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# Potato Journal

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

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## KUFRI JAMUNIA: A PURPLE FLESHED BIOFORTIFIED POTATO VARIETY

SK Luthra<sup>1\*</sup>, Dalamu<sup>2</sup>, Jagesh Tiwari<sup>2</sup>, Babita Chaudhary<sup>1</sup>, VK Gupta<sup>1</sup>, Vinod Kumar<sup>2</sup>, Pinky Raigond<sup>2</sup>, Bandana<sup>1</sup>, Arvind Jaiswal<sup>3</sup>, Brajesh Singh<sup>2</sup>, Jagdev Sharma<sup>2</sup>, VK Dua<sup>2</sup>, Sanjay Rawal<sup>1</sup> and Mehi Lal<sup>1</sup>

**ABSTRACT:** Kufri Jamunia, is a table purpose purple fleshed main season potato variety recommended for cultivation in North Indian plains (Northern, Central and Eastern Plains). It is a clonal selection developed from the cross between MS/8-1148 × CP4242. Its plants are medium tall with medium maturity and produce dark purple oblong tubers with shallow eyes, purple flesh and mealy texture. The variety is capable of producing a total tuber yield of 32-35 t/ha. Kufri Jamunia possesses medium dormancy of 6-8 weeks with very good keeping quality and moderate tuber dry matter of 17-19%. It is moderately resistant to late blight under laboratory conditions; however, it was found susceptible in field conditions. Owing to its purple colour and good organoleptic taste, the variety will attract growers, traders and consumers, adding novelty in the preparation of various dishes.

**KEYWORDS:** Kufri Jamunia, purple skin, purple flesh, antioxidant, high yield, keeping quality, North Indian plains.

### INTRODUCTION

Potato is one of the predominant non-grain, starchy, readily available energy-rich, important tuber crop in terms of food and nutritional security. The preference for red skin potatoes had been region specific, but now the era of coloured potato varieties like red, purple, and blue fleshed has started, offering both nutritional and visual appeal. Pigmented potato cultivars offer numerous health-promoting phytonutrients and an excellent matrix for developing functional foods and nutraceuticals (Ezekiel *et al.*, 2013). Apart from the high-yielding varieties, few native pigmented potato landraces are traditionally grown in the North-Eastern and Terai agro-ecological regions of India. The production scale of these pigmented landraces is small

and regional to date and their predominant uses are in culinary applications due to their special taste and appearance (Kumar *et al.*, 2024). In Bihar, red-skinned potatoes are favored over white-skinned varieties due to culinary practices that utilize potato varieties suitable for “bhujia” (fried sabzi) preparation (Yadav *et al.*, 2024). These coloured potatoes contain high levels of anthocyanins and carotenoids, natural pigments that render them distinct hues of red, purple and yellow (Luthra *et al.*, 2018). In addition, the coloured potatoes are also enriched with micronutrients such as iron and zinc, which are typically found in lower concentrations in white/yellow fleshed varieties. Over the past decades, consumers have become more interested in nutritious food fortified with micronutrients

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and antioxidants, driven by the increasing awareness of health benefits. However, shifts in preferences vary according to region, taste, and availability. For instance, people of eastern India and J&K have their inclination towards red skinned potatoes, while, Bareilly red variety of potato, distinguished with dark red tubers, variegated flesh colour is prominent in Bareilly district of Uttar Pradesh (Luthra, 2015). Also, purple or purple-black varieties locally grown in some pockets of Himachal Pradesh and North eastern regions are being favored owing to their slow degeneration rate and better taste (Luthra *et al.*, 2020a). In this regard, ICAR-CPRI has so far developed ten indigenous varieties with red skin and white or white-cream flesh colour and as well as two purple-skinned varieties: Kufri Neelkanth with yellow flesh colour (Luthra *et al.*, 2020b) and Kufri Jamunia with purple skin as well as purple flesh (Luthra *et al.*, 2025). Therefore, taking into account the preferences of consumers supplementing with nutrient rich fortified foods, the efforts were directed to develop a new coloured antioxidant and micronutrient rich variety, having good keeping quality with purple skinned tubers with purple flesh colour. The work in this respect led to the development of a new specialty potato variety Kufri Jamunia.

