)	0.44 (95.65)	1.21 (93.08)	1.65 (93.75)
2	Leased in	0.01 (3.03)	0.08 (9.52)	0.09 (7.69)	0.03 (5.17)	0.03 (1.72)	0.06 (2.59)	0.02 (4.35)	0.06 (4.62)	0.08 (4.55)
3	Leased out	0 (0.00)	0.01 (1.19)	0.01 (0.85)	0 (0.00)	0.04 (2.30)	0.04 (1.72)	0 (0.00)	0.03 (2.31)	0.03 (1.70)
4	Total land holding	0.33 (100.00)	0.84 (100.00)	1.17 (100.00)	0.58 (100.00)	1.74 (100.00)	2.32 (100.00)	0.46 (100.00)	1.3 (100.00)	1.76 (100.00)
i	Operational holding	0.08 (24.24)	0.49 (58.33)	0.57 (48.72)	0.12 (20.69)	0.76 (43.68)	0.88 (37.93)	0.1 (21.74)	0.63 (48.46)	0.73 (41.48)
ii	Orchards	0.05 (15.15)	0.07 (8.33)	0.12 (10.26)	0.02 (3.45)	0.1 (5.75)	0.12 (5.17)	0.04 (8.70)	0.09 (6.92)	0.12 (6.82)
iii	Pastures/grasslands	0.09 (27.27)	0.1 (11.90)	0.19 (16.24)	0.18 (31.03)	0.38 (21.84)	0.56 (24.14)	0.14 (30.43)	0.24 (18.46)	0.38 (21.59)
iv	Fallow land	0.08 (24.24)	0.12 (14.29)	0.2 (17.09)	0.23 (39.66)	0.43 (24.71)	0.66 (28.45)	0.16 (34.78)	0.28 (21.54)	0.43 (24.43)
v	Others	0.03 (9.09)	0.06 (7.14)	0.09 (7.69)	0.03 (5.17)	0.07 (4.02)	0.1 (4.31)	0.03 (6.52)	0.07 (5.38)	0.1 (5.68)

Note: Figures in parentheses indicate percentages to the total in each category. UIR= Un-irrigated, IR= Irrigated.

was leased, whereas an average farm leases 10% of its area. It was discovered that the average operational holding size was 0.62 hectares, accounting for approximately 76% of total land holdings. The average operational holding size increased with holding size, according to a comparison of small and large farms. Pasture and meadow areas accounted for a sizable portion of total land holdings, ranging from 11% to 14% for small to large farms. The data also revealed that, on average, farms had irrigation covering more than 80% of their operating area. In the research area, kulhs were the primary irrigation source. The table also shows that as holding size increased, the proportion of fallow land to total holding decreased. On large farms, it ranged between 7.61 and 11.43% of the total holding on small farms. Dahal *et al.* (2023) found a similar pattern in their study of potato farming in Nepal, where the average landholding size was 0.48 hectares, 62% of the land was irrigated, and the practice of leasing in and leasing out land was common. The findings demonstrated the prevalence of smallholder agriculture and the importance of livestock rearing as a complement to crop cultivation. Furthermore, the practice of land leasing, as well as the availability of irrigation facilities via kulhs, were critical to the region's efficient use of land resources.

Livestock inventory and investment

Raising cattle and farming together maximizes income and benefits from their mutual association. Table 8 shows an

Table 8. Inventory of livestock on sample farms (per farm).

S. No.	Particulars	Small		Large		Overall	
		No.	Rs.	No.	Rs.	No.	Rs.
1	Local cow						
	In milk	0.65	9750 (17.32)	0.61	9150 (12.36)	0.63	9450 (14.51)
	Dry	0.07	560 (1.00)	0.1	800 (1.08)	0.09	680 (1.04)
	Total	0.72	10310 (18.32)	0.71	9950 (13.45)	0.72	10130 (15.55)
	Improved cow						
	In milk	1.25	28750 (51.08)	1.91	43930 (59.36)	1.58	36340 (55.79)
	Dry	0.13	1170 (2.08)	0.15	1350 (1.82)	0.14	1260 (1.93)
	Total	1.38	29920 (53.16)	2.06	45280 (61.19)	1.72	37600 (57.72)
2	Buffaloes						
	In milk	0.36	12240 (21.75)	0.44	14960 (20.22)	0.4	13600 (20.88)
	Dry	0.07	560 (1.00)	0.09	720 (0.97)	0.08	640 (0.98)
	Total	0.43	12800 (22.74)	0.53	15680 (21.19)	0.48	14240 (21.86)
3	Heifer						
	Cow (local)	0.11	550 (0.98)	0.16	800 (1.08)	0.14	675 (1.04)
	Cow (improved)	0.25	500 (0.89)	0.12	240 (0.32)	0.19	370 (0.57)
	Buffalo	0.18	1440 (2.56)	0.19	1520 (2.05)	0.19	1480 (2.27)
4	Calves	0.04	40 (0.07)	0.03	30 (0.04)	0.04	35 (0.05)
5	Bullocks	0.36	720 (1.28)	0.25	500 (0.68)	0.31	610 (0.94)
6	Others	1.15	3450 (6.13)	1.2	3600 (4.86)	1.18	3525 (5.41)
	Total livestock	4.62	56280 (100.00)	5.25	74000 (100.00)	4.97	65140 (100.00)

Note: Figures in the parentheses indicate percentages to the total in each category

examination of the sample farms' livestock inventories. According to the available data, the average farm in the study area kept 4.97 animals. Large farms kept slightly more animals than small farms (4.62), with 5.25. Typically, farmers kept one or no buffaloes and three cattle. Raising sheep, goats, and horses was uncommon in the study area, accounting for only 1.17 percent of average farms. Furthermore, the findings revealed that neither type of farm kept many local cows; rather, farmers kept better animals because they produced more milk. The percentage of farmers who kept bullocks for ploughing was discovered to be quite low, ranging from 0.25 bullocks on large farms to 0.36 bullocks on small farms. All farms spent a total of Rs. 65,140 on animals; large farms spent more than Rs. 74,000, compared to small farms (Rs. 56,280), as shown in Table 8. The data also revealed that, across all farms, cow investments accounted for approximately 57.72% of total farm animal investments. Nonetheless, it was found that large farms had a higher percentage (61%) than small farms (53%). The significance of the local cattle came in second. On an average farm, dairy animals received a higher combined value of all livestock investments (95.13%). The percentage differed between small farms (94.22%) and large farms (95.83%). It was discovered that the amount invested in bullocks was relatively small, between one and two percent of the total amount. This phenomenon can be explained by the widespread use of tractors and power tillers for ploughing and other field operations in the study area. This trend is consistent with findings from Sharma *et al.* (2019) and Kumari *et al.* (2023), indicating a broader regional shift toward modern agricultural practices. The data revealed that dairy animals, particularly cows, dominated the livestock inventory, indicating the importance of milk production as a major agricultural activity in the region. Furthermore, the low investment in bullocks and widespread use of mechanized equipment for field operations emphasized the region's transition to modern agricultural practices.

Cropping patterns

The cropping pattern sheds light on how operational holdings are distributed among various crops at a given time, revealing the relative importance of each crop in the cultivated region. Cropping patterns must be analyzed in order to understand the level of crop diversification in a given region. Table 9 details the cropping patterns of farms in the study area. Notably, during the *kharif* season, vegetable crops were the most important crop, accounting for 24% of total cropped area, followed by paddy (11.64%), fodder crops, and maize (7.53%). Radish, tomato, cucumber, and okra were among the most popular vegetables grown during the *kharif* season. In the *kharif* season, there was no discernible difference between small and large farms in terms of total cropped area allocation to different crops.

Potatoes emerged as the most important crop during the *rabi* season, covering approximately 21.23% of the total area planted on an average farm. Vegetable crops accounted for approximately 10% of the total planted area, with wheat emerging as the main crop. During the *rabi* season, there was a noticeable difference in how large and small farms divided their total cultivated area between crops. Potatoes occupied two and a half times the total cultivated area of large farms (27.12%) as they did on small farms (12.28%). Large farms, on the other hand, dedicated a higher percentage of their total cultivated area (39.55) to vegetable crops than small farms (29%). Both large and small farms allocated land to fodder crops in a similar pattern. Crop intensification on the farm was 200% overall, 200% for small farms, and 201%

Table 9. Cropping pattern on sample farms.

S. No.	Particulars	Small		Large		Overall	
		Area (ha)	% of total cropped area	Area (ha)	% of total cropped area	Area (ha)	% of total cropped area
A	Kharif						
1	Maize	0.07	6.14	0.14	7.91	0.11	7.53
2	Paddy	0.14	12.28	0.19	10.73	0.17	11.64
3	Vegetables	0.26	22.81	0.43	24.29	0.35	23.97
i	Tomato	0.05	4.39	0.07	3.95	0.06	4.11
ii	Capsicum	0.02	1.75	0.03	1.69	0.03	2.05
iii	Radish	0.03	2.63	0.1	5.65	0.07	4.79
iv	Brinjal	0.03	2.63	0.02	1.13	0.03	2.05
v	Cucumber	0.05	4.39	0.07	3.95	0.06	4.11
vi	Okra	0.04	3.51	0.08	4.52	0.06	4.11
vii	Other vegetables	0.04	3.51	0.06	3.39	0.05	3.42
4	Fodder (Chari/Bajra)	0.1	8.77	0.12	6.78	0.11	7.53
	Sub-Total	0.57	50	0.88	49.72	0.73	50
B	Rabi						
1	Wheat	0.18	15.79	0.12	6.78	0.15	10.27
2	Fodder (Berseem/Oat)	0.06	5.26	0.07	3.95	0.07	4.79
3	Vegetables	0.33	28.95	0.7	39.55	0.52	35.62
i	Potato	0.14	12.28	0.48	27.12	0.31	21.23
ii	Cauliflower	0.06	5.26	0.06	3.39	0.06	4.11
iii	Cabbage	0.04	3.51	0.05	2.82	0.05	3.42
iv	Onion	0.02	1.75	0.03	1.69	0.03	2.05
v	Garlic	0.02	1.75	0.02	1.13	0.02	1.37
vi	Other vegetable	0.05	4.39	0.06	3.39	0.06	4.11
	Sub-total	0.57	50	0.89	50.28	0.73	50
C	Total cropped area	1.14	100	1.77	100	1.46	100
D	Net sown area	0.57		0.88		0.73	
	Cropping intensity (%)	200		201.14		200	

for large farms. Similar results were reported by Pandit *et al.* (2010) and Sharma *et al.* (2019) reported similar findings, observing that larger farms in Himachal Pradesh allocated more land to potato cultivation than smaller farms. The findings highlight the importance of vegetable cultivation and potato production as major agricultural activities in the region, with large farms placing a greater emphasis on potato cultivation than smaller farms. Furthermore, the high cropping intensity observed across farm sizes suggests intensive agricultural practices and effective land use.

Crop production

Table 10 displays the calculated per-farm production of various crops. The table shows that among food grains, paddy produced the most (10.54 q/farm on average), followed by wheat (5.4 q/farm) and maize (4.7 q/farm).

Table 10. Production and productivity of different crops on sample farms.

S.No.	Crops	Small		Large		Overall	
		(q/farm)	(q/ha)	(q/farm)	(q/ha)	(q/farm)	(q/ha)
1	Maize	3.12	44.57	6.27	44.79	4.7	44.68
2	Paddy	6.4	45.71	9.43	49.63	10.54	47.67
3	Wheat	6.3	35	4.5	37.5	5.4	36.25
4	Chari	35.6	356	42.85	357.11	39.23	356.56
5	Bajra	42.3	423	51.6	430	46.95	426.5
6	Oats	12.67	456.33	15.21	459.43	13.94	457.88
7	Berseem	13.4	398	14	400	13.7	399
8	Vegetables						
i	Cucumber	7.2	144	10.76	153.71	8.98	148.86
ii	Cabbage	5.12	128	6.5	130	5.81	129
iii	Okra	4.45	111.25	11.32	141.5	7.89	126.38
iv	Brinjal	7.54	251.33	5.12	256	6.33	253.67
v	Tomato	9.35	187	13.3	190	11.33	188.5
vi	Potato	**34.5**	**246.43**	**121.8**	**253.75**	**78.15**	**250.09**
vii	Cauliflower	8.15	135.83	8.56	142.67	8.36	139.25
viii	Radish	5.23	174.33	18.34	183.4	11.79	178.87
ix	Capcicum	3.85	192.43	5.95	198.45	4.9	195.44
x	Onion	4.56	228.22	7.03	234.43	5.8	231.33
xi	Garlic	2.37	118.32	2.43	121.59	2.4	119.96

Large farms had higher per-farm maize and paddy production than small farms. The data also shows that small farms had higher per farm wheat production (6.3 q/farm) than large farms (4.5 q/farm). Bajra had the highest per farm production of any fodder crop (46.95 q/farm), followed by chari (39.23 q/farm), oats (13.94 q/farm), and berseem (13.7 q/farm). Large farms produced more potatoes per farm than small farms, with an average of 75.13 quintals per farm. In terms of other vegetables grown on farms, radish had the highest per farm production (11.79 q/farm), followed by tomato (11.33 q/farm), cucumber (8.98 q/farm), and other vegetables such as cauliflower, okra, and brinjal. This pattern sheds light on the varying levels of crop production across crops and farm sizes, highlighting the importance of crop selection and management practices in optimizing yields. Birthal*et al.* (2015) and Kumari *et al.* (2023) found similar trends in their studies, supporting these observations about crop productivity differences between large and small farms. These findings highlight the importance of crop selection and management practices in maximizing yields. The findings show that paddy and potato cultivation is dominant in the region, with large farms producing more of these crops than small farms. Furthermore, the large production of fodder crops emphasizes the importance of livestock rearing as a supplement to crop cultivation.

Crop productivity

A crop's output per unit area is represented by its yield rate, which generally indicates its economic importance. Table 10 shows the average yields of different crops in the study area. The table shows that all food grain crops were more productive on large farms. The average farm yield was 44.68 q/ha for maize, 47.67 q/ha for paddy, and 36.25 q/ha for wheat. Potato productivity averaged 250.09 q/ha, with large farms producing slightly more (253.75 q/ha) than small farms (246.43 q/ha). Large farms produced more vegetables than small farms, including cucumber, brinjal, cauliflower, radish, and garlic. Crops such as cabbage, okra, and tomato, on the other hand, yielded similarly across both farm sizes, indicating that the relationship between farm size and vegetable productivity varies. These findings are consistent with those reported by Rana *et al.* (2016), who discovered that potato cultivation is more economically viable on larger farms in Andhra Pradesh, India. Sharma *et al.* (2019) also discovered that potato yields were higher on larger farms in the Kangra district of Himachal Pradesh, India. These studies back up the observation that farm size can affect crop productivity, especially for crops like potatoes and other vegetables. The findings highlight large farms' relatively higher productivity levels for major crops such as paddy, maize, wheat, and potatoes, which could be attributed to better resource access and the adoption of improved agricultural practices. However, the differences in yield across vegetables indicate that factors other than farm size, such as crop management techniques, soil fertility, and environmental conditions, may play a more important role in determining vegetable productivity.

Farm, off farm and non-farm income

Farm and non-farm activities generate the majority of income, with off-farm income accounting for only a small portion of total farm income. Farm income was calculated as the value of the primary product and byproducts minus costs such as seed, fertilizers, pesticides, hired labor, and draft power. Off-farm income was defined as income earned by family members working as agricultural labourers on other farmers' fields. Non-farm income was defined as income generated by non-agricultural activities such as services, business/trade/shop, and non-agricultural labor. Table 11 presents the various components of farm and non-farm income. According to the data, agriculture provided approximately 45.19% of total farmer income, with potato crops accounting for 8.63%. Livestock contributed approximately 2.7% of farmer income. When comparing small and large farms, potatoes contributed three times more to total income

Table 11. Composition of farm and non-farm income on sample farms.

(Rs /farm/annum)

S. No.	Particulars	Small	Large	Overall
I	Farm income			
1	Agriculture	216788 (49.69)	326657 (42.62)	271723 (45.19)
i	Potato	20360 (4.67)	83461 (10.89)	51911 (8.63)
ii	Other crops	65000 (14.9)	87500 (11.42)	76250 (12.68)
2	Livestock	14050 (3.22)	18440 (2.41)	16245 (2.70)
3	Horticulture	20455 (4.69)	31000 (4.04)	25728 (4.28)
	Sub-total	336653 (77.16)	547058 (71.38)	441857 (73.48)
II	Non-farm income			
1	Trade/shop	21076 (4.83)	40685 (5.31)	30881 (5.14)
2	Government service	34224 (7.84)	76500 (9.98)	55362 (9.21)
3	Private service	41334 (9.47)	98500 (12.85)	69917 (11.63)
4	Non- agricultural labourer	3000 (0.69)	3672 (0.48)	3336 (0.55)
III	Sub-total	99634 (22.84)	219357 (28.62)	159496 (26.52)
	Total	436287 (100.00)	766415 (100.00)	601353 (100.00)

Note: Figures in the parentheses indicate percentages to the total in each category

on large farms than on small farms. However, the contribution of livestock to total farm income was similar between small and large farms. Farm income accounted for about 73.48% of total income on average, with little difference between small (77.17%) and large farms (71.38%). Non-farm income was dominated by services, including government and private services, which accounted for more than 20.84% of total income. This sector contributed more to large farms (22.83%) than to small farms (17.31%). Business/trade/shop contributed about 10% of total income, while non-agricultural labour contributed only 5.14%. Non-farm income accounted for approximately 26.53% of the total, ranging from 22.82% in large farms to 28.62% in small farms. These findings are consistent with those reported by Pandit *et al.* (2010), who discovered that potato cultivation significantly increased farm income in both irrigated and rainfed conditions in Himachal Pradesh. Furthermore, Rana *et al.* (2016) found that potato cultivation was economically viable in Andhra Pradesh, with the potential to generate income for farmers. Sharma *et al.* (2019) also highlighted the importance of potato cultivation as a source of income for farmers in Himachal Pradesh's Kangra district. The findings emphasize the importance of agriculture, particularly potato cultivation, to the overall income of farmers in the region. Furthermore, non-farm income sources, such as services and business activities, play a significant role in supplementing household income, indicating that farming communities' livelihood strategies are becoming more diverse.

CONCLUSION

The study conducts a comprehensive socioeconomic analysis of potato growers in Himachal Pradesh's Kangra district. It emphasizes the importance of various socioeconomic factors in shaping potato cultivation in the region, including family size, household head age, educational status, land holdings, and income diversification. The findings highlight the importance of agriculture, particularly potato cultivation and livestock rearing, as primary sources of income, while also emphasizing the importance of non-farm and agriculture-related activities in sustaining rural livelihoods. Furthermore, the study shows that larger farms have higher potato yields per hectare than smaller farms, indicating the influence of resource availability on production. To improve potato growers' resilience and well-being, the study recommends developing targeted interventions that take into account the relationship between agricultural outcomes and socioeconomic factors. Furthermore, policies aimed at promoting equitable growth and long-term agricultural development should consider how socioeconomic factors affect farm organization and productivity.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

ETHICAL STATEMENT

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

LITERATURE CITED

Birthal PS, Hazrana J and Negi DS (2015). Crop diversification and farm labor use in India. *Agricultural Economics Research Review* **28**(2): 171-184.

Chand R, Srivastava SK and Singh J (2017). Changing structure of rural economy of India: Implications for employment and growth. NITI Aayog. https://niti.gov.in/writereaddata/files/document_publication/Rural_Economy_DP.pdf

Dahal S, Regmi B, Panta HK, Timalsina P, Chaudhary R, Khadka T and Poudel A (2023). Analysis of economic, production, and marketing aspects of potato farming in Changunarayan Municipality of Bhaktapur, Nepal. *Archives of Agriculture and Environmental Science* **8**(4): 545–552.

Department of Economics and Statistics, Himachal Pradesh. (2022-23). Statistical Year Book of Himachal Pradesh. https://himachalservices.nic.in/economics/pdf/YearBook2022-23.pdf

FAO,(2023). Global potato statistics. Latest. https://www.potatogrower.com/2023/01/global-potato-statistics-latest

Gautam Y and Andersen P (2016). Rural livelihood diversification and household well-being: Insights from Humla, Nepal. *Journal of Rural Studies* **44**: 239-249.

Kashyap R and Guleria A (2015). Socio-economic and marketing analysis of apple growers in Mandi district of Himachal Pradesh. *Journal of Hill Agriculture* **6**(2): 202-206.

Kumari J, Singh AK and Maji S (2020). Analysis of communication profile of beneficiaries under skill development mission in Chhattisgarh. *Research Journal of Agricultural Science* **11**(4): 881-884.

Kumari S, Maurya M, Kumar S and Noel AS (2023). Analysis of socio-economic characteristics of potato farmers and trend, growth rate of area, production of potato in Nalanda district of Bihar, India. *International Journal of Environment and Climate Change* **13**(8): 53-60.

Kushwaha RR, Kumar P, Singh VK, Supriya, Singh A and Yadav RS (2019). An economic analysis of potato cultivation: A case study in Kannauj district of Uttar Pradesh. *Journal of Pharmacognosy and Phytochemistry* **8**(3): 4609–4612.

Pandit A, Kumar A, Rana RK, Pandey NK and Kumar NR (2010). A study of socio-economic profile of potato farmers: comparison of irrigated and rainfed conditions in Himachal Pradesh. *Potato Journal* **37**(1–2): 56–63.

Peer QJA, Ahmad N, Kaur J, Chesti MH, Ahmad HS, Bhat A and Bhat BA (2013). Study on economics of potato growing towards livelihood security. *African Journal of Agricultural Research* **8**(45): 5639–5644.

Rana RK, Arya S, Kadian MS, Singh BP, Quiroz R and Monneveux P (2016). Socio-economic feasibility of potato cultivation in Andhra Pradesh, India. *Potato Research* **59**: 167–179.

Sharma V, Lal H, Debnath U and Hatte V (2017). Economics of potato production in Kangra district of Himachal Pradesh, India. *International Journal of Current Microbiology and Applied Sciences* **6**(10): 123-129.

Sharma V, Lal H, Rajput AS and Sharma I (2019). Socio-economic analysis of potato growing farmers in Kangra district of Himachal Pradesh. International Journal of *Agriculture Sciences* **11**(3): 7844-7848.

MS Received : June 14, 2024; Accepted : June 28, 2024

Potato J (2024) 51 (1): 41-48

GROUNDWATER QUALITY INFLUENCING THE POTATO TUBER YIELD IN DOABA REGION OF PUNJAB, INDIA

Prince Kumar[1*], Jagdev Sharma[2], Anil Sharma[1], Yogesh Garde[3], Raj Kumar[4], Vineeta Sharma[2] and Brajesh Singh[2]

ABSTRACT: Groundwater is extensively used for irrigation in the Doaba region of Punjab, where it supports the cultivation of various crops, including potatoes. This region relies heavily on chemical fertilizers and pesticides for growing different crops, which pose a dual threat by potentially degrading groundwater quality and depleting its reserves. To address these concerns, a survey-based investigation was conducted to evaluate the quality of irrigation water and assess potato tuber yields. It was observed that farmers are drawing groundwater from borewells with an average depth of 254.0 feet, and the water is delivered from a depth of 145.67 feet. The analytical results showed that all the groundwater samples tested were suitable for irrigation. Additionally, a significant positive correlation was found between potato tuber yield and the nitrate content of the groundwater. Consequently, it is essential to factor in the nitrate contribution from groundwater when making recommendations for nitrogen usage in the region.

KEYWORDS: Groundwater, Nitrate, Physico-chemical, Potato and Tuber yield

INTRODUCTION

In the post-Green Revolution era, characterized by high cropping intensity and increasing human population, anthropogenic activities, inappropriate use of fertilizers, overexploitation, quality deterioration, and groundwater depletion have emerged as major challenges for humanity (Kumar *et al.*, 2007a; Srivastava *et al.*, 2017; Sekhon *et al.*, 2019a; Kumar *et al.*, 2021). In India, groundwater is used for more than 90% of irrigation (Jain *et al.*, 2019a), making it a vital and critical input for achieving sustainable crop yields. As global demand for potatoes continues to rise (Danielescu *et al.*, 2022; Stark *et al.*, 2020), so too will the water requirements for crop production, raising concerns about irrigation water resources and water quality (Haverkort and Struik, 2015a; Levy *et al.*, 2013).

In an era marked by escalating environmental challenges and population growth, sustainable agriculture has become a paramount concern (Foley et al., 2011). It is within this context that the significance of groundwater quality comes to the fore. Groundwater, often relied upon for irrigation, not only provides the essential moisture required for plant growth but also carries with it a suite of chemical and physical attributes that can profoundly impact crop health and yield (Boithias et al., 2016).

Potatoes (*Solanum tuberosum*) are a staple crop of paramount importance, particularly in regions like the Doaba region of Punjab, India, where agriculture plays a vital role in sustaining livelihoods and ensuring food security (Singh et al., 2019). The yield and quality of potato tubers are influenced by a multitude of factors, ranging from

---

[1]ICAR-Central Potato Research Institute, Regional Station, Jalandhar - 144003, Punjab, India
[2]ICAR-Central Potato Research Institute, Shimla - 171 001, Himachal Pradesh, India
[3]Department of Agricultural Statistics, NMCA, NAU, Navsari - 396 450, Gujarat, India
[4]ICAR-IARI (RS), Katrain- 175 129, Kullu Valley, Himachal Pradesh, India
*Corresponding author; email: princevgc@gmail.com

climatic conditions to agricultural practices and irrigation methods. In this context, groundwater quality has emerged as a critical determinant in the pursuit of optimal potato production within the Doaba region. This region is characterized by its intense agricultural activity, primarily relies on groundwater for irrigation purposes (Jain et al., 2019b). However, the quality of this groundwater is subject to a host of variables, including natural geochemical processes and anthropogenic activities such as fertilization and industrial discharge (Kumar et al., 2021). These factors can introduce a wide range of contaminants and variations in groundwater parameters, potentially impacting potato crops at various stages of their growth cycle.

This introductory exploration aims to investigate the intricate relationship between groundwater quality and potato tuber yield in the specific context of the Doaba region of Punjab, India. It delves into the diverse parameters and contaminants that can infiltrate the groundwater in this region, examining their potential effects on potato plants throughout their growth cycle (Sekhon et al., 2019b). Furthermore, it considers the implications of groundwater quality on agricultural practices and food security within this agriculturally significant region (Kumar et al., 2007). Through this investigation, we endeavor to shed light on the importance of proactively addressing groundwater quality issues to ensure sustained and robust potato production in the Doaba region, ultimately contributing to the region's agricultural prosperity.

MATERIALS AND METHODS

Description of the study area

The present investigation was carried out in the year 2019-20 in three districts of the Doaba region of Punjab, namely Jalandhar, Hoshiarpur, and Kapurthala (Figure 1). Potato is a major cash crop in the Doaba region, typically following rice as preceding and wheat/maize as succeeding crop, playing a vital role in meeting the country's seed potato requirements. The climate in this study area varies from sub-humid to semi-arid and is generally dry, except during the monsoon season (Anonymous, 2013). The soil in the study area is characterized by light texture, with significant variations in organic carbon content (ranging from 0.17% to 0.77%), soil pH (ranging from 6.5 to 8.4), and low levels of available nitrogen (ranging from 131.7 to 211.0 kg/ha). In contrast, there are high levels of available phosphorus (ranging from 25.3 to 30.3 kg/ha) and medium levels of available potassium (ranging from 223.9 to 259.9 kg/ha) (Kumar *et al.*, 2021).

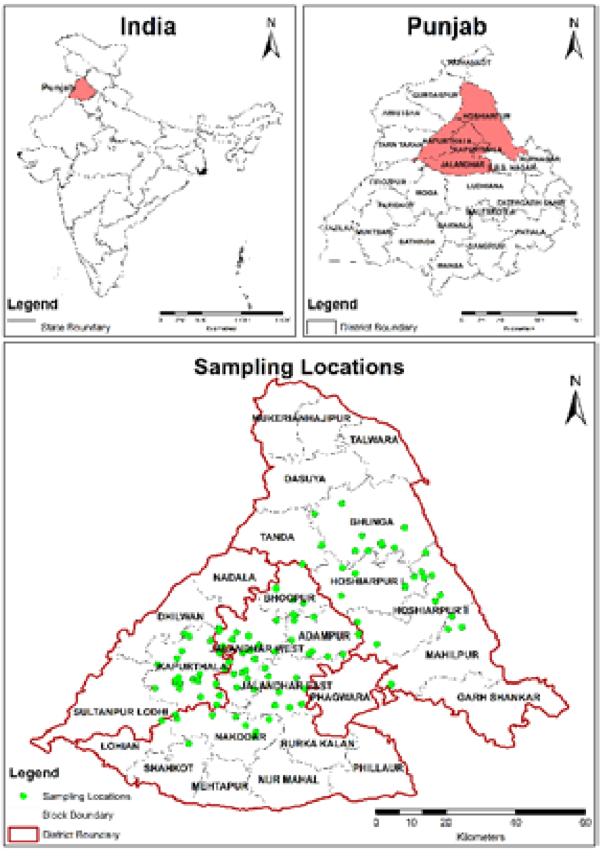


Fig. 1. Study area and ground truth points.

Selection of farmers

The study was conducted in the Doaba region of Punjab, specifically focusing on three districts: Jalandhar, Hoshiarpur, and Kapurthala. These districts were deliberately selected due to their significant contributions to seed potato production in the country and their dedicated focus on potato cultivation in the state of Punjab (Ministry of Agriculture and Farmers' Welfare, 2018). An extensive survey was undertaken to collect and authenticate the necessary information using structured questionnaires administered through interviews. A total of 100 farmers were contacted, each having a minimum of 10 years or more of experience in potato cultivation within the region (Figure 1). All required information was systematically gathered from the respondents, including data related to the application of various inputs such as fertilizers (NPK), the source of irrigation, and the depth of groundwater delivery. Additionally, information on tuber yield of single year harvested during 2020 for each farm was recorded, along with Global Positioning System (GPS) coordinates using GPS essential mobile application.

Water samples collection and analysis

Groundwater samples were systematically collected from 100 locations, specifically from selected farmers' tubewells using Global Positioning System (GPS) coordinates during the months of March to June in 2019. The sampling procedure involved collecting the samples after 15 minutes of pumping and storing them in high-quality 250 ml polythene bottles. These bottles had been pre-soaked in a 10% nitric acid solution for 24 hours and rinsed with deionized water to ensure their cleanliness. All the collected samples were stored at 4°C until they were used for further analysis.

The chemical analysis of the groundwater samples was conducted in triplicate. Bicarbonate and chloride contents were determined by titration method and sulphate content by turbidimetric method (Tondon, 2001). Nitrate (NO_3^-) concentration was determined using a UV-visible spectrophotometer at wavelengths of 220 nm and 275nm. Concentrations of Iron (Fe), Zinc (Zn) , Manganese (Mn), Copper (Cu), calcium (ca) and Magnesium (Mg) were determined using a Flame Atomic Absorption Spectrophotometer (FAAS). Sodium (Na) and Potassium (K) were determined by flame photometer method. Double distilled water was used to prepare reagents and solutions for the analysis (Tandon, 2001).

Determination of groundwater quality for irrigation

The crucial criteria for classifying the quality of groundwater for use in irrigation are Sodium Absorption Ratio (SAR), Magnesium Ratio (MR) and Corrosivity Ratio (CR) (Tripathi *et al.*, 2012). The SAR value of each samples of groundwater was calculated by using,

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

The MR value of each samples of groundwater was calculated by

$$MR = \frac{Mg^{2+}}{(Ca^{2+} + Mg^{2+})} \times 100$$

and CR value of each samples of groundwater was by using following relation as,

$$CR = \frac{\frac{Cl^{-}}{35.5} + \frac{2(SO_4^{2-})}{96}}{\frac{2(HCO_3^{2-} + CO_3^{2-})}{100}}$$

Statistical analysis

All the responses obtained from farmers and the water quality data were meticulously organized using the MS-Excel program (MS office version 2014) to prepare them for further statistical analysis. Descriptive statistics were also derived for the physicochemical parameters of the groundwater samples. Correlation and regression analyses were performed to examine the relationships between tuber yield and various elements. Statistical analysis was carried out using R software version 2.15.1, while QGIS version 3.22.16 was employed for creating spatial distribution maps.

RESULTS AND DISCUSSION

The physico-chemical parameters of groundwater samples

The data presented in Table 1 shown that out of a total of 100 observations, the mean tuber yield in the Doaba region of Punjab was recorded at 23.06 t/ha. The borewell depth and groundwater delivery depth for the region averaged 254.00 feet and 145.67 feet, respectively. Additionally, the mean values for pH (7.98) and EC (0.60 ds/m) were observed.

Table 1. Descriptive statistics of the physico-chemical parameters of groundwater samples (N=100).

Parameters	Unit	Mean	SD	Min.	Max.	CV (%)
pH		7.98	0.22	7.40	8.40	2.77
EC	ds/m	0.60	0.15	0.35	0.96	24.88
Nitrate (NO_3^-)	ppm	34.97	28.40	1.90	130.10	81.22
Chloride (Cl^-)	me/L	3.07	0.66	2.00	5.00	21.34
Carbonate (CO_3^{2-})	me/L	0.40	0.00	0.40	0.40	0.00
Bicarbonate (HCO_3^-)	me/L	0.53	0.19	0.20	1.10	36.82
Sulphate (SO_4^{2-})	ppm	8.98	5.89	0.39	23.70	65.62
Sodium (Na^+)	ppm	55.56	23.36	15.00	131.30	42.05
Calcium (Ca^{2+})	ppm	119.09	74.21	20.41	422.51	62.31
Magnesium (Mg^{2+})	ppm	30.57	6.67	16.45	46.55	21.82
Zinc (Zn^{2+})	ppm	0.05	0.07	0.00	0.58	148.28
Iron (Fe^{2+})	ppm	0.05	0.04	0.00	0.21	65.37
Copper (Cu^{2+})	ppm	0.19	0.38	0.00	3.39	202.28
Manganese (Mn^{2+})	ppm	0.07	0.07	0.00	0.22	94.20
SAR		2.43	1.14	0.51	6.41	1.31
MR		23.99	10.83	0.30	54.70	117.30
CR		0.31	0.23	0.05	1.41	0.05

Note: SD=Standard deviation; SAR=Sodium Absorption Ratio; MR=Magnesium Ratio; CR=Corrosivity Ratio

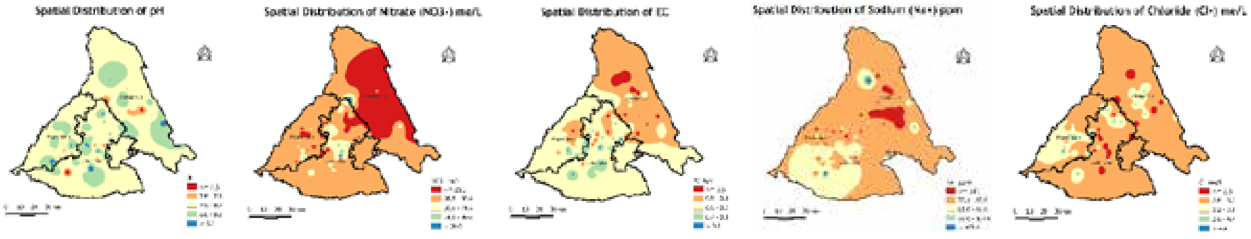
The mean concentrations of major anions were as follows: NO_3^- (34.97 ppm), Cl^- (3.07 me/L), CO_3^{2-} (0.40 me/L), HCO_3^- (0.53 me/L), and SO_4^{2-} (8.59 ppm). For cations, the mean concentrations were Na^+ (55.56 ppm), Ca^{2+} (119.09 ppm), Mg^{2+} (30.57 ppm), Zn^{2+} (0.05 ppm), Fe^{2+} (0.05 ppm), Cu^{2+} (0.19 ppm), and Mn^{2+} (0.07 ppm). Key ratios were calculated as follows: Sodium Absorption Ratio (SAR) at 2.43, Magnesium Ratio (MR) at 23.99, and Corrosivity Ratio (CR) at 0.31. The mean application rates for $N:P_2O_5:K_2O$ nutrients were 198.61:160.64:92.72 kg/ha.

Relationship between tuber yield and various elements

The results of the correlation study reveal the relationships between variables in this investigation, we have documented the relationship between tuber yield and various elements. The correlation matrix of 14 variables, as shown in Figure 3, highlights a strong, positive, and highly significant correlation between EC-SO_4^{2-} (r=0.62), EC-Na^+ (r=0.58), and EC-Mg^{2+} (r=0.77). This indicates that the presence of sulfate, sodium, and magnesium in groundwater has a significant impact on electrical conductivity (EC). Notably, pH did not exhibit any significant correlation with any parameter.

Furthermore, we found a significant positive correlation between EC-NO_3^- (r=0.34) and EC-Zn^{2+} (r=0.32). These results align with the findings of Kaur et al., 2016. Nitrate displayed a highly significant positive correlation with sulfate (r=0.26) but had a negative correlation with chloride (r=-0.24). A strong, positive, and highly significant correlation was observed between Ca^{2+} and Mn^{2+} (r=0.58). Tuber yield exhibited a significantly positive correlation with nitrate (r=0.20) but showed a negative correlation with magnesium (r=-0.21) only.

Potato crops are known to be highly responsive to nitrogen, which significantly



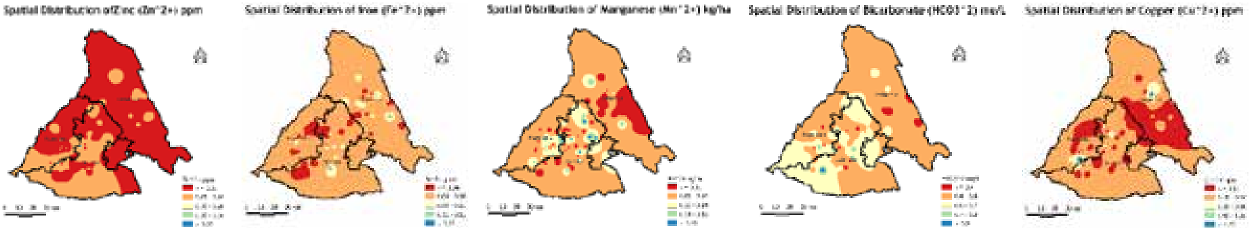
Spatial distribution of pH

Spatial distribution of Nitrate (NO_3^-)

Spatial distribution of EC

Spatial distribution of Sodium (Na^+)

Spatial distribution of Chloride (Cl^-)



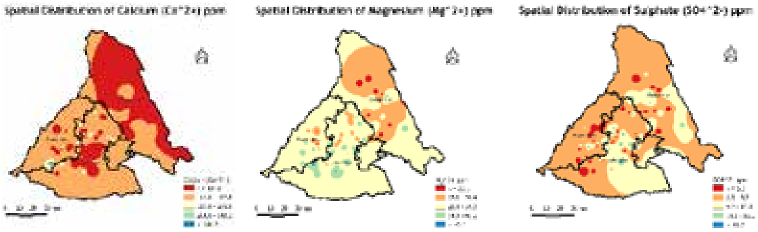
Spatial distribution of Zinc (Zn^{2+})

Spatial distribution of Iron (Fe^{2+})

Spatial distribution of Manganese (Mn^{2+})

Spatial distribution of Bicarbonate (HCO_3^-)

Spatial distribution of Copper (Cu^{2+})



Spatial distribution of Calcium (Ca^{2+})

Spatial distribution of Magnesium (Mg^{2+})

Spatial distribution of Sulphate (SO_4^{2-})

Fig.2. Spatial distribution of the chemical parameters of groundwater.

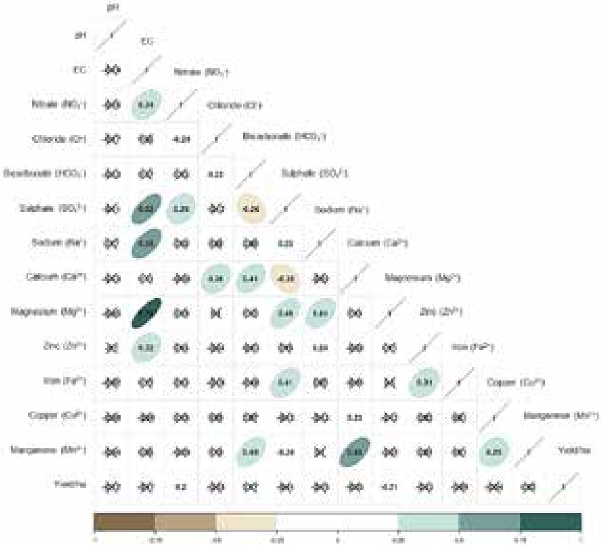


Fig.3. Correlation matrix of tuber yield and groundwater elements.

contributes to increased tuber yields. Considering an average irrigation supply of 430 mm for potato crops (Anonymous, 1990), groundwater contributes nitrate-nitrogen in the range of 1.84 to 125.87 Kg/ha, with an average of 33.65 Kg per ha. This average nitrogen contribution is equivalent to about 19.22 percent for seed crops (175 kg per ha) and 14.02 percent for ware crops. Since plants primarily take up nitrogen in the form of nitrate, it is crucial to consider the nitrate content in groundwater when recommending nitrogen application. In addition, this groundwater is also contributing appreciable level of calcium, magnesium and sulphate-sulphur in the range of 87.76 to 1816.79 kg/ha, 70.74 to 200.17 kg/ha and 0.50 to 30.57

kg/ha with mean level of 512.19, 130.93 and 11.51 kg/ha, respectively.

Given the substantial variability in nitrate content, it is essential to adjust nitrogen fertilizer doses accordingly to avoid excessive use. Excessive nitrogen not only leads to pollution but also contributes to carbon footprints (Kumar et al., 2021). Regression analysis was conducted to identify which groundwater quality parameters significantly influence tuber production. The results indicated that EC, nitrate, and sulfate content in groundwater have a positive and significant contribution to tuber yield (Table 3), with an R^2 value of 0.248.

Groundwater assessment for irrigation quality

The groundwater quality parameters are categorized in Table 4. Electrical conductivity (EC) serves as an indicator of the salinity hazards to crops, reflecting the Total Dissolved Solids (TDS) value of groundwater. According to Wilcox's classification (1955), 83 percent of the samples were categorized as "good," while 17 percent fell into the "permissible" class. None of the samples were classified as "excellent," "doubtful," or "unsuitable."

Table 3. Groundwater chemical constituents influencing tuber yield.

Variable	Estimate	S.E.	t-value	p-value
Intercept	32.22^{**}	8.24	3.91	0.00
pH	-0.90	0.98	-0.92	0.36
EC	-6.78^{*}	3.12	-2.17	0.03
NO_3^-	0.02^{**}	0.01	2.55	0.01
Cl^-	0.06	0.33	0.18	0.85
HCO_3^-	2.88^{*}	1.34	2.15	0.03
SO_4^{2-}	0.15^{**}	0.06	2.51	0.01
Na^+	0.00	0.01	0.30	0.76
Ca^{2+}	0.00	0.00	0.53	0.59
Mg^{2+}	-0.05	0.05	-1.07	0.28
Zn^{2+}	-0.29	3.07	-0.10	0.92
Fe^{2+}	-8.64	6.47	-1.34	0.18
Cu^{2+}	-0.75	0.56	-1.35	0.18
Mn^{2+}	0.86	4.13	0.21	0.83
		Model accuracy		
	R^2		Residual Std. error	
	0.248	1.888		

*Significant at 0.05 level; **Significant at 0.01 level

Table 4. Classification of groundwater samples quality for irrigation.

Attribute	Range	Classification	No. of samples
Salinity hazard (EC) (μs/cm)	<250	Excellent	-
	250-750	Good	83
	750-2000	Permissible	17
	2000-3000	Doubtful	-
	>3000	Unsuitable	-
Alkalinity hazard (SAR) (Richards, 1954)	<10	Excellent	100
	10-18	Good	-
	18-26	Doubtful	-
	>26	Unsuitable	-
Magnesium ratio (MR) (Palliwal, 1972)	<50%	Suitable	99
	>50%	Unsuitable	1
Corrosivity ratio (CR) (Raman, 1985)	<1	Safe	99
	>1	Unsafe	1

Additionally, the Sodium Absorption Ratio (SAR) characterizes the sodium or alkali hazards to crops. In the present study, all the collected groundwater samples were rated as "excellent" for irrigation, indicating no alkali hazards for crops being cultivated in the region. Furthermore, the current investigation revealed that 99 percent of the samples were deemed suitable and safe in terms of magnesium ratio and corrosivity ratio.

In conclusion, this study underscores the pivotal role of nitrogen in potato cultivation and stresses the need to consider nitrate content in groundwater when recommending nitrogen application. Groundwater quality parameters indicate that salinity and alkali hazards to crops are negligible, ensuring favorable conditions for cultivation. Moreover, specific parameters such as electrical conductivity, nitrate, and sulfate content are found to significantly and positively impact tuber yield, offering insights for optimizing potato production. The majority of groundwater samples are deemed suitable for irrigation according to Wilcox's classification. Additionally, the study highlights the safety of groundwater in terms of magnesium and corrosivity ratios, reducing the risk of adverse effects on crop growth. These findings can be used to devise strategies to enhance potato crop yields while minimizing environmental concerns in the region. Consequently, it is imperative for farmers to continually test their irrigation water when making decisions regarding nutrient application by considering the nutrient contribution through irrigation. This approach ensures the optimal and sustainable management of resources for improved potato cultivation practices.

ACKNOWLEDGEMENT

Authors are thankful to the Director ICAR-CPRI, Shimla (HP) for providing necessary support during the investigations.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

ETHICAL STATEMENT

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

LITERATURE CITED

Anonymous (1990). ICAR-Central Potato Research Institute, Shimla (HP).

Anonymous (2013). Central CGWB, Ground water board, Government of India, Ministry of water resources, Chandigarh: North Western Region.

Boithias L, Sauvage S, Merlina G, Jean S, Proton L and Sánchez-Pérez J M. 2016. Assessing pesticides and nitrate in groundwater and subsurface drainage water at the watershed scale: A combined hydrogeological and physicochemical approach. *Science of The Total Environment* **545**: 266-276.

Danielescu S, MacQuarrie K T B, Zebarth B, Nyiraneza J, Grimmett M and Levesque M (2022). Crop Water Deficit and Supplemental Irrigation Requirements for Potato Production in a Temperate Humid Region (Prince Edward Island, Canada). *Water* https://doi.org/10.3390/w14172748

Foley J A, Ramankutty N, Brauman K A, Cassidy E S, Gerber J S, Johnston, M., ... & Zaks D P (2011). Solutions for a cultivated planet. *Nature* **478**(7369): 337-342.

Haverkort A J and Struik P C (2015a). Yield levels of field crops in Europe: Effects of crop protection and soil tillage. *European Journal of Agronomy* **64**: 35-61.

Jain R, Kishore and Singh D K (2019a). Irrigation in India: status, challenges and options. *Journal of Soil and Water Conservation* **18**(4): 1-11.

Jain A K, Smedema L K and Mondal M K (2019b). Groundwater depletion and its impact on irrigation in the agriculturally intensive northwest India. *Water Resources Research* **55**(2): 1307-1324.

Kaur T, Bhardwaj R and Arora S (2016). Assessment of groundwater quality for drinking and irrigation purposes using hydrochemical studies in Malwa region, south western part of Punjab, India. *Applied Water Science* https://DOI 10.1007/s13201-016-0476-2.

Kumar M, Kumari K, Ramanathan A L and Saxena R (2007a). A comparative evaluation of groundwater suitability for irrigation and drinking purposes in two intensively cultivated districts of Punjab, India. *Environmental Geol* **53**: 553-574.

Kumar Prince, Sharma J, Kumar D, Sharma V, Dua V K, Sharma A, Kumar R and Kumar M (2021). Apposite macronutrient fertilization (AMNF) – an effective modus operandi for potato crop. *Indian Journal of Agricultural Sciences* **91(2)**: 244-248.

Kumar Prince, Sharma J, Sharma A, Dua VK, Kumar R, Singh M, Nare B and Kumar M (2021). Carbon footprint of potato production system of North – West India. In: Extended Summaries & Abstracts. International Potato e- conference. 94p.

Kumar A, Kumar A, Mishra S and Singh R S (2021). Water quality assessment and mapping of Satluj River basin, India, using GIS techniques. *Journal of Earth System Science* **130**(3): 57.

Kumar A, Kumar A, Singh D K and Mishra S (2007b). Groundwater quality and its suitability for drinking and agricultural use in the Satluj River basin, India. *Environmental Monitoring and Assessment* **132**(1-3): 163-177.

Levy D, Coleman W K and Veilleux R E (2013). Adaptation of potato to water shortage: Irrigation management and enhancement of tolerance to drought and salinity. *American Journal of Potato Research* **90**: 186–206.

Palliwal K V (1972). Irrigation with saline water, ICARI Monograph No. 2, New Delhi. pp. 198.

Raman V. 1985. Impact of corrosion in the conveyance and distribution of water. *JIWWA* **11**: 115-121.

Richards L A (1954). Diagnosis and improvement of saline and alkali soils. Agri. Handbook 60. US. Department of Agriculture. Washington, DC. 969p.

Sekhon K S, Kaur A, Thaman S, Sidhu A S, Garga N, Choudhary O P, Buttar G S, Chawla N (2019a). Irrigation water quality and mulching effects on tuber yield and soil properties in potato (*Solanum tuberosum* L.) under semi-arid conditions of Indian Punjab. *Field Crops Research* https://doi.org/10.1016/j.fcr.2019.06.001

Sekhon B S, Singh B, Singh A and Singh N (2019b). Sustainable potato production for food and nutritional security. *Potato Research* **62**(4): 369-414.

Singh N, Sharma A and Singh S K (2019). Potato: A globally important crop. *Potato Research* **62**(4): 305-317.

Srivastava S K, Chand R, Singh J, Kaur A P, Jain R, Kingsly I and Raju S S (2017). Revisiting groundwater depletion and its implications on farm economics in Punjab, India. *Current Science* **113**(3): 422-429.

Stark J, Thornton M, Nolte P. (Eds.) Potato Production Systems; Springer International Publishing: Berlin/Heidelberg, Germany 2020. p. 635, ISBN 978-3-030-39156-0.

Tandon H L S (2001). Methods of Analysis of Soils, Plants, Waters and Fertilizers; Fertilizer Development and Consultation Organization, New Delhi.

Tripathi A K, Mishra U K, Mishra A, Tiwari S and Dubey P (2012). Studies of hydrogeochemical in groundwater quality around Chakghat area, Rewa District, Madhya Pradesh, India. *Int J Mod Eng Res Technol* **2(6)**: 4051-4059.

Wilcox L V (1955). Classification and use of irrigation waters. US. Department of Agriculture. Circ, Washington, DC. 160p.

MS Received : March 06, 2024; Accepted : July 31, 2024

Potato J (2024) 51 (1): 49-61

EFFECT OF IRRIGATION METHODS AND NUTRIENT MANAGEMENT PRACTICES ON PRODUCTION AND ECONOMICS OF POTATO UNDER DIFFERENT PRECEDING CROP SEQUENCES IN CENTRAL INDIA

SP Singh[1], MJ Sadawarti[2], SK Sharma[2], RK Singh[1], S Rawal[3], Manoj Kumar[3], J Sharma[4] and S Katare[2]

ABSTRACT: A field experiment was conducted at ICAR-Central Potato Research Institute-RS, Gwalior, in split-plot design: 3 irrigation methods (main plots) and 5 fertilizer doses in various crop sequences (sub-plots), with four replications. Results revealed that the highest total tuber number (604 thousand/ha) was recorded with dhaincha - potato (75% RDF NPK) which was significantly higher than all other treatments except green gram - potato (75% RDF NPK). Drip irrigation resulted in highest total tuber yield (35.8 t/ha), significantly surpassing other methods. Dhaincha - potato (75% RDF NPK) combination yielded (37.5 t/ha) highest, significantly outperforming others except fallow - potato (50% RDF NPK/ha + 15 t FYM) sequence. Drip irrigation x fallow - potato (50% RDF NPK/ha + 15 t FYM) combination recorded the highest total tuber yield at 40.3 t/ha. Drip irrigation resulted in water-use efficiency of 137 kg/ha-mm and harvest index of 72%, significantly surpassing other methods. Fallow – potato {FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers (*Azotobacter* and PSB)} sequence recorded highest harvest index 73%, significantly surpassing other treatments. Drip irrigation resulted in highest WUE (137 kg/ha-mm), significantly surpassing other methods. Combination of drip irrigation x fallow – potato (FYM 7.5 t/ha + 50% RDF NPK) sequence recorded highest WUE (155 kg tuber/ha-mm), significantly outperforming other treatments. Dhaincha – potato (75% RDF NPK) sequence resulted in the highest **nitrogen content (216 kg/ha),** significantly surpassing others**. Dhaincha - potato (75% RDF NPK) sequence significantly out performed in tuber nitrogen uptake (77 kg/ha) to other sequences. Combination of drip irrigation x dhaincha - potato (75% RDF NPK) sequence recorded highest N uptake (83 kg/ha). Benefit : cost was highest with drip irrigation (3.1) among irrigation methods and it was highest with dhaincha - potato (75% RDF NPK) sequence (2.99) among crop sequences.**

KEYWORDS: Irrigation methods, crop sequence, nutrient management, water use efficiency, nutrient uptake

INTRODUCTION

Potato (*Solanum tuberosum* L.) is a principal food crop, and an essential source of nutrients for human populations. The annual world production of potato tubers, obtained from the cultivated area of 19.3 M ha during 2019, was around 380 million tons (FAOSTAT, 2023). Potato is ranked as the fourth crop after wheat, rice, and maize, among other crops according to the total production, and is the number one among non-grain food commodity.

The excessive inputs in agricultural systems that can achieve high productivity and quality of crops to feed a growing population are considered to be some of the most troublesome agricultural practices for environmental resources (Ekin, 2019; El Mokh, 2015; Badr *et al*., 2010). Thus, increasing food crop cultivation requires the rationalization of the inputs such as water and fertilizer applications. Additionally, due to the expense of water and its limited supply, it is important to provide better irrigation management that

---

[1]ICAR-Central Potato Research Institute, Regional Station, Patna -801506, Bihar, India
[2]ICAR-Central Potato Research Institute, Regional Station, Gwalior - 474020, Madhya Pradesh, India
[3]ICAR-Central Potato Research Institute, Regional Station, Modipuram, Meerut - 250110, Uttar Pradesh, India
[4]ICAR-Central Potato Research Institute, Shimla - 171 001, Himachal Pradesh, India
*Corresponding author; email: drshivpratapsingh@yahoo.co.i

can increase its effective and efficient use to save water. Drip irrigation offers many agronomic and water conservation benefits for irrigated agriculture, such as the improved efficiency of plant nutrition. A positive relationship exists between the total applied water and tuber yield, particularly under drip irrigation (Badr *et al.,* 2010). Potatoes have a shallow root system, with 85% growing within the upper 40 cm of soil (in some cases, it may extend to 100 cm or more (Wang *et al.,* 2006). Water stress, as well as excessive water, can decrease potato yield: The former decreases plant growth and the later hinders normal plant physiological processes, since different growth stages of potato plants are sensitive to inadequate irrigation (Yuan *et al.,* 2003).

Potato yield and fertilizer applications are significantly correlated, and suitable fertilizers can significantly improve quality and yield (Šrek *et al.*, 2010). Potato crops require high rates of fertilizers, particularly those containing Nitrogen (N) and Potassium (K); the requirement for N is approximately twice that of K (Bélanger, 2002).

Among the different environmental factors, water supply and its management and nitrogen fertilization are considered to be the two major limiting factors affecting potatoes' yield and quality. Water deficiency causes physiological disorder of potato and a decrease in dry matter and tuber starch content (Carli *et al*., 2014). Potato is a nitrogen-intensive plant with low nitrogen uptake efficiency (Gitari *et al*., 2018). Potato planting under over-fertilization conditions in pursuit of high yield has a high potential for N loss. The high nitrate nitrogen content in the potato root zone caused by excessive fertilization is the main problem faced by farmers (Abdo *et al*., 2020). The increase in nitrate accumulation in potato tubers caused by excessive application of nitrogen fertilizer will cause many diseases to humans and threaten the health of the whole society. Excessive nitrogen and potassium application and excessive soil nutrient levels may reduce tuber yield and quality. A balanced application of nitrogen is required to obtain adequate biomass yield, which leads to a stable yield and the production of good quality tubers. Appropriate soil moisture can promote potatoes' absorption and utilization of soil nutrients. Modern production practices include optimizing nitrogen and water use to optimize crop production and minimize the risk of leaching nitrogen into groundwater (Badr *et al*., 2012). In the present day context, the effective and economical utilization of water and fertilizers is essential to reduce the cost of cultivation. It can best be achieved through the use of improved irrigation techniques, *viz* drip and sprinkler and supplying balanced and adequate doses of fertilizers. Drip and sprinkler irrigation can increase the yield up to 20–40% and save water up to 39% in potato crop. The response of applied fertilizers is also expected to vary with different irrigation methods as the water application frequency is different in sprinkler, drip and conventional furrow irrigation systems. Therefore, the present studies were conducted to evaluate variable nutrient options in combination with varying methods of irrigation to assess the economic feasibility of these techniques.

MATERIALS AND METHODS

The experiment was conducted at Research Farm of ICAR-Central Potato Research Institute-RS, Gwalior (MP) which is situated at 26^{0}16′32″N78^{0}13′13″E at an elevation of 222.27m as per GPS location. Gwalior has a subtropical climate, reaching extreme highs of 48°C in summer and lows of 4.0°C in winter. Annual rainfall ranges from 750 to 800 mm, mainly between end-June and end-September, with occasional winter showers. Farm soil: 42.04% sand, 30.66% silt, 27.12% clay (silty clay loam) with Granular structure, soil bulk density 1.29 g/m^3, particle density 2.61 g/m^3. Soil pH is 6.81, OC 0.45%, available N 190 kg, P 20.2 kg, and available K 395 kg/ha. Total rainfall received during the crop growth period was 49.4 mm. The average maximum and minimum temperature during crop growth period was 36 °C and 10 °C, respectively. The relative humidity ranged from 29.7% to 97.8%.

The gross plot size measured 3.0 m x 5.4 m, while the net plot size was 1.8 m x 5.0 m. Employing a split-plot design, the experiment included three main plot treatments (drip irrigation, sprinkler irrigation, and furrow irrigation) and five sub-plot treatments replicated four times. Main plot treatments focused on irrigation methods, while sub-plot treatments involved fertilizer doses: i) control, ii) 100% RDF N, P_2O_5, K_2O @ 180:80:120 kg/ha, iii) 75% RDF N, P_2O_5, K_2O @ 135:60:90 kg/ha, iv) 50% RDF N, P_2O_5, K_2O @ 90:40:60 kg/ha + 15 t FYM/ha, v) Compost + FYM @ 7.5 (t/ha each) + Bio fertilizer. Sprinkler irrigation was scheduled at IW/CPE = 1.2 when CPE reached 3.0 cm. The variety used was the Kufri Jyoti, with spacing set at 60 cm x 20 cm in the ridge furrow system and 120 cm wide raised beds. Two potato rows were planted at a 40 cm row distance under drip and sprinkler methods, while intra-row spacing in micro-irrigations was also maintained at 20 cm.

Potato was planted during first week of November in both 2020 and 2021 and harvested during second week of February, 2021 and 2022. Well sprouted seed tubers were planted manually. Irrigations were applied as per schedule through drip and sprinklers and at 15 days interval in ridge furrow systems. At planting, 1/3rd doses of fertilizers in drip and sprinkler systems and half dose N and full doses of phosphorus and potassium were applied at planting as basal dose. Remaining 2/3rd dose of fertilizers were applied in 8 equal splits twice weekly after tuber emergence in micro irrigated treatments. Remaining half dose of nitrogen in ridge – furrow system was applied at hoeing and earthing up at 26 days after planting. Different doses of fertilizers, manures and crop residue based compost along with bio fertilizers were applied as per treatment. Well decomposed organic manure *viz.* FYM along with residue based compost were applied three days before planting. Half dose of nitrogen and full doses of phosphorus and potassium were applied through urea, dia-ammonium phosphate (DAP) and muriate of potash (MOP), respectively, as basal dose at the time of planting. Weed management was done using Metribuzin which was applied @ 500 g a.i. /ha as a pre-emergence herbicide (one day after planting). Plant protection measures include spraying Imidacloprid @ 4ml/10 litre and Dithane M45@ 2 kg /ha during both the years. Haulm uprooting was done during 1st week of February and harvesting was done in 2nd week of February during both the years. The first irrigation was given immediately after planting since planting was done under dry soil condition. Subsequent irrigations were given at about 2-3 days interval using drip and sprinkler irrigation and 12-15 days interval using ridge - furrow irrigation method, as per crop requirement. After uprooting haulms, fresh plant samples (250 g haulm from each plot) were sun dried and oven drying at 62^{o} C until constant weight was achieved. After harvesting, 100 g tubers were randomly sampled from each plot. Sampled tubers were sliced for drying. Sliced tubers were sun dried and then oven dried at 62^{0}C until constant weight was achieved. Oven dried samples were weighed. Based on oven dried haulm and tuber weight, total haulm and tuber dry weight were worked out in t/ha. The harvest index was calculated by dividing the economic yield (total tuber yield) with total biological yield per net plot and then expressed as per cent.

$$\text{Harvest index (\%)} = \frac{\text{Economic yield per plot}}{\text{Biological yield per plot}} \times 100$$

$$\text{Tuber dry matter content (\%)} = \frac{\text{Dry weight of tuber}}{\text{Fresh weight of tuber}} \times 100$$

A total of 252, 270 and 360 mm water was applied in drip, sprinkler and ridge-furrow irrigated potato, respectively including 49.4 mm winter rains. Cost of irrigation and nutrient management was calculated by taking into account all items as per prevailing market rates. Both costs including common cost was added to get the total cost of cultivation of each treatment. Tuber yield was multiplied with market sale rate to get gross return. For getting net return of each treatment, cost of cultivation was subtracted by gross return with respective treatments. B : C ratio was worked out dividing gross return with cost of cultivation.

At the end of experiment, soil samples were drawn from each plot to access the nutrient status under different treatments. The yield of tubers/plot was recorded at the end of the experiment , graded in <25g, 26-50g, 51-75g, >76g and total (all) grades and expressed into metric tonnes/ha. The results obtained were subjected to statistical analysis. At the end of the experiment, total amount of water applied was calculated for each irrigation treatment and the water use efficiency (kg/ha-mm) was calculated as per the formula:

$$\text{Water-use efficiency (kg/ha-mm)} = \frac{\text{Total yield of tubers (kg/ha)}}{\text{Total water applied (mm)}}$$

RESULTS AND DISCUSSION

Growth attributes: Highest emergence was recorded under drip irrigation (94%) which was significantly higher than ridge – furrow irrigation system (92.4%). Emergence under sprinkler system was statistically similar with drip irrigation system. Among nutrient management practices, dhaincha (green manure) – potato with 75% RDF NPK recorded highest emergence count (94.6%) which was significantly higher than Fallow – potato (FYM7.5 t/ha + Crop residue 7.5 t/ha + biofertilizers –*Azotobacter* and PSB) but statistically similar with other nutrient management treatments. Significantly higher emergence count (97%) was recorded under drip irrigation x green gram – potato (75% RDF NPK) interaction. Highest plant height was recorded under drip irrigation system (66.5 cm) which was significantly higher than ridge – furrow irrigation system (62.8 cm). Plant height under sprinkler system was statistically same with drip irrigation system. Among nutrient management practices, dhaincha (green manure) – potato with 75% RDF NPK recorded the highest plant height (67.9 cm), significantly higher than all other nutrient management treatments. Significantly higher plant height (71.3 cm) was recorded under drip irrigation x dhaincha green manure – potato (75% RDF NPK) interaction. Number of stem/plant was statistically same under all irrigation treatments. Nutrient management practices did not significantly affect the number of stem/plant. Similarly, interaction of irrigation method and nutrient management practices did not significantly affect the number of stem/plant. Highest number of compound leaves/plant was recorded with drip irrigation (63.0) which was significantly higher than ridge – furrow irrigation but statistically same with sprinkler irrigation. Number of compound leaves / plant was statistically same under all nutrient management practices (Table 1). Significantly higher compound leaves/plant (72.1) was recorded under drip irrigation x dhaincha green manure – potato (75% RDF NPK) interaction. Badr *et al.* (2012) also observed appropriate soil moisture can promote the absorption and utilization of soil nutrients by potatoes.

Table 1. Effect of irrigation methods and nutrient management practices on growth and yield attributes of potato (two years mean data).

Treatments	Growth attributes				Number of tubers ('000/ha)					
	Plant Emergence (%)	Plant height (cm)	Stem/ plant	Compound leaves/ plant	<25g	25-50g	51-75g	>76g	Total	Crack tuber (%)
Irrigation methods (A)										
Drip irrigation	94.0	66.5	4.8	63.0	183	119	92	181	575	6.6
Sprinkler	92.9	66.1	4.6	61.1	178	124	92	158	552	4.9
Ridge-furrow	92.4	62.8	4.5	56.0	181	124	95	172	572	4.6
SEm+	0.4	0.7	0.1	1.2	6.3	3.4	3.1	1.8	11.2	0.6
CD (P=0.05)	1.3	2.6	NS	4.2	NS	NS	NS	6.2	NS	NS
Nutrient management /previous crop (B)										
Fallow - potato (100% RDF NPK)	93.5	64.6	4.6	58.1	173	123	91	163	550	5.7
Green gram - potato (75% RDF NPK)	93.8	64.7	4.7	60.9	200	125	93	169	587	4.9
Dhaincha - potato (75%RDF NPK)	94.6	67.9	4.9	62.1	189	120	104	191	604	6.0
Fallow – potato (FYM15 t/ha + 50% RDF NPK)	94.2	65.8	4.7	61.7	167	123	95	184	569	5.0
Fallow – potato {FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers (*Azotobacter* and PSB)}	89.3	62.8	4.4	57.3	176	121	82	144	523	5.0
SEm+	0.9	0.7	0.2	1.9	5.7	4.9	2.7	5.1	9.2	1.0
CD (P=0.05)	2.5	2.0	NS	NS	16.5	NS	7.9	14.5	26.4	NS
Interaction										
Factor(B) at same level of A										
SEm+	0.8	1.7	0.3	2.7	14.0	7.6	7.0	3.9	25.1	1.3
CD (P=0.05)	4.4	3.7	NS	9.7	30.8	NS	NS	25.5	NS	NS
Factor(A) at same level of B										
SEm+	1.4	1.3	0.3	3.2	10.9	8.3	5.3	8.0	18.1	1.6
CD (P=0.05)	4.1	4.1	NS	9.4	33.6	NS	NS	23.4	NS	NS

Number of tubers

Effect of irrigation methods

Irrigation methods showed non-significant effect on <25g, 26-50g, 51-75g and total tubers which ranged from 178 to 183, 119 to 124, 92 to 95, and 552 to 574 thousand/ ha, respectively. Highest number of >76g tubers was recorded with Drip irrigation (181 thousand/ha) which was significantly higher than other two irrigation methods (Table 1).

Effect of nutrient sources and interaction of nutrients and irrigation

Highest number of <25g tubers (200 thousand/ha) was recorded with greengram-potato which was significantly higher than all other treatments except dhaincha-potato (75% RDF). Interaction of drip irrigation methods x green gram – potato (75% RDF NPK/ha) nutrient application recorded highest number of <25g tubers. Number of 25-50g tubers/ha was statistically same under different nutrient management practices.

Similarly method of irrigation x nutrient management practices did not significantly affect 25-50g tubers. Highest number of 51-75g tubers (104 thousand/ha) was recorded with dhaincha-potato (75% RDF NPK/ha) which was significantly higher than all other treatments. Interaction of irrigation x nutrient management method did not show any significant effect on number of 51-75g tubers. Drip irrigation method recorded highest number of >76g tubers (181 thousand/ ha) which was significantly higher than all other irrigation methods. Number of >76g tubers differed significantly due to nutrient management practices. Highest number of >76g tubers(191 thousand/ha) was recorded with dhainch-potato (75% RDF NPK/ha) which was significantly higher than all other treatments except fallow-potato (50% RDF + FYM@15 t/ha). Interaction of drip irrigation methods x dhainch-potato (75% RDF NPK/ ha) nutrient application recorded highest number (210 thousand/ha) of >76g tubers. Highest total number (604 thousand/ha) was recorded with dhaincha - potato (75% RDF NPK/ha) which was significantly higher than all other treatments except green gram - potato (75% RDF NPK/ha). Interaction of irrigation x nutrient management method did not significantly affect the total number of tubers (Table 1). This might be due to the beneficial residual effect of kharif dhaincha as a green manure crop by fixing atmospheric nitrogen through biological means and which may be available to mineralization of plant residues, thereby increasing the growth and yield of succeeding crop. The observations are in agreement with Carter *et al.* (2009).

Grade wise yield

Effect of irrigation methods

The grade wise yield of tubers (t/ha) at harvest showed non-significant effect under irrigation methods on 25-50g. Highest tuber yield (2.6 t/ha) of <25g tubers was recorded with sprinkler irrigation which was significantly higher than other two irrigation methods. Highest yield of 51-75g tuber (6.4 t/ha) was recorded with drip irrigation which was significantly higher than all other treatments. Similarly, highest yield of >76g tuber (22.5 t/ha) was recorded with drip irrigation which was significantly higher than all other irrigation treatments. The highest total tuber yield (35.8 t/ha) was recorded with drip irrigation, significantly higher than all other treatments.

Effect of nutrient sources and interaction of nutrients and irrigation

The grade wise yield of 25-50g tubers (t/ ha) at harvest showed non-significant effect under different nutrient management practices and irrigation methods x nutrient management interaction. Highest tuber yield (2.9 t/ha) of <25g tubers was recorded with green gram-potato (75% RDF NPK) which was significantly higher than all other treatments. Interaction of Sprinkler irrigation method x green gram-potato (75% RDF NPK) nutrient management recorded highest tubers yield (3.1 t/ha). Highest tuber yield (6.9 t/ha) was recorded with dhaincha - potato (75% RDF NPK/ha) under 51-75g tubers which was significantly higher than all other treatments. Highest tuber yield (7.5 t/ha) was recorded in Drip irrigation method x fallow- potato (15 t FYM + 50% RDF NPK/ha) nutrient management practices. Similarly, highest >76g tuber yield (23.9 t/ ha) was recorded with dhaincha - potato (75% RDF NPK/ha) which was significantly higher than all other treatments. Highest >76g tuber yield (25.9 t/ha) was recorded in Drip irrigation method x dhaincha - potato (75% RDF NPK/ha) nutrient management. Highest total tuber yield (37.5 t/ha) was recorded with dhaincha - potato (75% RDF NPK) which was significantly higher than all other treatments except fallow - potato (15 t FYM + 50% RDF NPK/ha). Highest total tuber yield (40.3 t/ha) was recorded in Drip irrigation method x fallow-potato (15 t FYM + 50% RDF NPK/ha) nutrient management. A reduced nutrient supply leads stomatal closure, thus indirectly impairing photosynthesis. The observations are in agreement with those recorded by Carter *et al.* (2009).

Tuber cracking

Effect of irrigation methods

The Number of crack tubers at harvest showed non-significant effect under irrigation methods. Maximum number of crack tuber (6.6%) was recorded with drip irrigation and minimum number of crack tuber (4.6%) was recorded with furrow irrigation. The Yield of crack tubers (t/ha) showed non-significant effect under irrigation methods. Maximum Yield of crack tubers (11.9 t/ha) was recorded with Drip irrigation and minimum yield of crack tubers (9.0 t/ha) was recorded with ridge-furrow irrigation.

Effect of nutrient sources and interaction of nutrients and irrigation

The Number of crack tubers at harvest showed non-significant effect with respect to nutrient sources. Number of maximum crack tuber (6.0%) under dhaincha – potato (75% RDF NPK/ha) sequence and minimum number of crack tuber (5.0%) under fallow – potato FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers – (*Azotobacter* and PSB) sequence. The yield of crack tubers (t/ha) showed significant effect on nutrient sources. Maximum yield of crack tubers (12.9%) was recorded under dhaincha - potato (75% RDF NPK/ha) sequence which was significantly higher than fallow - potato FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers – (*Azotobacter* and PSB) (5.4%) but statistically same with other treatments. Interaction of Drip irrigation method x fallow - potato (100% RDF NPK/ha nutrient management) recorded highest value 17.8%.

Fresh and dry haulm yield, dry tuber yield and biological yield on dry weight basis (t/ha)

Effect of irrigation methods

It was observed that differences in fresh and dry haulm yield, dry tuber yield and biological yield on dry weight basis (t/ha) at harvest were significant under different irrigation methods. Maximum fresh haulm yield (25.6 t/ha) was recorded under drip irrigation, which was significantly higher than that of sprinkler and ridge-furrow irrigation methods. Maximum dry haulm yield (3.3 t/ha) was recorded under drip irrigation which was significantly higher than sprinkler (3.0 t/ha) and ridge-furrow irrigation (2.9 t/ha). Maximum biological yield (10.3 t/ha) on dry weight basis was recorded under drip irrigation which was significantly higher than other two irrigation methods. These findings are accordance with Pawar *et al.* (2002).

Effect of nutrient sources and interaction of nutrients and irrigation

Each plant passes through the vegetative as well as reproductive phases of growth to complete its life cycle. Yield can be considered the final expression of plants' physiological and metabolic activities and is governed by various factors. These yield-attributing factors have direct bearing on plant productivity and for increasing the yield that means the yield attributing parameter play an important role. The fresh and dry haulm yield (t/ha) differed significantly with respect to nutrient sources (Table 2). The maximum fresh haulm yield (26.6 t/ha) was recorded under fallow - potato (50% RDF NPK/ha + 15 t/ha FYM) sequence which was significantly higher than

Table 2. Effect of irrigation methods and nutrient management practices on yield and fresh and dry haulm yield and harvest index of potato (two years mean data).

Treatments	Yield of tubers (t/ha)					Crack tuber yield (%)	Haulm yield (t/ha)		Dry tuber yield (t/ha)	Biological yield (t/ha)
	<25g	25-50g	51-75g	>76g	Total		Fresh	Dry		
Irrigation methods (A)										
Drip irrigation	2.4	4.5	6.4	22.5	35.8	11.9	25.6	3.3	7.4	10.7
Sprinkler	2.6	4.2	5.6	21.3	33.7	9.3	23.2	3.0	6.5	9.5
Ridge-furrow	2.3	4.3	5.6	18.6	30.8	9.0	22.7	2.9	5.6	8.5
SEm+	0.0	0.1	0.2	0.3	0.2	0.8	0.4	0.0	0.0	0.1
CD (P=0.05)	0.1	NS	0.6	1.1	0.8	NS	1.3	0.2	0.2	0.3
Nutrient management /previous crop (B)										
Fallow - potato (100% RDF NPK)	2.2	4.4	5.1	19.4	31.1	11.4	21.7	2.9	5.6	8.5
Green gram - potato (75% RDF NPK)	2.9	4.5	5.8	20.5	33.7	9.7	25.9	3.3	6.4	9.7
Dhaincha - potato (75%RDF NPK)	2.5	4.2	6.9	23.9	37.5	12.9	25.5	3.2	7.3	10.5
Fallow – potato (FYM15 t/ha + 50% RDF NPK)	2.3	4.3	6.2	23.2	36.0	11.0	26.6	3.3	6.6	9.9
Fallow – potato {FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers (*Azotobacter* and PSB)}	2.3	4.3	5.4	17.1	29.1	5.4	19.3	2.4	6.6	9.0
SEm+	0.1	0.2	0.2	0.5	0.5	1.2	0.5	0.1	0.1	0.1
CD (P=0.05)	0.1	NS	0.5	1.3	1.5	3.5	1.3	0.2	0.3	0.3
Interaction										
Factor(B) at same level of A										
SEm+	0.1	0.3	0.4	0.7	0.5	1.9	0.9	0.1	0.1	0.2
CD (P=0.05)	0.3	NS	0.8	2.3	2.6	6.3	2.4	0.3	0.5	0.6
Factor(A) at same level of B										
SEm+	0.1	0.3	0.3	0.8	0.8	2.1	0.8	0.1	0.2	0.2
CD (P=0.05)	0.2	NS	0.9	2.3	2.4	6.2	2.4	0.3	0.5	0.6

fallow - potato (100% RDF NPK/ha) and fallow-potato FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers – (*Azotobacter* and PSB). Interaction of Drip irrigation method x fallow - potato (50% RDF NPK/ha + 15 t/ha FYM) nutrient management recorded highest value (29.6 t/ha). The maximum dry haulm yield (3.3 t/ha) was recorded under fallow - potato (50% RDF NPK/ha + 15 t FYM/ ha) sequence which was significantly higher than fallow-potato 100% RDF NPK/ha and fallow-potato FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers – (*Azotobacter* and PSB). Interaction of Drip irrigation method x fallow - potato (75% RDF NPK/ha + 15 t FYM/ha) nutrient management recorded highest value (3.7 t/ha).

The maximum dry tuber yield (7.3 t/ ha) was recorded under dhaincha - potato (75% RDF NPK/ha) sequence which was significantly higher than all other treatments. Interaction of Drip irrigation method x FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers – (*Azotobacter* and PSB nutrient management recorded highest value 8.5 t/ ha. The maximum biological yield (10.5 t/ha) on dry weight basis was recorded under dhaincha - potato (75% RDF NPK/ ha) sequence, significantly higher than all other treatments. Interaction of Drip irrigation method x dhaincha - potato (75% RDF NPK/ ha) nutrient management recorded highest value11.0 t/ha. This might be because of beneficial residual effect of kharif dhaincha as a green manuring crop by fixing atmospheric nitrogen through biological means and which may be available to mineralization of plant residues thereby increases the growth and yield of succeeding crop. The dhaincha – potato cropping sequence improved the soil health in respect of physical, chemical and biological properties which creates favorable condition for growth and development of crops and ultimately helps to increase the yield of potato crop. These results conform with the findings of Mohammed *et al.* (2016).

Harvest index (%)

Effect of irrigation methods

It was observed that differences in harvest index (%) was significant under different irrigation methods. Highest harvest index (72%) was recorded with drip irrigation which was significantly higher than other two irrigation methods. The present results are in conformity with the findings of Mohammed *et al.* (2016).

Effect of nutrient sources and interaction of nutrients and irrigation

The harvest index differed significantly with respect to nutrient sources. The maximum harvest index (72 %) was recorded under fallow – potato sequence with FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers (*Azotobacter* and PSB) which was significantly higher than all other treatments. Interaction of Drip irrigation method x fallow-potato FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers – (*Azotobacter* and PSB) sequence nutrient management recorded highest value 78.4%. Similar results were recorded by Waqas *et al.* (2021).

Water-use efficiency

Effect of irrigation methods

Water being a scarce input, its efficient use in agriculture is the serious concern for the country. Maximization of crop production per unit of water used had to be opted by using modern irrigation methods in agriculture. Looking to the performance of different irrigation methods on water use efficiency (Table 3), it was observed that differences in Water-use efficiency(WUE) (kg/ha-mm) was significant under different irrigation methods. Maximum Water-use efficiency (137 kg/ha-mm) was recorded under drip irrigation which was significantly higher than sprinkler and ridge-furrow irrigations (107 kg/ha-mm). This might be due to maintaining proper moisture and nutrient availability in rootzone through out growth period as per crop need which resulted in higher yield with lesser applied water. These results are in accordance with Pawar *et al.*, (2002) and Yuan *et al.*, (2003).

Effect of nutrient sources and interaction of nutrients and irrigation

The water-use efficiency differed significantly with respect to nutrient sources. Maximum water-use efficiency (130 kg/ha-mm) was recorded under fallow - potato (50% RDF NPK + 15 t/ha FYM) sequence which was significantly higher than all other treatments. Interaction of Drip irrigation method x fallow – potato (FYM 7.5 t/ha + 50% RDF NPK) sequence recorded highest value 155 kg tuber/ha-mm.