## BACKGROUND

The advanced clone MSP/16-307 was developed from the cross between MS/8-1148 × CP4242 made in 2015 at Modipuram. The clone MSP/16-307 was selected in 2016 from the seedling stage and since then, it has passed successfully through various clonal generation trials. It was evaluated in a preliminary (2018-19) and two confirmatory yield trials (2019-20 and 2020-21) at Modipuram followed by multi-location replicated trials under AICRP (Potato) during 2021-22 and 2022-23 (15

locations) in North Indian plains comprising northern, central and eastern plains. The pedigree of Kufri Jamunia is described in Figure 1. The female parent MS/8-1148 is an indigenous advanced clone with medium maturity, high yield, moderate resistance to late blight, good keeping quality and rich in ascorbic acid (vitamin C) content (Luthra *et al.*, 2021). It produces attractive, medium sized 8-10 light yellow ovoid tubers with shallow eyes and yellow flesh colour. The male parent CP4242 produces dark purple oblong tubers with shallow eyes and purple flesh colour. The data was analyzed following standard statistical procedures using the online statistical software OPSTAT, CCS HAU, Hisar, Haryana (Sheoran *et al.*, 1998). Based on its performance, the advanced clone was recommended for release by the 41<sup>st</sup> Group Meeting of AICRP (Potato) held during October 16-18, 2023 at CCS HAU, Hissar, Haryana and subsequently it has been released and notified as variety in the name of Kufri Jamunia in the 31<sup>st</sup> meeting held on 19<sup>th</sup> July, 2024 by Central Sub-Committee on Crop Standards Notification and Release of Varieties for Horticultural Crops, Ministry of Agriculture, Department of Agriculture and Co-operation, Government of India, New Delhi vide F.No. No.3-76/2024-SD-IV dated 23<sup>rd</sup> September, 2024 and Official Gazette S.O. 4917(E dated 13<sup>th</sup> November, 2024

## VARIETAL DESCRIPTION

**Plants:** Morphological characteristics of variety Kufri Jamunia (leaf, flower, sprout and tuber) have been depicted in Figure 2.

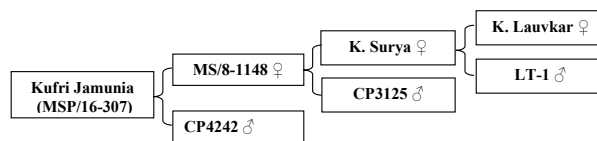


Fig. 1. Pedigree of Kufri Jamunia



Fig. 2. Morphological characteristics of Kufri Jamunia: Leaf, flower, tuber and sprout

**Plant:** Medium, plant canopy semi-compact, stem medium thick, predominantly green, secondary stem colour purple throughout lightly scattered, wings poorly developed and wavy.

**Foliage:** Grey green, leaves intermediate, leaf large with medium width, leaflets ovate

lanceolate, leaflet coalescence absent, rachis coloured, midrib coloured only at base.

### Inflorescence

**Flower:** Flowering medium, inflorescence medium, floral stalk medium coloured, floral stalk-pedicle articulation clearly visible and located above the middle, calyx light purple, corolla white, corolla shape semi-stellate, anther orange black striped, anther cone normally developed, stylar length equal than stamen column and stigma round.

### Tubers

**Size:** Medium to large, 10-12 tubers per plant; **Shape:** oblong; **Skin:** dark purple; **Eyes:** shallow; **Eyebrows:** normal; **Flesh:** purple having mealy texture.