Soil analysis

pH and OC of soil after potato harvest

Effect of irrigation methods

The chemical properties of soil viz., pH and organic carbon were determined before experiment and after experiment of crop under different irrigation methods. Table

Table 3. Effect of irrigation methods and nutrient management practices on nutrient uptake, nutrient status of soil and WUE (two years mean data)

Treatments	Tuber nutrient uptake (kg/ha)			Nutrient status of soil					Harvest index (%)	WUE (kg/ha-mm)
	N	P	K	pH	OC (%)	N (kg/ ha)	P (kg/ ha)	K (kg/ ha)		
Irrigation methods (A)										
Drip irrigation	75	15	136	6.9	0.47	216	20	424	72	137
Sprinkler	67	16	124	6.9	0.46	207	20	423	69	107
Ridge-furrow	60	13	104	6.9	0.46	200	20	422	63	107
SEm+	3.5	0.8	1.1	0.0	0.01	1.38	0.0	0.8	0.3	0.6
CD (P=0.05)	NS	NS	4.0	NS	NS	4.02	NS	NS	1.1	2.3
Nutrient management /previous crop (B)										
Fallow - potato (100% RDF NPK)	56	13	103	6.9	0.44	204	19	409	66	105
Green gram - potato (75% RDF NPK)	68	14	119	6.9	0.47	208	20	430	66	120
Dhaincha - potato (75%RDF NPK)	77	18	142	6.8	0.49	216	21	446	69	122
Fallow – potato (FYM15 t/ha + 50% RDF NPK)	69	16	124	6.9	0.46	211	21	425	66	130
Fallow – potato {FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers (*Azotobacter* and PSB)}	66	13	120	6.9	0.45	200	19	405	72	109
SEm+	1.9	0.6	2.2	0.0	0.01	1.97	0.1	2.6	0.5	1.6
CD (P=0.05)	5.4	1.8	6.5	NS	0.03	6.14	0.2	7.6	1.6	4.7
Interaction										
A x B										
SEm+	7.7	1.7	2.6	0.1	0.01		0.1	1.7	0.7	1.4
CD (P=0.05)	10.5	NS	11.4	NS	NS	NS	NS	NS	2.8	8.3
BxA										
SEm+	4.5	1.3	3.7	0.1	0.02		0.1	4.2	0.9	2.6
CD (P=0.05)	14.7	NS	10.8	NS	NS	NS	NS	NS	2.7	7.6

3 presented a slight improvement, but no remarkable change was found in chemical properties under different irrigation methods. It was observed that differences in pH and OC of soil after potato harvest were non-significant under different irrigation methods.

Effect of nutrient sources and interaction of nutrients and irrigation

The pH, after potato harvest differed non-significantly with respect to nutrient sources. (Table 3) and OC of soil showed slight variation which was significant. Highest OC (0.49%) was recorded with dhaincha - potato which was significantly higher than fallow-potato (100% RDF NPK) and fallow-potato without inorganic suppy of nutrients. Interaction of irrigation method x nutrient management was found to be non-significant.

Available N, P, and K (kg/ha) of soil after potato harvest.

Effect of irrigation methods

It was observed that differences in available nitrogen of soil after potato harvest were significant under different irrigation methods. However, phosphorus and potassium were non- significant under different irrigation methods (Table 3). The maximum nitrogen of soil (216 kg/ha) was recorded under drip irrigation which was significantly higher than other two methods.

Effect of nutrient sources and interaction of nutrients and irrigation

The available nitrogen, phosphorus and potassium of soil after potato harvest differed significantly with respect to nutrient sources. The maximum nitrogen (216 kg/ha) was recorded under dhaincha – potato sequence with 75% RDF NPK which was significantly higher than all other treatments except fallow-potato (50%RDF NPK + 15 t FYM/ha). Results are in conformity with Wang *et al.* (2020). Interaction of irrigation method x nutrient management was found to be non-significant. The maximum phosphorus (21 kg/ha) was recorded under dhaincha - potato sequence with 75% RDF NPK which was significantly higher than all other treatments except fallow-potato (50%RDF NPK + 15 t FYM/ha). Interaction of irrigation method x nutrient management was found to be non-significant for available P. Similar trend was also recorded for potassium wherein highest available K content (446 kg/ha) was recorded with dhaincha - potato sequence with 75% RDF NPK which was significantly higher than all other treatments except fallow-potato (50%RDF NPK + 15 t FYM/ha). Interaction of irrigation method x nutrient management was found to be non-significant for available K. This clearly reveals that, dhaincha as green manuring crop in rotation helps to maintain the organic matter and increases the availability of nutrients to potato crop. The observations are in agreement with Xing *et al.* (2022).

Uptake of N, P, and K by tuber

Effect of irrigation methods

It was observed that differences in uptake of potassium by tuber were significant under different irrigation methods. While tuber nitrogen and phosphorus uptakes were non-significant under different irrigation methods (Table 3). Maximum tuber potassium uptake (136 kg/ha) was recorded under drip irrigation which was significantly higher than sprinkler (124 kg/ha) and ridge furrow (104 kg/ha) irrigation.

Effect of nutrient sources and interaction of nutrients and irrigation

The uptake of nitrogen, phosphorus and potassium by tuber differed significantly with respect to nutrient sources (Table 3). Maximum tuber nitrogen uptake (77 kg/ha) was recorded under dhaincha - potato sequence with 75% RDF NPK, significantly higher than all other treatments. Gitari *et al.* (2018) also reported that potatoes are nitrogen-intensive plants with low nitrogen uptake efficiency. The interaction of drip irrigation x dhaincha - potato (75% RDF NPK) sequence recorded the highest value of 83 kg/ha for N uptake. Maximum tuber phosphorus uptake (18 kg/ha) was recorded under dhaincha - potato sequence with 75% RDF NPK, significantly higher than all other treatments. Interaction of irrigation method x nutrient management was found to be non- significant for P uptake. Similar trend was also recorded for potassium uptake also.

Economics

The data on economics indicating cost of cultivation, gross return, net return and benefit cost ratio under different nutrient sources and irrigation methods are presented in Table 4. The cost involved in field operations common to all treatments. Highest cost of cultivation incurred in drip irrigation (₹ 149906/ha) among irrigation methods and with fallow - potato sequence (100% RDF NPK) (₹ 147306/ha). The lowest cost of cultivation (₹ 149180/ha) was recorded with ridge-furrow irrigation and with fallow – potato (FYM 7.5 t/ha + Crop residue 7.5t/ha + Biofertilizers – *Azotobacter* and PSB)

Table 4. Effect of irrigation methods and nutrient management practices on economics of potato production (two years mean data).

Treatments	Economics (₹/ha)			B:C
	Cost of cultivation	Gross return	Net return	
Irrigation methods (A)				
Drip irrigation	149906	459986	310080	3.10
Sprinkler	149180	409234	260054	2.74
Ridge-furrow	149180	349744	200564	2.34
SEm+		2709	2708	0.02
CD (P=0.05)		9558	9551	0.07
Nutrient management /previous crop (B)				
Fallow - potato (100% RDF NPK)	147306	385524	238218	2.60
Green gram - potato (75% RDF NPK)	146580	421633	275053	2.90
Dhaincha - potato (75%RDF NPK)	146580	439205	292625	2.99
Fallow – potato (FYM15 t/ha + 50% RDF NPK)	146353	421653	275300	2.88
Fallow – potato {FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers (*Azotobacter* and PSB)}	141600	363592	221992	2.56
SEm+	-	6226	6226	0.04
CD (P=0.05)	-	17929	17929	0.12
Interaction				
A x B				
SEm+	-	6058	6054	0.04
CD (P=0.05)	-	31564	31564	0.22
BxA				
SEm+	-	10018	10017	0.07
CD (P=0.05)	-	29325	29323	0.20

sequence (₹ 141600/ha). Highest gross return of ₹ 459986/ha was recorded under drip irrigation and ₹ 439205/ha with dhaincha - potato sequence (75% RDF NPK). The lowest gross return ₹ 349744/ha was recorded under ridge-furrow irrigation and ₹363592/ha with fallow – potato (FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers – *Azotobacter* and PSB) sequence. Highest net return ₹ 310080/ha was recorded under Drip irrigation and ₹ 292625/ha with dhaincha - potato (75% RDF NPK) sequence. The lowest net return ₹ 200564/ha was recorded under furrow irrigation and ₹ 221992/ha with fallow-potato (FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers *Azotobacter* and PSB). Highest benefit : cost (3.1) was recorded under drip irrigation, significantly higher than other irrigation methods. Benefit : cost was highest (2.99) with dhaincha - potato (75% RDF NPK) sequence which was significantly higher than Fallow -potato (100% RDF NPK) and Fallow – potato (FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers *Azotobacter* and PSB). The lowest benefit : cost (2.34) was recorded under ridge - furrow irrigation however it was lowest with fallow – potato (FYM 7.5 t/ha + crop residue 7.5 t/ha + biofertilizers (*Azotobacter* and PSB) sequence.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

ETHICAL STATEMENT

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

LITERATURE CITED

Abdo AI, Ahmed S E, Mohamed K Abdel-Fattah, El-Sayed M Desoky, Li Huitong and Linquan Wang (2020) Mitigating nitrate accumulation in potato tubers under optimum nitrogen fertilization with K-humate and calcium chloride *Journal of Cleaner Production* **259**:0-8

Badr MA, Abou Hussein SD, El-Tohamy WA and Gruda N (2010) Efficiency of subsurface drip irrigation for potato production under different dry stress conditions. *Gesunde Pflanz* **2**:63–70

Badr MA, El-Tohamy WA, Zaghloul AM (2012) Yield and water use efficiency of potato grown under different irrigation and nitrogen levels in an arid region. *Agric Water Manag* **110**:9–15

Bélanger G, Walsh JR, Richards JE, Milburn PH and Ziadi N (2002) Nitrogen fertilization and irrigation affects tuber characteristics of two potato cultivars. *Am J Potato Res* **79**:269–279

Carli C, Yuldashev F, Khalikov D, Condori B and Mares V (2014) Effect of different irrigation regimes on yield, water use efficiency and quality of potato (*Solanum tuberosum* L.) in the lowlands of Tashkent, Uzbekistan: A field and modeling perspective *Field Crops Research:* **163** (1): 90–99

Carter MR, Noronha C, Peters RD and Kimpinski J (2009) Influence of conservation tillage and crop rotation on the resilience of an intensive long-term potato cropping system: restoration of soil biological properties after the potato phase. *Agric Ecosyst Environ* **133**:32–39

El Mokh F, Nagaz K, Masmoudi MM and Mechlia NB (2015) Yield and water productivity of drip-irrigated potato under different nitrogen levels and irrigation regime with saline water in arid Tunisia. *Am J Plant Sci* **6**:501–510

Ekin Z (2019) Integrated use of humic acid and plant growth promoting rhizobacteria to ensure higher potato productivity in sustainable agriculture. *Sustainability* **11**:3417

FAOSTAT (2023) Food and Agriculture Organisation (FAOSTAT). Available at:http://www.fao.org/faostat/en/#data/QC. Revised on September 2023

Gitari HI, Nancy NK, Charles KKG, Kamau S, Sharma K and Schulte-Geldermann E (2018) Nitrogen and phosphorous uptake by potato (*Solanum tuberosum* L.) and their use efficiency under potato-legume intercropping systems *Field Crops Research* **222**: 78-84

Mohammed ZA, Derek HL, Sharifi M, David LN and Andrew MH (2016) The effect of green manure and organic amendments on potato yield, nitrogen uptake and soil mineral nitrogen *Biological Agriculture & Horticulture* **32**: 221-236

Pawar DD, Bhoi PG and Shinde SH (2002) Effect of irrigation methods and fertilizer levels on yield of potato (Solanum tuberosum). *Indian Journal of Agricultural Sciences* **72**(2):80–2

Šrek P, Hejcman M and Kunzová E (2010) Multivariate analysis of relationship between potato (Solanum tuberosum L.) yield, amount of applied elements, their concentrations in tubers and uptake in a long-term fertilizer experiment. *Field Crop Res* **118**:183–193

Wang F, Kang Y and Liu S (2006) Effects of drip irrigation frequency on soil wetting pattern and potato growth in North China Plain. *Agric Water Manag* **79**:248–264

Wang X, Guo T, Wang Y, Xing Y, Wang Y and He X (2020) Exploring the optimization of water and fertilizer management practices for potato production in the sandy loam soils of Northwest China based on PCA *Agricultural Water Management* **237**:106-180

Waqas MS, Cheema MJM, Hussain S, Ullah MK and Iqbal MM (2021) Delayed irrigation: An approach to enhance crop water productivity and to investigate its effects on potato yield and growth parameters *Agric Water Manag* **245**:106-576

Xing Y, Zhang T, Jiang W, Li P, Shi P, Xu G, Cheng S, Cheng Y, Zhang F, Xiukang (2022) Effects of irrigation and fertilization on different potato varieties growth, yield and resources use efficiency in the Northwest China *Agricultural Water Management* **261**:01-23

Yuan B, Nishiyama S and Kang Y (2003) Effects of different irrigation regimes on the growth and yield of drip-irrigated potato. *Agric Water Manag* **63**:153–167

MS Received : September 22, 2023; Accepted : May 31, 2024

Potato J (2024) 51 (1): 62-77

SELECTION OF POTENTIAL CHIPPING ADVANCED POTATO CLONES FOR THE PROCESSING INDUSTRY IN SOUTHERN AND EASTERN INDIA

VK Gupta, Salej Sood, Vinay Bhardwaj[2], Vikas Mangal[2*], SK Luthra[1] and Bandana[1]

ABSTRACT: A multi-location evaluation of 60 advanced processing clones was undertaken in the selected locations of south viz., Karnataka (Rabi and Kharif), Tamil Nadu (Kharif), Telangana (Rabi) and in Rabi crop season of West Bengal. Based on four-year trials, among advanced clones, viz., MP/12-126 consistently outperformed others during 2020-21, 2021-22 and 2022-23 in the Rabi season at different locations in Karnataka. However, MP/12-126 had almost similar yield but acceptable quality parameters as compared to controls in the Kharif seasons of Karnataka and Tamil Nadu. MP/14-171 was found to have higher yield and acceptable quality traits during 2020-21, 2021-22 in the rabi season of Karnataka and Kharif season of Tamil Nadu during 2023. During the rabi season of West Bengal (2020-21, 2022-23) and the rabi season of Karnataka (2022-23) advanced clone MP/15-698 had superior performance. MP/15-651 was found to be the most widely adapted clone as it has superior performance in all states either in Rabi/Kharif or both. Based on a four-year field trial at multiple locations (6 locations) and seasons (rabi and kharif), advanced clones namely MP/12-126, MP/14-171, MP/15-651 and MP/15-698 have the potential to provide a suitable alternative to the potato growers of south and eastern India as against the existing variety/ varieties with acceptable chip colour, high dry matter (>20%) and lesser total potato defects including higher process grade potato yield as compared to controls.

Keywords: Potato, advanced clones, chipping, processing, Southern India, Eastern India

INTRODUCTION

Potato is the world's leading non-grain food crop, ranking fourth after wheat, maize, and rice (Devaux *et al.*, 2014). Potato varieties are classified into four types based on their intended use: table potatoes, food processing, industrial (starch and alcohol) production, and others like colourful potatoes (Mori *et al.*, 2015). Potato processing has been increasing in India at a rapid pace due to the changing habits of consumers, the growing interest of farmers and rapid expansions of the processing industry (Gupta *et al.*, 2021a). Processed products cannot be made with any potato variety and need varieties with specific traits. The tuber specific gravity, dry matter, chip colour, reducing sugars, glycoalkaloids and starch contents of a variety are critical features determining the quality of processed potato products (French fries and chips) (Kaur and Aggarwal, 2014; Wayumba, 2019). Therefore, the selection of varieties should not be limited only to high yield but also to the desired aforementioned traits (Hussen, 2019).

The industry requirements for processing chips regarding tuber appearance are shallow eyes, appropriate size, and round-oval shape. In addition, tubers should be free from hollow hearts, cracks, secondary damage, rusty spots, and greening. Tubers ranging from 45 to 85 mm diameter are ideal for producing the desired chip size. To make uniform chips round tubers are preferred; however, oval tubers can also be used for chip production. A dry matter content of >20 per cent is considered acceptable for chips, French fries and dehydrated products. Higher dry matter or solids content results in higher processed

---

[1]ICAR-Central Potato Research Institute, Regional Station, Modipuram, Meerut - 250110, Uttar Pradesh, India
[2]ICAR-Central Potato Research Institute, Shimla - 171 001, Himachal Pradesh, India
*Corresponding author; email: vikas90bharatpur@gmail.com

product recovery, lower oil absorption, less energy consumption, and a crispy texture in the finished products. The reducing sugars (glucose and fructose) found in tubers play an important role in the colour of fried products such as chips and French fries. Processing potatoes recorded moderate tuber yield but had high soluble protein and high ascorbic acid, low reducing sugars, low sucrose, low phenols and low total free amino acids (Luthra *et al.,* 2018). Reducing sugar content below 100 mg/100g fresh tuber weight is acceptable for producing chips. On the Colour score card, a colour up to 3 is desirable for chips and a colour up to 4 is desirable for French fries (Luthra *et al.*, 2020).

The potato processing industry has expanded all across the country and in that line several processing units have been established in Southern and Eastern India. There are several challenges in growing processing potatoes in Southern India including poor quality and low yield. Similarly, the availability of processing varieties is a major issue in Eastern India. The processing potatoes are transported from Central India to Southern potato processing units, which incur huge losses in transportation. Moreover, the industry has the viewpoint that either they have to transport air or water to these places. Therefore, CPRI in collaboration with Industry started the evaluation of advanced processing clones for their suitability in south and east Indian conditions where late blight and high temperatures during growth and development are major limiting factors. This study was designed to identify specialized potato clones with acceptable tuber quality for processing into chips under different Eastern and South Indian locations.

MATERIALS AND METHODS:

The material included in the study varied across the locations and years based on the availability of tuber material of selected clones. Multi-location field experiments were conducted across three locations, *Viz.*, Karnataka (Hiriyalachenahalli- Chikkaballapur District), West Bengal (Kotulpur – Bankura District) and Telangana (Zaheerabad District) in 2020-21, 2021-22 and 2022-23 during rabi season. In addition, the field experiments were also conducted across three locations, Viz., Kamalappur, Dharwad District & Lingadahalli, Chikmagalur District in Karnataka and Thalavadi- Erode District in Tamil Nadu during Kharif season 2021, 2022 and 2023. The entries' details are provided in Tables 1 to 17. The field trial locations in the North Eastern Plain Zone and Southern Plateau & Hills Zone were at an altitude of 78-915 meters above mean sea level (Chikkaballapur-915m, Zaheerabad-622m & Bankura-78 m). The soil was light red sandy loam in Chikkaballapur, clay loam in Zaheerabad, Dharwad, Chikamagalur, light sandy in Bankura and red sandy loam in Thalavadi. The experiment was laid in larger strips in entry row order. The plot size was 21.6 m^2. The good, healthy and pre-sprouted tubers were planted at a spacing of 6020 cm in all the locations. NPK fertilizers were supplied with urea, diammonium phosphate and muriate of potash respectively. A recommended package of practices was followed along with need-based plant protection measures. Tubers collected from each plot were weighed in kg for yield determination. The weight obtained per plot was then converted to tonnes per hectare. The yield (t/ha) data were recorded for process grade size (t/ha), undersize (t/ha) as well as total tuber yield (t/ha). The samples were analysed for standard quality attributes like dry matter (solid %), chip colour, external defects (ED), internal defects (ID) and total potato defects (TPoD).

The data collected from the multi-location field experiments were analyzed using mean values to compare the performance of the advanced potato clones. Mean yield and quality parameters were calculated for each clone across different locations and seasons using Microsoft Excel to identify superior clones based on overall performance.

RESULTS AND DISCUSSION

A total of 60 genotypes including 6 controls (Kufri Jyoti, K Kiran, K Surya, K Chipsona-5, K Sangam and Kufri Pukhraj) comprising popular/newly recommended heat tolerant, processing and table varieties over different years, seasons and locations were evaluated. The details of genotypes, locations and years are given in Table 17. The potential genotypes shortlisted in one season based on yield and quality parameters were assessed subsequently along with newly added entries during the next year. This is done continuously for six seasons and four potential entries were selected based on overall results.

Rabi 2020-21

In Karnataka and Telangana, the incidence of late blight was high due to mid-season rain

Table 1: Yield and quality parameters of advanced clones and varieties at Chikkaballapur, Karnataka (Rabi 2020-21)

Genotypes	Yield (t/ha)		% Increase Over Kufri Jyoti	Quality parameters (%)				
	Processable	Total		Solid	UC	ED	ID	TPOD
HT/12-830	11.8	17.2	-44.5	19	0	1.3	1.3	2.6
HT/12-834	13.6	22.2	-28.3	16.6	NA	NA	NA	NA
MP/9-73	17.7	27.0	-12.6	22.1	0	0	0	0
MP/10-172	15.7	22.3	-27.8	19	0	0	0	0
MP/13-1045	19.0	22.7	-26.7	16.8	NA	NA	NA	NA
MP/13-662	13.8	16.7	-46.1	22	8.1	0	0	8.1
MP/9-28	24.8	28.0	-9.4	22.6	0	0	0	0
MP/11-142	8.4	16.9	-45.4	21.5	1.7	0	0	1.7
MP/12-126	28.7	33.3	7.5	22	0	0.7	1.8	2.5
MP/14-1003	19.2	26.1	-15.6	19.8	0	0	0	0
MP/14-171	28.9	32.6	5.5	19.7	0	0	0	0
MP/14-1029	16.8	21.6	-30.2	20.6	0	0.6	0.7	1.3
MP/15-207	19.1	24.3	-21.4	19.6	0	0.7	1.4	2.1
MP/14-169	21.9	28.8	-6.9	23	0	0	0	0
MP/14-332	7.7	14.9	-52	19.9	0	5.4	0	5.4
MP/12-105	21.8	27.9	-9.9	22.7	1.6	0.9	0.5	3
MP/15-667	16.1	20.2	-34.8	23.1	0	0	0	0
MP/13-602	19.5	29.1	-5.8	21.5	4.2	3.2	5.3	12.7
MP/15-750	24.4	28.2	-8.9	22.8	0	0	0	0
MP/15-698	19.5	25.3	-18.2	20.3	0	0	0	0
K. Bhaskar	23.3	29.7	-3.9	18	24	7	2.3	33.3
K. Kiran	12.2	15.0	-51.7	19	1.5	3.6	1.5	6.6
K. Surya	11.8	12.8	-58.5	18.9	0	0	0	0
K. Chipsona-5	16.8	23.8	-23	21.9	0	0	7.1	7.1
K. Sangam	18.8	25.3	-18.3	17.9	0	0	0	6.5
K. Jyoti	27.7	30.9		17.5	8.3	2.8	2.2	14

***UC:** Undesirable Colour; **ED:** External Defects; **ID:** Internal defects; **TPOD:** Total Potato Defects; **NA:** Not Available and cloudy weather due to cyclonic depression. In West Bengal, the weather was conducive to potato growth and development, leading to successful cultivation. Based on yield potential and processing quality parameters, the promising entries were short-listed for further evaluation. Advanced clones viz., MP/12-126, MP/14-171 (33 t/ha) recorded 8% and 6 % higher total tuber yield and acceptable quality traits than the popular variety Kufri Jyoti in Karnataka (**Table 1**). In Telangana MP/13-1045 (31 t/ha), and HT/12-830 (36 t/ha) were found to be promising concerning total tuber yield and acceptable quality parameters (**Table 2**). K Chipsona-5 (32 t/ha), MP/13-662 (29 t/ha) and MP/15-698 (46 t/ha) outperformed others in total tuber yield and quality parameters in West Bengal (**Table 3**). Out of the selected entries across the locations three genotypes K. Chipsona-5 (West Bengal), MP/14-171 (Karnataka) and MP/15-698 (West Bengal) exhibited zero TPoD which is a desirable character for the chip industry, while the control variety Kufri Jyoti showed 14 and 46.2 TPoD at Karnataka and West Bengal, respectively (**Table 1, 2, 3**).

Kharif 2021

All the shortlisted entries of the previous season (Rabi 2020-21) along with new entries were evaluated in this season. The weather conditions were very conducive across all the trial locations for optimum growth and

Table 2: Yield and quality parameters of advanced clones and varieties at Zaheerabad, Telangana (Rabi 2020-21)

Genotypes	Yield (t/ha)		% Increase Over Kufri Pukhraj	Quality parameters (%)				
	Processable	Total		Solid	UC	ED	ID	TPOD
HT/12-830	31.5	35.7	6.7	17.3	0	0.8	0.7	1.5
HT/12-834	29.0	38.4	14.9	16.1	NA	NA	NA	NA
MP/9-73	11.6	19.3	-42.3	20.7	0	0	0	0
MP/10-172	14.3	18.9	-43.6	18.2	0	1.1	1.6	2.7
MP/13-1045	26.6	30.7	-8.3	19.5	0	0.9	0.6	1.5
MP/13-662	23.2	27.6	-17.6	19.4	0	0	0	0
MP/9-28	22.1	27.9	-16.5	21.3	0	0.8	0	0.8
MP/11-142	16.7	26.5	-20.7	18.6	0	1.6	0	1.6
MP/12-126	22.9	24.5	-26.7	19.6	5	1.6	1.5	8.1
MP/14-1003	14.7	19.6	-41.5	16.7	NA	NA	NA	NA
MP/14-171	19.1	21.8	-35	18.3	0	0	0	0
MP/14-1029	9.1	16.3	-51.4	19.2	0	0.5	0	0.5
MP/15-207	9.5	16.0	-52.3	17.6	3.8	2.2	2.7	8.7
MP/14-169	14.2	19.9	-40.6	19	0	0	0	0
MP/14-332	11.2	16.3	-51.2	17.5	24	3.4	1.2	28.6
MP/13-602	9.7	13.8	-58.8	19	2.1	2.7	3.7	8.5
K. Bhaskar	22.3	24.1	-27.9	16.1	NA	NA	NA	NA
K. Kiran	18.0	19.5	-41.6	18.5	0	5.4	0	5.4
K. Surya	28.3	30.8	-7.9	16	NA	NA	NA	NA
K. Chipsona-5	16.5	19.9	-40.6	20	0	0	0	0
K. Sangam	17.1	24.8	-25.9	18.1	0	0	0	0
K. Pukhraj	31.2	33.4		16.4	NA	NA	NA	NA

Table 3: Yield and quality parameters of advanced clones and varieties at Bankura, West Bengal (Rabi 2020-21)

Genotypes	Yield (t/ha)		% Increase Over Kufri Jyoti	Quality parameters (%)				
	Processable	Total		Solid	UC	ED	ID	TPOD
HT/12-830	36.0	40.4	27.9	18.7	29.7	3.4	2.3	35.4
HT/12-834	25.9	32.0	1.3	16.8	NA	NA	NA	NA
MP/9-73	17.7	23.2	-26.7	20.1	0	0	0	0
MP/10-172	22.0	26.3	-16.7	17.8	0	0	0	0
MP/13-1045	22.8	25.1	-20.6	15.9	NA	NA	NA	NA
MP/13-662	25.3	28.9	-8.5	20.5	0	0	0.5	0.5
MP/9-28	21.1	25.3	-19.9	20.3	1.2	0	0	1.2
MP/11-142	12.8	21.9	-30.5	18.6	33	4.3	6.3	43.6
MP/12-126	26.8	30.1	-4.7	20.4	3.4	26.4	0.8	30.6
MP/14-1003	20.2	25.1	-20.5	16.8	NA	NA	NA	NA
MP/14-171	20.0	23.1	-27	21	4.9	0.6	0.4	5.9
MP/14-1029	19.2	26.5	-16.2	20	0	2.3	0.9	4
MP/15-207	15.5	18.0	-42.9	18.9	37	0	13.2	50.2
MP/14-169	18.5	21.3	-32.5	17.2	2.2	0.7	0.8	4.8
MP/14-332	19.0	22.9	-27.4	20.2	0	0	0	0
MP/12-105	21.9	26.3	-16.6	21.2	49.7	12.6	14.6	76.9
MP/15-667	15.4	18.5	-41.4	20.6	0	0	0	0
MP/15-750	15.4	17.1	-45.9	19	37.3	0.9	4.4	42.6
MP/15-698	39.4	46.1	46.1	19	0	0	0	0
K. Bhaskar	31.9	35.3	11.7	16	NA	NA	NA	NA
K. Kiran	22.6	27.1	-14.2	18.6	0	0.7	0	0.7
K. Surya	19.8	25.1	-20.5	17.8	0	0.7	0	0.7
K. Chipsona-5	26.7	31.8	0.8	20.2	0	0	0	0
K. Sangam	14.6	17.6	-44.2	18.2	10.6	3.3	0	15.4
K. Jyoti	26.5	31.6		17.2	4.1	16.7	25.4	46.2

development in the initial crop growth period. This resulted in good early vigour and a lower incidence of disease. However, in the later stages of crop growth, high rainfall was received across all the trial locations, severely impacting the quality. Differential response of experimental entries was observed across locations for disease tolerance, bulking, tuber yield, grade outturn, quality, and sensory parameters. Among all, field tolerance to the hopper, mite and late blight was observed in MP/12-126, MP/12-105, MP/13-1045, MP/13-662 and earliness in MP/15-651. In trial entries, early tuberization and fast bulking were observed in the MP/12-126, MP/15-651 and MP/13-662 clones. Advanced clone MP/13-662 showed fast bulking and performed better in multiple locations. Based on field performance, yield and quality specifications two entries MP/13-662 (27 t/ha) and MP/15-651 (25 t/ha, **Table 4**) at Thalavadi and two clones MP/13-662 (13 t/ha) and MP/9-28 (15 t/ha, **Table 5**) at Dharwad locations were selected for further evaluation. Genotype MP/12-105 and MP/15-651 were noted for higher yield but MP/15-667, MP/16-334 and MP/16-173

Table 4: Yield and quality parameters of advanced clones and varieties at Thalavadi, Tamil Nadu (Kharif 2021)

Genotypes	Yield (t/ha)		% Increase Over Kufri Jyoti	Quality parameters (%)				
	Processable	Total		Solid	UC	ED	ID	TPOD
MP/10-172	16.0	20.1	-4.9	16.1	-	-	-	-
MP/13-1045	13.9	16.9	-34.2	21	2	1.5	0.7	4.2
MP/12-105	19.6	23.0	-10	18.2	7	26	15	48.0
MP/13-662	24.4	27.0	5.4	21.7	0	4.7	5.8	10.5
MP/9-28	16.9	19.0	-25.8	19.5	1.1	0	1.5	2.6
MP/12-126	20.6	23.5	-8.2	16.7	0	-	-	-
MP/14-171	12.2	16.4	-35.9	16.8	-	-	-	-
MP/15-207	9.7	12.1	-52.9	16.1	-	-	-	-
MP/15-698	12.4	12.6	-50.8	18.8	4.5	29	0	33.5
MP/15-667	8.4	10.0	-61.1	18	0.7	0	0.8	1.5
MP/14-635	15.5	18.9	-26.3	20	20	18	15	53
MP/16-104	10.0	13.4	-47.5	-	-	-	-	-
MP/16-86	19.0	24.3	-5	16.3	-	-	-	-
MP/16-334	1.5	1.9	-92.5	-	-	-	-	-
MP/16-185	9.3	11.8	-53.8	-	-	-	-	-
MP/16-178	7.2	10.3	-59.7	-	-	-	-	-
MP/16-431	10.7	21.8	-15	16.8	-	-	-	-
MP/16-171	4.9	5.4	-70	-	-	-	-	-
MP/16-173	11.0	15.1	-40.8	19	0	9.5	0	9.5
MP/15-651	24.2	25.3	-1	19.5	2	12	5.6	19.6
MP/15-699	5.3	6.6	-74.2	-	-	-	-	0.0
MP/16-315	14.5	18.6	-27.5	18.1	0	2.1	0.6	2.7
MP/16-157	7.8	10.5	-58.9	20.5	0	2	3.5	5.5
MP/16-316	7.8	10.8	-57.9	17.8	1.6	17.6	1	20.2
K. Chipsona-5	15.1	18.5	-27.7	17.8	3	12	6	21.0
K. Jyoti	23.2	25.6		16.1	-	-	-	-

exhibited 0, 0 and 1.7% undesirable colour (UC), respectively, whereas, Kufri Jyoti showed 35.9% (**Table 6**) **N**one of the clones/varieties were accepted due to moisture-induced tuber rot and related internal defects.

Rabi 2021-22

The trial was conducted in Karnataka and Telangana. In Karnataka, shortlisted entries *viz.*, MP/12-126 (40t/ha, field resistant to late blight) and MP/14-171 (26 t/ha) were promising for tuber yield and processing quality (**Table 7**). In Telangana, MP/15-651 (46 t/ha) and MP/17-745 (40t/ha) were promising in yield and quality parameters for making chips. However, MP/16-334 produced a higher yield (42 t/ha) but had high total potato defects 31% as against the permissible 15 % hence, it was not short-listed. (**Table 8**). Out of the selected entries at Karnataka and Telangana, four clones viz., MP/15-651, MP/16-315, MP/17-745 and MP/14-171 exhibited zero TPoD which is a desirable character for the chip industry.

Table 5: Yield and quality parameters of advanced clones and varieties at Dharwad, Karnataka (Kharif 2021)

Genotypes	Yield (t/ha)		% Increase Over Kufri Jyoti	Quality parameters (%)				
	Processable	Total		Solid	UC	ED	ID	TPOD
MP/10-172	14.5	16.8	-7.6	16.7	-	-	-	-
MP/13-1045	12.9	15.6	-13.8	-	-	-	-	-
MP/12-105	10.3	15.9	-12.3	18.8	2.15	4.83	0	7.0
MP/13-662	11.4	13.4	-26.2	17.8	0	20.4	7.2	27.6
MP/9-28	12.5	15.0	-17.1	19.1	0	4.7	1.1	5.8
MP/12-126	14.9	18.1	-0.4	16.8	-	-	-	-
MP/14-171	9.1	10.6	-41.6	-	-	-	-	-
MP/15-207	3.3	4.8	-73.7	-	-	-	-	-
MP/15-698	7.7	9.9	-45.3	-	-	-	-	-
MP/15-667	8.0	9.6	-47	-	-	-	-	-
MP/14-635	9.0	13.1	-28	-	-	-	-	-
MP/16-104	10.0	13.4	-47.5	-	-	-	-	-
MP/16-86	7.8	10.8	-40.7	18.5	0	0	0	0
MP/16-334	6.0	7.6	-58	-	-	-	-	-
MP/16-185	3.0	4.7	-73.9	-	-	-	-	-
MP/16-178	8.9	12.7	-29.9	-	-	-	-	-
MP/16-431	4.3	6.0	-67.1	17.5	0	28	12	40
MP/16-171	4.9	5.4	-70	-	-	-	-	-
MP/16-173	9.2	12.9	-28.7	21	-	-	-	-
MP/15-651	10.4	13.5	-25.5	18.8	0	0	33.4	33.4
MP/16-315	4.6	5.8	-68	-	-	-	-	-
MP/16-157	2.8	3.8	-79.1	-	-	-	-	-
K Chipsona-5	6.3	8.3	-54	-	-	-	-	-
Kufri Jyoti	14.5	18.1	-	-	-	-	-	-

Kharif 2022

All the trial locations received continuous and excessive rainfall throughout the cropping season. Rainfall intensity was high in Dharwad, followed by Chikmagalur and Thalavadi. Previously shortlisted entries viz., MP/12-126, MP/15-651 performed better in terms of both yield and quality at Thalavadi. Similarly, a new clone, MP/17-746 was found superior and stable across locations in terms of yield. However, it failed to qualify in the quality test due to high TPoD and bitter taste. Few entries exhibited some special traits like field tolerance to the hopper, mite & late blight (MP/12-126, & MP/13-1045), earliness in maturity (MP/15-651), faster bulking (MP/12-126 & MP/15-651) and exceptionally high yield potential (MP/17-746). Advanced clones MP/13-662, MP/12-126, MP/16-178, MP/15-651, MP/17-428, MP/17-60, MP/17-216, were found to be promising at Thalavadi (**Table 9**). Low yield was found at Dharward (**Table 10**) except in clone MP/17-746 (25 t/ha). Clones MP/13-1045, MP/13-662, MP/16-178, MP/17-610, MP/17-60 & MP/17-216 were found to be the best at Chikmagalur (**Table 11**).

Table 6: Yield and quality parameters of advanced clones and varieties at Chikamaglur, Karnataka (Kharif 2021)

Genotypes	Yield (t/ha)		% Increase Over Kufri Jyoti	Quality parameters (%)				
	Processable	Total		Solid	UC	ED	ID	TPOD
MP/10-172	11.3	13.9	-52.1	-	-	-		-
MP/13-1045	23.8	26.5	-8.6	16	-	-	-	-
MP/12-105	28.8	32.4	11.6	22.3	22.3	0	0	22.3
MP/13-662	13.3	18.1	-37.6	-	-	-	-	-
MP/14-171	6.5	8.0	-72.4	16.1	-	-	-	-
MP/15-207	14.5	20.8	-28.2	-	-	-	-	-
MP/15-698	13.6	15.6	-46.3	-	-	-	-	-
MP/15-667	8.4	14.5	-50.1	21.4	0	0	-	0
MP/16-104	4.8	5.6	-80.8	-	-	-	-	-
MP/16-334	17.1	23.0	-20.8	19.2	25.8	0	0	25.8
MP/16-431	12.4	14.7	-49.4	18.2	47.8	-	-	47.8
MP/16-171	6.0	8.6	-70.5	17.1	97.5	0	0	97.5
MP/16-173	14.1	20.5	-29.5	21.3	1.7	0	0	1.7
MP/15-651	24.8	29.3	1	21.3	42.8	-	-	42.8
MP/15-699	6.0	8.1	-72	-	-	-	-	-
MP/16-315	2.9	3.8	-86.9	-	-	-	-	-
MP/16-157	1.1	1.5	-95	-	-	-	-	-
MP/16-316	8.1	11.5	-60.5	18	37.6	-	-	37.6
K Chipsona-5	15.9	20.2	-30.4	18.1	18.8	-	-	18.8
Kufri Jyoti	26.8	29.0	-	23.4	35.9	-	-	35.9

Rabi 2022-23

The trial locations in Karnataka and Telangana experienced adverse weather conditions resulting in reduced yield. The short-listed entries viz., MP/12-126 (21 t/ha), MP/14-171 (19 t/ha), MP/15-698 (21 t/ha) and MP/15-651 (20 t/ha) confirmed their consistency in yield and quality in Karnataka (**Table 12**). Similarly, the previously shortlisted entries MP/15-651 in Telangana and MP/12-126, MP/15-698 in West Bengal were found superior concerning yield and quality. The entries viz., MP/12-126 & MP/15-698 showed field tolerance to the hopper, mite and late blight. Similarly, natural senescence was observed in the clone MP/12-126, early maturity in MP/15-651, faster bulking in MP/12-126, MP/16-431 and MP/15-651and high tuber yield in MP/15-698. The clone MP/15-651 was observed natural senescence and better yield and quality performance across diverse environments and seasons. In West Bengal (**Table 13**), MP/15-698 (36 t/ha), MP/12-126, MP/15-651 (35 t/ha), MP/16-315 (34 t/ha) and MP/14-171 (27 t/ha) were found promising. In Telangana (**Table 14**), MP/15-651 (21 t/ha) and MP/17-155 (22 t/ha) showed promise for yield and quality traits.

Kharif 2023

In the Kharif season of 2023, previously shortlisted entries viz., MP/12-126, MP/15-651 and MP/17-746 outperformed others in yield and quality. Similarly, a new clone MP/18-285 was found superior and stable across locations in yield. The location-wise quality accepted clones were MP/13-662 (14 t/ha), MP/12-126

Table 7: Yield and quality parameters of advanced clones and varieties at Chikkaballapur, Karnataka (Rabi 2021-22)

Genotypes	Yield (t/ha)		% Increase Over Kufri Jyoti	Quality parameters (%)				
	Processable	Total		Solid	UC	ED	ID	TPOD
MP/16-334	17.0	20.7	-18.2	20.5	12.3	0	3	15.3
MP/16-185	23.3	26.4	4.5	21.3	0	0	0	0
MP/16-178	24.2	33.2	31.6	22.4	0	0	0	0
MP/16-173	28.4	37.8	49.8	22.4	0	7	0	7
MP/15-651	24.4	30.0	18.7	22	0	0	0	0
MP/15-699	9.3	11.1	-56	19	0	14.8	0	14.8
MP/16-315	23.6	26.0	2.9	22.3	0	0	0	0
MP/16-157	7.3	7.3	-71.3	21.9	18.9	0	13	31.9
MP/16-316	11.8	16.8	-33.5	21.3	3	2.1	9.9	15.0
MP/17-296	23.3	31.1	23	22.3	0	0	0	0
MP/17-709	19.6	23.6	-6.7	22.4	0	16.4	0	16.4
MP/17-745	21.6	25.9	2.4	23.1	0	0	0	0
MP/12-105	29.0	32.1	27.3	21.3	0	0	0	0
MP/12-126	37.0	40.4	60	22.3	0	2	4.8	6.8
MP/14-171	23.6	25.9	2.4	20.5	0	0	0	0
MP/14-169	8.1	11.8	-53.1	22.3	0	0	0	0
MP/14-635	17.4	21.0	-16.7	23.5	0	3.9	6.4	10.3
MP/16-104	18.9	26.7	5.7	21	0	22.2	0	22.2
MP/16-431	5.6	5.6	-78	19.2	3	7.6	0	10.6
Kufri Jyoti	22.6	25.3		19.2	0	0	6	6

Table 8: Yield and quality parameters of advanced clones and varieties at Zaheerabad, Telangana (Rabi 2021-22)

Genotypes	Yield (t/ha)		% Increase Over Kufri Jyoti	Quality parameters (%)				
	Processable	Total		Solid	UC	ED	ID	TPOD
MP/16-334	35.3	41.6	12.4	20.5	0	12.8	17.7	30.5
MP/16-185	25.1	30.0	-18.9	20.3	0	19.2	7.1	26.3
MP/16-178	28.5	33.4	-9.8	18.6	0	0	0	0
MP/16-173	16.7	23.7	-35.7	19.2	0	6.9	0	6.9
MP/15-651	41.1	45.9	24.2	19	0	4.2	2.1	6.3
MP/15-699	32.4	34.8	-5.9	18.7	0	0	0	0
MP/16-315	26.6	33.8	-8.4	18.7	0	0	0	0
MP/16-157	13.1	20.3	-45.1	22.3	0	22.2	0	22.2
MP/16-316	14.3	20.3	-45.1	19.6	0	2.7	11.8	14.5
MP/17-296	12.6	15.0	-59.4	19.5	0	0	0	0
MP/17-709	31.9	39.2	5.9	18.6	3	4.8	8.7	16.5
MP/17-745	31.4	39.6	7.2	21.3	0	3.9	6.6	10.5
MP/13-1045	34.1	37.5	1.4	16.1	0	8.3	1.6	9.8
MP/16-86	21.3	23.7	-35.9	19.4	0	0	0	0
MP/16-171	23.2	32.9	-10.9	19.4	0	0	0	0
HT/12-830	22.2	31.9	-13.7	17.5	0	6.3	0	6.3
Kufri Pukhraj	36.5	37.0		15.7	0	32.5	25.2	57.7

Table 9: Yield and quality parameters of advanced clones and varieties at Thalavadi, Tamil Nadu (Kharif 2022)

Genotypes	Yield (t/ha)		% Increase Over Kufri Jyoti	Quality parameters (%)				
	Processable	Total		Solid	UC	ED	ID	TPOD
MP/13-662	6.1	12.9	-30.6	19.2	4.8	1.1	6.3	12.2
MP/12-126	12.6	18.3	-1.4	18.6	5.6	3.2	6.9	15.7
MP/15-207	2.3	4.8	-73.9	18	8.6	3.2	4.8	16.6
MP/16-178	6.7	13.1	-29.4	17.5	3.4	3.1	2.9	9.4
MP/16-431	14.7	16.0	-13.9	20.2	7.2	2.9	5.6	16.4
MP/15-651	12.9	18.5	-0.3	20.2	4.8	1.2	2.1	8.3
MP/17-610	4.1	9.7	-47.6	18	11.2	2.1	3.9	17.2
MP/17-155	3.0	10.4	-21.5	19.2	7.7	3.2	5.6	17.4
MP/17-378	6.8	14.0	-24.3	20.2	5.2	1.2	3.6	10
MP/16-442	4.4	7.1	-61.4	18.2	100	0	0	100
MP/17-428	5.9	13.5	-27	18.2	2.3	3.1	3.9	9.3
MP/17-157	5.8	11.1	-40	18.2	3.9	2.1	11.3	17.3
MP/17-60	7.9	16.1	-13.3	18.7	4.6	2.4	5.5	13.4
MP/17-746	19.2	31.4	69.6	17.5	6.7	2.3	11.1	20.1
MP/18-747	7.5	13.3	-28.3	19	12.5	3.9	2.9	19.9
MP/17-216	5.3	6.8	-63.5	19.1	3.6	1.7	8.4	13.7
MP/15-750	2.5	4.1	-78.1	18.8	6.8	3.2	6.7	18.6
K Chipsona-5	9.1	17.8	-3.8	18.2	6.7	2.7	5.4	15.6
K. Jyoti	14.0	18.5		19.2	9.6	4.5	5.4	20.3

Table 10: Yield and quality parameters of advanced clones and varieties at Dharwad, Karnataka (Kharif 2022)

Genotypes	Yield (t/ha)		Quality parameters (%)				
	Processable	Total	Solid	UC	ED	ID	TPOD
MP/13-662	2.7	4.1	NC	6.7	2.1	6.4	15.2
MP/16-178	3.0	6.1	NC	9.3	6.9	6.7	22.9
MP/15-651	6.2	7.3	20.2	16.7	6.1	3.2	26.0
MP/17-265	1.5	2.2	NC	45.3	6.6	0	51.9
MP/17-428	5.2	7.2	18	3.2	6.9	0	10.1
MP/17-746	15.8	24.9	20.2	19.3	0	4.1	23.4
MP/15-750	3.4	5.3	NC	12.3	6.3	2.1	20.7
K. Chipsona-5	2.7	5.1	17.5	28.3	18.7	0	47.0

(16 t/ha), MP/17-746 (25 t/ha), MP/18-285 (22 t/ha) at Thalavadi (Table 15), MP/13-662 (25 t/ha), MP/15-651 (22 t/ha) at Hasannur **(Table 16).** The results over the years and locations along with short-listed entries are presented in **Table 17**. The evaluation across the locations and years helped to identify the best clones for processing quality with good tuber yields. The preliminary data of some of the clones mentioned above has already been published as an abstract at the international conference (Gupta *et al.,* 2021).

Based on the four-year field trial at multiple locations (6 locations) and seasons, advanced clone MP/12-126 consistently outperformed others during 2020-21, 2021-22 and 2022-23

Table 11: Yield and quality parameters of advanced clones and varieties at Chikamagalur, Karnataka (Kharif 2022)

Genotypes	Yield (t/ha)		Quality parameters (%)				
	Processable	Total	Solid	UC	ED	ID	TPOD
MP/13-1045	15.3	21.2	23.2	0	1.7	1.2	2.9
MP/13-662	1.8	2.7	23.2	0	1.1	0	1.1
MP/12-126	2.9	4.6	-	-	-	-	-
MP/15-207	4.1	8.9	20.8	7.2	7.9	5.6	21.35
MP/16-178	3.6	8.6	20.8	0	0	0	0
MP/15-651	1.3	1.4	-	-	-	-	-
MP/16-315	1.0	2.1	19.2	14.5	3.9	6.7	25.9
MP/17-610	6.3	9.8	20.8	1.2	2.3	6.2	9.93
MP/17-155	1.9	3.3	NC	10.2	5.4	3.2	18.8
MP/17-378	3.9	6.6	21.8	7.8	4.9	3.4	17
MP/17-265	2.0	3.6	NC	7.8	4.5	10.1	23.18
MP/17-428	4.4	9.9	22.3	9.7	6.7	3.2	19.6
MP/17-157	0.9	1.5	-	-	-	-	-
MP/17-60	8.0	12.6	23.2	1.1	0	1.2	4.2
MP/17-746	11.0	14.7	20.2	7.9	5.6	2.9	16.4
MP/17-216	0.9	1.8	18.2	28	10.3	6.2	44.5
MP/15-750	2.5	5.1	23.2	0	0	0	0
K. Chipsona-5	1.2	3.0	NC	14.5	23.2	8.9	46.6

Table 12: Yield and quality parameters of advanced clones and varieties at Chikkaballapur, Karnataka (Rabi 2022-23)

Genotypes	Yield (t/ha)		% Increase over Kufri Pukhraj	Quality parameters (%)				
	Processable	Total		Solid	UC	ED	ID	TPOD
MP/12-126	16.1	21.3	5.8	22.5	1.2	0.8	0.3	2.3
MP/14-171	14.2	19.4	-3.9	22.5	0	0	0	0
MP/15-207	7.3	12.7	-36.7	20.2	0	0	0.3	0.3
MP/15-698	14.3	20.6	2.2	20.7	0	0	0	0
MP/16-178	10.4	16.3	-19.1	24.4	0	0	0	0
MP/16-431	9.1	12.4	-38.6	19.5	0	0.8	0.9	1.7
MP/16-173	8.8	16.7	-17	23.4	0.3	0	0.6	0.9
MP/15-651	15.6	19.6	-2.5	21.2	0	0	0	0
MP/16-315	6.9	11.2	-44.1	19	0	0	0	0
MP/17-745	10.1	16.6	-17.5	23.5	0	0	0	0
MP/17-610	11.2	15.0	-25.4	21.5	0	0	0	0
MP/17-378	6.4	10.3	-48.8	20.6	0	0	0	0
MP/17-155	6.3	12.8	-36.3	23.4	0	0	0	0
MP/17-265	3.2	8.4	-58.4		0	0	4.9	4.9
MP/16-442	13.5	17.9	-11.2	22.3	nc	nc	nc	nc
MP/17-428	9.0	14.3	-29.1	23.4	0	0	0	0
MP/17-157	10.0	14.1	-30.1	23	0	0	0	1.2
MP/17-60	10.2	15.8	-21.5	24.4	0	0	0	0
MP/15-750	15.7	21.8	8	23.4	0	0	0	0
K. Jyoti	17.0	20.1		18.5	0	0	0	0

Table 13: Yield and quality parameters of advanced clones and varieties at Bankura, West Bengal (Rabi 2022-23)

Genotypes	Yield (t/ha)		% Increase over Kufri Pukhraj	Quality parameters (%)				
	Processable	Total		Solid	UC	ED	ID	TPOD
MP/12-126	31.4	35.0	11.3	22.2	0	1.4	0.8	2.2
MP/14-171	21.0	27.0	-14.4	22.3	0	1	0	1
MP/15-207	23.0	30.1	-4.4	19.5	0	4.8	2.3	7.1
MP/15-698	28.5	36.3	15.3	22.4	0	3	2.4	5.4
MP/16-178	12.1	22.0	-30.1	22.6	0	4.4	1.9	6.3
MP/16-431	25.0	35.4	12.6	22.2	0	2.8	2	4.8
MP/15-651	24.1	34.7	10.3	21.3	0	2.8	0	2.8
MP/16-315	24.9	34.4	9.2	21.1	0	0	0	0
MP/17-610	15.8	23.0	-26.8	21.3	0.4	3.8	0	4.2
MP/17-378	19.4	26.0	-17.5	23.4	0	0.8	1.8	2.6
MP/17-155	21.2	28.7	-8.7	22.3	2.6	3.8	3.2	9.5
MP/17-265	18.6	26.8	-15	22.3	0	6	1.2	7.2
MP/16-442	14.6	16.3	-48.2	NA	NA	NA	NA	NA
MP/17-428	19.6	26.3	-16.6	24	0	1	2.4	3.4
MP/17-157	20.7	22.7	-27.9	25.2	0	9.9	0	9.9
MP/17-60	20.2	24.1	-23.5	24.4	0	0	4.4	4.4
MP/15-750	19.1	22.8	-27.6	21.2	0	0.8	0	0.8
MP/13-662	22.8	26.3	-16.6	22.3	0	0.8	0	0.8
K. Jyoti	28.0	31.5		19.3	25	7.4	6.6	39

Table 14: Yield and quality parameters of advanced clones and varieties at Zaheerabad, Telangana (Rabi 2022-23)

Genotypes	Yield (t/ha)		% Increase over Kufri Pukhraj	Quality parameters (%)				
	Processable	Total		Solid	UC	ED	ID	TPOD
MP/15-207	9.3	12.4	-38	22.3	0	0	0	0
MP/15-698	12.0	14.9	-26	21.3	0	0	0	0
MP/16-178	11.5	13.8	-31.4	21.8	0	0	0	0
MP/16-173	12.8	15.9	-21	20.8	0	0	0	0
MP/15-651	14.3	21.4	6.5	21.3	0	0	0	0
MP/16-315	4.0	4.7	-76.5	NA	NA	NA	NA	NA
MP/17-745	5.6	9.5	-52.6	22.3	0	0	0	0
MP/17-610	14.6	20.2	0.8	23.4	0	0	0	0
MP/17-378	10.9	13.2	-34.3	21.3	0	0	0	0
MP/17-155	16.5	21.6	7.6	23.1	0	0	0	0
MP/17-265	8.9	11.4	-43.1	21	0	0	0	0
MP/16-442	7.5	9.6	-52.2	NA	NA	NA	NA	NA
MP/17-428	11.8	15.8	-21.3	20.2	0	0	0	0
MP/17-157	2.6	2.9	-85.8	NA	NA	NA	NA	NA
MP/17-60	12.3	16.0	-20.2	22.3	0	0	0	0
MP/15-750	9.1	12.0	-40.3	22.1	0	0	0	0
MP/13-662	6.0	9.1	-54.7	22.3	0	0	0	0
MP/17-746	17.9	19.0	-5.2	21.8	0	0	0	0
MP/18-747	13.5	15.0	-25.1	21.3	0	0	0	0
Kufri Pukhraj	14.6	20.1		19.2	0	0	0	0

Table 15: Yield and quality parameters of advanced clones and varieties at Thalavadi, Tamil Nadu (Kharif 2023)

Genotypes	Yield (t/ha)		% Increase over Kufri Jyoti	Quality parameters (%)				
	Processable	Total		Solid	UC	ED	ID	TPOD
MP/13-662	9.1	13.8	-28.6	20.5	1.2	0	0	1.2
MP/12-126	11.9	15.8	-18.5	17.5	4.8	13.4	3.3	**21.5**
MP/14-171	20.2	23.3	20.2	17.2	16.3	6.7	6.5	29.5
MP/15-698	6.9	9.1	-53.2	21.2	3.7	3.2	4.9	**11.8**
MP/16-431	11.1	14.9	-23.2	18.5	0	5.5	9.5	15
MP/17-155	4.6	7.7	-60.2	19.2	1.2	1.2	3.2	**5.6**
MP/17-428	4.6	6.4	-67	19.2	4.1	4.3	8.9	17.3
MP/17-157	1.1	1.7	-91	-	-	-	-	-
MP/17-746	18.9	25.2	30.1	19.2	0	0	0	0
MP/18-786	14.8	17.9	-7.4	21.1	1.2	4.2	2.3	**7.7**
MP/18-136	12.0	14.2	-26.6	20.8	1.2	3.9	28	33.1
MP/18-87	2.1	2.7	-85.8	-	-	-	-	-
MP/18-534	5.9	9.4	-51.3	21.3	2.3	1.9	3.6	**7.8**
MP/18-285	16.3	21.8	12.6	17.4	0	3.1	3.8	6.9
Kufri Jyoti	16.3	19.4		17.1	7.8	6.2	0	14

Table 16: Yield and quality parameters of advanced clones and varieties at Hasannur, Tamil Nadu (Kharif 2023)

Genotypes	Yield (t/ha)		% Increase over Kufri Pukhraj	Quality parameters (%)				
	Processable	Total		Solid	UC	ED	ID	TPOD
MP/13-662	20.1	24.9	34.6	21.6	0	0	1.3	1.3
MP/12-126	13.8	18.6	0.7	20.8	0	0	1.2	1.2
MP/14-171	21.6	24.6	32.9	19.2	0	6.2	19.4	25.6
MP/16-431	16.3	20.5	11.1	19.8	0	4.1	9.1	13.2
MP/15-651	18.9	21.9	18.5	19.6	0	0	0	0
MP/18-136	6.9	8.8	20.2	20.2	0	0	8.5	8.5
MP/18-534	7.9	9.7	-47.7	16	NA	NA	NA	NA
MP/18-285	19.1	23.4	26.5	17.8	0	1.9	0	1.9
MP/16-315	3.3	4.4	-76.5	16.1	NA	NA	NA	0
Kufri Jyoti	15.7	18.5		18.6	3.2	9.8	14.7	27.7

in the Rabi season at different locations of Karnataka. However, MP/12-126 had almost similar yield but acceptable quality parameters as compared to controls in the Kharif seasons of Karnataka and Tamil Nadu. On an overall basis, MP/14-171 had a higher yield and acceptable quality traits during 2020-21, 2021-22 in the rabi season of Karnataka and Kharif season of Tamil Nadu during 2023. Advanced clone MP/15-698 performed well in West Bengal (rabi 20220-21 and 2022-23) and Karnataka (rabi 2022-223). MP/15-651 was found to be the most widely adapted clone as it has superior performance in all states either in Rabi/Kharif seasons or both (**Table 18, 19**). Photographs of selected clones namely MP/12-126 (**Fig.1)**, MP/14-171(**Fig.2)**, MP/15-651(**Fig.3)** and MP/15-698 **(Fig.4)** and characteristic features are given in the **Table 19.**

Table 17: Advanced potato clones evaluated at different locations

Trial and Year	Trial Location	No. of tested entries
Rabi 2020-21	Hiriyalachenahalli, Chikkaballapur-Karnataka	26
	Ranzole, Zaheerabad –Telangana	22
	Kotulpur, Bankura –West Bengal	25
Kharif 2021	Thalavadi (Tamil Nadu)	26
	Dharwad (Karnataka)	24
	Chikamagalur (Karnataka)	20
Rabi 2021-22	Hiriyalachenahalli, Chikkaballapur-Karnataka	20
	Magidi, Zaheerabad - Telangana	20
Kharif 2022	Thalavadi- Erode (Tamil Nadu)	19
Rabi 2022-23	Hiriyalachenahalli, Chikkaballapur-Karnataka	20
	Magidi, Zaheerabad - Telangana	20
	Kotulpur, Bankura –West Bengal	19
Kharif 2023	Thalavadi- Erode (Tamil Nadu)	15
	Hasanur, Erode (Tamil Nadu)	10
	Lingadahalli, Chikamagalur – Karnataka	7

Fig.1. MP/12-126-Leaf, tubers and chips

Fig.2. MP/14-171-Leaf, tubers and chips

Fig.3. MP/15-651-Leaf, tubers and chips

Fig.4. MP/15-698-Leaf, tubers and chips

CONCLUSION

Earlier no specific processing variety was available for these areas and raw material was transported from distant places. The selected new processing clones exhibited outstanding chip processing attributes, including high dry matter content (>20%), fewer total potato defects, and higher yields compared to existing varieties. The availability of the selected new processing clones viz., MP/12-126, MP/14-171, MP/15-651 and MP/15-698 in these areas of southern and eastern India can provide a suitable alternative to farmers and better sustenance for the potato processing industry.

ACKNOWLEDGEMENT

The authors are highly grateful to Director, ICAR-CPRI and Head, ICAR-CPRI, RS, Modipuram for their support and guidance

Table 18: Yield and quality of four shortlisted potential advanced potato clones along with control over the locations

Year	Location	Yield (t/ha)		% Increase over controls#	Quality Parameters (%)				
		Process Grade	Total		Solid	UC	ED	ID	TPOD
MP/12-126									
Rabi 2020-21	Karnataka	28.7	33.2	7.5	22	0	0.7	1.8	2.5
Kharif 2021	Karnataka	14.9	18.1	-0.4	16.8	-	-	-	-
Rabi 2021-22	Karnataka	37.0	40.4	60	22.3	0	2	4.8	6.8
Kharif 2022	Tamil Nadu	12.6	18.3	-1.4	18.6	5.6	3.2	6.9	15.7
Rabi 2022-23	Karnataka	16.1	21.3	5.8	22.5	1.2	0.8	0.3	2.3
Rabi 2022-23	West Bengal	31.4	35.0	11.3	22.2	0	1.4	0.8	2.3
Kharif 2023	Tamil Nadu	13.8	18.6	0.7	20.8	0	0	1.2	1.2
MP/14-171									
Rabi 2020-21	Karnataka	28.9	32.6	5.5	19.7	0	0	0	0
Rabi 2021-22	Karnataka	23.6	25.9	2.4	20.5	0	0	0	0
Kharif 2023	Tamil Nadu1	20.2	23.3	20.2	17.2	16.3	6.7	6.5	13.2
Kharif 2023	Tamil Nadu2	21.6	24.6	32.9	19.2	0	6.2	19.4	25.6
MP/15-698									
Rabi 2020-21	West Bengal	39.4	46.1	46.1	19	0	0	0	0
Rabi 2022-23	Karnataka	14.3	20.6	2.2	20.7	0	0	0	0
Rabi 2022-23	West Bengal	28.5	36.3	15.3	22.4	0	3	2.4	5.4
MP/15-651									
Kharif 2021	Tamil Nadu	24.2	25.3	-1.0	19.5	2	12	5.6	19.6
Kharif 2021	Karnataka	24.8	29.3	1.0	21.3	42.8	-	-	-
Rabi 2021-22	Karnataka	24.4	30.0	18.7	22	0	0	0	0
Rabi 2021-22	Telangana	41.1	45.9	24.2	19	0	4.2	2.1	6.3
Kharif 2022	Tamil Nadu	12.9	18.5	-0.3	20.2	4.8	1.2	2.1	8.3
Rabi 2022-23	Karnataka	15.6	19.6	-2.5	21.2	0	0	0	0
Rabi 2022-23	Telangana	14.3	21.4	6.5	21.3	0	0	0	0
Rabi 2022-23	West Bengal	24.1	34.7	10.3	21.3	0	2.8	0	2.8
Kufri Jyoti									
Rabi 2020-21	Karnataka	27.7	30.9		17.5	8.3	2.8	2.2	14
Rabi 2020-21	West Bengal	26.5	31.6		17.2	4.1	16.7	25.4	46.2
Kharif 2021	Tamil Nadu	23.2	25.6		16.1	-	-	-	-
Kharif 2021	Karnataka	14.5	18.1		-	-	-	-	-
Kharif 2021	Karnataka	26.8	29.0		23.4	35.9	-	-	35.9
Rabi 2021-22	Karnataka	22.6	25.3		19.2	0	0	6	6
Rabi 2022-23	Karnataka	17.0	20.1		18.5	0	0	0	0
Rabi 2022-23	West Bengal	28.0	31.5		19.3	25	7.4	6.6	39
Kufri Pukhraj									
Rabi 2020-21	Telangana	31.2	33.4		16.4	NA	NA	NA	NA
Rabi 2021-22	Telangana	36.5	37.0		15.7	0	32.5	25.2	57.7
Rabi 2022-23	Telangana	14.6	20.1		19.2	0	0	0	0
Mean									

Kufri Jyoti/ Kufri Pukhraj

Table 19: Characteristics of shortlisted advanced potato clones

Advanced clones/characters	MP/12-126	MP/14-171	MP/15-651	MP/15-698
Parentage	CP 4047 × MP/99-322	K Chipsona-3 × MP/9-68	MP/9-90 × MP/9-11	MP/9-90 × MP/9-11
Maturity	Medium	Medium	Early-Medium	Medium
Late blight resistance	Field resistant	Field resistant	Field resistant	Field resistant
Tubers	Round	Round	Ovoid	Round
Skin-set	Good	Good	Good	Russet
Yielders	Good	Good	Good	Very Good
Tuber dry matter	21%	21%	21%	21%
Chip colour score	Acceptable (<3)	Acceptable (<3)	Acceptable (<3)	Acceptable (<3)
Internal defects	Low	Low	Low	Low
Adaptability	Rabi season in southern & eastern plains	Diverse southern environments/ seasons	Diverse environments and season	Eastern plains.

during the entire study period. We sincerely thank the ITC R&D team particularly, Dr. Sai Prasad and Dr. Mahavishnan K. for evaluation (under MoU) of the CPRI bred processing clones at different locations in Southern and Eastern India. The technical help by CPRI, RS Modipuram staff, Mr. Gyan and Mr. Himanshu in tuber multiplication and maintenance of clones is duly acknowledged.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

ETHICAL STATEMENT

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

LITERATURE CITED

Devaux, A., Kromann, P. & Ortiz, O. (2014) Potatoes for sustainable global food security In Kiptoo S, Kipkorir EC, Kiptum CK. Effects of Deficit Irrigation and Mulch on Yield and Quality of Potato Crop. *African Journal of Education, Science and Technology*, vol 4(4).

Gupta VK, Vinay Bhardwaj, SK Luthra and Bandna (2021) Advanced potato processing hybrids identified through public-private collaborations. in International Potato e-Conference New Paradigms in Food Security and Industrial Applications 23-26 November. IPeC2021: APBSR_19

Gupta VK, Vinay Bhardwaj, SK Luthra, Sanjay Rawal, Bandna, Salej Sood, Mehi Lal and Arvind Jaiswal (2021a) Two-decade journey of potato processing in India and future prospects. in International Potato e-Conference New Paradigms in Food Security and Industrial Applications 23-26 November. IPeC2021: ES_02

Hussen, E. S. (2019) Review on Genetic Variation in Potato (Solanum Tuberosum L.) for Processing Quality Traits. *Journal of Natural Sciences Research*, Vol.9, No.12.

Luthra SK, VK Gupta, Bandana Kaundal and JK Tiwari. (2018) Genetic analysis of tuber yield, processing and nutritional traits in potato (Solanum tuberosum). Indian Journal of Agricultural Sciences 88 (8):1214-1221.

Luthra SK, VK Gupta, JK Tiwari, V Kumar, V Bhardwaj, S Sood, Dalamu, RP Kaur, R Kumar, G Vanishree, D Kumar, P Mhatre and SK Chakrabarti. (2020) *Potato Breeding in India*. CPRI Technical Bulletin No 74 (revised), ICAR-Central Potato Research Institute, Shimla, Himachal Pradesh, India, 214p.

Mori K, Asano K, Tamiya S, Nakao T and Mori M. (2015) Challenges of breeding potato cultivars to grow in various environments and to meet different demands. *Breeding Science* 65: 3–16.

Wayumba, B. O., Choi, H. S., & Seok, L. Y. (2019) Selection and evaluation of 21 potato (*Solanum tuberosum*) breeding clones for cold chip processing. *Foods*, *8*(3), 98.

MS Received : May 08, 2024; Accepted : July 29, 2024

Potato J (2024) 51 (1): 78-82

SEED POTATO PRODUCTIVITY AS INFLUENCED BY ELECTRICAL CONDUCTIVITY OF THE NUTRIENT SOLUTION IN SOILLESS MEDIA DURING SPRING SEASON IN SUBTROPICAL REGIONS OF N- W INDIA

Sugani Devi[1], R P Kaur[1]*, Brajesh Nare[1], Khushdil Bharti[2] and Anil Sharma[1]

ABSTRACT: Soilless cultivation under controlled conditions is used for rapid multiplication of early generation virus-free potato seed using aeroponics and other mediums. The plant growth under these systems is affected by different factors like soilless media, nutrient solution concentration used, environment, genotype etc. Besides the composition of nutrient solution its electrical conductivity (EC) influences availability of nutrients and affects plant growth and yield. The two-factorial study on water source and EC was carried out on a cocopeat based medium for a nutrient efficient variety Kufri Gaurav. Well sprouted aeroponically produced minitubers of the variety were planted (at 30 x 15 cm planting density) in soilless medium filled troughs placed under net house. The water source normal tap water was compared with RO (demineralized) water, while EC was considered at three levels 1.0, 1.5 and 2.0. The results indicated a proficient growth of the genotype at EC 2.0 (plant height, number of leaves, stem diameter, leaf length and number of stems). However, for the yield characters, EC 1.0 was found to produce both higher number of tubers, yield as well as harvest index per meter square. Based on the observations it can be inferred that at lower EC the partitioning of the photosynthates is towards the sink (tubers) as compared to the vegetative growth, which would be more desirable under the soilless systems, where limited/ managed canopy growth is more desirable, with higher productivity. The study also indicated virus free seed production in soilless medium during the spring season (seed plot period lasts up to December) in northwestern plains of India under net house, giving indication for successive/ multiple seed crops under soilless controlled conditions.

KEYWORDS: Soilless cultivation, Electrical conductivity (EC), aeroponics, minitubers, potato

INTRODUCTION

Potato is a global crop cultivated throughout the world across varying climates and terrains. The crop produces the maximum calories per unit area and time, making it an important crop identified for addressing the looming food insecurity in face of rapidly increasing world population. There has been consistent increase in potato area and production over the years.

India has emerged as the second largest producer of potato in the world after China with 54.23 mtons (FAO STAT, 2023). Out of the total production achieved in the country, the great Indian plains contribute more than 90 % production and area. The crop is grown here under short day conditions in the winter months from October to March of succeeding year. However, a short growing period, rapid degeneration of potato seed and its slow multiplication rates, decrease overall productivity of the crop in the region. Further, only the north western plains of India offer ideal conditions for growing seed using the seed plot technique and positive selection, where a low vector (white flies and aphids) period is observed from Mid-October to December end allowing cultivation of virus free seed. In view of this limitation and with

---

[1]ICAR- Central Potato Research Station, Jalandhar, Punjab-144 003, India
[2]PhD scholar, Punjab Agricultural University, Ludhiana, Punjab-141 004, India
*Corresponding author; email: kaur.rp@gmail.com

the objective of increasing early generation seed, hi tech seed systems have been developed in the country. Virus free tissue culture microplants are grown in net houses and aeroponics under controlled conditions, during the potato growing period. Although using these facilities cultivation period can be extended beyond the seed growing period, the aeroponics facility is limited by its high cost and net house by the soil borne pathogens. In such a scenario, soilless (SL) cultivation becomes a prospective option offering several advantages.

SL cultivation is generally carried out in cocopeat based medium and supplemented with macro and micro nutrients to achieve optimum growth. Various factors like pH, nutrient medium composition, SL media, EC, genotype, climate etc. reportedly affect SL cultivation. Several SL mediums have been reported for potato minituber production (Awati *et al.* 2019). Similarly, CPRI-Aeroponic nutrient solution has already been standardized for potato growth in the region. However, EC of solution and source of water under SL cultivation (coco peat based) has not been evaluated, which can affect both plant growth and cost of cultivation. Electrical conductivity is an important parameter governing plant growth and is known to affect photosynthesis, quality and antioxidant enzyme activity in plants (Savvas *et al.* 2008; Signore *et al.* 2016; Ding *et al.* 2018). It defines the index of salt concentration and is used as an indicator for electrolyte concentration of the solution. Studies on EC for aeroponic cultivation were done by (Calori *et al.* 2017) in Brazil for two cultivars Agata and Asterix in the winter/ spring conditions, using different plant densities. They reported that EC of 2.2 and 2.1 dS m^{-1} gave the highest productivities. However, their study was under aeroponics for Brazil, so it needs standardization for not only cocopeat media systems but also based on the Indian agroclimate and Indian potato varieties. Development of efficient SL cultivation system will go a long way in increasing climate resilience and increasing production of early generation seed, ensuring increased availability in the country in advanced generations (Awati *et al.* 2019; Pradhan and Deo, 2019). The present study also evaluated the effectiveness of cultivation of potato seed beyond January in the North western plains under SL conditions. This can be a significant intervention to further increase early generation seed by taking two successive seed crops in SL controlled conditions. Successive cropping under net house has been reported previously from the same region by (Kaur *et al.* 2021).

MATERIAL AND METHODS

The experiment was conducted in the insect-proof net house of ICAR-Central Potato Research Institute (Regional Station), Jalandhar (31°23′N and 75°79′E, altitude 237 m amsl) 2020-21. Aeroponically produced Minitubers of variety Kufri Gaurav (weighing 2–5 g) were withdrawn from the cold store and allowed to sprout under diffused light at 22-24°C for 20 days and planted in the third week of February at the spacing of 30 x 15 cm (row to row x plant to plant). Cocopeat media was sterilized by drenching with Nano silver hydrogen peroxide (3%) followed by thorough washing with clean water. Growing containers (troughs) of size 600 cm x 100 cm, made of HDPE sheet of 700-micron thickness was placed on a raised bench and used for planting of these sprouted minitubers. Nutrient management in this cocopeat soilless culture (CSC) was done using the standardized ICAR-CPRI liquid formulation containing macro and micro essential nutrient elements. EC of the solution was regulated through dilution with water to maintain EC and pH. All cultural practices for net house cultivation, recommended for the region were followed with haulm cutting at approximately 60 days, in all the treatments.

Experiment was carried out using factorial RBD with two factors with three replications. The first factor water source had two treatments Tap water (TW) and R.O. purified water (without mineralization) (RO). For the second factor electrical conductivities at 1.0 (1.0EC), 1.5 (1.5EC) and 2.0 (2.0 EC) mS/cm were considered. Observations were recorded on various plant growth and yield parameters. Growth observations (plant height (PH), number of leaves (NL), leaf length (LL), leaf breadth (LB), stem diameter (SD), number of stems (NS)) for five plants in a single replication were recorded at 30 and 55 days to evaluate the growth pattern of different treatments. The data was analyzed statistically by using 2 factor analysis of variance (ANOVA). Mean values were calculated and separated using F-test at 5% level of significance and means of different treatments were compared using critical difference (CD).

RESULTS AND DISCUSSION

The effect of EC and water source on growth and yield have been summarized as follows:

Plant height (PH): Plant height at 30 DAP showed significant difference among different EC of nutrient solution but water source used for irrigation had not affected plant height at 30 DAP. The tallest plants (27.83 cm) were recorded in 2.0EC; shortest (19.50 cm) plants were produced with 1.0EC (Table 1). This may be due to faster growth of plant with more available nutrients with higher electrical conductivity of nutrient solution. Plant height at 55 days was influenced by both water source and EC of nutrient solution and maximum plant height was observed with RO water among water sources and with 2.0EC among different EC.

Number of leaves (NL): The source of water showed non-significant differences between different treatments for number of leaves at 30 DAP as well as 55 DAP under SL media. However, EC showed significant results as highest number of leaves were observed with 2.0EC (13.78) at 30 DAP and 55 DAP (18.83). More number of leaves are desirable for photosynthetic activity in the plant.

Leaf length (LL) and breadth (LB): Leaf length and breadth of 4th leaf from the top was measured at 30 DAP. More leaf length

Table 1. Growth parameters as influenced by water source and EC.

	PH30	PH55	NL30	NL55	LL30	LB30	SD30	NS55
Water Source								
RO	23.93	54.18	13.30	17.74	15.01	7.91	6.41	4.00
TW	23.59	50.89	13.04	17.48	17.43	8.66	6.93	3.998
SEM	0.528	0.897	0.180	0.359	0.282	0.245	0.203	0.350
LSD (0.05)	NS	2.863	N.S.	N.S.	0.900	N.S.	N.S.	NS
Electrical Conductivity								
1.0 EC	19.50	37.61	12.50	15.22	14.75	7.87	5.61	2.72
1.5 EC	23.95	58.11	13.22	18.78	16.20	8.10	7.11	3.66
2.0 EC	27.83	61.89	13.78	18.83	17.73	8.90	7.29	5.61
SEM	0.674	1.099	0.221	0.440	0.345	0.300	0.249	0.428
LSD (0.05)	2.064	3.507	0.705	1.404	1.102	N.S.	0.795	1.366

Note: PH30- Plant height at 30 DAP; PH55- Plant height at 55 DAP; NL30-Number of compound leaves per plant at 30 DAP; NL55- Number of compound leaves per plant at 55 DAP; LL30- length of 5th leaf from top at 30 DAP; LB30- Breadth of 5th leaf from top at 30 DAP; SD30- Stem diameter at 30 DAP; NS55- Number of stems at 55 DAP.

was obtained with tap water (17.43 cm) compared with RO water (15.01). Regarding effect of EC, it was recorded that maximum leaf length was observed for 2.0EC followed by 1.5EC. Results of leaf breadth were non-significant for both the factors.

Stem diameter (SD): Stem diameter is a desirable growth parameter of plant as it provides stable and sturdy plants in soilless media. Stem diameter was measured at 30 DAP and was significantly affected by EC of nutrient solution. It was observed that the stem diameter of plants irrigated with tap water was non-significantly higher than RO water irrigated plants. Regarding stem diameter with different EC, it was found that the significantly highest diameter was observed in 2.0EC (7.29 mm) which was found at par with 1.5EC (7.11 mm) and lowest in 1.0EC (5.61 mm).

Stems/plant (NS): More stems per plant were observed with higher EC of nutrient solution compared to lower EC. The difference in plant vigor may be due to abridged availability of nutrients for the plants to develop to their full vigor under higher EC's. Highest number of stems were observed with 2.0 EC (5.61) followed by 1.5EC (3.66).

Total number of tubers/m² (TN): A significant difference ($P \leq 0.05$) was noted in the number of tubers (per m²) obtained with different electrical conductivities (Figure 1). Interesting results were observed regarding tuber number, although results were non-significant for differences in water source, a greater number of tubers were observed in TW. Regarding effect of EC, it was observed that significantly highest tuber number per m² were recorded with 1.0 EC (200.91) which was statistically at par with that of 1.5 EC (180.54).

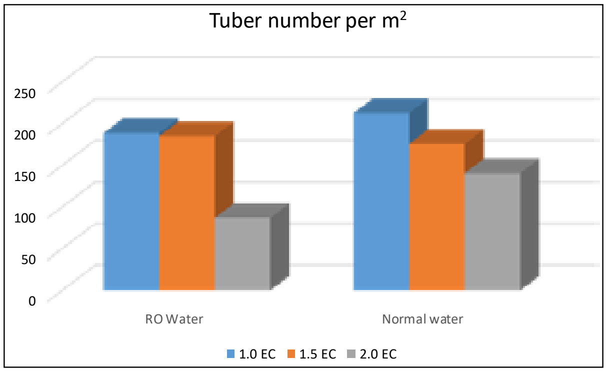


Fig.1. Tuber number/m² as influenced by water source and EC.

Total tuber yield/m² (TW): Although the tuber yield per m² differed non-significantly among water sources, electrical conductivity of water significantly influenced the yield just similar to tuber number. Tap water irrigated plants produced higher tuber yield as compared to RO water irrigated, although difference was non-significant. When we compared tuber yield between different EC within same water source, the trend was 1.0 EC (3461.69 g) followed by 1.5 EC (2745.09 g) and lowest yield with 2.0 EC (1126.74 g).

Harvest Index (HI): It is evident from the table 2 that the influence of water source as well as electrical conductivity with respect to harvest index, depicted significant variation under insect-proof net house. TW irrigated

Table 2. Yield parameters as influenced by water source and EC.

	TN	TW	HI
Water Source			
RO	153.69	2226.32	31.29
TW	176.53	2662.70	41.47
SEM	10.922	150.685	1.556
LSD (0.05)	NS	NS	4.966
Electrical Conductivity			
1.0 EC	200.91	3461.69	58.84
1.5 EC	180.54	2745.09	35.82
2.0 EC	113.88	1126.74	14.47
SEM	13.376	184.550	1.906
LSD (0.05)	42.694	589.044	6.082

Note: TN-represents here tuber number per m²; TW-tuber weight per m²; HI-Harvest index plants produced more HI than RO water irrigated. The maximum value of harvest index was observed 1.0 EC (58.84 percent) followed by 1.5 EC (35.82 percent) and minimum in 2.0 EC (14.47 percent). The higher value of harvest index with 1.0 EC indicated plants produced higher tuber yield with minimal biological yield.

The results indicated a proficient growth of the genotype at EC 2.0 (plant height, number of leaves, stem diameter, leaf length and number of stems). However, for the yield characters, EC 1.0 was found to produce both higher number of tubers, yield as well as harvest index per meter square. Based on the observations it can be inferred that at lower EC the partitioning of the photosynthates is towards the sink (tubers) as compared to the vegetative growth, which would be more desirable under the soilless systems, where limited/ managed canopy growth is more desirable, with higher productivity. The study also indicated virus free seed production in soilless medium during the spring season (seed plot period lasts up to December) in northwestern plains of India under net house, giving indication for successive/ multiple seed crops under soilless controlled conditions. In the study by Kaur *et al.*, 2021 two successive crops from minitubers were planted (October-April). Successive dual cropping resulted in 2.52 times higher tuber number as compared to single cropping (November- January) under net house cultivation in N-W plains.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

ETHICAL STATEMENT

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

LITERATURE CITED

Awati R, Bhattacharya A and Char B (2019) Rapid multiplication technique for production of high-quality seed potato (Solanum tuberosum L.) tubers . *J Appl Biol Biotechnol* **7**(1):1-5.

Calori AH, Factor TL, Feltran JC, Watanabe EY, Moraes CC de and Purquerio LFV (2017) Electrical conductivity of the nutrient solution and plant density in aeroponic production of seed potato under tropical conditions (winter/spring) . *Bragantia* **76**: 23-32.

Ding X, Jiang Y, Zhao H, Guo D, He L, Liu F, Zhou Q, Nandwani D (2018) Electrical conductivity of nutrient solution influenced photosynthesis, quality, and antioxidant enzyme activity of pakchoi (*Brassica campestris L. Ssp. Chinensis*) in a hydroponic system. *PLoS One.* **13**(8): e0202090.