### Sprout

Sprout purple, shape cylindrical, pubescence at the sprout base is weak

## YIELD PERFORMANCE

### Station trials at Modipuram, Meerut

In station trials at Modipuram (2018-19, 2019-20, 2020-21 (Table 1), the advanced clone

Table 1. Performance of MSP/16-307 at Modipuram during 2018-19 to 2020-21

Genotypes	Total tuber yield (t/ha)							Yield increase (%) over controls		
	2018-19		2019-20		2020-21		Mean			
	90 days	75 days	90 days	75 days	90 days	75 days	90 days	75 days	90 days	
MSP/16-307	47.04	33.49	54.06	35.67	45.93	34.58	49.01			
Kufri Lalima	51.98	34.48	41.68	37.01	46.77	35.75	46.81	-3.26	4.70	
Kufri Lalit	48.83	30.16	43.66	36.25	44.41	33.21	45.63	4.14	7.40	
Kufri Neelkanth	47.02	35.35	45.24	39.44	50.13	37.40	47.46	-7.53	3.26	
CD (0.05)	1.95	1.62	2.23	2.42	2.20	2.02	2.13			
	Marketable tuber yield (t/ha)									
MSP/16-307	45.64	28.55	48.90	33.74	43.57	31.15	46.04			
Kufri Lalima	48.95	31.89	38.04	35.66	44.72	33.78	43.90	-7.79	4.86	
Kufri Lalit	46.91	27.76	40.20	34.58	42.62	31.17	43.24	-0.08	6.46	
Kufri Neelkanth	41.63	31.45	40.10	37.12	46.17	34.29	42.63	-9.16	7.98	
CD (0.05)	2.05	1.76	2.91	2.30	2.36	2.03	2.44			

MSP/16-307 (34.58 t/ha) yielded 4% higher total tuber yield over Kufri Lalit (33.21 t/ha) at 75 days with nearly 90% marketable tuber yield. At 90 days, advanced clone MSP/16-307 (49.01 t/ha) yielded 5, 7 and 3% higher total tuber yield over Kufri Lalima (46.81 t/ha), Kufri Lalit (45.63 t/ha) and Kufri Neelkanth (47.46 t/ha). It produced nearly 94% marketable tuber yield as compared to Kufri Lalima (93%), Kufri Lalit (95%) and Kufri Neelkanth (90%). It is pertinent to mention that existing control varieties were used due to non-availability of matching control for purple flesh colour available in the advanced clone MSP/16-307.

### Multi-location testing

Replicated multi-location yield trials along with controls were conducted under AICRP on Potato during 2021-22 and 2022-23 at 15 locations (Table 2 and 3) in North Indian

plains comprising northern, central and eastern plains at 75 and 90 days crop duration.

### Crop duration (75 days)

**Northern plains:** Based on performance at Hisar, Jalandhar, Modipuram and Pantnagar, the advanced clone MSP/16-307 produced a total tuber yield of 31.49 t/ha and it varied from 23.39 t/ha (Modipuram) to 38.44 t/ha (Pantnagar). The performance of the advanced clone MSP/16-307 (/31.49 t/ha) was at par with the control Kufri Manik (31.79 t /ha). The advanced clone MSP/16-307 produced nearly 89% marketable tuber yield (Table 2).

**Central plains:** Based on performance at Chhindwara, Gwalior, Deesa, Kanpur and Raipur, the advanced clone MSP/16-307 produced 30.15 t/ha total tuber yield and it varied from 17.87 t/ha (Kanpur) to 47.55 t/ha (Gwalior). The performance of MSP/16-307

Table 2. Performance of MSP/16-307 in AICRP replicated yield trials at 75 days (pooled over 2021-22 and 2022-23)

Regions	Locations	Total tuber yield (t/ha)			Marketable tuber yield (t/ha)		
		MSP/16-307	Kufri Manik	Kufri Neelkanth	MSP/16-307	Kufri Manik	Kufri Neelkanth
Northern plains	Hisar	30.42	32.54	33.65	26.46	28.22	30.36
	Jalandhar	33.31	33.09	37.24	31.18	30.62	33.66
	Modipuram	23.39	25.97	29.53	18.48	22.32	25.23
	Pantnagar	38.84	35.54	33.86	36.24	33.24	30.23
	Mean	31.49	31.79	33.57	28.09	28.60	29.87
Central plains	Chhindwara	24.03	26.20	31.37	21.08	23.02	27.49
	Gwalior*	47.55	-	47.10	42.64	-	42.12
	Deesa	35.91	30.46	35.41	33.04	29.57	32.54
	Kanpur	17.87	18.66	33.96	15.31	14.93	29.50
	Mean	30.15	24.87	37.24	27.02	22.49	33.50
Eastern plains	Bhubaneswar	21.97	16.05	22.80	19.16	14.67	20.75
	Faizabad	26.48	30.58	27.93	24.03	27.62	25.08
	Jorhat	15.66	16.47	17.17	10.56	11.03	11.89
	Kalyani	30.83	28.82	29.71	28.79	26.69	28.00
	Mean	23.53	24.12	24.45	20.62	21.37	21.50
Overall mean		28.17	26.71	31.62	25.04	23.94	28.18
*2021-22	CD (0.05)	Genotype: 0.65 Year × Location × Genotype: 3.30			Genotype: 0.59 Year × Location × Genotype: 3.02		

Table 3. Performance of MSP/16-307 in AICRP replicated yield trials at 90 days (pooled over 2021-22 and 2022-23)

Regions	Locations	Total tuber yield (t/ha)			Marketable tuber yield (t/ha)		
		MSP/16-307	Kufri Manik	Kufri Neelkanth	MSP/16-307	Kufri Manik	Kufri Neelkanth
Northern plains	Hisar	34.33	37.23	37.33	31.03	33.75	33.98
	Jalandhar	43.10	40.95	45.87	40.71	38.08	41.47
	Modipuram	27.89	29.55	32.93	24.96	27.31	29.52
	Pantnagar	41.75	39.82	37.25	38.68	38.04	33.41
	Mean	36.77	36.89	38.35	33.84	34.30	34.60
Central plains	Chhindwara	27.04	28.86	35.05	23.71	26.04	30.73
	Gwalior*	53.48	-	56.23	50.45	-	53.35
	Deesa	41.05	40.44	44.19	39.39	39.14	42.11
	Kanpur	21.22	24.55	39.41	18.82	18.93	35.02
	Kota	30.77	32.90	42.54	29.75	31.96	40.88
	Raipur	29.21	31.31	42.57	26.37	27.60	39.58
	Mean	33.79	31.61	43.33	31.41	28.73	40.28
Eastern plains	Bhubaneswar	20.22	17.77	22.48	18.13	16.43	20.76
	Faizabad	27.76	32.93	29.55	24.81	31.75	28.06
	Jorhat	19.70	20.15	21.06	14.39	15.36	15.74
	Kalyani	32.88	32.08	31.88	31.27	30.08	30.20
	Patna	28.99	32.68	30.84	25.38	30.24	27.36
	Mean	25.91	27.12	27.16	22.80	24.77	24.42
Overall mean		31.96	31.52	36.61	29.19	28.91	33.48
*2021-22	CD (0.05)	Genotype: 0.63 Year × Location × Genotype: 3.33			Genotype: 0.63 Year × Location × Genotype: 3.31		

(30.15 t /ha) was superior to the control Kufri Manik (24.87 t/ha) by 21%. The advanced clone MSP/16-307 produced nearly 90% marketable tuber yield.

**Eastern plains:** Based on performance at Bhubaneswar, Faizabad, Jorhat, Kalyani and Patna, the advanced clone MSP/16-307 produced 23.53 t/ha total tuber yield and it varied from 15.66 t/ha (Jorhat) to 30.83 t/ha (Kalyani). The advanced clones with a total tuber yield of 23.53 t/ha remained at par with Kufri Manik (24.12 t/ha) and Kufri Neelkanth (24.45 t/ha). The advanced clone MSP/16-307 produced nearly 88% marketable tuber yield.