Kaur RP, Devi S, Singh S, Minhas JS, Singh AK, Rana RK, Rawal S and Singh RK (2021) Successive double cropping of potato minitubers under insect proof net house for increased seed productivity . *Indian J Agric Sci.* **91**(2): 202-207.

Pradhan B and Deo B (2019) Soilless farming - The next generation green revolution . *Curr Sci.* **116**(5):728-732.

Savvas D, Ntatsi G and Passam HC (2008) Plant nutrition and physiological disorders in greenhouse grown tomato, pepper and eggplant . *Eur J Plant Sci Biotechnol* **2**(1):45-61.

Signore A, Serio F and Santamaria P (2016) A targeted management of the nutrient solution in a soilless tomato crop according to plant needs . *Front Plant Sci.* **7**:391.

MS Received : January 02, 2024; Accepted : June 26, 2024

Potato J (2024) 51 (1): 83-90

GROWTH PERFORMANCE AND ECONOMICS OF POTATO CULTIVATION IN HIMACHAL PRADESH

Shivalika Sood[1], Diksha Sethi[2]* and Komal Sharma[3]

ABSTRACT: This research paper studied the growth and economic performance of potato cultivation in Himachal Pradesh over a period of 21 years (2001-02 to 2021-22). The study was entirely based on secondary data, employing growth rate analysis, instability indices, decomposition analysis, and cost concept to fulfill the objective. The findings of the study revealed a significant increase in area, production, and productivity of potatoes, with the decomposition analysis highlighting the major role of expanded cultivation area in production growth. Instability indices reveal fluctuations in production, mainly attributed to variability in cultivation area. Input-use patterns show a decrease in input quantity but an increase in their value. The cost structure analysis emphasizes the capital-intensive nature of potato cultivation, with operational costs, particularly seed and human labor, contributing significantly. The study underscores the need for measures to stabilize potato production and mitigate the impact of rising input prices.

KEYWORDS: Growth rate, instability indices, decomposition analysis, cost of cultivation and potato

INTRODUCTION

Potato (*Solanum tuberosum L.*) is the most important food crop in India and ranks fourth after rice, wheat and maize. In comparison to other main food crops, it has significantly greater levels of carbohydrates, fibre, vitamin C, and vitamin B, making it the most affordable and abundant source of nutrients and calories (Bisht and Sharma, 1997). Potato is one of the important commercial cash crops grown in Himachal Pradesh. It occupies an area of 15165 ha with the production and productivity of 195350 tonnes and 12.89t/ha, respectively in the year 2021-22 (Statistical Yearbook of Himachal Pradesh 2021-22). Most of the farmers in Himachal Pradesh are small and marginal who diversified their cropping pattern by shifting from cereal based farming system to high value cash crops like potato and other vegetables (Sharma, 2011). In Himachal Pradesh, potato farming is an important part of the state's agricultural terrain (Singh *et al.* 2015).

The unique agro-climatic conditions of the region, characterized by varying altitudes, diverse topography, and distinct seasons, create an ideal environment for potato cultivation (Sati and Wei, 2018). In the backward areas of the state, seed potato has been identified as one of the major remunerative crop. It boosts the state's economy and improves its residents' income as well as their standard of living. Moreover, the harvesting time of potato in higher hills of the state coincide with the sowing period in the plains area which ensure the year around production of potato in the state (Thakur and Moorti, 1991). Then it is sold in various parts of the country as *Pahari Aloo* which gets premium price as it is fresh and does not have sweet taste like the cold stored potatoes (Pandit *et al.* 2010). This *kharif* potato from

---

[1]Department of Agricultural Economics and Extension, School of Agriculture, Lovely Professional University, Jalandhar-144 411, Punjab, India.

[2]Department of Agricultural Economics, Extension Education and Rural Sociology, COA, CSKHPKV, Palampur -176 062, Himachal Pradesh, India.

[3]Department of Agricultural Economics, School of Agriculture, Abhilashi University, Mandi-175 045, Himachal Pradesh, India.

*Corresponding author; email: diksha.hpkv@gmail.com

hills has been fetching 1.5 to 2 times higher price in the market as compared to cold stored potato produced under *rabi* season in the plains (Singh *et al.* 2018). That is why the state government is laying emphasis on production of off-season vegetables, through timely and adequate supply of inputs, demonstration and effective dissemination of improved farm technology, replacement of old variety seed, promotion of integrated pest management, bringing more area under efficient use of water resources and implementation of Wasteland Development Projects (Economic survey 2021). However, during the last few years state's potato growers have faced new challenges on production fronts. The cost of inputs has increased affecting the profitability matrix of different commercial crops (Lal and Sharma, 2006). Keeping in view the significance of potato in the state, the present study was carried out to examine the growth performance and economics of potato cultivation in Himachal Pradesh. By unraveling the intricacies of potato cultivation in Himachal Pradesh, this research seeks to provide a foundation for informed decision-making, and the enhancement of the potato value chain in the region.

MATERIAL AND METHODS

The study relied mainly on the secondary data i.e. time series data on area, production and productivity of potato in Himachal Pradesh. The data for a period of 21 years from the year 2001-02 to 2021-22 were collected from various published sources or official websites. The entire study was split into two sub periods. The sub period was framed as period I (2001-02 to 2010-11), period II (2011-12 to 2021-22) and Overall period (2001-02 to 2021-22).

Growth Rate

The compound annual growth rates were worked out to examine the growth in area, production and productivity of potato in Himachal Pradesh using exponential production function:

$$Y = ab^t$$

$$\text{Log}Y = \text{Log } a + t \text{ Log } b$$

where,

Y= Area, Production and Productivity,

a = Constant term,

b = Regression coefficient,

t = Time variable in year

Instability Index

An index of instability was computed to examine the nature and degree of instability in area, production and productivity of potato in Himachal Pradesh. The co-efficient of variation (CV) was worked out for area, production, and yield to measure variability which is given by

$$\text{Coefficient of Variation (CV)} = \frac{\text{SD}}{\text{Mean}} \times 100$$

where,

SD = Standard deviation of area/production/productivity

Decomposition Analysis

To measure the relative contribution of area and productivity towards the total output, a decomposition model was used (More et al. 2015). In the decomposition analysis the change in production was taken as the effect of three factors such as yield effect, area effect and interaction effect.

$$\Delta P = A_0 \, \Delta Y + Y_0 \, \Delta A + \Delta A \, \Delta Y$$

where;

ΔP = Change in production

A_0 = Area in base year

Y_0 = Yield in the base year

Y_t = Yield in the current year

A_t = Area in the current year

ΔA = Change in area (A_t - A_0)

ΔY = Change in the yield (Y_t - Y_0)

Change in production = Yield effect + Area effect + Interaction effect.

Thus, the total change in production was decomposed into three effects *viz.* yield effect, area effect and interaction effect due to change in yield and area.

To examine the economic performance of potato, the published data on cost of cultivation from cost of cultivation scheme, of past years were used. The structural changes in cost of cultivation were analyzed by working out the difference in cost at two points of time (i.e. 2001-02 to 2021-22), along with relative share to total cost. The cost structure of potato was analyzed by working out the share of each item of cost in total cost of cultivation. The changes in structure of cost of cultivation of crops were assessed by comparing the cost structure of potato during 2021-22 compared to 2001-02.

RESULTS AND DISCUSSION

Growth in area, production and productivity of potato

It is evident from the Table 1 that in period I the area has increased significantly at the rate of 4.09 per cent per annum but production and yield could not record growth. In period II the area has increased but not significantly whereas production and yield increased significantly at the rate of 7.80 and 3.67 per cent per annum, respectively. During the overall period, area, production and yield of potato crop have significantly increased at the rate of 3.60, 4.88 and 1.24 per cent per annum, respectively. The results are in collaboration with the studies conducted by Rana and Anwer (2018) and Pant *et al.* (2020).

In overall period, the coefficient of determination for potato indicates that 67.47 per cent of variation in model was explained together with variables area and time. Similarly, the value of the coefficient of determination indicates that 66.56 per cent of variation in model was explained together with variables production and time and about 33.44 per cent of variation remains unexplained. In yield 23.68 per cent variation was explained and about 76.32 per cent of variation remains unexplained. This explained variation may increase if we have taken more variables into account like price of crop, rainfall etc.

Instability analysis in area, production and productivity of potato

The index of instability was computed to study the variability in area, production and productivity of potato in different periods. The instability index indicates the risk of crop cultivation. Instability indices have been shown in Table 2. The instability in area was quite low in period-I (16.42%) compared to period-II (22.42%). The instability was found to be 27.70 per cent in the overall period which implies that area has remained almost stable in the state. The instability in the production was to the extent of 34.90 per cent in the overall period, while it was low in the period-I (22.30%). The yield instability remained consistently low at around 14 per cent throughout period I, period II, and the

Table 1. Annual compound growth rates (per cent) in area, production and productivity of Potato in Himachal.

Items	Period I			Period II			Overall		
	A	P	Y	A	P	Y	A	P	Y
GR	4.09*	3.81	-0.26	3.99	7.80*	3.67*	3.60*	4.88*	1.24*
Std error	1.23	2.54	1.79	2.00	2.12	0.91	0.58	0.81	0.51
r	0.5893	0.2262	0.0026	0.3145	0.6189	0.6474	0.6747	0.6656	0.2368

Note: A= Area, P =Production, Y=Productivity, GR = Growth rate, Std error = Standard error, r = coefficient of determination
*Significant at 5 per cent level of significance
Period I = 2001-02 to 2010-11, Period II = 2011-12 to 2021-22, Overall period = 2001-02 to 2021-22

Table 2. Instability in area, production and productivity of Potato in Himachal (Per cent).

	Area			Production			Productivity		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
Period I	10186.00	1672.71	16.42	1041990.20	232364.15	22.30	102.02	14.43	14.14
Period II	14730.36	3301.96	22.42	1679200.18	447044.99	26.62	113.18	16.44	14.53
Overall	12566.38	3481.26	27.70	1375766.86	480171.23	34.90	107.87	16.17	14.99

Note: Period I = 2001-02 to 2010-11, Period II = 2011-12 to 2021-22, Overall period = 2001-02 to 2021-2

overall period. Thus, it can be clearly seen from the table that the instability in production is mainly attributed to variability in area at the state level. Pant *et al.* (2020) in their study also found that instability was highest in production followed by area than productivity.

Decomposition analysis of growth in potato production

The decomposition analysis has been carried out to examine the yield effect, area effect and interaction effect on the production of potato crop. The analysis enables to comprehend the change in the production of a crop and whether this change is attributed more to the expansion of area or to the improvement in the yield. The results presented in Table 3 shows that in period 1, the production of potato increased by 31319 tonnes per year in which area contributed to 93.02 per cent while yield effect was 7.15 per cent and interaction effect was negative. This clearly indicates that the yield has not increased to that extent and increase in production was mainly due to area effect. In period 2, production increased approximately by 81442 tonnes per annum which was mainly due to area (57.13%) and yield effect (54.06%) while the interaction effect was negative. In overall period, production increased by 57017 tonnes per year. This increase was mainly due to area effect (63.54%) and yield (44.98%) while the interaction effect was negative. It was clearly seen that, increase in area was the major reason behind increase in the production in overall study period followed by improvement in yield while the interaction effect was negative. The findings align with the research carried out by Sagolsem *et al.* (2017).

Input use pattern in potato

The input-use pattern of potato crop is presented in Table 4. The results showed that the quantity of input decreased over the years but the value has increased by a high percentage. The quantity of fertilizers decreased by 69.48 per cent from 181.97 to 55.54 kg/ha. The quantity of manures increased from 107.59 qtl to 169.87 qtl/ha. The value of input increased at a rate of 3442.76 per cent in animal labour followed by human labour (528.16%) and seed (278.70%), respectively.

Break-up of total cost, cost concept wise and income over different cost in potato

The cost and income on the basis of the cost concept in the production of potato have been presented in Table 5 at two different time

Table 3. Decomposition analysis of potato in Himachal Production (Qtl/year)

	Annual Change in Production	Yield Effect	Area Effect	Interaction Effect
Period I	31319.00 (100.00)	2239.61 (7.15)	29134.02 (93.02)	-54.64 (-0.17)
Period II	81442.55 (100.00)	44031.70 (54.06)	46524.42 (57.13)	-9113.57 (-11.19)
Overall	57017.14 (100.00)	25645.90 (44.98)	36230.92 (63.54)	-4859.67 (-8.52)

Note: Period I = 2001-02 to 2010-11, Period II = 2011-12 to 2021-22, Overall period = 2001-02 to 2021-22

Table 4. Input use pattern of Potato in Himachal

Items	2021-22		2001-02		% Change in 2021-22 over 2001-02	
	Quantity	Value (Rs./ha)	Quantity	Value (Rs./ha)	Quantity	Value (Rs./ha)
Seed (Kg.)	1899.74	7.09	1745.30	26.85	-8.13	278.70
Fertilizer (Kg.)	181.97	13.22	55.54	26.89	-69.48	103.40
Manure (qtl.)	107.59	25.98	169.87	98.06	57.89	277.46
Human Labour (Man Hrs.)	707.98	9.48	612.10	59.55	-13.54	528.16
Animal Labour (Pair Hrs.)	137.12	4.21	49.66	149.15	-63.78	3442.76

Table 5. Break–up of total cost, cost concept wise and income over different costs in Potato.

S. No.	Different Costs	Break up of total cost (Rs./ha)			Income over different cost (Rs./ha)		
		2001-02	2021-22	% Change	2001-02	2021-22	% Change
1	A_1	21059.34	78849.15	274.41	54316.18	75551.22	39.09
2	A_2	21059.34	78849.15	274.41	54316.18	75551.22	39.09
3	B_1	22425.63	80903.08	260.76	52949.89	73497.29	38.80
4	B_2	30993.03	101710	228.17	44382.49	52690.38	18.71
5	C_1	28536.32	115182.6	303.63	46839.2	39217.74	-16.27
6	C_2	37103.72	135989.5	266.51	38271.8	18410.83	-51.89

periods. It is clear from table that per hectare Cost A_1, Cost B_1, Cost B_2, and Cost-C_2 have increased over the years. The highest change was observed in Cost C_1 (303.63%) followed by Cost A_1 (274.41%), Cost C_2 (266.51%), and Cost B_1 (260.76%). The average income per hectare over Cost A_1 increased from Rs. 54316.18 in 2001-02 to Rs. 75551.22 in 2021-22 with per cent change of 39.09. Income over Cost B_1 and Cost B_2 also increased from Rs. 52949.89/ha and Rs. 44382.49/ha during 2001-02 to Rs. 73497.29/ha and Rs. 52690.38/ha in 2021-22, showing an increase of 38.80 and 18.71 per cent, respectively. Income over Cost C_1 and C_2 decreased by 16.27 and 51.89 per cent, respectively as the cost of cultivation increased in the year 2021-22 compared to 2001-02. It is revealed from the table that income over cost A_1, A_2, B_1 and B_2 has increased over the years, but showed a gradual decrease over cost C_1 and C_2. This may be because farmers received very low prices due to market gluts in that year. Similar finding was reported by Pandey *et al.* (2004).

Measure of farm profit

The details of measures of profit of potato for the state are given in Table 6. The gross income of potato has increased from Rs. 75375.52/ha in 2001-02 to Rs. 154400.37/ha in 2021-22 with per cent change of 104.84. During this period, farm business income has also increased by 39.09 per cent from Rs. 54316.18/ha in 2001-02 to Rs. 75551.22/ha in 2021.22. The net income which is the residual of gross return over total cost has recorded a decrease of 51.89 per cent. As far as the farm investment income is concerned, it decreased by 14.38 per cent. It is clear from the table that the farm investment income and net income decreased in 2021-22 compared to 2001-02, which may be due to a disproportionate increase in input cost as compared to the revenue generated.

Cost structure and change in cost structure

The cost of cultivation of potato in the state for the years 2001-02 to 2021-22 has been given in Table 7 and revealed that

Table 6. Measures of farm profits in Potato.

S. No.	Items (Rs./ha)	2001-02	2021-22	% Change
1	Value of Main Product	75375.5	154400.37	104.84
2	Value of By- Product	-	-	-
3	Gross Income	75375.52	154400.37	104.84
4	Farm Business Income (GI- Cost A2)	54316.18	75551.22	39.09
5	Family Labour Income (GI-CostB2)	44382.49	52690.38	18.71
6	Farm Investment Income (GI- (Cost A2+IFL)	48205.48	41271.67	-14.38
7	Net Income (GI- Cost C2)	38271.80	18410.83	-51.89

Table 7. Cost structure and change in cost of cultivation.

S. No.	Items	Cost of cultivation				Change in 2021-22 over 2001-02	
		2001-02 (Rs./ha)	%	2021-22 (Rs./ha)	%	(Rs./ha)	%
(A)	Operational Cost						
1	Human Labour						
	Family	6110.70	16.47	34279.55	25.21	28168.85	28.49
	Attached	73.09	0.20	0.00	0.00	-73.09	-0.07
2	Casual						
	Animal Labour	530.22	1.43	2169.57	1.60	1639.35	1.66
	Hired	155.03	0.42	0.00	0.00	-155.03	-0.16
	Owned	421.65	1.14	7407.29	5.45	6985.64	7.06
3	Machine Labour						
	Hired	44.43	0.12	342.17	0.25	297.74	0.30
	Owned	0.00	0.00	651.89	0.48	651.89	0.66
4	Seed	13474.90	36.32	46862.12	34.46	33387.22	33.76
5	Fertilizer	2405.45	6.48	1493.33	1.10	-912.12	-0.92
6	Manure	2795.45	7.53	16658.15	12.25	13862.70	14.02
7	Insecticides	184.70	0.50	414.38	0.30	229.68	0.23
8	Irrigation Charges	-	-	87.42	0.06	87.42	0.09
9	Miscellaneous	-	-	48.03	0.04	48.03	0.05
10	Interest on Working Capital	627.65	1.69	2379.19	1.75	1751.54	1.77
	Total Operational Cost	26823.27	72.29	112793.09	82.94	85969.82	86.94
(B)	Fixed Costs						
1	Rental Value of Owned Land	8567.40	23.09	20806.91	15.30	12239.51	12.38
2	Rent Paid For Leased-in-Land	-	-	-	-	-	-
3	Land Revenue, Taxes, Cesses	15.18	0.04	7.27	0.01	-7.91	-0.01
4	Depreciation on Implements & Farm Building	331.59	0.89	328.34	0.24	-3.25	0.00
5	Interest on Fixed Capital	1366.28	3.68	2053.93	1.51	687.65	0.70
	Total Fixed Cost	10280.45	27.71	23196.45	17.06	12916.00	13.06
(C)	Total Cost (A+B)	37103.72	100.00	135989.54	100.00	98885.82	100.00

the total cost of cultivation per hectare has increased from Rs. 37103.72/ha in 2001-02 to Rs. 135989.54/ha in 2021-22 over the years. During 2001-02, the operational cost and fixed cost were in the ratio of 72:28 and during 2013-14, the ratio was 83:17. It indicates that the proportion of operational cost and fixed cost has changed only marginally. The increase in cost of cultivation has occurred in all major items of cost such as human labour, animal labour, machine labour, seed, rental value of owned land and interest on fixed capital whereas, fertilizer cost has decreased over the years. Out of total increase of Rs. 98885.82/ha in cost of cultivation over the years, 86.94 per cent was attributable to operational cost and 13.06 per cent to fixed cost items. The major items of operational cost which caused for the increase in cost of cultivation were seed (33.76%), family labour (28.49%) and manure (14.02%). Out of total fixed cost items, rental value of owned land contributed maximum i.e. 12.38 per cent increase in fixed cost. The findings are in collaboration with the study conducted by Pandey *et al.* (2004) in Shimla district of Himachal Pradesh.

CONCLUSION

The foregoing results revealed that the area, production and productivity of potato crop significantly increased over the period. The instability was found to be highest in production in the overall period compared to area and productivity. The decomposition analysis showed that an increase in area was the major reason behind the increase in the production in overall period, followed by an improvement in yield, while the interaction effect was negative. The quantity of input decreased but the value of inputs has increased which indicates higher prices of agricultural inputs over the years. The cost of cultivation analysis revealed that operational cost contributed more towards the total cost as compared to fixed cost. The potato crop is capital intensive thus major items attributed to operational cost were value of seed followed by human labour. It is necessary to implement measures to stabilize potato production by focusing on sustainable farming practices, providing support for improved yield, and addressing negative interaction effects. Also, it is advisable to develop such policies which mitigate the impact of rising agricultural input prices by promoting cost-effective technologies, subsidizing essential inputs, and fostering initiatives to enhance input efficiency in potato cultivation.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

ETHICAL STATEMENT

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

LITERATURE CITED

Bisht BS and Sharma HC. (1997). Potato Statistics - India and the world. Tech. Bull No. 40. Central Potato Research Institute, Shimla. pp. 124

Economic Survey. 2021-22. Government of India, Ministry of Finance, Department of Economic Affairs, Economic Division, North Block, New Delhi-110001

Lal L & Sharma HR. 2006. Economics of potato production in Lahaul valley of Himachal Pradesh. *Potato Journal* 33 (3-41): 39-143

More SS, Singh N and Kuthe SB. (2015). Performance of pulses crops in Gujarat state - a decomposition analysis. *International Journal of Agriculture Sciences* 7: 510-515

Pandey NK, Kumar NR, Dahiya PS and Srinivas K. (2004). Economic analysis of potato cultivation in Shimla district (HP). *Potato Journal* 31(3-4): 171-175

Pandit A, Kumar A, Rana RK, Pandey N K and Kumar NR. (2010). A study on socio-economic profile of potato farmers: Comparison of irrigated and rainfed conditions in Himachal Pradesh. *Potato Journal* 37(1-2): 56-63

Pant DK, Singh V and Mourya OP. (2020). Growth and Instability analysis of Potato cultivation in Pithoragarh district of Uttarakhand. *International Journal of Current Microbiology and Applied Sciences* 11: 1035-1044

Rana R and Anwer ME. 2018. Potato production scenario and analysis of its total factor productivity in India. *Indian Journal of Agricultural Sciences* 88(9): 1354-1361

Sagolsem S, Mitra A and Leivang S. (2017). Growth and instability analysis of major crops in North East India. *Journal of Crop and Weed* 13(1): 72- 76

Sati VP and Wei D. (2018). Crop productivity and suitability analysis for land-use planning in Himalayan ecosystem of Uttarakhand, India. *Current Science* 115(4): 767-772

Sharma HR. 2011. Crop diversification in Himachal Pradesh: patterns, determinants and challenges. *Indian Journal of Agricultural economics* 66 (1): 97-114

Singh DK, Pandey NK and Kharumnuid P. (2018). An economic analysis of marketing of potato from Shimla hills of Himachal Pradesh. *Economic Affairs* 63(2): 419-424

Singh DK, Pandey NK, Rana RK and Singh BP. (2015). Extent and correlates of knowledge of farmers regarding scientific potato production technologies in Himachal Pradesh. International *Journal of Agriculture, Environment and Biotechnology* 8(2): 381-385

Statistical Year Book of Himachal Pradesh. 2021-22. Department of Economic & Statistics. Government of Himachal Pradesh.

Thakur DR and Moorti TV. (1991). Economics of potato in Himachal Pradesh. Daya Publishing House, New Delhi.

MS Received : January 08, 2024; Accepted : May 29, 2024

Potato J (2024) 51 (1): 91-96

RICE HUSK ASH (RHA) - A POTENTIAL SOURCE FOR IMPROVING PHOSPHORUS NUTRITION IN POTATO (*S. TUBEROSUM* L.)

Jagdev Sharma[1], Prince Kumar[2*], Anil Sharma[2], VK Dua[1], Vineeta Sharma[1] and Brajesh Singh[1]

ABSTRACT: Use of alternative sources of nutrients such organic manures, residues and by-products to chemical fertilizers may enhance not only the yield but cut down the fertilizers use. Therefore, present investigation was carried out to explore the possibility of using rice husk ash (RHA) as a source of phosphorus in potato crop. Two pot experiments were conducted on Kufri Jyoti and Kufri Girdhari to determine the effect of rice husk ash on phosphorus nutrition of the crop during 2020-21. Application of rice husk ash (RHA) significantly increased the plant height, haulms (leaf plus stem) biomass, root weight, chlorophyll content (SPAD value) and P content. In Kufri Jyoti, application of 20g RHA per pot significantly increased haulms biomass, tuber yield, relative leaf chlorophyll content and P content in haulms by 17.8 per cent over control. In Kufri Girdhari, application of 40g RHA/ pot also increased the P content by (14.6 %) in haulms over control besides significant increase in haulm yield, root mass and relative leaf chlorophyll content. It was observed that subjecting the crop to moisture stress by withholding the irrigation towards harvest, senescence was delayed in plants fertilized with rice husk ash. RHA application showed a significant and positive correlation with root length and tuber yield (r=0.70). The results of the present study revealed that RHA can be used as a source of phosphorus for potato crop and has potential to improve water relations and nitrogen nutrition as indicated by improved relative leaf chlorophyll content in plants fertilized with RHA.

KEYWORDS: Macro-nutrient, Potato, phosphorus, rice husk ash and tuber yield

INTRODUCTION

Potato (*S. tuberosum* L.) is third most important crop of world can play a key role in food and nutritional security of ever-increasing global population. In India, potato is grown in entire Indo-gangatic plains during the rabi season preceding by paddy (Kumar *et. al.,* 2023). Owing to its short duration cash crop and high bulking potential in plains, crop require appreciable amount of macro-nutrients NPK in readily available form and in sufficient amount (Kumar *et. al.,* 2021). Phosphorus is a yield limiting nutrient followed by nitrogen, which is applied through inorganic fertilizers to the crop.

Rock phosphate, a non-renewable resource, is the main raw material for phosphatic fertilizers and this high-grade reserves of rock phosphates are likely to be exhausted within the next 50 to 100 years. The recovery efficiency of phosphatic fertilizers is low about 25 per cent (Kumar *et. al.*, 2018), as phosphorus (P) is easily immobilized in soil. Therefore, improving P use efficiency either by exploiting genetic diversity or use of alternative sources such as crop residues/ wastes/ by-product is necessary for achieving sustainable yields.

Plants have evolved diverse strategies to cope with P deficiency and to counteract P-deficiency stress secretion of organic acid anions like malate, citrate and oxalate by plant roots is one of the effective strategy (Chen and Liao, 2016). Current evidence indicates that Silicon (Si) application strongly

---

[1]ICAR-Central Potato Research Institute, Shimla - 171 001, Himachal Pradesh, India
[2]ICAR-Central Potato Research Institute, Regional Station, Jalandhar - 144003, Punjab, India
*Corresponding author; email: princevgc@gmail.com

promotes the exudation of both malate and citrate by roots (Kostic *et al.*, 2017). Although the precise nature of the role still remains unclear, evidence suggests that Si plays a significant role in P nutrition and an alleviating effect of Si under P limiting conditions has been reported in rice (Hu *et al.*, 2018) in tomato (Zhang *et al.*, 2019).

Rice husk Ash (RHA) is the product of incineration of rice husk. It has the highest proportion of silica content among all plant residues and is an abundantly available and renewable agriculture by-product from rice milling in the rice-producing countries like India. In India, RHA production is estimated to be around 4.4 million tons per year and its disposal is an issue for rice mills. The rice husk contains about 50% cellulose, 25–30% lignin and 15–20% silica (Ismail and Waliuddin, 1996) and every 100 kg of husks burnt in a boiler yields about 25 kg of RHA containing about 60-70% depending up on composition of the rice husks, burning temperature and burning time. RHA besides being a rich source of silicon also contains considerable carbon and small amounts of P, K and other micronutrients. Positive effects of RHA has been reported in wheat (Kostic *et al*. 2017; Singh *et. al.,*2019) and tomato (Hu *et al.*, 2021), however, the studies on usefulness of RHA in potato crop are lacking. RHA application has shown increased soil P availability both directly (by supplying P contained in the ash) or indirectly (Gao et al., 2019).

Considering the limited reservoirs of rock phosphate used for P fertilizer production, use of agricultural residues like RHA is necessary to ensure future food production. Hence this study was carried out to generate first-hand information on its beneficial effects on potato crop with special reference to P nutrition.

MATERIALS AND METHODS

Two independent pot experiments were conducted under glass house condition during the year 2020-21 at ICAR-Central Potato Research Institute, Shimla (HP). The popular varieties of potato *viz.* Kufri Jyoti and Kufri Girdhari were chosen to investigate the effect of rice husk ash (RHA) on crop performance. In the first experiment, thoroughly washed cocopeat was used as a growing media. The first experiment on Kufri Jyoti consisted of three treatments *viz.* T_1 = Cocopeat alone; T_2 = Cocopeat + 10g RHA/pot; T_3 = Cocopeat + 20g RHA/pot. The treatments were replicated five times. Second experiment was conducted on Kufri Girdhari using acid washed sand as growing media and three doses of RHA were tested in the following treatment combinations: T_1 = Sand alone; T_2 = Sand + 10g RHA/pot; T_3 = Sand + 20g RHA/pot; T_4 = Sand + 40g RHA/pot and T_5 = Sand + RDF P/pot and the treatments were replicated three times. RHA was applied around the seed piece at the time of planting. Half dose of nitrogen (as urea) and potassium (as SOP) and full dose of micronutrients (Zn, Fe, Cu, Mn & B) was applied uniformly at planting by mixing in the respective growing media used in the experiment and remaining half dose of N and K was incorporated in the rootzone 20 days after emergence. The RHA used had a pH =9.36 (1:2 ratio) and OC = 10.2%; N = 0.01%; P = 0.30%; K = 0.52%; Ca = 0.40%; Mg = 0.12% and S = 0.08%. Observations on plant height, SPAD value were recorded 60 days after planting. Haulms (leaf plus stem) and root were harvested separately, oven dried and biomass yield is reported on oven dry weight basis. Chlorophyll content was measured indirectly by chlorophyll meter SPAD - 502 Plus. Nutrient content of RHA and potato samples (haulms and tuber) was determined as per standard methods after acid digesting the samples in nitric and perchloric acid mixture. The experiment was laid out in completely randomized design (CRD) and statistically analysed by following the methodology proposed by Gomez and Gomez, 1984.

RESULTS AND DISCUSSION

Currently residue wastes and by-products as an organic fertilizers can play an important role as complementary sources with inorganic fertilizers to improve not only the productivity but also water and nutrient use efficiency along with the soil health. In the present investigation, addition of rice husk ash had shown superiority in terms of growth and tuber yield. In the first study conducted on Kufri Jyoti in cocopeat, 10 and 20 g RHA per pot increased the biomass as well as tuber yield per pot (**Table 1 and Figure 1**). Haulm (leaf plus stem) biomass on dry weight basis was 32.47 per cent (10 g RHA per pot) and 40.00 per cent higher (20 g RHA per pot). Application of 20 g RHA per pot increased P content significantly in haulms by 17.85 per cent and statistically at par with control over control. The SPAD value was also increased significantly to the tune of 11.52 per cent and 19.63 per cent with the application of rice husk ash at the rate of 10 g and 20 g/pot, respectively, compared to the control treatment. Tuber yield also increased significantly with the application of RHA (10 g and 20 g) to the tune of 13.68 and 17.70 per cent over control with the application of 10g and 20g RHA, respectively. When the plants were subjected to moisture stress by withholding the irrigation towards harvest, the senescence was delayed in plants fertilized with RHA compared to in control treatment. The alleviating effects of Si on drought stress has been observed in a wide variety of crop plants including both monocots and dicots. Silicon enhanced water stress tolerance in *Solanum lycopersicum* L by improving root hydraulic conductance (Gong *et al.*, 2005 and Thorne *et al., 2021).* The underlying mechanism by which Si alleviates oxidative damage is not clear.

Table 1. Effect of different rates of RHA on growth and yield of potato *cv* Kufri Jyoti.

Treatment number	Plant height (cm)	SPAD value	Haulms biomass (dry weight basis) (g/pot)	Haulms P (%)	Tuber yield (g/pot)
T_1	23.20	32.80	4.65	0.224	74.10
T_2	33.40	36.60	6.16	0.236	84.24
T_3	37.00	39.24	6.51	0.264	87.22
$CD_{(p=0.05)}$	2.20	1.69	0.45	0.021	4.91

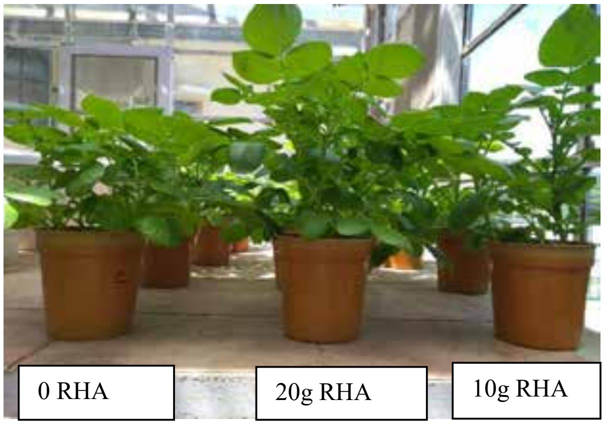


Fig. 1. Effect of RHA on growth of Kufri Jyoti in cocopeat.

In second experiment on Kufri Girdhari variety, RHA application rates of 40g per pot significantly increased (14.65) the phosphorus content in haulms, plant height and root dry weight over control (**Table 2**). The highest P concentration (0.52%) in haulms was observed in T_5 with the addition of chemical P fertilizer. The differences in plant height were more pronounced during the initial growth stage and narrowed down as the season progressed (**Figure 2**). Evidence suggests that Si plays a significant role in P nutrition, but the precise nature of that role still remains unclear. Two major mechanisms of Si-mediated alleviation of P deficiency are proposed based on different studies: (i.) increased root uptake and (ii.) enhanced utilization of P within

Table 2. Effect of different rates of RHA on growth and yield of potato *cv* Kufri Girdhari.

Treatment number	Plant height (cm)	SPAD value	Haulms biomass (dry weight basis) (g/ pot)	Haulms P (%)	Root weight (g)/ pot	Tuber yield (g)/ pot
T_1	33.07	32.20	8.00	0.41	1.648	63.36
T_2	36.27	32.93	8.25	0.42	1.722	64.67
T_3	40.17	34.43	8.53	0.45	1.802	73.87
T_4	41.97	35.40	8.64	0.47	1.815	74.88
T_5	45.60	33.77	9.55	0.52	1.857	76.74
$CD_{(p=0.05)}$	2.26	1.66	0.48	0.04	0.056	4.90

Fig 2. Effect of RHA on shoot and root growth in sand (LHS-control and RHS with RHA)

Fig. 4. Effect of RHA on leaf chlorophyll in Kufri Girdhari (LHS (0RHA+P) and RHS (40g RHA alone) in sand culture

the plant tissues. Increase in P concentration and plant growth parameters due to RHA application in the present study is attributed to utilization of P present in RHA. Root biomass exhibited significant and positive relationship with haulms biomass and tuber yield (**Figure 3**). Application of rice husk ash also increased the SPAD index significantly in Kufri Girdhari (**Table 2 and Figure 4**). SPAD index is indirect measure of plant nitrogen status. Although, the exact mechanisms by which Si induces change in N metabolism still remain unknown, increased N uptake under suboptimal N supply mediated by Si has been reported in different plant species, e.g., cowpea (*Vigna unguiculata*) (Mali and Aery, 2008), maize (*Zea mays*) (Mabagala *et al.*, 2020) and rice (*Oryza sativa*) (Deus et al., 2020). Increased tissue concentration of N due to application of Si has been attributed enhanced transport efficiency (Sheng *et al.*, 2018).

As observed in the present study, increase in P uptake with the application of Si under P limiting conditions has been reported in wheat (Kostic *et al.*, 2017; Neu *et al.*, 2017),

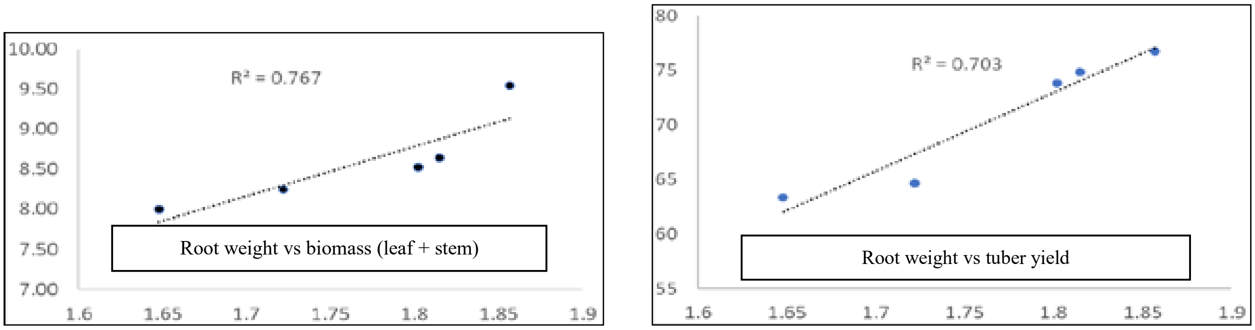


Fig.3. Relationship between root weight and haulms biomass (LHS) and tuber yield (RHS).

maize (Owino-Gerroh and Gascho, 2005), tomato (*Solanum lycopersicum*) (Zhang *et al*., 2019), rice (Ma and Takahashi, 1990; Pati et al., 2016; Hu et al., 2018) and potato (*Solanum tuberosum*) (Soltani *et al*., 2017; Soratto *et al*., 2019), although the precise nature of the role of Si plays in P nutrition still remains unclear. Priyadharshini and Seran (2009) found that RHA application @ 4.5 t ha^{-1} results the high number of nodules and nodule weight and significantly higher yield in cowpea. Application of RHA to soil increases soil P availability directly by supplying P contained in the ash and indirectly as well (Gao *et al*., 2019). Although the root exudates were not determined in present study, evidence indicates that Si application strongly promotes the exudation of both malate and citrate by roots which increases the P availability (Kostic *et al*. 2017).

CONCLUSION:

Overall, the results of the present study concluded that RHA besides being a source of nutrients like P, it also has the potential to improve drought tolerance in potato crop by positively impacting the root growth. Apart from increased nutrient uptake silicon application can be attractive approach to improving plant water status and maintaining plant water balance under drought stress conditions. Further studies should evaluate the benefits of RHA using in different types of soils under natural farm conditions to enhance our understanding of RHA for improving tuber yield and nutrient use efficiency and the underlying mechanisms by which Si alleviates oxidative damage under drought needs to be investigated in potato.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

ETHICAL STATEMENT

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

LITERATURE CITED

Chen ZC and Liao, H (2016) Organic acid anions: An effective defensive weapon for plants against aluminum toxicity and phosphorus deficiency in acidic soils. *Journal of Genetics and Genomic Research* **43**: 631–638

Deus ACF, de Mello PR, de Cássia FAR, de Oliveira, RLL and Felisberto, G (2020) Role of silicon and salicylic acid in the mitigation of nitrogen deficiency stress in rice plants. *Silicon* **12**: 997–1005

Gao S, DeLuca, TH and Clevel CC (2019) Biochar Additions Alter Phosphorus and Nitrogen availability in agricultural ecosystems: a meta-analysis. *Science of Total Environment* **654**: 463-472

Gong H, Zhu X, Chen K, Wang S and Zhang C (2005) Silicon alleviates oxidative damage of wheat plants in pots under drought. *Plant Sci.* **169**: 313–321

Gomez KA and A.A. Gomez (1984). Statistical procedures for agricultural research (2 ed.). John wiley and sons, NewYork, 680p.

Hu AY, Che J, Shao JF, Yokosho K, Zhao XQ, Shen RF *et al*. (2018) Silicon accumulated in the shoots results in down-regulation of phosphorus transporter gene expression and decrease of phosphorus uptake in rice. *Plant and Soil* **423**: 317–325

Hu AY, Xu SN, Qin DN, Li W and Zhao XQ (2021) Role of silicon in mediating phosphorus imbalance in plants. *Plants* **10**:51-65

Ismail MS and Waliuddin A (1996) Effects of rice husk ash on high strength concrete. *Construction of Building Materials* **10**: 521-526

Kostic L, Nikolic N, Bosnic D, Samardzic J and Nikolic M (2017) Silicon increases phosphorus (P) uptake by wheat under low P acid soil conditions. *Plant and Soil* **419**: 447–455

Kumar Prince, Dua VK, Sharma Jagdev, Byju G, Minhas JS and Chakrabarti SK (2018) Site specific nutrient requirements of NPK for potato (*Solanum tuberosum* L.) in western Indo-gangatic plains of India based on QUEFTS. *Journal of Plant Nutrition*. **41**(15):1988-2000

Kumar Prince, Kumar Raj, Shah M Abas, Singh RK, Sharma AK, Kumar Raj and Dua VK (2023) Tuber yield and incidence of virus-vectors in late-planted seed potato crops in north-western plains of India. *Potato Research*. https://doi.org/10.1007/s11540-022-09604-6.

Kumar Prince, Sharma J, Kumar D, Sharma V, Dua VK, Sharma A, Kumar R and Kumar M (2021) Apposite macronutrient fertilization (AMNF) – an effective modus operandi for potato crop. *Indian Journal of Agricultural Sciences* **91**(2): 244-248

Ma JF and Takahashi E. (1990) Effect of silicon on the growth and phosphorus uptake of rice. *Plant and Soil* **126**: 115–119

Mabagala FS, Geng YH, Cao GJ, Wang LC, Wang M and Zhang M L (2020) Effect of silicon on crop yield, and nitrogen use efficiency applied under straw return treatments. *Applied Ecology and Environmental Research* **18**: 5577–5590

Mali M, and Aery NC (2008) Silicon effects on nodule growth, dry-matter production, and mineral nutrition of cowpea (*Vigna unguiculata*). *Journal of Plant Nutrition and Soil Science* **171**: 835–840

Neu S, Schaller J and Dudel EG (2017) Silicon availability modifies nutrient use efficiency and content, C:N:P stoichiometry, and productivity of winter wheat (*Triticum aestivum L.*). *Scientific Reports* **7**: 40829

Owino-Gerroh C and Gascho GJ (2005) Effect of silicon on low pH soil phosphorus sorption and on uptake and growth of maize. *Communications in Soil Science and Plant Analysis* **35**: 2369–2378

Pati S, Pal B, Badole S, Hazra GC and Mandal B (2016) Effect of silicon fertilization on growth, yield, and nutrient uptake of rice. *Communications in Soil Science and Plant Analysis* **47**: 284–290

Priyadharshini J and Seran TH (2009) Paddy husk ash as a source of potassium for growth and yield of cow pea (*Vigna unguiculate* L.). *The Journal of Agricultural Sciences* **4** (2): 67-76

Sheng H, Ma J, Pu J and Wang L (2018) Cell wall-bound silicon optimizes ammonium uptake and metabolism in rice cells. *Annals of Botany* 1**22**: 303–313

Shi Y *et al*. (2016) Silicon enhances water stress tolerance by improving root hydraulic conductance in *Solanum lycopersicum* L. *Front. Plant Sci.* **7**: 196.

Singh R, Srivastava P, Singh P, Sharma AK, Singhe H, Raghubanshi AS (2019) Impact of rice-husk ash on the soil biophysical and agronomic parameters of wheat crop under a dry tropical ecosystem. *Ecological Indicators* **105**: 505-515

Soltani M, Kafi M, Nezami A and Taghiyari, HR (2017) Effects of silicon application at nano and micro scales on the growth and nutrient uptake of potato mini-tubers (*Solanum tuberosum* var. Agria) in greenhouse conditions. *Bio Nano Science* **8:** 218–228

Soratto RP, Fernandes, AM, Pilon C and Souza MR (2019) Phosphorus and silicon effects on growth, yield, and phosphorus forms in potato plants. *Journal of Plant Nutrition* **42:** 218–233

Thorne S J, Hartley S E and Maathuis FJM (2021) The effect of silicon on osmotic and drought stress tolerance in wheat landraces. *Plants* **10:** 814.

Zhang Y, Liang Y, Zhao X, Jin X, Hou L, Shi Y and Ahmed GL (2019) Silicon compensates phosphorus deficit-induced growth inhibition by improving photosynthetic capacity, antioxidant potential, and nutrient homeostasis in tomato. *Agronomy* **9**:733-749.

MS Received : March 23, 2024; Accepted : July 31, 2024

Potato J (2024) 51 (1): 97-108

AN ECONOMICS OF POTATO PRODUCTION IN KANGRA DISTRICT OF HIMACHAL PRADESH

A Raina[1], P Sharma[1], Garima Gupta[2*] and S Kumari[2]

ABSTRACT: In Kangra district of Himachal Pradesh is renowned for its disease-free quality seed potato production, an economic study of 200 growers grouped into small (105) and large (95) farms revealed an overall cost of cultivation at Rs. 94,667 per farm and Rs. 3,08,051 per ha in 2022-23. Among all inputs, potato seed accounted for 29% per hectare, while human labor constituted 27% of costs. The total variable cost was 89%, with fixed costs at 11% per ha. Gross income averaged Rs. 4,67,705 per ha. Efficiency analysis across farm categories showed the cost of potato production at Rs. 250 per quintal (q). Large farms exhibited a slightly higher output-input ratio (1.52) compared to small farms. Production costs ranged from Rs. 1,195 to Rs. 1,270 per q for large and small farms, respectively, with variable costs higher on small farms (Rs. 1,117) than on large ones (Rs. 1,074) per q. The reported benefit-cost ratio stood at 1.88, indicating favorable returns. Potato prices ranged from Rs. 1,860 to Rs. 1,880 per q, with larger farms realizing higher prices. Break-even analysis suggested the need for small, large, and overall farm categories to achieve at least 50.72, 38.02, and 44.14 q of potatoes, respectively, to maintain a no-profit, no-loss condition. The analysis underscores potential profit increase by optimizing human labor, manure, and fertilizer use.

KEYWORDS: CACP cost concepts, Cost-benefit analysis, economic analysis, net returns.

INTRODUCTION

The potato (*Solanum tuberosum*), grown for its starchy tubers, belongs to the nightshade family (Solanaceae) and is cultivated worldwide, originating in the Peruvian and Bolivian Andes (Singh *et al.*, 2020). China and India lead global potato production, contributing about one-third of the total crop (FAOSTAT, 2023). In 2022-23, global production reached 376 million tonnes (mt), with China producing 94 mt and India 54 mt. In Himachal Pradesh, agriculture comprises 14% of the state's Gross State Domestic Product (GSDP) (Economic Survey of Himachal Pradesh, 2022-23), with potatoes being a significant crop, yielding 1,94,500 metric tonnes on 15,100 ha (Statistical Yearbook of Himachal Pradesh, 2022-23). Kangra district alone produces 16,030 tonnes on over 1,250 ha, representing nearly 11% of the state's vegetable production (Statistical Yearbook of Himachal Pradesh, 2022-23). Sharma *et al.* (2017) highlight Kangra's potatoes for their high dry matter content (20%), ideal for chip manufacturing. Harvested typically in May, but usable till July, Kangra's potatoes are in demand by food processing industries, particularly in Palampur and NagrotaBagwan. However, geographical and topographical constraints limit agricultural land availability (Sharma *et al.*, 2017). To address the profitability and efficiency of potato cultivation, including cultivation costs, marketing, technical efficiency, and climate change impacts, an economic analysis of Himachal Pradesh's potato output is vital. Insights from this research can guide policymakers and farmers in improving the financial performance of the potato farming industry in the region.

MATERIALS AND METHODS

The study was carried out during 2022-23 for Kangra district employing a

---

[1]University School of Business, Chandigarh University, Gharuan (Mohali), Punjab- 140413, India
[2]University Institute of Agricultural Sciences, Chandigarh University, Gharuan (Mohali), Punjab- 140413, India
*Corresponding author; email: garima.e8884@cumail.in / hod.agri@cumail.in

systematic sampling approach. Initially, a list of potato-growing blocks was compiled based on cultivation area, with the first two blocks selected purposively. Then, a two-stage stratified random sampling method was utilized to select farmers and villages. Working closely with revenue and agriculture department representatives, a comprehensive list of potato-growing communities within each selected block was created. Subsequently, five villages were randomly chosen in each block, resulting in a total of ten sample villages. With the help of revenue officials, a list of potato-cultivating farmers in each sample village was generated. Employing the proportionate allocation technique, 200 farmers were sampled from these villages, considering time and resource constraints. Using the square root cumulative frequency approach by (Sharma *et al.*, 2017; Kumari *et al.*, 2020); and the farmers were categorized into two groups: 95 large farmers and 105 small farmers. Data collection involved structured interviews with growers following carefully planned schedules. Production function analysis and tabular techniques were applied to analyze the collected data. Cost and return calculations for potato cultivation were conducted using established methodologies.

Cost concepts

The tabular technique and production function analysis were used to analyse the gathered data. The following ideas were applied for calculating the costs and returns of potatoes.

- Cost A consists of the material cost, bullock/tractor fees, and working capital interest.
- Cost B is equal to Cost A plus interest on fixed capital and the land's rental value.
- Cost B + estimated value of family labour equals Cost C.
- Cost D is equal to Cost C plus 10% of Cost C.

The interest rate on working capital was calculated based on the current lending rates for 2022–2023 and was set at 10% for half of the crop period and 8% for fixed capital. The typical average land rental value was employed, based on the sample survey. Same approach was employed by and (Sapkota *et al.*, 2019; Dahal *et al.*, 2023).

Benefit-cost ratio

Cost/benefit analysis: A benefit/cost analysis was also conducted to determine the financial viability of potato farming. Any company's economic strengths can be identified using the benefit-to-cost ratio (Shively, 2013). It was computed as follows: Revenue total divided by manufacturing costs equals BCR. Same approach was employed by Sapkota *et al.* (2019) and Dahal *et al.* (2023).

Farm efficiency measures

To assess farm revenue and profit efficiency, the following metrics were utilized, following the approach of Sinha and Singh (2023):

1. Gross farm income (GFI): Represents the gross value of output, adjusted for by-products, and valued at farm harvest rates.
2. Net farm income (NFI): Calculated by subtracting farm expenses from gross farm income, reflecting compensation for farmers' management. NFI = GFI – Cost C.
3. Farm family labour income (FLI): Indicates returns to family labor, derived from gross farm income less Cost B. FLI = GFI – Cost B.
4. Farm business income (FBI): Determined by deducting Cost A from Gross Farm Income, FBI reflects returns to labor, owned land, owned fixed capital, and management. FBI = GFI – Cost A.

5. Farm investment income: Represents the sum of land rental value, interest on owned fixed capital, and net agricultural revenue.

These metrics provide a comprehensive understanding of farm revenue and profit efficiency, facilitating an assessment of different aspects of farm management and resource allocation

Production function analysis

Using input-output data from individual farmers, production functions were approximated to investigate the degree to which different resources were used in potato production. Various log-linear functions were employed, chosen based on R2 values and regression coefficient significance. This methodology propounded by Mahaboob*et al.* (2019), Sharma *et al.*(2017), and Sapkota *et al.*(2019). It aims to assess resource contributions, informing efficient resource allocation strategies.

The following form of production function was employed:

$$Y = b_0\ X_1 b_1\ X_2 b_2\ X_3\ b_3\ X_4 b_4\ X_5 b_5 e_U$$

The function's logarithm is:

$$\text{Log } Y = \text{Log} b_0 + b_1 \text{Log} X_1 + b_2 \text{ Log } X_2 + b_3 \text{ Log } X_3 + b_4 \text{ Log} X_4 + b_5 \text{ Log} X_5 + U$$

Where,

Y= Output of potato (q/ha), X_1 = Seed rate (kg/ha), X_2 = Farmyard manure (q/ha), X_3 = Fertilizers (kg/ha), X_4 = Human labour (Man days/ha), X_5 = Operational holding (ha), b_0 = Constant term, $b_{i's}$ = Regression coefficients, i= 1, 2,..,5

U = Random term

Statistical tools

T-statistics were used to examine the regression coefficient of production elasticity for statistical significance.

Return to scale

Return to scale in the Cobb-Douglas production function was calculated by adding the elasticity coefficients of the independent variables, or ($\Sigma in=1bi$). Same approach was also employed by Sharma *et al.*(2017) and Sapkota *et al.*(2019).

If $\Sigma bi=1$, implies constant return to scale.

If $\Sigma bi>1$, implies increasing return to scale.

If $\Sigma bi<1$, implies decreasing return to scale.

RESULTS AND DISCUSSION

Because of the state's inherent advantages in the production of seed potato, this crop plays a significant role in the economy of Himachal Pradesh. The perfect environment for growing disease-free potatoes in the state includes mild, temperate climate with high wind speeds, moderate humidity in the higher hills, and negligible to low aphid populations. Potatoes took up 15,100 ha of land in Himachal Pradesh, yielding 1.94 lakh tones.

Labour utilization pattern

Human labor is pivotal for profitable farming, especially for labor-intensive crops like potato. Field preparation, planting, inter-cultivation, and harvesting require a significant labor. Labor needs vary based on farm mechanization levels. The study assessed labor requirements by converting time spent on farm tasks into man-days, with one man-day equating to eight hours. Table 1 details labor distribution for potato cultivation. On average, 208 man-days per hectare were required, ranging from 214 on small farms to 205 on large ones. Family labor contributed 35% overall, with hired labor constituting the remaining 65%. Harvesting/digging (17%), cleaning and transporting (17%), field preparation (18.75%), andweeding/ inter-cultivation/planting (14%) were the most labor-intensive tasks. These primary operations comprised 63.46% of total labor. Srinivas and Ramanathan (2007) have also reported similar findings.

Table 1. Operation-labour utilization for potato cultivation on sample farms.

(Mandays)

S. No.	Particulars	Small		Large		Overall	
		Per farm	Per ha	Per farm	Per ha	Per farm	Per ha
1	Field preparation	5 (16.67)	36 (16.82)	18 (18.37)	38 (18.54)	12 (18.46)	39 (18.75)
2	Seed preparation & treatment	3 (10.00)	21 (9.81)	9 (9.18)	19 (9.27)	6 (9.23)	19 (9.13)
3	Sowing/ planting of tubers	4 (13.33)	29 (13.55)	13 (13.27)	27 (13.17)	9 (13.85)	29 (13.94)
4	Weeding/ interculture	4 (13.33)	29 (13.55)	14 (14.29)	29 (14.15)	9 (13.85)	29 (13.94)
5	Manuring & fertilizer application	3 (10.00)	21 (9.81)	9 (9.18)	19 (9.27)	6 (9.23)	19 (9.13)
6	Plant Protection measures/ sprays	3 (10.00)	21 (9.81)	9 (9.18)	19 (9.27)	6 (9.23)	19 (9.13)
7	Irrigation	3 (10.00)	21 (9.81)	9 (9.18)	19 (9.27)	6 (9.23)	19 (9.13)
8	Harvesting/ digging of tubers	5 (16.67)	36 (16.82)	17 (17.35)	35 (17.07)	11 (16.92)	35 (16.83)
9	Total Labour	30 (100.00)	214 (100.00)	98 (100.00)	205 (100.00)	65 (100.00)	208 (100.00)
i	Family labour	11 (36.67)	79 (36.92)	34 (34.69)	71 (34.63)	23 (35.38)	73 (35.10)
ii	Hired Labour	19 (63.33)	135 (63.08)	64 (65.31)	134 (65.37)	42 (64.62)	135 (64.90)

Note: Figures in the parentheses indicate percentages to the total in each category.

Input use pattern

Table 2 illustrates input usage for potato cultivation, offering insights into farm technology levels crucial for crop yield. Seeds are a key input, constituting a significant portion of the cost, averaging 22.58 q/ha, slightly below the recommended rate of 25 q/ha. Farmyard manure (FYM) averaged 195.16 q/ha, falling short of the recommended 250 q, with no notable difference between farm sizes. Farmers predominantly utilized IFFCO mixture (12:32:16) and urea, applying an average of 177.42 kg/ha and 216.13 kg/ha, respectively. Larger farms tended to use more of these inputs per hectare. Pesticide and chemical usage for disease and insect control incurred costs of Rs 2,143 and Rs 1,250 per hafor small and large farms, respectively. Tractor services averaged 29.9 hours per ha, with no significant difference between farm sizes. Bullocks, tractors, and power tillers were crucial for field ploughing, with a preference for tractors and power tillers. Bullock labor averaged at 4.84 bullock pairs per farm, with

Table 2. Input use pattern for potato crop on sample farms.

S. No.	Particular	Small		Large		Overall	
		Per farm	Per ha	Per farm	Per ha	Per farm	Per ha
1	Seed(q)	3	21.43	11	22.92	7	22.58
2	FYM(q)	27	192.86	94	195.83	60.5	195.16
3	Fertilizers						
i	Urea(kg)	29	207.14	105	218.75	67	216.13
ii	IFFCO mixture(kg)	20	142.86	90	187.5	55	177.42
	Total	79	350	300	625	122	393.55
4	Pesticides/ chemicals(Rs)	300	2143	600	1250	400	1290
5	BPD	2	14.29	1	2.08	1.5	4.84
6	Tractor/power tiller hours	4.04	28.86	14.5	30.21	9.27	29.9

Note: BPD: Bullock Pair Days, FYM: Farm Yard Manure small farms utilizing more per ha. Human labor requirement averaged 208 man-days per ha, slightly more for small farms (214 man-days). This data informs agricultural optimization, enhancing productivity and overall farm efficiency.

Variable cost structure for potato cultivation on sample farms

The variable cost structure for potato production, comprising inputs like seed, fertilizer, pesticides, and hired labor depicted in Table 3. Seed costs were paramount, constituting 60.38% of the material cost and 32.38% of the total variable cost. Farmyard manure (FYM) costs followed closely, representing about 23.81% of the material cost and approximately 13% of the variable cost. Fertilizer and insecticide costs accounted for 14.65% and 1.15% of the material cost, respectively. Interestingly, fertilizer expenses were higher on large farms compared to small ones, while pesticide expenses per ha were higher on small farms. Hired labor constituted about 19.65% of the total variable cost, with charges for tractor/power tiller/bullock accounting for approximately 10%. Additional variable costs included miscellaneous charges like irrigation channels and tool repairs. Family labor contributed around 11% of the total variable cost. Lal and Sharma (2006) echoed these findings, emphasizing the capital and labor intensity of potato cultivation due to significant costs associated with seed, fertilizer, and human labor.

Costs and returns for potato cultivation on sample farms

A breakdown of per-ha costs and returns, incorporating fixed expenses like interest on fixed capital, depreciation, and rental value of owned land is presented in table 4. Total annual interest and depreciation on fixed capital were proportionally allocated across all crops, with small farms bearing 17.48% and large farms 9.75%. Net returns over variable costs surpassed net returns over total costs by 19.6%, indicating efficient management

Table 3. Variable cost structure for potato cultivation on sample farms.

(Rs)

S. No.	Particulars	Small		Large		Overall	
		Per farm	Per ha	Per farm	Per ha	Per farm	Per ha
1	Material cost						
i	Seed	12000	85714 (31.14)	44000	91667 (33.64)	28000	88691 (32.38)
ii	FYM	4860	34714 (12.61)	16920	35250 (12.93)	10890	34982 (12.77)
iii	Fertilisers	2860	20429 (7.42)	10860	22625 (8.30)	6860	21527 (7.86)
iv	Pesticides	300	2143 (0.78)	600	1250 (0.46)	450	1697 (0.62)
	Sub total	20020	143000 (51.95)	72380	150792 (55.33)	46200	146897 (53.63)
2	Family labour	4400	31429 (11.42)	13600	28333 (10.40)	9000	29881 (10.91)
3	Hired labour	7600	54286 (19.72)	25600	53333 (19.57)	16600	53810 (19.65)
4	Bullock labour/tractor/power tiller charges	4032	28800 (10.46)	12000	25000 (9.17)	8016	26900 (9.82)
5	Miscellaneous Charges (Rs)	550	3929 (1.43)	600	1250 (0.46)	575	2590 (0.95)
6	Working Capital (1+3+4+5)	32202	230014 (83.57)	110580	230375 (84.53)	71391	230195 (84.05)
7	Interest on working capital (@6%p.a)	1932	13800 (5.01)	6635	13823 (5.07)	4284	13812 (5.04)
8	Cash variables expenses	34134	243814 (88.58)	117215	244198 (89.60)	75675	244006 (89.09)
9	Total variable Cost (2+6+7)	38534	275243 (100.00)	130815	272531 (100)	84675	273888 (100)

Note: Figures in the parentheses indicate percentages to the total in each category

Table 4. Costs and returns for potato cultivation on sample farms.

(Rs)

S. No.	Particulars	Small		Large		Overall	
		Per farm	Per ha	Per farm	Per ha	Per farm	Per ha
1	Total variable cost	38534	275243	130815	272531	84675	273887
2	Total fixed cost	5276	37686	14708	30642	9992	34164
a)	Interest on fixed capital	886	6329	1710	3563	1298	4946
b)	Depreciation on fixed capital	890	6357	998	2079	944	4218
c)	Rental value of own land	3500	25000	12000	25000	7750	25000
d)	Imputed management cost	2155	15393	8700	18125	5428	16759
3	Total cost (1+2)	43810	312929	145523	303173	94667	308051
4	Quantity of output (q)	34.5	246.43	121.8	253.75	78	250
5	Price per quintal (Rs)	1860	1860	1880	1880	1870	1870
6	Value of output/Gross returns	64170	458360	228984	477050	146577	467705
7	Net returns over total cost	20360	145431	83461	173877	51911	159654
8	Net returns over variable cost	25636	183117	98169	204519	61903	193818
9	Net returns over cash variable expenses (excluding family labour)	30036	214546	111769	232852	70903	223699
10	Total cost of production (Rs./q)	1270	1270	1195	1195	1233	1233
11	Variable cost of production (Rs./q)	1117	1117	1074	1074	1096	1096
12	Output-input Ratio	1.46	1.46	1.57	1.57	1.52	1.52

of variable inputs. However, lower net returns over total costs imply significant fixed expenses that could impact overall profitability. Total fixed costs per hectare totaled Rs. 37,686, and total variable costs were Rs. 2,75,243, with small farms facing higher fixed costs. Effective cost management strategies are imperative in light of these findings.

Moving from small to large farms, there is an evident decreases in the total cost of cultivation, from Rs. 3,12,929 to Rs. 3,03,173, indicating that larger farms have the capacity to invest more in modern agricultural inputs. This encompasses high-quality seeds, hired labor, manure, fertilizers, plant protection, and machine labor costs, aligning with findings reported by Pandey *et al.* (2004). Raghuvanshi *et al.* (2018) similarly observed a rise in cultivation costs from marginal to large farmers. Gross returns per hectare were notably higher on large farms (Rs. 4,77,050) compared to small farms (Rs. 4,58,360), possibly due to economies of scale. Larger farms can leverage scale efficiencies, achieving higher production and potentially reducing per-unit production costs. The total cost of production (Rs./q) ranged from 1,195 for large farms to 1,270 for small farms, with small farms incurring higher variable production costs (Rs. 1,117) compared to large farms (Rs. 1,074). This disparity in production costs suggests efficiency and cost structure discrepancies, with small farms possibly encountering challenges in achieving cost-effective production. The output-input ratio slightly favored large farms (1.57) over small farms (1.46), with an overall ratio of 1.52, indicating that for every Rs. 1 invested in potato cultivation, Rs. 1.52 was gained. This suggests efficiency potentially stemming from superior management practices and economies of scale. The reported average potato yield of approximately 250 q/ha is pivotal for assessing productivity, emphasizing the importance of consistent and high yields to sustain profitability and agricultural sustainability. The reported benefit-cost ratio of 1.88 as noted by Mohammadi *et al.*(2018), further bolsters the profitability standpoint, indicating that, on average, returns from potato cultivation are 1.88 times the costs incurred, a generally favorable outcome.

Different costs and returns for potato cultivation on sample farms according to CACP cost concepts

The economic evaluation of costs and returns in potato cultivation, as depicted in table 5, serves as a vital instrument for grasping the financial dynamics of farming operations. The computation of operational costs (Cost A) per ha, totaling Rs. 1,87,608 across all farms, and its subsequent augmentation with interest on fixed capital and rental value of owned land to form Cost B at Rs. 2,17,554 per ha, offers invaluable insights. The comparison of these costs across various farm categories unveils nuances in operational efficiency and resource allocation. Further examination of Cost C and Cost B per ha, averaging Rs. 2,34,313 and Rs. 2,17,554, respectively, provides a comprehensive perspective of the overall financial landscape. Remarkably, these costs demonstrate a slightly higher trend on large farms, consistent with the findings of Singh et al. (2020). The analysis of gross returns per ha, totaling Rs. 4,67,705, showcases a marginal increase of about 4% on large farms compared to small farms. This disparity underscores the influence of scale and resource utilization on overall returns.

After looking into total cost (Cost D) per ha, which was estimated to be Rs. 2,57,745 for all farms, it was discovered that large farms had a greater value (Rs. 2,59,933) than small farms (Rs. 2,55,557), which indicates potential and challenges for cost control. The variation in profitability across different farm sizes is reflected in the nuanced analysis of net returns per hectare above operational costs (Cost A) from large (Rs. 2,87,435) to small farms (Rs. 2,72,760), with an average of Rs. 2,80,098. In addition, the analysis of net returns per acre over Costs C and B,

Table 5. Different costs and returns for potato cultivation on sample farms according to CACP cost concepts.

(Rs)

S. No.	Particulars	Small		Large		Overall	
		Per farm	Per ha	Per farm	Per ha	Per farm	Per ha
1	Cost A	25984	185600	91015	189615	58500	187608
2	Cost B	30370	216929	104725	218178	67548	217554
3	Cost C	32525	232322	113425	236303	72975	234313
4	Cost D	35778	255557	124768	259933	80273	257745
5	Gross Farm Income	64170	458360	228984	477050	146577	467705
6	Net returns over						
i	Cost A	38186	272760	137969	287435	88078	280098
ii	Cost B	33800	241431	124259	258872	79030	250152
iii	Cost C	31645	226038	115559	240747	73602	233393
iv	Cost D	28392	202803	104216	217117	66304	209960
7	Output-input ratio	1.46	1.46	1.57	1.57	1.52	1.52

which come to Rs. 2,33,393 and Rs. 2,50,152, respectively, further demonstrates the impact of variables and family work on financial results.

The observed differences in these indicators between large and small farms emphasize the necessity for customized manpower management and cost containment strategies. To sum up, it is critical that scholars, politicians, and farmers carefully examine these past costs and returns. It helps in making well-informed judgements, creating efficient agricultural policies, and pinpointing areas where the farming industry needs to improve. This analysis reveals a dynamic interaction of financial forces that directs the development of profitable and sustainable farming practices.

Farm efficiency

A key component of comprehending the economic dynamics and productivity of potato production across various farm categories was the analysis of various farm efficiency indices. A thorough analysis of important metrics, including net farm income, gross farm revenue, labour income from farm families, income from farm businesses, and income from farm investments, has been given in Table 6. Beginning with gross farm income, the data presented showed that Rs. 4,67,705 was the total amount per hectare. Farmers and other stakeholders were able to assess the total revenue derived from farming operations thanks to this complete metric. Large farms' gross farm revenue (Rs. 4,77,050) was notably higher than small farms' (Rs. 4,58,360), suggesting possible differences in productivity and scale efficiency. Next, we looked at net farm income, which was the total value per hectare after all costs were subtracted. It was Rs. 2,33,393. This important measure shed light on how profitable potato production is when both variable and fixed costs are taken into account. Notably, net farm income provided a complete picture of financial performance by matching net returns over Cost C.

The function and contribution of family labour in farming operations were clarified by examining farm family labour income, which is equal to net returns over Cost B. The revenue from family work on small farms (Rs. 2,41,431) was surpassed by the amount reported by large farms, which was Rs. 2,50,152. This discrepancy suggested differences in how family labour resources were used, with larger farms showing a more active involvement of family members in farming. The differences in efficiency between small and large farms were further highlighted by the trends in farm business income and farm investment income that were seen. These metrics offered a comprehensive picture of the financial gains made from both the main farming operation and the associated investments. In conclusion, academic and farmers benefited much from the examination

Table 6. Measures of farm business returns for potato on sample farms.

(Rs)

Sr. No.	Particulars	Small		Large		Overall	
		Per farm	Per ha	Per farm	Per ha	Per farm	Per ha
1	Gross farm income	64170	458360	228984	477050	146577	467705
2	Net farm income	31645	226038	115559	240747	73602	233393
3	Farm family labour income	33800	241431	124259	258872	79030	250152
4	Farm business income	38186	272760	137969	287435	88078	280098
5	Farm investment income	36031	257367	129269	269310	82650	263339

of these efficiency metrics. It supported well-informed decision-making, the creation of successful agricultural policies, and the identification of areas where the farming industry needed to improve.

Break-even analysis

A crucial component of farm management is determining the break-even output, which is the production level at which no profit or loss is realized. The break-even analysis for potato crop in terms of both money and physical factors is shown in Table 7 for different farm categories. The total fixed cost per hectare for small, large, and overall farm categories was clearly Rs. 37,686, Rs. 30,642, and Rs. 34,164, according to the table. The total variable cost per hectare varied from Rs. 2,72,531 to Rs. 2,75,243 in large and small farms respectively. Potato prices realized per quintal varied between 1,860 and 1,880 rupees, with larger farms realizing higher prices. Large to small category farms have production costs per quintal ranging from Rs. 1,195 to Rs. 1,270. The break-even study indicates that in order to maintain a no-profit, no-loss condition, the small, big, and overall farm categories must produce at least 50.72 quintals, 38.02 quintals, and 44.14 quintals of potatoes, respectively. Small farms had a greater break-even output (Rs. 94,339) in terms of money than large farms (Rs. 71,478). For small farms, the break-even output as a percentage of total output followed a similar pattern, with 20.58% for small farms and 14.98% for large farms.

Table 7. Break-even output of potato on sample farms.

Sr. No.	Particulars	Small	Large	Overall
1	Total fixed cost (Rs./ha)	37686	30642	34164
2	Total variable cost (Rs./ha)	275243	272531	273887
3	Total Cost (Rs./ha)	312929	303173	308051
4	Price per quintal (Rs)	1860	1880	1870
5	Output per ha (q)	246.43	253.75	250
6	Cost of Production (Rs./q)	1270	1195	1233
7	Average Variable Cost (Rs./q)	1117	1074	1096
8	Break-even output (q)	50.72	38.02	44.14
9	Break-even output in monetary terms (Rs.)	94339	71478	82542
10	Break-even output as percent to total output	20.58	14.98	17.66

A thorough grasp of the output levels necessary to cover costs and prevent losses is provided by break-even analysis. It helps farmers with financial planning, pricing tactics, and realistic output targets. Through the assessment of break-even outputs at several farm sizes, producers can customize their approaches to maximize both sustainability and profitability when growing potatoes. Making wise decisions requires these insights, particularly in the competitive and dynamic agricultural environment. Finally, farmers can use the break-even analysis as a useful tool to help them navigate the intricacies of cost and production dynamics.

Production function analysis

Both linear and Cobb-Douglas production functions were used in the regression analysis to look at the input-output relationship in the potato crop under various farmer groups. Based on economic and statistical criteria, the Cobb-Douglas form of the production function was found to be the best match. It was then used to investigate how various factors affected output, production elasticities, and resource usage efficiency. Table 8 provides the regression coefficients, standard errors, and adjusted coefficients of multiple determinations () for potato production. Roughly 72% of the difference in potato production across the farm was explained by the production function. Potato production on an overall farm was significantly and favourably impacted by

Table 8. Estimated regression coefficients of different factors influencing potato production.

S. No.	Particulars	Regression coefficient	Small	Large	Overall
1	Constant	b0	0.890 (0.310)	-3.940 (1.840)	-0.370 (0.341)
2	Seed (X_1)	b1	0.411** (0.112)	1.910* (0.830)	0.270** (0.100)
3	FYM (X_2)	b2	0.013 (0.081)	0.510 (0.272)	0.261** (0.062)
4	Fertilizer (X_3)	b3	-0.330** (0.080)	0.142 (0.341)	0.051 (0.05)
5	Human labour (X_4)	b4	0.952** (0.210)	0.501** (0.180)	0.982** (0.110)
6	Operational holding (X_5)	b5	0.710** (0.120)	1.211** (0.291)	0.361** (0.081)
7	Adjusted coefficient of multiple determination		0.71	0.78	0.72
8	Return to scale	Σb_i	1.1251	1.0149	1.0568

Note: Figures in parentheses indicate standard errors; ** Significant at 1% level of significance; *Significant at 5% level of significance

the value of seed (X_1), labour (X_4), farm yard manure (X_2), and the area of the land holding beneath potatoes (X_5). This suggested that a 1% increase in potato seed quantity and labour cost translated into an approximately 0.27 and 0.98 percent increase in output, respectively. This implies that there was room to increase both profit and potato production. (Lal and Sharma, 2006; Sharma *et al.*, 2017) also reported similar results. On an average farm, the yield of potatoes was positively and significantly impacted by the area under potato crop (X_5) and FYM (X_2). This suggests that increasing the amount of land planted to potatoes could boost production. The chart also demonstrates that, in the case of small farms, the fertiliser (X_3) showed a statistically significant negative impact on productivity. Production decreased by around 0.33 percent for every 1% increase in fertiliser use. Potato crop acreage (X_5), human labour (X_4), and seed (X_1) all significantly increased potato productivity on small farms. More specifically, on large farms, human labour (X_4) and area under potato crop (X_5) showed the most positive significant effect on potato production. A one percent increase in seed quantity and area under potato production was expected to result in 0.41 and 0.71 percent increase in total production.

Resource use efficiency

By contrasting the marginal value product with the factor cost, the resource usage efficiency in the potato production process was examined. If the ratio of factor cost to marginal value production is equal to one, then the resources were employed efficiently. A value of marginal value product (MVP) greater than or equal to one indicates inefficient utilization of the resources. If the MVP was less than one, resources were used excessively. Table 9 displays the calculated level of marginal value productivities for the factors that affected production in a statistically significant way. The table made it clear that for nearly all of the significant factors, the ratio of marginal value productivity to factor cost was found to be more than one for farms of average size. The data further indicates that, across all farms, the MVP for human labour (X_4) was 8.41,

Table 9. Ratio of marginal value productivity to factor cost.

S. No.	Particulars	Small	Large	Overall
1	Seed (X_1)	1.41538	8.51370	1.07070
2	FYM (X_2)	-	-	0.45729
3	Fertilizer (X_3)	-0.08860	-	-
4	Human Labour (X_4)	6.58569	4.43557	8.41321
5	Area under potato crop (X_5)	1.91982	3.86798	1.05597

while the MVP for seed (X_1), FYM, and area under potato crop were 1.07, 0.45, and 1.05 respectively. This suggests that there was a somewhat inefficient use of these resources and more effort from humans must be used in the potato industry. More benefits from potato production would also come from an expansion in the area planted to potatoes. In the case of small farms, the ratio of the MVPs to factor cost for fertilizers (X_3) was found to be negative, indicating that a one-unit increase in fertilizer use would result in a fall in marginal value output. This further suggests that there is room to enhance the efficiency of resource use on small farms and raise production levels by rationalizing this input. Since the marginal value productivity to factor cost ratio for seed on large farms was greater than one (8.51), there was potential for increased use of this input, which would raise potato production. Small farms have a higher MVP (6.58) for human labour (X_4) than large farms (4.43). Additionally, it was discovered that the marginal value productivity for the area planted to potatoes (X_5) was greater than one (3.86). This indicates that by planting more of this crop, there was still room to increase potato production. With a total elasticity of 1.0568, which deviated significantly from unity, increasing returns to scales were discovered. This shows the potential for increasing production while using more seed (X_1), fertiliser (X_2), and operational storage space (X_5). It also illustrates the economics of scale. Similar results were also reported by Sharma *et al.* (2017)

CONCLUSIONS

It was observed that 208 mandays of labour were needed overall per hectare to complete different farm operations in potato. This number fluctuated between 214 mandays on small farms and 205 mandays on large farms. The completion of the field preparation, tuber harvesting and digging, and weeding/interculture required the greatest number of work man-days. On an average farm, these field tasks made for 65% of the entire amount of hired labour needed. The seed was the most important and vital input, accounting for the majority of the cost with the farmers using a seed rate of 22.58 q/ha. Fertiliser and FYM use showed the greatest technological disparity amongst the inputs. Farmers were employing more man-days of labour than advised on an average farm. The cost per hectare for potato growing was Rs 3,08,051. Human effort accounted for a significant portion of the cultivation costs, contributing almost 26% of the entire expenditure. The next largest expense component after labour was seed, making up roughly 23% of the entire cultivation cost. Eleven percent of the entire cost was attributed to fixed costs, with the total variable cost amounting to Rs 2,73,888 per ha. The output-input ratio for all farms was 1.52, meaning that every rupee invested in potato farming would yield a return of that much. According to the break-even analysis, farmers in the small, big, and overall categories would experience no profit, no loss scenario if they produced at least 50.72, 38.02, and 44.14 quintals of potatoes. The results of a production function analysis showed that the main variables influencing potato production were seed, fertilizer, and operational holding size. The efficiency of resource usage shows where there is room to improve productivity while using more seed, fertilizer, and operational holding area. Since the cost of potato seed made up one-fourth of the entire cost, giving farmers access to affordable, high-quality seed will enable them to increase output levels while lowering production costs. It was discovered that far less seed, fertilizer, farm yard manure, and insecticide were used than advised. Therefore, in order to increase potato profitability, farmers must be trained to use these inputs in accordance with a package of techniques.

ACKNOWLEDGMENT

The authors express their sincere gratitude to Chandigarh University of Agricultural Sciences and Business School, India, for their invaluable support and provision of essential research facilities.

AUTHORS CONTRIBUTIONS

Aditi Raina: Data collection, draft manuscript preparation, Pushpak Sharma: Study conception and design, reviewing, Garima Gupta: Data analysis and reviewing, Interpretation of results and reviewing. Sangya Kumari: Data analysis and reviewing.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

ETHICAL STATEMENT

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

LITERATURE CITED

Dahal S, Regmi B, Panta HK., Timalsina P, Chaudhary R, Khadk T, Poudel A (2023). Analysis of economic, production, and marketing aspects of potato farming in Changunarayan Municipality of Bhaktapur, Nepal. *Archives of Agriculture and Environmental Science*8(4): 545.

Department of Economics and Statistics, Himachal Pradesh (2022-23). Statistical Year Book of Himachal Pradesh, 66-81. Retrieved from https://himachalservices.nic.in/economics/pdf/YearBook2022-23.pdf

Department of Economics and Statistics, Himachal Pradesh (2022-23). Statistical Year Book of Himachal Pradesh, 9-60. Retrieved from https://himachalservices.nic.in/economics/pdf/YearBook2022-23.pdf

Food and Agriculture Organization (FAO) FAOSTAT (2023). Global potato statistics. Retrieved from https://www.potatogrower.com/2023/01/global-potato-statistics.

Kumari J, Singh AK and Maji S (2020). Analysis of Communication Profile of Beneficiaries under Skill Development Mission in Chhattisgarh. *Research Journal of Agricultural Sciences***11**(4): 881-884.

Lal B, Sinha TK, Kumar A, Pandit A and Pandey NK (2011). Constraints perceived by the farmers in adoption of potato technology. *Potato Journal***38**(1): 73-77.

Mahaboob B, Ajmath KA, Venkateswarlu B, Narayana Cand Praveen JP (2019). On Cobb-Douglas production function model. *AIP Conference Proceedings 2177*(1).

Mohammadi A, Tabatabaeefar A, Shahin S, Rafiee S and Keyhani A (2018). Energy use and economic analysis of potato production in Iran: A case study of Ardabil province. *Energy Conversion and Management***49***:* 3566-3570.

Pandey NK, Kumar NR, Dahiya PS and Srinivas K (2003). Economic analysis of potato cultivation in Shimla district (HP). *Potato Journal***31**: 3-4.

Raghuvanshi A, Gauraha AKand Chandrakar MR (2018). Trends and economics of cultivation of potato in Chhattisgarh. *Journal of Pharmacognosy and Phytochemistry***7***:* 3150-3153.

Sapkota SC, Raj PR, Acharya Hand Uprety S (2019). An economic analysis of potato production in Achhamm District of Nepal. *International Journal of Horticulture & Agriculture***4**(2): 1-9.

Sharma V, Lal H, Debnath U and Hatte V (2017). Economics of potato production in Kangra district of Himachal Pradesh, India. *International Journal of Current Microbiology and Applied Sciences***6**(10): 123-129.

Shively G(2013). An overview of benefit-cost analysis. Retrieved from http://www.agecon.purdue.edu/staff/shively/COURSES/AGEC406/reviews/bca.htm

Singh B, Raigond P, Dutt Sand Kumar M (2020). Potatoes for food and nutritional security. *In Potato: Nutrition and Food Security*, pp 1–12.

Sinha A and Singh SK (2023). Resource utilization and their efficiency in potato production in Northern hills of Chhattisgarh. *The Pharma Innovation Journal***12**(1): 2305-2309.

Srinivas T and Ramanathan S (2007). Economic analysis of Chinese potato cultivation in Tamil Nadu. *Journal of Root Crops***33**(1): 57-61.

MS Received : June 05, 2024; Accepted : July 07, 2024

Potato J (2024) 51 (1): 109-117

ASSESSMENT OF EARLY BLIGHT RESISTANCE IN INDIAN POTATO CULTIVARS AND ASSOCIATED BIOCHEMICAL CHANGES DURING DISEASE DEVELOPMENT

J. V. Patel[1] and N. M. Gohel[2]

ABSTRACT: Among the twenty-three varieties of potato screened against early blight disease under field conditions during *Rabi* 2020-21 and *Rabi* 2021-22 in Gujarat at Anand agricultural University, Anand, varieties were categorized into resistant (R), moderately resistant (MR), moderately susceptible (MS), susceptible (S) and highly susceptible (HS). For biochemical analysis some varieties disease reaction revealed Kufri Lima as resistant, Kufri Himalini and Kufri Nilkanth as moderately resistant, Kufri Mohan and Kufri Chadramukhi as moderately susceptible Kufri Pukhraj and Kufri Kesar as susceptible and Kufri Lalit as highly susceptible varieties to early blight disease. These varieties biochemical analysis revealed that healthy leaves of resistant, moderately resistant, moderately susceptible, susceptible and highly susceptible varieties showed higher content of moisture, total soluble sugar and total chlorophyll as compared to diseased leaves. While diseased leaves of resistant, moderately resistant, moderately susceptible, susceptible and highly susceptible varieties contained higher content of phenol and true protein compared to healthy leaves.

KEYWORDS: Potato, early blight, phenol, true protein, moisture, chlorophyll, total soluble sugar

INTRODUCTION

Potato (*Solanum tuberosum* L.) occupies a significant position in vegetable production. China stood first among the potato-growing countries, followed by India. During the 2019-20 period in India, potato production averaged 48,662 MT from 2,055 ha, achieving an average productivity of 23.67 MT per hectare (Anonymous, 2020).Potato production is currently threatened by a number of biotic and abiotic factors.

Protection of the crop is a serious issue as it is attacked by a huge number of pests which includes fungi, bacteria, viruses, nematodes and insect pests followed by never-ending vagaries of nature causing significant yield loss in the field and storage conditions. Early blight [*Alternaria solani* (Ellis and Martin) Jones and Grout] disease is one of the most common and widespread diseases of potatoes. Both foliage and tubers can be affected by the disease, which can result in yield losses of up to 50 per cent (Waals *et al.*, 2001). Potato crops severely infected with early blight often produced 30-50 per cent lower yields than those of uninfected (Rouse, 1985). When *Alternaria* attacks the host leaf, morphologically it produces a series of concentric rings around the initial site of the attack. This gives a "target spot" effect that is associated with early blight. Over the decades, the application of pesticides has become a dominant and routine practice of pest management to save crops from devastating pests and diseases. Increasing food demand is another force behind it. However, problems associated with the frequent and heavy use of pesticides are creating many issues. The cost of cultivation is rising, fungicide

---

[1]Department of Plant Pathology, B. A. College of Agriculture, Anand Agricultural University, Anand, Gujarat, India-388 110
[2]Department of Plant Pathology, B. A. College of Agriculture, Anand Agricultural University, Anand, Gujarat, India-388 110
*Corresponding author; email: jainapatel31095@gmail.com

resistance to pathogens is another concern and increased pesticide residues are contaminating soil, water and air. The adverse effects of chemicals used in agriculture over decades have changed the mindset of farmers and consumers who are now producing and buying organic foods for their health (Vyas *et al.*, 2019). The use of resistant cultivars for managing the early blight offers an economical and environmentally friendly alternative consistent with the objectives of integrated pest management. Unfortunately, no potato cultivar has been reported to be completely resistant to early blight. Very little work has been done on varietal screening, biochemical factors responsible for disease resistance and eco-safe management of the disease.

MATERIALS AND METHODS

The experiment was conducted over two consecutive *Rabi* cropping seasons, namely November 2020-21 and November 2021-22 at the Agronomy farm of B. A. College of Agriculture, Anand Agricultural University, Anand, Gujarat.

Screening of potato varieties:

Twenty-two potato varieties were screened (each in two rows -15 tubers planted per row) along with a susceptible check to identify the resistant source. Each plot size was (0.9 × 1.5 m). The experimental area was kept unsprayed without any pesticide and micronutrient spray throughout the crop season. The tubers of different varieties (Table 1) along with a susceptible check (K. Lauvkar) were procured from Potato Research Station, SDAU, Deesa, Gujara

From the time the disease first appeared until the crop reached physiological maturity, ten randomly selected and labeled plants from each variety were used to measure the early blight intensity at weekly interval. In results section data of disease intensity is terminal disease intensity. A standard scale (Mayee and Datar, 1986) *i.e.* 0 to 5 (Table 1) was used to record the observations of the percentage disease intensity on ten randomly chosen plants each entry. Three leaves- one from the basal, middle, and top portions of the plants were observed in order to determine the severity of the disease.

Table 1. Per cent disease intensity and the reactions of varieties against early blight of potato.

Per cent leaf area covered	Disease grade	Reactions
0	0	Immune (I)
1-5	1	Resistant (R)
6-20	2	Moderately Resistant (MR)
21-40	3	Moderately Susceptible (MS)
41-70	4	Susceptible (S)
>70	5	Highly Susceptible (HS)

Estimation of biochemical factors responsible for disease resistance

The effect of early blight (*A. solani*) of potato on biochemical constituents *viz.*, moisture content, phenol, total sugar, chlorophyll and true protein content were estimated from potato varieties representing different reactions from diseased and healthy leaves when the disease intensity was severe (more than 40%) in the field and susceptible variety was 55% infected.

Sampling of leaves

Sampling was conducted after 40-45 days after planting in the early morning, selecting five plants exhibiting various responses at random. For biochemical analysis, the top three leaves from both diseased and healthy specimens were chosen from same plants. To preserve enzymatic integrity, the leaves were carefully transferred to polythene bags and transported in an icebox with ice cubes to the laboratory. Standard procedures were employed to assess biochemical parameters including phenol, true protein, total soluble sugar, total chlorophyll, and moisture content. The biochemical analysis was performed at the Department of Biochemistry, B. A. College of Agriculture, Anand Agricultural University, Anand.

Phenol content

Using a mortar and pestle, the 1 g leaf sample was homogenized in 80% methanol, resulting in a final volume of 10 ml. The supernatant was collected after the content was centrifuged for 10 min at 10,000 rpm. The extract was used for the assay of total phenol. Phenol content was estimated by following the method of Bray and Thorpe (1954). Glass 10 ml tubes were filled with diluted extracts at varying concentrations, and the total amount was filled up with 1 ml of distilled water and mixed with 1 ml Folin-Ciocalteau (1:2 with water) and after 3 min, After adding 1 ml of 20% Na_2CO_3, the tubes were heated to a boiling point for one minute, cooled, and then filled to a full 5 ml with distilled water. The absorbance was measured at 650nm. Phenol content was calculated from the standard curve and expressed as a percentage.

$$\text{Phenol content (\%)} = \frac{\text{Graph factor} \times \text{O.D.} \times \text{Total volume} \times 100 \times 10^{-6}}{\text{Taken volume} \times \text{Sample weight}}$$

True protein content

The protein content was estimated using the Lowry method (Lowry *et al.*, 1951).A 100 mg leaf sample was weighed, homogenized in 2 ml of 0.1 N NaOH, and then filtered using Whatman No. 1 filter paper. The sample extracts of 0.2 ml were taken and 3 ml volume made with distilled water. 5 ml of alkaline copper solution (50 ml 2% Na2CO3 in 0.1 N NaOH + 1 ml 0.5 % CuS04 in 10 % sodium potassium tartrate) was added. 0.5 ml of the Folin-Ciocalteu reagent solution (1:1 v/v) was added after the content allowed standing at room temperature for 10 min. After 30 min at the room temperature, the material was stored and the absorbance was measured at 750 nm. The protein content was calculated using bovine serum albumin as standard range from 50 - 300 mg. The result was expressed as a percentage.

$$\text{True protein (\%)} = \frac{\text{Graph factor} \times \text{O.D.} \times \text{Total volume} \times 100 \times 10^{-6}}{\text{Taken volume} \times \text{Sample weight}}$$

Total soluble sugar content

Total soluble sugars (%) were estimated as the method suggested by Bhatnagar *et al.* (2006).

Sample preparation

A 1 gm sample was dissolved in 10 ml of 80% alcohol and left to incubate on a shaker for two hours. Following centrifugation, 1 ml of the clear solution was collected and dried in a hot water bath. It was mixed with 1 ml of distilled water. The extract was used in the total soluble sugar test.

$$\text{TSS (\%)} = \frac{\text{Graph factor} \times \text{O.D.} \times \text{Total volume} \times 100 \times 10^{-6}}{\text{Taken volume} \times \text{Sample weight}}$$

Estimation

Working standards (0.2, 0.4, 0.6, 0.8 and 1 ml) were pipetted into a series of test tubes. 0.1 and 0.2 ml of the sample solution were pipetted into two separate test tubes and volume was made up to 1 ml with distilled water. A blank of 1 ml of distilled water was also prepared. Then 1 ml of phenol was added to each test tube followed by 5 ml sulphuric acid (96%) to each test tube and shaken well for 10 min. The test tubes were then placed in a water bath at 25-30 °C for 20 min. The colour development was measured at 490 nm in a spectrophotometer. TSS present in the sample was calculated from the standard graph.

Total chlorophyll content

The quantitative estimation of total chlorophyll content (mg/g fresh weight) was done by using the DMSO method as described by Hiscox and Israelstam (1979).

Fifty mg of the fresh leaf was chopped into small pieces and placed in to test tube containing 10 ml of DMSO. The tubes containing leaf tissue and DMSO were kept in the (oven 65 °C for 3 hrs). During incubation, chlorophyll was extracted into fluid and these were transferred to graduated tubes and making a total volume of 10 ml by adding DMSO. Three ml of the sample of chlorophyll extract was transferred into a cuvette and absorbance or optical density was measured at 663 nm and 645nm using spectrophotometry. Total chlorophyll contents were calculated on a fresh weight basis employing the following formula given by Arnon (1956).

Total Chlorophyll (mg/g fresh wt.) = 22.2 × O.D. at 663 + 8.02 × O.D. at 645

Moisture content

The moisture content of potato leaves was determined by drying the weighed sample of potato leaf at 105 °C for 5 hrs. and the loss of weight was expressed as moisture content. Five-gram leaf sample from each treatment and calculate the moisture by the following formula:

$$\text{Moisture content (\%)} = \frac{\text{Initial weight - Oven dry weight}}{\text{Oven dry weight}} \times 100$$

RESULTS AND DISCUSSION

Screening of Potato Varieties for Resistance Sources against Early Blight Disease under Field Conditions

This study aimed to identify resistant sources against the early blight of potato. During *Rabi* 2020-21 and *Rabi* 2021-22, a total of 23 potato varieties including a susceptible check (K. Lauvkar) were evaluated against early blight disease under field conditions. Based on the per cent disease intensity, varieties were divided into groups with varying degrees of reactions.

The results presented in Table 2 revealed that there were considerabledifferences among the varieties in the level of resistance against the early blight of potato during two years of experimentation.

Rabi 2020-21

Among the twenty-three varieties of potato screened, only one variety (Kufri Lima) showed

Table 2. Reactions of different potato varieties to early blight disease under field conditions.

Sr. No.	Varieties	Disease intensity (%)		Final reaction
		2020-21	2021-22	
1	Kufri Sinduri	20.00	16.33	MR
2	Kufri Mohan	40.00	31.00	MS
3	Kufri Lalima	30.67	24.00	MS
4	Kufri Nilkanth	18.00	19.67	MR
5	Kufri Jyoti	26.00	19.33	MS
6	Kufri Kesar	41.00	43.33	S
7	Kufri Bahar	33.00	17.67	MS
8	Kufri Badshah	19.33	14.67	MR
9	Kufri Khyati	30.33	27.33	MS
10	Kufri Gaurav	19.00	24.33	MS
11	Kufri Arun	17.33	18.00	MR
12	Kufri Surya	24.67	22.67	MS
13	Kufri Chandramukhi	32.67	29.67	MS
14	Kufri Himalini	18.33	15.00	MR
15	Kufri Garima	19.00	17.00	MR
16	Kufri Pukhraj	43.33	42.00	S
17	Kufri Anand	15.00	10.33	MR
18	Kufri Lima	5.00	4.00	R
19	Kufri Lalit	73.67	71.00	HS
20	Kufri Ashoka	15.33	21.33	MS
21	Kufri Chipsona-1	25.67	23.00	MS
22	Kufri Ganga	37.67	34.00	MS
23	K. Lauvkar (Susceptible check)	84.33	86.00	HS

a resistant reaction. Nine varieties *viz.*, K. Sinduri, K. Nilkanth, K. Badshah, K. Gaurav, K. Arun, K. Himalini, K. Garima, K. Anand and K. Ashoka were showed a moderately resistant reaction and recorded disease intensity ranged from 15.00-20.00%. While nine varieties (K. Mohan, K. Lalima, K. Jyoti, K. Bahar, K. Khyati, K. Surya, K. Chandramukhi, K. Chipsona-1 and K. Ganga) showed moderately susceptible reactions having disease intensity ranged from 24.67-40.00 %. Two varieties *viz.*, K. Pukhraj and K. Kesar were found susceptible to disease and recorded disease intensity ranged from 41.00-43.33% while only two varieties *i.e.* K. Lalit and K. Lauvkar were found highly susceptible with a disease intensity of 73.67 and 84.33%, respectively (Tables 2).

Rabi 2021-22

Out of 23 varieties that were evaluated against early blight, one variety *i.e.* K. Lima still performed better and gave a resistant reaction. The varieties *viz.*, K. Sinduri, K. Nilkanth, K. Jyoti, K. Bahar, K. Badshah, K. Arun, K. Himalini, K. Garima and K. Anand showed moderately resistant reactions and recorded disease intensity ranging from 14.67-19.67 %. Nine varieties *viz.*, K. Mohan, K. Lalima, K. Khyati, K. Gaurav, K. Surya, K. Chandramukhi, K. Ashoka, K. Chipsona-1 and K. Ganga experienced a moderately susceptible reaction to early blight. Whereas two varieties *viz.*, K. Pukhraj and K. Kesar were categorized in susceptible disease reaction and recorded disease intensity ranged from 42.00-43.33% while K. Lalit and K. Lauvkar were found highly susceptible with disease intensity of 71.00 and 86.00%, respectively (Tables 2).

Final reactions

Based on two years of data, the final disease reaction has been worked out. The final results showed that none of the varieties was immune to early blight, although only one variety *i.e.* K. Lima showed a resistant reaction while seven varieties *viz.*, K. Sinduri, K. Nilkanth, K. Badshah, K. Arun, K. Himalini, K. Garima and K. Anand which showed a moderately resistant reaction. The eleven varieties *viz.*, K. Lalima, K. Mohan, K. Jyoti, K. Bahar, K. Khyati, K. Gaurav, K. Surya, K. Chandramukhi, K. Ganga and K. Ashoka and K. Chipsona-1 showed as moderately susceptible reactions. Two varieties *viz.*, K. Pukhraj and K. Kesar were as susceptible to the disease and K. Lalit and K. Lauvkar emerged as highly susceptible varieties (Tables 2).

Due to disease pressure and congenial environmental factors present at the experimental site, the result indicated significant variation in disease reactivity among potato varieties. The results of the present study revealed a considerable variation in disease reaction among potato varieties.

A similar type of results was also reported by earlier workers *viz.,* Ganie and Ghani in Jammu and Kashmir (2013), Singh *et al*. in Faizabad, Uttar Pradesh (2017) and Manjamma in Karnataka (2020) against the early blight of potato.

Estimation of Biochemical Factors Responsible for Disease Resistance

In recent years, it has been clear that host plants have several natural and induced defence systems that protect them from a wide range of diseases. One such defence mechanism is the presence of pathogen-inhibiting biochemical components. The host's pre-existing, pre-formed or induced compounds play a huge role in the plant's biochemical resistance or susceptibility to disease. The nutritional state and concentration of biochemical elements in plants before infection may be used to estimate the severity of the disease. Phenol, true protein, total soluble sugar, total chlorophyll and moisture are all essential biochemical components in conferring resilience to crop plants (Mahesh, 2024).

In this study, eight varieties were identified based on the final disease reactions to understand more about the biochemical components that trigger such reactions. An attempt was made to determine the impact of biochemical constituents present in potato plants.

Diseased and healthy plant leaves were selected from different varieties showing different reactions and the biochemical variation phenol, true protein, total soluble sugar, total chlorophyll and moisture were estimated. The diseased plant leaves had a lower percentage of moisture, chlorophyll content and total soluble sugar than healthy plant leaves whereas the phenol content and true protein was higher in the diseased plants (Table 3).

Phenol content

Phenol compounds are well-known antifungal, antibacterial and antiviral compounds occurring in plants. The first step of the defence mechanism in plants involves a rapid accumulation of phenols at the infection site, which restricts or slows the growth of the pathogen. The presence of more phenolic compounds in diseased leaves of potato varieties could be due to several factors, including increased phenolic synthesis or translocation to the site of infection which helped to cease the spread of the pathogen.

The result presented in Table 3 revealed that healthy leaves of resistant (K. Lima: 0.19%) and moderately resistant varieties (K. Himalini: 0.18%, K. Nilkanth: 0.15%) contained a higher amount of total phenol than moderately susceptible (K. Mohan: 0.14%, K. Chandramukhi: 0.13%), susceptible (K. Pukhraj: 0.11%, K. Kesar: 0.11%) and highly susceptible varieties (K. Lalit: 0.10%).

The phenol amount was increased in resistant, moderately resistant, moderately

Table 3. Effect of early blight on biochemical parameters in potato.

Varieties	Phenol content (%)		True protein content (%)		Total soluble sugar (%)		Total chlorophyll content (mg/g fresh weight)		Moisture content (%)	
	Healthy leaves	Infected leaves	Healthy leaves	Infected leaves	Healthy leaves	Infected leaves	Healthy leaves	Infected leaves	Healthy leaves	Infected leaves
Resistant										
K. Lima	0.19	0.37	1.21	1.98	4.04	3.73	2.43	2.00	87.83	80.19
Moderately Resistant										
K. Himalini	0.18	0.34	0.93	1.67	3.90	3.43	2.21	1.71	85.79	79.53
K. Nilkanth	0.15	0.30	0.87	1.56	3.60	3.06	1.83	1.26	83.38	77.46
Moderately Susceptible										
K. Mohan	0.14	0.28	0.78	1.50	3.46	2.91	1.72	1.17	82.78	77.33
K. Chandramukhi	0.13	0.25	0.71	1.36	3.43	2.81	1.62	1.09	79.51	74.14
Susceptible										
K. Pukhraj	0.11	0.23	0.67	1.25	2.38	1.73	1.53	1.06	76.72	73.32
K. Kesar	0.11	0.21	0.61	1.09	2.14	1.42	1.48	0.81	75.06	69.06
Highly Susceptible										
K. Lalit	0.10	0.20	0.55	0.97	2.07	1.27	1.43	0.64	68.77	61.72
S. Em. ±	0.002	0.007	0.025	0.029	0.038	0.030	0.027	0.032	1.769	0.680
C.D. at 5%	0.007	0.021	0.075	0.088	0.114	0.090	0.080	0.096	5.304	2.040
C.V. (%)	2.99	4.53	5.45	3.58	2.11	2.04	2.61	4.54	3.83	1.59

susceptible, susceptible and highly susceptible varieties of diseased leaves, but a higher increase of phenol was observed in resistant and moderately resistant varieties, while it was low in highly susceptible varieties.

The current findings are consistent with Shahbazi *et al*. (2010) and Mehboob *et al*. (2013) who reported significant higher phenol activity in potato plants after artificial inoculation with *A. solani*.

Patel *et al*. (2011), Meena *et al*. (2017), Awan *et al*. (2018), Garg *et al*. (2020) and Shoaib *et al*. (2020) remarked a significant increase in total phenol values during *A. solani* infection in tomato.

True protein content

The result presented in Table 3 revealed that a higher amount of protein content was present in resistant varieties than in susceptible varieties.

The result revealed that protein content was higher in diseased (K. Lima: 1.98% and K. Himalini: 1.67%, K. Nilkanth: 1.56%) as well as healthy leaves (K. Lima: 1.21% and K. Himalini: 0.93%, K. Nilkanth: 0.87%) of resistant and moderately resistant varieties than diseased (K. Pukhraj: 1.25% and K. Kesar: 1.09%, K. Lalima: 0.97%) and healthy leaves of (K. Pukhraj: 0.67% and K. Kesar: 0.61%, K. Lalima: 0.55%) susceptible and highly susceptible varieties.

Many plant pathogens interactions have shown that protein components play a vital role in defense mechanisms under biotic or abiotic stress conditions. Infected plants typically have a high protein content, which could also be linked to respiration. Increased nitrogen intake by sick plants, combined with fast respiration most likely aids in the production of additional amino acids. The information generated in the biochemical study, which presumably triggered some disease symptoms in susceptible tissue and the host-pathogen interaction could help to detect the efficacy of the pathogen.

According to Veeramohan and Ramaswamy (1995), *A. solani* infection in chilli leaves increased protein content drastically.

The present findings are also in harmony with the similar studies carried out on the activity of protein changes due to *A. solani* infection in tomato by Awan *et al*. (2018), Garg *et al*. (2020) and Shoaib *et al*. (2020).

Total soluble sugar content

In healthy leaves of resistant (K. Lima: 4.04%) and moderately resistant varieties (K. Himalini: 3.90%; K. Nilkanth: 3.60%), a higher amount of total soluble sugars content was estimated for early blight than in infected leaves (K. Lima: 3.73% and K. Himalini: 3.43%; K. Nilkanth: 3.06%), as shown in Table 3. The lowest total soluble sugars were found in infected leaves of susceptible (K. Pukhraj: 1.73%, K. Kesar: 1.42%) and highly susceptible varieties (K. Lalit: 1.27%).

Since *Alternaria* spp. thrive in low-sugar environments (Abuley *et al*., 2019). healthy leaves have higher sugar content. Sugars are important in inhibiting the pathogen's essential pectinolytic and cellulolytic enzymes. Sugars are also precursors to phenolic compounds, which are highly toxic to varieties. When plants become infected with pathogens, the respiratory rate generally increases. This means that infected tissues consume fewer carbohydrates than healthy tissues. These may be the probable reasons for higher sugar content in healthy leaves of resistant varieties. In diseased leaves, their amount was decreased in resistant and susceptible varieties. Nevertheless, this decrease in sugar content was at higher rates in susceptible varieties compared to resistant varieties.

According to Veeramohan *et al*. (1994), *A. solani* infection in chilli caused a reduction in total sugar content.

Various scientists, including Meena *et al.* (2017), Parmar (2019) and Garg *et al.* (2020) have also came to similar conclusions. They reported high sugar content in resistant genotypes compared to susceptible genotypes in tomato.

Total chlorophyll content

Total chlorophyll and the proportions of its components were shown to influence plant development stages and biological processes. In healthy leaves of resistant (K. Lima: 2.43 mg/g fresh weight) and moderately resistant varieties (K. Himalini: 2.21 and K. Nilkanth: 1.83 mg/g fresh weight), the total chlorophyll content was higher than in infected leaves. Lower chlorophyll content was found in the healthy leaves of susceptible (K. Pukhraj: 1.53, K. Kesar: 1.48 mg/g fresh weight) and highly susceptible varieties (K. Lalit: 1.43 mg/g fresh weight). Infected leaves of susceptible (K. Pukhraj: 1.06, K. Kesar: 0.81 mg/g fresh weight) and highly susceptible varieties (K. Lalit: 0.64 mg/g fresh weight) had the lowest chlorophyll content and the loss of chlorophyll due to foliar infection caused by pathogens must have a significant impact on the photosynthetic area. The establishment, spread and rapid cell changes may have contributed to the accumulation of reactive oxygen species, which may have resulted in thylakoid membrane disruption.

A similar result was also confirmed by Ginoya (2014), Meena *et al.* (2017), Garg *et al.* (2020) and Shoiab *et al.* (2020) in solanaceous crops. Srivastava and Kumar (2012) found a difference in biochemical changes in diseased and healthy leaves of potato and concluded that chlorophyll content in potato leaves was reduced due to early blight disease.

Moisture content

The data presented in Table 3 revealed that infection of early blight in potato with *A. solani* results in a loss of moisture. Healthy leaves of all varieties contained a higher amount of moisture per cent than diseased leaves. Moisture content was found higher in healthy leaves (87.83%) of resistant variety (K. Lima) followed by 85.79 and 83.38% in moderately resistant varieties *i.e.* K. Himalini and K. Nilkanth. Moderately susceptible varieties *i.e.* K. Mohan and K. Chandramukhi contained 82.78 and 79.51% moisture, respectively. Susceptible varieties *i.e.* K. Pukhraj and K. Kesar contained 76.72 and 75.06% moisture, respectively. The lowest moisture content of 68.77% was recorded in highly susceptible variety (K. Lalit). Diseased leaves contained 80.19% of moisture in the resistant variety (K. Lima) followed by 79.53% in the moderately resistant variety (K. Himalini) and 77.33% in the moderately susceptible variety (K. Mohan) and 73.32% in the susceptible variety (K. Pukhraj). Lowest moisture content recorded in highly susceptible variety (K. Lallit.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

ETHICAL STATEMENT

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

LITERATURE CITED

Abuley IK, Nielsen BJ and Hansen HH (2019) The influence of timing the application of nitrogen fertilizer on early blight (*Alternaria solani*). Pest management science **75**(4): 1150-1158

Anonymous (2020) Horticultural statistics at a glance 2020 https://nhb.gov.in/statistics/Publication/Horticulture%20Statistics%20at%20a%20Glance-2018.pdf, 9 Jan 2020

Awan ZA, Shoaib A and Khan KA (2018) Variations in total phenolics and antioxidant enzymes cause phenotypic variability and differential resistant response in tomato genotypes against early blight disease. *Scientia Horticulturae* **239**: 216-223

Bhatnagar R, Shukla YM and Talati JG (2006) Biochemical methods for Agricultural Sciences. Department of

Biochemistry, Anand Agricultural University,Anand, Gujarat, India: 51-52p

Bray HG and Thorpe WV (1954) Analysis of phenolic compounds of interest in metabolism. *Methods of Biochemical Analysis* **1**: 27-52

Ganie SA and Ghani MY (2013) Field evaluation of potato germplasm for resistance to *Alternaria solani*. *Indian Journal of Plant Protection* **41**(2): 152-155

Garg S, Kumhar DR, Verma RK and Chaudhary K (2020) Evaluation of biochemical changes in infected and non-infected plants of tomato with *Alternaria solani*. *International Journal of Chemical Studies* **8**(1): 1232-1235

Ginoya CM (2014) Morphological, biochemical and molecular characterization of isolates of *Alternaria alternata* (Fr.) Keissler incitant of fruit rot of chilli and its management Departement of Plant Pathology, Anand Agricultural University, Anand, Gujarat, India, M.Sc. thesis: 65p

Haware MP (1968) Assessment of yield losses due to early blight of potato. *Jawaharlal Nehru Krishi Vishwa Vidyalaya Research Journal* **2**(1): 67-68

Hiscox JD and Israelstam GF (1979) A method for the extraction of chlorophyll from leaf tissue. *Canadian Journal of Botany* **57**(12): 1332-1334

Lowry OH, Rosebrough NJ, Farr AL and Randall RL (1951) Protein measurement with folin phenol reagent. *Journal of Biological Chemistry* **193**: 265-275

Mahesh D, Bhattiprolu S, Kumari VP and Chiranjeevi C (2018) Biochemical analysis of resistant and susceptible cotton genotypes against *Alternaria* and *Corynespora*. The Journal of Research ANGRAU, **52**(1): 39-50

Manjamma D (2020) Survey and management of early blight of potato caused by *Alternaria solani* Department of Plant pathology, University of Horticultural Sciences, Bagalkot, Karnataka, India, M.Sc. thesis: 122p

Mayee C D and Datar V V (1986) Phytopathometry, Marathwada Agricultural University, Parabhani, p. 95

Meena M, Prasad V and Upadhaya R (2017) Evaluation of biochemical changes in leaves of tomato infected with *Alternaria alternata* and its metabolites. *Vegetos* **30**(1): 1-5

Mehboob S, Khan MA, Rehman A and Idrees M (2013) Role of epidemiological and biochemical factors against early blight of potato. *European Journal of Plant Pathology* **2**(1): 114-118

Parmar TD (2019) Epidemiology and management of early blight [*Alternaria solani* (Ellis and Martin) Jones and Grout] in tomato (*Solanum lycopersicum* L.) Department of Plant Pathology, Anand Agricultural University, Anand, Gujarat, India, M.Sc thesis: 68p

Patel S J, Subramanian R B and Jha Y S (2011) Biochemical and molecular studies of early blight disease in tomato. *Phytoparasitica* **39** (3): 269-283

Rouse DI (1985) Some approaches to prediction of potato early dying disease severity. *American Potato Journal* **62** (4): 187-193

Shahbazi H, Aminian H, Sahebani N, Halterman D (2010) A biochemical evaluation of resistance responses of potato to different isolates of *Alternaria solani*. Phytopathology **100**(5): 454-459

Shoaib A, Iqbal J and Khan KA (2020) Evaluation of phenotypic, physiological and biochemical attributes connected with resistance in tomato against *Alternaria solani*. *Acta Physiologiae Plantarum* **42**(5): 1-17

Singh SP, Singh SK, Lal B, Singh SK (2017) Effect of planting date on incidence of early blight (*Alternaria solani*) and yield of potato due to climate change. *Journal of Pharmacognosy and Phytochemistry* **1**: 369-371

Srivastava A and Kumar S (2012) Study of biochemical changes in *Solanum tuberosum* due to infection and storage. *Journal of Chemical and Pharmaceutical Research* **4**(5): 2733-2739

Veeramohan R and Ramaswamy V (1995) Some biochemical and enzymatic changes in chilli leaves inoculated with *Alternaria solani*. *Advances in Plant Sciences* **8**(2): 414-416

Veeramohan R, Govindaraj and Ramaswamy V (1994) Biochemical and physiological changes in chilli fruit inoculated with *Alternaria solani*. *Advances in Plant Sciences* **7**(1): 29-34

Vyas RV, Patel P, Shelat HN and Rajput A (2019) In: Strategies for Doubling the Farmers' Income: A Gujarat Perspective (edited by NC Patel, OS Mbuya and RV Vyas). Satish Serial Publishing House, Delhi: 55-77.

Waals JE, Korsten L and Aveling TAS (2001). A review of early blight of potato. *African Plant Protection* **7**(2): 91-102

MS Received : March 15, 2024; Accepted : July 31, 2024

Potato J (2024) 51 (1): 118-128

BABY POTATOES-A NOVEL WAY OF POTATO CONSUMPTION

S K Luthra[1*], Dalamu[2], VK Gupta[1] and Vikas Mangal[3]

ABSTRACT: In potato production, optimum tuber size is important to maximize crop value and hence growers target different tuber sizes at harvest to meet the localized market demand as produce size affects the pricing. Normally medium sized and large sized tubers get premium rates as compared to small tubers in the market, however, small sized tubers of specific varieties are also liked for some specific purposes and therefore get premium rates. In the changing food habit scenario, tubers weighing 20-40 grams specially packed and marketed as "*baby potatoes*" attract consumers. Baby potatoes are valued by consumers for freshness, taste, size and shape. Baby potatoes are consumed worldwide in a variety of dishes through various culinary methods.

KEYWORDS: Baby potatoes, tuber size, crop duration, utilization, nutritional values

INTRODUCTION

Potatoes, a staple in global diets, serve both fresh consumption and processing purposes. Potato production goals require optimizing tuber size to maximize crop value and hence, potato growers and researchers target different tuber size at harvest depending on localized market demand as produce size affects the pricing. Growers can maximize price through optimization of tuber size distribution to maximize crop value (Love and Thompson-Johns, 1999). For the fresh market, potato prices are more variable over different types of potatoes like small (<20 gram), medium (20-75 gram) and large (>75 gram) sized tubers and market location as well as period of year. In the market normally medium sized and large sized tubers get premium rates as compared to small tubers, however, in specific locations, small sized tubers of specific varieties are liked and therefore get premium rates. Nowadays tubers of 20-40 grams specially packed and marketed as "*baby potatoes*" are getting consumer attention in the market. This review cites the updates on baby potatoes right from varietal selection to production details and success stories in this segment.

Baby potatoes

Baby potatoes are small sized potatoes that are produced either due to genotypic character or byproducts of the grading of tuber size during processing and either produced by agronomic management practices. Very small sized potatoes of fully matured crops are also prevalent in some areas. The review explores their diverse names, characteristics, and nutritional values, underscoring their appeal to consumers for freshness, taste and size. Baby potatoes are known by different names in different regions or countries like *New potatoes*, *small potatoes*, *little potatoes*, *marble sized potatoes*, *chote aloo*, *petite potatoes*, *pearl sized potatoes*, *little luxury*, *bite sized potatoes*, *miniature potatoes,* etc. Baby potatoes are low in starch and high in fiber (with skin on) and therefore considered healthier than the large size potatoes. Freshly harvested small sized potatoes appeal to consumers due to freshness, size, taste and shape and fetch

---

[1]Principal Scientist, ICAR-Central Potato Research Institute, Regional Station, Modipuram, Meerut-250110, UP, India.
[2]Senior Scientist, ICAR-Central Potato Research Institute, Kufri Fagu Unit, Shimla-171012, HP, India
[3]Scientist, ICAR-Central Potato Research Institute, Shimla-171001, HP, India
*Corresponding author email: skluthra@hotmail.com

premium rates in the market. These ' little luxuries' are getting preference in high-end retail and food service markets. The main quality characteristics of fresh-cut potatoes include a bright appearance, firm texture, and absence of darkening and dehydration (Tudela and Gil, 2020). In recent years, the demand for small or baby potatoes with a target size of 20-40 mm in diameter is catching the culinary market under the fresh potato segment. In India, recent market trends indicated that baby potatoes are now visible in megamalls, supermarkets etc., in NCR and fetch premium rates (Singh, 2013).

The popularity of baby potatoes

The potato crop was introduced in the beginning of the 17th century to India. In India, naturally occurring variants are known as indigenous or desi varieties that are known by different local names in diverse dialects. Desi varieties are either *Solanum tuberosum* ssp. *andigena* or hybrids of *S. tuberosum* ssp. *tuberosum* and *S. tuberosum* ssp. *andigena*. This group of varieties has distinguished characteristics of local adaption; tolerance to abiotic stresses i.e. heat and drought, slower rate of degeneration, shorter dormancy, preferred culinary properties in terms of taste, lesser cooking time, early maturity etc. Although, local varieties do not have organized seed potato production programmes but they do have their presence in a limited area and scale for one or the other reasons. These varieties are, however, preferred for their special traits like skin and flesh colour, taste, and preparation of other local dishes (Gupta and Luthra, 2020). After reviewing the historical context of potato cultivation in India, among indigenous varieties the popularity of baby potatoes has been well documented. It presents insights into locally grown varieties like Badami aloo, Rangpuria, and Phulwa, emphasizing their adaptation to specific climates and consumer preferences.

Most of local varieties produce numerous small tubers (Luthra *et al*. 2015) and many such local varieties like Phulwa had been a highly valued potato variety in the Indian household due to its excellent keeping quality, waxy texture, pleasant flavour and ability to withstand prolonged cooking without losing shape (Pushkarnath, 1976), however it is susceptible to degeneration diseases. It has long stolen, small scattered tubers and is late maturing. Phulwa produces white, round medium to large small tubers, deep eyes and blue purple colour on crown eyes and yellow flesh. Phulwa was cultivated in North Indian plains covering Assam, Bihar, Madhya Pradesh, Orissa, Punjab, Haryana, Uttar Pradesh and West Bengal (Pushkarnath, 1969) before the suitable replacement was released by CPRI.

So far, some locally grown varieties like Badami aloo (North Eastern region and West Bengal), Rangpuria (North Eastern region), Pakri Alu, Cooch Behar Local-1 (West Bengal), Bareilly red (Bareilly, Uttar Pradesh) and Phulwa (Farukhabad, Uttar Pradesh) are grown and sold in the market in limited scale. Tubers of Badami aloo and Rangpuria are very small and dark red. Rangpuria is round shaped and have minimal tuber yield reduction under high temperature, while Badami is nut-shaped (Paul *et al*. 2017). The tubers of Pakri Alu are round (Roy, 2019). Pushkanath 1969 reported a synonym of Pakri as Darjeeling Red Round, which was being cultivated in West Bengal and a synonym of Rangpuria as Phuwla, which was being cultivated in Assam. The information on some baby producing genotypes is presented in **Table 1.**

Small size potato tubers are highly acclimatized with the climate of north-

Table 1: Some potato genotypes suitable for baby potatoes

Varieties	Localities	Tuber characters	Total tuber yield (t/ha)	Tubers/ plant	References
Phulwa	Assam, Bihar, Madhya Pradesh, Orissa, Punjab, Haryana, Uttar Pradesh and West Bengal	White, round, deep eyes yellow flesh	-	Large number of small tubers	Pushkarnath, 1969
Kufri Himsona	Meerut, Uttar Pradesh	White, round, shallow eyes, creamy flesh (<40 mm)	10.40 (60 days crop)	18-20	Rawal *et al.*, 2011; Singh 2013
Rangpuria	Tezpur, Assam	Round, medium tuber dormancy, good keeping quality, tuber dry matter (19%)	1.55	Small tubers	Paul *et al.*, 2017
Badami	Tezpur, Assam, India	Nut-shaped	1.28	Small tubers	Paul *et al.*, 2017
MSP/15-51	Meerut, Uttar Pradesh	Purple skin, ovoid, medium eyes, red purple flesh	26.08	33	Luthra *et al.*, 2018b
MSP/15-60	Meerut, Uttar Pradesh	Red skin, round-ovoid, medium eyes, yellow flesh with red vascular ring	35.62	47	Luthra *et al.*, 2018b
Bareilly Red	Meerut, Uttar Pradesh	Red skin, round, deep eyes, cream flesh with red broad vascular ring, extremely long tuber dormancy, tuber dry matter (16%)	8.56	18-20	Luthra *et al.*, 2018b; Gupta and Luthra. 2020
Badami Alu	Alipurduar/ Cooch Behar district, West Bengal	Reddish purple, reniform, medium deep, cream with dark pink vascular bundle	15.82	42	Roy, 2019
Pakri Alu	Alipurduar/ Cooch Behar, West Bengal	White-cream skin, round, medium deep eyes, cream flesh	15.03	36	Roy, 2019
Cooch Behar Local-1	Alipurduar/ Cooch Behar, West Bengal	White-cream skin, round, medium deep eyes, cream flesh	16.57	39	Roy, 2019
Badamia Aloo	Meerut, Uttar Pradesh	Red, ovoid, shallow-medium, yellow, extremely long tuber dormancy	6.6 t/ha, All tubers <10g	51	SK Luthra, 2022, unpublished
Phulwa Red	Meerut, Uttar Pradesh	Extremely long tuber dormancy, tuber dry matter content (22%)	15-16 t/ha	16-20	SK Luthra, 2022, unpublished

eastern hill region and terai agro-ecological region (Chowdhary and Datta, 2020). Due to consumer preference for delicious taste after cooking, the crop produce fetch a higher price in the market. The baby potatoes are not available throughout the year. The climatic condition favours the cultivation of small potatoes; however, cultivation is restricted due to a lack of quality planting material, suitable improved varieties and improved production technologies. The crop of baby potatoes is mostly grown in this region apart from some other northern parts of West Bengal, North eastern states like Meghalaya and Manipur (Chowdhary and Datta, 2020).

In Bangladesh, familiar local varieties producing small sized tuber are Sheel Bilateem, which produces red, oblong tubers weighing about 30 g and is mostly cultivated in Rangpur, whereas Lal Pakri produces red round tubers weighing about 30 g is mostly cultivated in Dinajpur, Bogra and Sirajganj and Du Hajari with pale round tubers weighing 25 g is mostly cultivated in the Chittagong area.

Salient features of baby potatoes

In general, small potatoes of uniform size are selected, so they cook through at the same time without the skin bursting. The larger potatoes are more prone to skin breaking when boiled or steamed. Baby potatoes are served as a salad or as a side dish and do not require peeling, thereby retaining the phytonutrients in the skin and drastically reducing preparation and cooking time due to their small size (Kaur *et al*., 2023a). Baby potatoes should be firm and free from dirt and blemishes. They should have smooth skin and be devoid of green patches. The green patches are indicative of the presence of solanine, a glyco-alkaloid that imparts bitter taste and hence green tuber should not be used. The general characteristics of baby potatoes are summarized in **Table 2**. The different factors that affect the production and quality of baby potatoes are described below-

Crop duration: The crop duration of potato varieties in India is generally more than 90 days. Small sized tubers of fully matured crops of these varieties are marketed as baby potatoes. Another way of production of baby potatoes is crop harvest before maturity. Under such situation there is risk of higher glyco-alkaloids accumulation in tubers which may give bitter taste and are poisonous. Pre-mature crop harvest leads to greater yield reduction per unit area than ware potatoes, however achieving the earliest possible marketable yield is of vital importance for baby potato production (Harasim *et al*., 2004) as the lower yield is usually offset by higher selling price (Sawicka, 1998). Shankar *et al*., 2018 reported that delay in harvesting time (>75DAP) reduced the percent of small and medium size tubers and their yield in Indian potato varieties K. Himsona, K. Khyati and K. Pukhraj. However, Kufri Himsona had the greatest percent of small and medium size tubers suitable for baby potatoes and hence can be recommended for baby potato production under tropical conditions. Singh, 2013 reported two crops of baby potatoes of nearly 60 days crop duration per year will

Table 2 General characteristics of baby potatoes

Traits	Baby potatoes	
	Pre-matured crop	Fully grown crop
Tuber size	<40 mm	<40 mm
Tuber colour	White cream/Red	White cream/Red
Tuber shape	Round/ovoid and uniform	Round/ovoid and uniform
Tuber eye depth	Shallow/medium	Shallow/medium
Tuber flesh colour	White cream/ Yellow/ partially coloured	White cream/ Yellow/ partially coloured
Greening	Nil	Nil
Internal defects	Nil	Nil
External defects	Nil	Nil
Texture	Waxy	Waxy or mealy
Flavour	Typical potato flavour	Typical potato flavor
Organoleptic attributes	Very good	Very good
Dry matter content	<18%	18-20%
Glyco-alkaloid content	<15 mg/100g FTW	<15 mg/100g FTW
After cooking blackening	Nil	Nil
Enzymic browning	Minimum	Minimum
Disease resistance	Medium	High
Keeping quality	Good	Very good

be profitable to farmers. The ideal variety yielding a higher percent and yield of baby potatoes under a growing climate could increase commercial sustainability. The varieties with high yielding potential can either be achieved through a greater number of small tubers (or) fewer number of very large size tubers per plant (Abbasi *et al.*, 2004), in which the former approach is imperative for baby potato production. Few elite lines have been identified for small tubers with high yields (Luthra *et al.*, 2005, Tariq *et al.*, 2008). The identification of suitable varieties for baby potatoes will not only be beneficial for India but also in other countries, as presently Indian varieties are grown in several other countries (Luthra *et al.*, 2004).

Total tuber yield**:** The yield of baby potato varieties is comparatively low as compared to new improved varieties (**Table 1**). Luthra *et al.,* 2018b reported a very low total tuber yield of Bareilly red (9 t/ha) as compared to new advanced clone MSP/15-60 (36 t/ha) developed from cross Bareilly red × CP3770 and control variety Kufri Bahar (44 t/ha). Rawal *et al.,* 2011 reported baby potato yield of Kufri Himsona (10.7 t/ha) from 60 days of harvested crop. Paul *et al.*, 2017 reported low yield in Rangpuria (1.55 t/ha) and Badami (1.28 t/ha) in Assam. However, Luthra 2022 (unpublished) noticed a tuber yield of 6.6 t/ha in Badami Aloo grown in Meerut.

Number of tubers**:** The number of tubers per plant varies with the genotype, physiological age of seed, number of stems/plant and climatic conditions during tuber initiation phase of growth. Environmental conditions affecting tuber initiation include planting date, early season temperature, nutrition and water management, and weather extremes such as hot climate, hail or frost. Hence, developing ideal cultivars for small size tuber production, harvesting time should be manipulated to achieve the optimum tuber weight (Mihovilovich *et al*. 2014). Although, tuber bulking duration is of greater importance in determining the final yield of ware potato, bulking rate has a greater impact on baby potatoes. Heat stress leads to a higher number of smaller tubers per plant and lower tuber specific gravity with reduced dry matter content (Haverkort, 1990). Potato genotypes with many thin stems are known to produce numerous small sized tubers and such genotypes could be exploited in breeding for the production of varieties suitable for baby potatoes (Luthra 2001, Luthra *et al*. 2018a). Recently an advanced clone MSP/15-60 has been developed through conventional breeding that produces up to 47 tubers per plant (Luthra *et al.,* 2018b). In another study, Chowdhary and Datta, 2020 reported tuber/plant range from 23 to 68 based on an investigation of 25 small size potato genotypes. The account of variation in tubers numbers has been presented in **Table 1.**

Tuber size**:** In general baby potatoes are bite size like cherry tomatoes. They are easy to prepare and offer a buttery taste and creamy texture. In India, the baby potatoes in general being sold in the market are simply regular potatoes being marketed after grading and selecting small sized tubers from the produce. The baby potatoes should have round tubers with shallow eyes and uniformity in size (<40 mm). Cowan (1985) found that size was one of the most important factors of concern to Irish urban potato consumers. Older consumers have a preference for small tubers compared to younger consumers. Average tuber size has been shown to decrease non-linearly in response to increasing crop density (Knowles and Knowles, 2006, Zebarth *et al.*, 2006). Some of the small size potato genotypes are highly acclimatized with the climate with North Eastern Hill and terai agro-ecological region (Chowdhary and Datta, 2020). The smaller size tubers are getting better market price during the initial phase of harvest season, hence farmers prefer to early harvest of any cultivar grown. A different grade standard for potatoes is being followed by Agmark and Codex in the country, where Codex defined a tuber size of 18.1 mm-28.0 mm as baby potatoes (Shankar *et al.*, 2018).

***Shape*:** Small tubers of potatoes having round to ovoid shapes are suitable for baby potato cousins. In the northern parts of West Bengal, there are two types (round shaped and nut shaped) of small sized potato are grown (Chowdhary and Datta, 2020). In general, stolon length is long in baby potato varieties. Tuber abnormalities likely crack, scar, hollow heart, internal necrosis etc. are absent in tubers.

***Skin and flesh colour*:** Generally white/yellow skinned small tubers are preferred, however, due to the prevalence of coloured varieties and changing perception of consumers, red/purple skinned/fleshed potatoes are also being liked. Chowdhary and Datta, 2020, based on results of 25 genotypes collected from different areas of West Bengal, Sikkim and Assam reported that majority of genotypes had red skin (84%). The predominant tuber flesh colour varied from white to yellow and the majority of tubers showed yellow-cream colour (76%) followed by yellow flesh colour (12%). Along with the predominant tuber flesh colour some secondary colour, red (60%) is also present in the flesh of the potato tuber, which was distributed in the flesh by a broad vascular ring (56%) and scattered (4%) manner.

***Internal and external defects*:** Internal or external defect in potato tubers affects the quality of produce and marketability. External defects may be due to unwanted shape or size, knobbiness, cracking, decay, greening etc. Internal defects are imperfections occurring within the tubers, such as hollow heart, brown centre, internal brown spots etc. These defects may be caused by physiological or pathological reasons. Higher defects in the tubers increase the labour requirement during the sorting of tubers and ultimately enhance the operational cost apart from reducing the quality of produce.

***General impression*:** The small tubers have special attention in the market due to fresh produce and shining skin. Some of locally grown potato varieties like Bareilly Red have a low general impression owing to deep eyes and small sized tubers (Luthra *et al.*, 2018b), however, they are liked by the consumer owing to appearance and specific culinary qualities. Similarly, another local variety Badami Alu grown in North Eastern regions and West Bengal had a moderate general impression but owing to fleet eyes and attractive coloured nut shaped tuber has preference by consumers.

***Glycoalkaloids content*:** Glycoalkaloids are secondary metabolites in potatoes and other members of the Solanaceae family, which serve as chemical defense against fungi, nematodes, herbivores and other stress conditions (Majeed *et al.,* 2014). High temperature stress during the vegetative stage and tuberization is known to trigger the accumulation of glyco-alkaloids in tubers. Cooking of green tubers should be avoided as they are known to contain high glyco-alkaloids and remain half cooked, if consumed give a bitter taste. Consumption of tubers with glyco-alkaloids concentrations above 20 mg/100 g fresh weight (FW) can cause nausea, vomiting, diarrhea, stomach and abdominal cramps, headache, fever, rapid and weak pulse, hurried breathing, hallucination, delirium, and in extreme cases coma (Friedman and McDonald, 1997). Therefore, for food safety purposes, an upper limit for glycoalkaloid content of 20 mg per 100 g FW has been established by the United States Department of Agriculture (Aziz *et al.*, 2012). Under Indian conditions, lower content i.e., <15 mg per 100 g FW has been considered as a desirable level (Luthra *et al.*, 2020).

Tuber dry matter content: Potatoes containing more than 20% dry matter content with a mealy texture are preferred for fried and dehydrated products, while small size potatoes of dry matter between 18-20% and waxy texture are preferred for salad making and canning (Luthra *et al.,* 2004). The crop of baby potatoes is harvested early so as to achieve maximum baby sized tubers and hence tuber dry matter is lower than 16%. The genotypes with more number of tubers have in general low tuber dry matter (Luthra *et al.,* 2018a). However, advanced clone MSP/15-60, producing baby potatoes when harvested at 90 days contain 20% tuber dry matter (Luthra *et al.,* 2018b).

***Nutritional values*:** Baby potatoes have fewer calories and are fat-free and can be included in low-calories diets. The prevalence of high fibre helps in lowering cholesterol levels. These potatoes are a good source of folate, vitamin C, B1 and B6 and aids in boosting immunity. Bite-sized baby potatoes are whole food, naturally gluten free, with good carbohydrates that are absorbed slowly into the body system and give a longer fuller feeling with energy to burn. Luthra *et al.,* 2018b reported higher anthocyanin/ carotenoids/ascorbic acid content in a locally grown baby potato variety Bareilly Red (0.87mg/1450µg/106 mg) on 100 g FW basis. Nutrients and dietary fibres are concentrated in the peel or just below, and peeling removes them. Unpeeled baby potatoes, due to their size, have a higher percentage of peel and hence might be considered healthier. Baby potatoes are eaten intact and hence provide an opportunity to enjoy the original flavour of potatoes. Processed potatoes (papads) prepared from skinned baby potatoes showed higher protein, fibre, bioactives and mineral values (Kaur *et al.*, 2023b) and were organoleptically more acceptable compared to that prepared from peeled table variety. Tuber growth and development impact certain nutritional elements. Baby potatoes have 3 fold phenylpropanoids compared to that of mature potatoes of the same genotype (Navarre *et al.*, 2013). Folate (Goyer and Navarre 2009) and total carotenoids (Kotikova *et al.,* 2007; Morris *et al.,* 2004) content are also documented higher in immature potato tubers.

***Organoleptic attributes*:** Baby potatoes of locally grown varieties are liked due to their special taste, flavor and culinary qualities. A mealy texture is associated with high solids and a waxy texture with low solids. To achieve the maximum proportion of baby potatoes of improved varieties, the premature crop is harvested and thus tubers have low tuber dry matter and waxy texture. However, local varieties producing the large number of small tubers in a long duration (>90 days) may contain moderate tuber dry matter and thus have a mealy texture. Baby potatoes, typically taste sweeter than a mature potato and have softer flesh. Some of the known varieties producing baby potatoes Bareilly red, Phulwa red and Rangpuria have waxy texture (Gupta and Luthra, 2020).

Production and utilization of baby potatoes

***Production practices*:** The production practices of baby potatoes are different from ware potato as it has a unique set of demands for suitable varieties and agronomic practices etc. Apart from variety, there are several other factors such as fertilization (nitrogen), seed spacing, climatic conditions and geographic location (Barry *et al.*, 1990, Arsenault *et al.*, 2001, Abbasi *et al.*, 2004) which had an influence on yield. Rawal *et al.,* 2011 standardized the one fourth of recommended dose of fertilizers (68 N + 20 P_2O_5 + 38 K_2O kg/ ha) for quick tuberization and optimum sized baby potato production of variety Kufri Himsona. By following this, 20-24 t/ha of baby grade potatoes in double cropping of Kufri Himsona can be achieved. Seed aging increases tubers per plant and decreases the size of harvested tubers. Delayed planting is also known to promote the production of small or medium sized more tubers/plant. The interaction effect of growing environments and harvesting time is also reported to have a greater influence on tuber size and shape (Lisinska and Leszczynski, 1989, Sood *et al.*, 2008). However, there are contradictory reports on growing environments with low (Bodlaender, 1958) or high temperature (Lafta and Lorenzen, 1995) favours the production of smaller tuber speculating selection of the ideal growing environments for greater baby potatoes production. Irrigation is to be stopped 10-12 days before harvest of baby potatoes for proper skin setting. Harvesting is to be completed within 2-3 days after haulm cutting. With these interventions, tubers can easily be utilized for a week as fresh or for preservation in the processing industry.

***Storage*:** Baby potatoes should be stored in a cool, dry and shady ambiance away from sunshine and dampness. The best location to store them is in a cool, dry, dark place. After cooking, the baby potatoes should be covered in cling film and stored in containers made of glass in the refrigerator. The cooked potatoes should be consumed within 2 to 3 days of refrigeration. Locally grown variety Phulwa red is known to have extremely long tuber dormancy, excellent keeping quality and tuber dry matter content of 22%, Rangpuria with medium tuber dormancy, good keeping quality possesses 19% tuber dry matter and Bareilly red possesses extremely long tuber dormancy, excellent keeping quality and tuber dry matter content of 16% (Gupta and Luthra. 2020).

***Packaging*:** In India, mostly loose tubers in graded or ungraded form were being sold in the traditional market and malls. During the last 10 years, the packaging of graded sugar free potatoes in nylon netted bags of 3 kg capacity has been adopted by the retailers to attract the consumers. However, baby potatoes in local markets are still being sold in loose form, but the packaging of baby potatoes is increasing in Delhi NCR and metro cities of the country. Tudela and Gill, 2020 reported that the best packaging method to preserve the sensory quality of fresh-cut potatoes up to 14 days at 4°C is vacuum or low O_2 in combination with sodium bisulfite to avoid browning, but off-odors can be developed if storage temperatures are not well maintained (> 4°C) or the length of storage time is prolonged (> 8 days).

***Marketing of Baby Potatoes*:** The quality of potatoes is of paramount importance to market acceptance. Appearance, colour, size, shape and defects are consumer's first impressions about the quality for fresh potatoes. Normally small sized baby potatoes are being sold in the market. However, baby potatoes of traditional varieties Bareilly red, Phulwa and Badami alu, Rangpuria, Pakri Alu, Cooch Behar Local-1 producing small sized tubers are also popular due to local consumer demands. In India, baby potatoes are also being traded through online companies like Big basket (Rs66/kg), Organic Siri (Rs49/0.5kg), Deep Rooted Inc. (Rs42/0.5 kg), FRUIT BOX & Co. (Rs38/kg), Amazan (Rs38/kg), Natur’s basket (Rs 16/0.2kg). These rates vary from season to season.

***Uses of baby potatoes*:** The baby potatoes are creamer, rich in vitamins and minerals and have low calories. Baby potatoes are used worldwide in a variety of dishes ranging from salad, vegetables and part of main course. Baby potatoes are consumed in hundreds of dishes through various culinary methods, like steamed, boiled, grilled, roasted, stir fried, oven baked, partially fried or in salad etc.

One more way suited to Indian taste may be in recipes like 'Dum aloo'. Pricking the potatoes all over with a fork followed by seasoning allow proper absorption of flavours. In Punjab, Sharla, aloo masale vale is quite famous made from freshly harvested baby potatoes. In general, after proper washing and cooking, they are eaten with their naturally nutritious tasty skin and sometimes a thin layer of skin is removed in boiled or baked potatoes for special cooking. The peeled ones are more on the sweetish side, while the unpeeled ones have a nutty tinge to it. The baby potatoes when used with skin provide more dietary fibre as compared to peeled potatoes. Baby potatoes are not only cooked at home but they are an integral part of the menu of famous restaurants.

Success stories of baby potatoes

In Canada, The Little Potato Company passionately focuses only on little potatoes, established in 1996 and are leading producer of creamer potatoes, highly nutritious, fully mature and naturally delicious small specialty potatoes. Coveted by foodies and chefs alike, these proprietary colorful creamers are available in produce sections across the US and Canada. These potatoes are sold prewashed, are nutritious and convenient, and special care is taken to ensure their consistent size so one can cook them in just 5 minutes. The product list includes Boomer Gold, Blushing Belle, Morning Pearl, Fingerling, Purely Purple, Garlic Parsley, Smoked Salt, etc. packed in fresh bags, kits ready for the microwave and also fully cooked easy sides.

In California, USA, Tasteful Selections (Bite Size Potatoes) was incorporated in 2009 by multi-generational potato farmers recognizing an opportunity to expand the potato category to meet the busy consumer's preference for simpler, convenient meals. Planting and harvesting more than 300 days a year, Tasteful Selections® owns the entire planting, growing, harvesting and packaging process and today is the brand leader of the baby potato category. They pioneered bite-size potatoes as a convenient source of nutrition, flavor versatility and variety for everyday meals and offer bite size potato varieties like Honey Gold, Purple Passion, Ruby Sensation, Sunburst Blend, Sunrise Medley, White Delights, Gold Fingerling, Red Fingerling, Sunset Fingerlings etc. to the customers as wide assortment of products, sizes and packaging types.

In India, Himalaya Food International Ltd. procures fully grown baby potatoes of 35-43 mm size naturally grown in the Himalayan foothills of India. Baby potatoes are hand cut in half and carefully scooped out. The product is IQF Frozen. The product is easy and quick to prepare and has a rich and special flavor. It has a rich golden exterior and light yellow from inside. They report that their baby potato skins are a great appetizer and chefs can use their culinary skills for stuffing the skins with cheese and Bacon, tomatoes, Garlic and Mushrooms, Cheese and pizza sauce etc., etc. The product is packed in bulk/retail packaging as per customer specifications. The product is stored at 0 degrees F or lower.

Future thrusts

The review emphasizes the growing preference for baby potatoes among consumers and the need for concentrated interventions in planting materials, variety development, and improved production technologies. It outlines the potential future directions for research and cultivation practices to further enhance the production and popularity of baby potatoes in the ever-evolving culinary segment market. This comprehensive review serves as a valuable resource for researchers, growers, and consumers interested in gaining insights into the dynamic world of baby potatoes

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

ETHICAL STATEMENT

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

LITERATURE CITED

Abbasi NA, Hafiz IA and Fazal B (2004) Evaluation of exotic potato varieties in ecological conditions of Islamabad during autumn season. *Int. J Agric. Biol.***6(3)**: 479-482

Arsenault WJ, LeBlanc DA, Tai GCC and Boswall P (2001) Effects of nitrogen application and seed piece spacing on yield and tuber size distribution in eight potato cultivars. *Am. J. Potato Res.***78**: 301-309

Aziz A, Randhawa MA, Butt MS, Asghar A, Yasin M and Shibamoto T (2012) Glycoalkaloids (alpha-chaconine and alpha-solanine) contents of selected Pakistani potato cultivars and their dietary intake assessment. *J. Food Sci.***77(3)**: T58-T61

Barry PB, Storey TS and Hogan R (1990) Effect of plant population and set size on yield of the main crop potato variety Cara. *Irish J. Agric. Res.***29**: 49-60

Bodlaender KBA (1958) Influence of various day lengths on the development of the potato (in Dutch). *Jaarb. Inst. Biol. Scheik. Onderz. Landbouwgew*, pp 45-57

Chowdhury RS and Datta S (2020) Characterization and variability studies of the local small size potato (*Solanum* sp.) Genotypes under sub-Himalayan foothills of India. *Int. J. Bio-resource Stress Manag.***11(1)**:27-34

Cowan CA (1985) Potato-Influences of age and regional differences on preferences for size. *Iran J. Agricl Econ Rural Sociol.* **10**: 119-127

Friedman M and McDonald GM (1997) Potato glycoalkaloids: Chemistry, analysis, safety, and plant physiology. *Crit. Rev. Plant Sci.***16(1)**: 55-132

Goyer A and Navarre DA (2009) Vitamin B9 is higher in developmentally younger potato tubers. *J. Sci. Food Agric.*, **89**: 579-583

Gupta VK and Luthra SK (2020) Storability and organoleptic performance of indigenous and exotic potato collections. *Potato J.***47 (1)**: 80-91

Harasim A, Pszczółkowski P and Sawicka B (2004) The possibilities to influence the production effectiveness of early potatoes through improvements of crop management. *Annals UMCS Sec. E* **59(1)**: 241-249

Haverkort AJ (1990) Ecology of potato cropping systems in relation to latitude and altitude. *Agricultural Sys.***32**: 251-272

Kaur RP, Luthra SK, Chaudhary B, Kumar R, Dalamu and Bhardwaj V (2023a) Perspectives in consumer-oriented breeding for potatoes in India. *Electronic J. Plant Breed.* **14(1)**:246-271

Kaur K, Kaur S, Aggarwa P and Kaur N (2023b) Formulation and characterization of phytonutrients-rich traditional dehydrated snack prepared from skinned baby potatoes. *International J. Food Sci. Tech.* **58(12)**:6862-6870.

Kotikova Z, Hejtmankova A, Lachman J, Hamouz K, Trnkova E and Dvorak P (2007) Effect of selected factors on total carotenoid content in potato tubers (*S. tuberosum* L.). *Plant Soil Environ.* **53**: 355-360

Knowles NR and Knowles LO (2006) Manipulating stem number, tuber set and yield relationships for northern and southern-grown potato seed lots. *Crop Sci.***46**:284-296

Lafta AM and Lorenzen JH (1995) Effect of high temperature on plant growth and carbohydrate metabolism in potato. *Plant Physiol.***105**: 637-643

Love SL and Thompson-Johns A (1999). Seed piece spacing influences yield, tuber size distribution, stem and tuber density, and net returns of three processing potato cultivars. HortScience 34:629–633.

Lisinska G and Leszczynski JH (1989) Potato Science and Technology, pp 11–202. Elsevier Science Publishers Ltd, New York

Luthra SK (2001) Heritability, genetic advance and character association in potato. *J. Indian Potato Assoc.***28**: 1-3

Luthra SK, Pande PC and Singh BP (2004) Perspective planning for developing potatoes for export. In: Processing & export potentials of Indian potatoes (Eds. SM Paul Khurana, BP Singh, SK Luthra, NR Kumar, D Kumar and D Kumar). International Potato Conference & fest-'04, CPRI Campus, Modipurarm, Meerut. Indian Potato Association, Shimla. Pp18-27

Luthra SK, Gopal J, Pandey SK and Singh BP (2005) Genetic parameters and characters associations in *tuberosum* potatoes. *Potato J.***32(3-4)**: 234

Luthra SK, Gupta VK, Srivastava AK, Gurjar MS and Singh BP (2015) Exploration of potato germplasm in Meghalaya. CPRI Newsletter 60 (April-June): 1-2

Luthra SK, Gupta VK, Kaundal B and Tiwari JK (2018a) Genetic analysis of tuber yield, processing and nutritional traits in potato (*Solanum tuberosum*). *Indian J. Agric. Sci.* **88 (8)**: 1214-1221

Luthra SK, Tiwari JK, Dalamu, Kaundal B, Riagond P, Sharma J, Singh B, Dua VK, Kumar V and Gupta VK (2018b) Breeding for coloured flesh potatoes: Molecular, agronomical and nutritional profiling. *Potato J.* **45 (2)**: 81-92

Luthra SK, Gupta VK, Tiwari JK, Kumar V, BhardwajV, Sood S, Dalamu, Kaur RP, Kumar R, Vanishree G, Kumar D, Mhatre PH and Chakrabarti SK (2020) Potato Breeding in India. CPRI Technical Bulletin No 74 (revised), ICAR-Central Potato Research Institute, Shimla, Himachal Pradesh, India,214 p

Majeed A, Chaudhry Z and Muhammad Z (2014) Changes in foliar glycoalkaloids levels of potato (*Solanum tuberosum*) triggered by late blight disease severity. *Int. J. Agric.Biol.***16(3)**: 609-613

Mihovilovich E, Carli C, de Mendiburu F, Hualla V and Bonierbale M (2014). Protocols for characterizing tuber bulking and dormancy developed and implemented for documentation and enhanced potato breeding capacity. CIP, Peru

Morris, WL, Ducreux L, Griffiths DW, Stewart D, Davies HV and Taylor MA (2004) Carotenogenesis during tuber development and storage in potato. *J. Exp. Bot* .**55**: 975-982

Navarre DA, Payyavula RS, Shakya R, Knowles NR and Pillai SS (2013) Changes in potato phenylpropanoid metabolism during tuber development. *Plant Physiol. Biochem.* **65**: 89-101

Paul S, Das MK, Baishya P, Ramteke A, Farooq M, Baroowa B, Sunkarf R and Gogoi N (2017) Effect of high temperature on yield associated parameters and vascular bundle development in five potato cultivars. *Sci.Hortic.* **225**:134-140

Pushkarnath. (1969). *Potato in India-Varieties*. ICAR, New Delhi, 493p.

Pushkarnath. 1976. *Potato in Sub-tropics*. Orient Longman, New Delhi, 289p.

Rawal S, Singh BP, Kumar D, Khan MA, Kumar R and Chaudhary V (2011) Baby potatoes: A novel venture for potato growers. CPRI Newsletter 45 (July-September):1-2

Roy B (2019) Characterization of Farmers' Varieties of Potato (*Solanum tuberosum* L.) of Cooch Behar District of West Bengal *Indian J. Plant Genet. Resour.* **32(3)**: 314-317

Sawicka B (1998) Technological and economical effects of cultivation of early potato varieties under polyethylene sheeting. *Roczniki Akademii Rolniczej w Poznaniu CCCVII Rolniczych.* **52**: 175-182

Shankar R, Mishra A, Nandekar DN, Verma D and Govindakrishnan PM (2018) Multivariable interaction analysis for enhanced baby potato (*S. tuberosum*) production in India. *Indian J. Agric. Sci* .**88 (1)**: 125-131

Singh BP (2013) Final Report of NAIP sub-project 'Value Chain on Potato and Potato Products'. Central Potato Research Institute, Campus, Modipuram, Uttar Pradesh, India, 73+ixp

Sood DR, Kalim S and Shilpa (2008) Biochemical evaluation of potato tubers and peels. *Indian J. Nutr. Diet.* **45**: 410-420

Tariq AH, Sadiq M, Hamid F, Iqbal M and Asghar KA (2008) Screening of CIP white skinned potato germplasm at Vegetable Research Institute, Faisalabad. Proceedings, Pakistan April, 277-283

Tudela JA and Gil MI (2020). Tubers: Fresh-cut potatoes, In Controlled and Modified Atmospheres for Fresh and Fresh-Cut Produce, (Eds Maria Isabel Gil, Randolph Beaudry), Academic Press, Pages 625-628

Zebarth BJ, Arsenault WJ and Sanderson JB (2006) Effect of seed piece spacing and nitrogen fertilization on tuber yield, yield components, and nitrogen use efficiency parameters of two potato cultivars. *Am. J. Potato Res.* **83**:289-296

MS Received : January 05, 2024; Accepted : August 12, 2024

MANUSCRIPT PREPARATION GUIDELINES FOR AUTHORS

1. The Potato Journal publishes reviews (by invitation), full length papers, short notes and book reviews (by invitation) on basic and applied research on potato. Manuscripts type-written in English, double spaced with at least 4 cm margin on all sides should be submitted online after getting registered on : http://epubs.icar.org.in/ejournal/index.php/PotatoJ/user. All the authors should be members of the association (foreign authors are exempted).

2. All manuscripts submitted for publication will be peer reviewed and assessed for their acceptability and necessary modifications. An already published paper or under consideration for publication, wholly or substantially elsewhere, cannot be accepted. The article submitted for publication in the journal **should not have data older than 5 years**. The cut-off date will be March 31 for winter (*rabi*) crop and September 30 for a summer/ rainy season (*kharif*) crop.

3. Title of the paper, name(s) and address(es) of authors, a short running title of the paper (<50 characters conveying main theme of the article), acknowledgements (if any), and name of the corresponding author (with **E-mail address)** should be submitted in seprate file (**supplementary file**). **Identity of authors** should not be disclosed/ indicated in any form in the text of the paper. **Footnotes** should be numbered in plain Arabic superscripts (Use MS word→insert footnote facility in default form).

4. **Full length paper** should consist of TITLE, ABSTRACT, KEYWORDS, INTRODUCTION, MATERIALS AND METHODS, RESULTS AND DISCUSSION, CONCLUSIONS and LITERATURE CITED (capitalize all section headings including the title). **Title** of the paper should be informative but concise and should not contain abbreviation(s). Title should contain most of the keywords for better indexing and information retrieval. In byline, all the name(s) with initial(s) of the **authors** should have an Arabic superscript (starting from first author *e.g*. **RL Singh[1], C Kumar[1], TK Nath[2], CP Mehta[1] and KR Kapur[3]**) which should subsequently explain the addresses of all the authors. **ABSTRACT** should not have reference to literature and tables/ figures and its length should be less than 200 words. Abstract is the most important section of the paper in the process of indexing of journals hence it should be written carefully. **KEYWORDS** (3-5) should indicate the most important findings, material and operations in the article. **INTRODUCTION** should be brief and limited to the statement of problem, gaps in research, justification of the research work and objectives of the study. **MATERIALS AND METHODS** section of the paper should be systematic and elaborative. Microsoft Equation facility should be used to write formula. Known methods of research/ analysis shouldn't be explained and a reference should be cited for further clarification. **RESULTS AND DISCUSSION** should be presented in single section to avoid the repetitions. Results should be discussed at 5% or less level of probability. Same data shouldn't be presented in tables as well as in figures. Simple narration of the data presented in tables and figures should be avoided in this section and an effort should be made to relate the flow of information to the objectives of the study with an emphasis on implications of the findings to fellow researchers, policy makers and other beneficiaries of the research. Statements not based on the current study should be supported with references. **CONCLUSIONS** section should crystallise the summary of results and their implications for further research and/ or solving the problem at various levels. Any part of the text in this section shouldn't be taken verbatim from other section(s) of the paper. **LITERATURE CITED** shouldn't be older than 10 years unless the reference is highly important or is a landmark in a particular field. References from standard scientific journals should be preferred for citation and as far as possible the unpublished references shouldn't be cited. Citation of literature should be strictly as per the details explained in following points. A paper of limited significance may be restricted to 4-5 pages in length and may be submitted as a '**SHORT NOTE**' in which the Abstract is omitted. In case of short notes text should not be divided into sections except for TITLE, KEYWORDS and LITERATURE CITED.

5. Due to the high cost of production, only essential information should be included in the paper. Normally the paper should be less than 15 typed pages including tables, figures, references and appendices. Manuscripts requiring more than minor corrections will be returned to the authors for modification.

6. Diagrams (avoid 3D unless really functional) should be about twice the size of the finished block. Photographs must be in black and white with adequate contrast. Digital (computer created) diagrams/ photographs are preferred. **Colour photographs will be printed only if authors agree to pay the charges for such printing**. Each table, diagram and photograph must have a caption. Both diagrams and photographs are considered figures and should be numbered serially as **(Fig. 1)** and **(Fig. 2)** *etc*. Tables and figures with their captions should be appended after the text and only their eventual position should be indicated in the text.

7. **Reference citations in text**

   The last name(s) of the author(s) and the year of publication should be cited in the text as per style given below.

   - .....the late blight of potato (**Singh, 2011**); or .....the late blight of potato (**Singh and Kumar, 2011**); or .....the late blight of potato (**Singh** *et al*.**, 2011**).
   - If the last name(s) of the author becomes a part of the narrative, cite the year in parenthesis; *e.g.* .....the late blight of potato was described by **Singh (2011)** as a perpetual challenge; or .....the late blight of potato was described by **Singh and Kumar (2011)** as a perpetual challenge; or .....the late blight of potato was described by **Singh** *et al.* **(2011)** as a perpetual challenge.
   - If the citation is a contribution of an organisation or anonymous author(s) then cite name of the organisation or mention 'Anonymous' like first name of the single author as given below.
   - .....the late blight of potato (**CPRI, 2011**) or ...the late blight of potato (**Anonymous, 2011**). Similarly .....the late blight of potato was described by **CPRI (2011)** as a perpetual challenge or .....the late blight of potato was described by **Anonymous (2011)** as a perpetual challenge.
   - References cited together in the text should be arranged chronologically (**Singh** *et al*.**, 2001; Kumar, 2004; Kapur and Nath, 2011**).

8. **Reference list**

   References cited in the text of a research paper must appear in the list of **LITERATURE CITED** and vice-versa, as per the style given below.

   - **Order:** References should be arranged in alphabetical order by authors' last names. Sources without authors are arranged alphabetically by the name of the institute (preferably in abbreviated form) or Anonymous as the author's last name.
   - **Sequence:** Name(s) and initial(s) of the authors should be followed by the year of publication (in parenthesis and distinguished by small a, b, c, ... where more than one papers published by the same author (s) in the same year are cited), full title of paper, abbreviated title of the journal (as per ISI journal title abbreviations)/ periodical, volume number in Arabic numerals (in bold font), issue number in Arabic (in parenthesis; without any character between volume number and start of parenthesis) and page numbers in Arabic. Use full stop after title of the paper to separate it from the title of the journal/ periodical. For further clarification see **examples** following the heading "Pagination", below.
   - **Authors and year of publication:** Write the last name and initials for all authors of a particular work followed by the year of publication in parenthesis.
   - **Journal title abbreviations:** The journal titles should be italicised and abbreviated as per ISI Journal Title Abbreviations. Use following link to download complete list from the internet.
     http://images.isiknowledge.com/WOK46/help/WOS/A_abrvjt.html
   - **Internet address:** A stable internet address directing the reader as close as possible to the actual work should be used. If available, use digital object identifier (DOI). If abbreviated name of the organisation is used as author name then expand name of the organisation with address after title of reference. It should be followed by the stable internet address and URL and then by the date of retrieval of the information.
   - **Separation of entities:** In order to separate multiple authors use "," (except the last author), however, use "and" to separate last author *e.g.* **Smith JD, Jones M, Lipton M and Thompson P (2011)**. Don't use "," after last name of the author(s) and full stop after initials. Use full stop to separate entities where one ends with alphabets and second also starts with alphabets. Where entities are separated by alphabets and numerals/ parenthesis, use only the blank space; however full stop has to be used at the end of the title of the reference in all cases. Don't use full stop(s) after title abbreviation(s). Use ":" followed by a blank before typing page number(s) of a reference in all cases.

- **Pagination:** First and last page number of the article separated by "-" should be given towards the end of the listed reference. Use "p" (without a dot after p) to describe total number of pages in the referred document where a specific range of page numbers is not relevant.

Some examples of reference citation style

Journals, magazines and newspapers

Scott G, Best R, Rosegrant M and Ringler C (2000) Global projection for root and tuber crops to the year 2020. *Food Policy* **25**(5): 561-97

Anonymous (2010) Agribusiness in India: green shoots. *Economist* **394**(13-19 March): 65-66

Chakravarty C and Pandey B (2005) Growing roots in farmlands: an interview with Ms Indra Nooyi, worldwide president and CFO, PepsiCo. *Econ Times* 29 August 2005

Online sources

FAO (2008) Potato world: Africa-international year of the potato 2008. Food and Agriculture Organisation, Rome. http://www.potato2008.org/en/world/africa.html, 31 December 2008

Hirtle PB (2008) Copyright renewal, copyright restoration, and the difficulty of determining copyright status. *D-Lib Magazine* **14**(7-8), DOI:10.1045/july2008-hirtle

Anonymous (2008) *Encyclopaedia Britannica*. http://search.eb.com, 6 May 2008

E-Views (2006) E-Views quantitative software. http://www.eviews.com, 28 September 2006

Book and book chapter

Guenthner J (2001) The International Potato Industry. Woodhead Publishing Limited, Cambridge: 312p, ISBN-13: 978 1 85573 465 4

Adiyoga W and Norton GW (2009) Costs and benefits of Bt potato with resistance to potato tuber moth in Indonesia. In, Projected Impacts of Agricultural Biotechnologies for Fruits and Vegetables in the Philippines and Indonesia. Norton GWH (ed), Los Banos, Philippines: 105-40

Annual report, bulletin or working paper

CPRI (2010) Annual report 2009-10. Central Potato Research Institute, Shimla, India: 203p

Chand R (2003) Government intervention in food grain markets in the new context. National Centre for Agricultural Economics and Policy Research, New Delhi. Policy paper-19: 118p

CPRI (1999) Package of practices of ware and seed potato production in central Indo-Gangetic plains. Central Potato Research Institute, Shimla, India. Extension bulletin-16: 9p

Theisen K and Thiele G (2008) Implementing CIP's vision: impact targeting. International Potato Center (CIP), Lima, Perú. Working paper 2008-4: 24p

Conference presentation

Haq I, Farooq K and Mahmood MM (2008) Screening of potato genotypes for late blight resistance/ tolerance in Pakistan. Poster presented in Global Potato Conference-2008, New Delhi, 9-12 December 2008

Bachem C, de Boer J, Borm T and Visser R (2008) Potato genome sequencing: status report. Paper presented in Global Potato Conference-2008, New Delhi, 9-12 December 2008

Raman KV (2000) Integrated pest management in potato production. In, Potato, Global Research & Development (Proceedings of the Global Conference on Potato, New Delhi, 6-11 December 1999) Khurana SMP, Shekhawat GS, Singh BP and Pandey SK (eds) **1**: 345-51

Bradshaw JE (2008) Have we reached yield plateau: a genetic perspective. In, Abstracts: Global Potato Conference-2008. Indian Potato Association, Shimla, India: 3-4

Thesis

Kaur RJ (2004) Effect of nitrogen management through organic and inorganic sources in potato. Department of Agronomy, Punjab Agricultural University, Ludhiana, India, Ph.D. thesis: 99p

Encyclopaedia or dictionary

Kinni TB (2004) Walt Disney (1901-1966): founder of the Walt Disney company. Encyclopaedia of Leadership. Sage Publications, Thousand Oaks, CA: **1**: 345-49

Cowie AP (1989) Oxford Advanced Learner's Dictionary, 2nd ed. Oxford University Press, Oxford

9. **SI units**: Use SI units; few examples are given below. No dot or full stop is used after the abbreviation of units. **Quintal** (q) and **Acre** should not be used. Use kg/ha, or t/ha. Similarly, prefer use of g/ha, mg/kg, mg/l, mg/g, ml/l *etc.* Do not follow the style kg ha^{-1} or t ha^{-1}. Standard symbol for INR/ Rupee/ Rupees (₹) should be used.

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

10. Authors may receive the galley proofs for correction. Only the corresponding authors shall receive a PDF reprint of the published article by E-mail. The corresponding author may further send PDF reprint to all the authors. The PDF reprint can be used by authors for scientific and technical purposes only and not for commercial use.

11. **Useful hints**: All scientific or technical names as well as all data and facts must be rechecked carefully before submitting the manuscript. Avoid expressing data in 'lakhs', instead use 'thousand' or '**million'**. Only standard **abbreviations** should be used and these should invariably be explained at first mention. Names of plant protection chemicals should not be capitalized, however, the trade names (avoid mentioning trade names unless essential) should be capitalized. Use of unnecessary abbreviations and treatment symbols such as T1, T2 *etc.* under MATERIALS AND METHODS or tables without actually using them under RESULTS AND DISCUSSION should be avoided. Use % after numbers (not per cent) *e.g.* 7 %. In a series or range of measurements, mention the units only at end, *e.g.* 30, 100, 170 and 300 cm (not 30 cm, 100 cm, 170 cm and 300 cm); 20 or 30 % more (not 20 % or 30 % more). Statistical analysis of data in the standard experimental design should be sound and complete in itself with both SEm± and CD (0.05) values given for comparison of treatment means in tables and figures.

Designed & Printed at Malhotra Publishing House, B-6, DSIDC Complex, Kirti Nagar, New Delhi-110 015
E-mail: vinay.malhotra@gmail.com