Overall, MSP/16-307 (28.17 t/ha) recorded 5% higher tuber yield than control Kufri Manik (26.71t/ha). However, the marketable yield of 89% recorded in the advanced clone was

statistically at par with both the controls viz. Kufri Manik and Kufri Neelkanth (89%).

### Crop duration (90 days)

**Northern plains:** Based on performance at Hisar, Jalandhar, Modipuram and Pantnagar, the advanced clone MSP/16-307 produced a total tuber yield of 36.77 t/ha and it varied from 27.89 t/ha (Modipuram) to 43.10 t/ha (Jalandhar). The advanced clone with a total tuber yield of 36.77 t/ha remained at par with Kufri Manik (36.89 t/ha) and Kufri Neelkanth (38.35 t/ha). The advanced clone MSP/16-307 produced nearly 92% marketable tuber yield (Table 3).

**Central plains:** Based on performance at Chhindwara, Gwalior, Deesa, Kanpur, Kota and Raipur, the advanced clone MSP/16-307

produced 33.79 t/ha total tuber yield and it varied from 21.22 t/ha (Kanpur) to 53.48 t/ha (Gwalior). The performance of MSP/16-307 (33.79 t /ha) is superior to the control Kufri Manik (31.61 t/ha) by 7%. The advanced clone MSP/16-307 produced nearly 93% marketable tuber yield.

**Eastern plains:** Based on performance at Bhubaneswar, Faizabad, Jorhat, Kalyani and Patna, the advanced clone MSP/16-307 produced 25.91 t/ha total tuber yield and it varied from 19.70 t/ha (Jorhat) to 32.88 t/ha (Kalyani). The advanced clones with a total tuber yield of 25.91 t/ha remained at par with Kufri Manik (27.12 t/ha) and Kufri Neelkanth (27.16 t/ha). The advanced clone MSP/16-307 produced nearly 88% marketable tuber yield.

On an overall basis, advanced clone MSP/16-307 produced a total tuber yield of 31.96 t/ha and remained at par with Kufri Manik (31.52 t/ha) with nearly 91% marketable tuber yield at 90 days crop duration.

**Tuber dry matter content:** In station trials conducted during 2019-20 and 2020-21 (Table 4), the advanced clone had comparable mean tuber dry matter content (%) of 15 and 17 at 75 and 90 days of crop respectively in comparison to the control Kufri Lalima (16 and 21%), Kufri Lalit (16 and 18%) and Kufri Neelkanth (17 and 20%). However, in multi-location AICRP potato trials during 2021-22 & 2022-23 (Table 5), the advanced clone possessed statistically at par tuber dry matter to the tune of 17%

and 19% in 75 and 90 days crop respectively over the control Kufri Manik (17 and 18%) and Kufri Neelkanth (17 and 19%).

**Keeping quality:** The advanced clone has a medium tuber dormancy period (6-8 weeks) and possesses very good keeping quality under country store conditions. Storage study at station trials (Table 6) revealed that advanced clone is a very good keeper due to less rottage (0.27%), and low total weight loss of 6.75% as compared to controls Kufri Lalima (0.72 and 6.37); Kufri Lalit (2.14 and 8.28%); Kufri Neelkanth (0.11 and 7.97) and Kufri Manik (2.44 and 14.60%). In AICRP (Potato) multi-location trials (Table 7), the advanced clone MSP/16-307 had a lower total weight loss of 19% as compared to control Kufri Neelkanth (21%).

**Nutritional content:** The nutritional properties of advanced clone MSP/16-307 render it more superior to the other control varieties. In station trials, the advanced clone exhibited maximum anthocyanin content to the tune of 42.05 and 80.66 mg/100g FW in its flesh and skin, respectively, in comparison to the controls. Also, ascorbic acid and flavouring compounds (42.75 mg/100g FW and 4.68 ug/g) present in flesh were highest in the MSP/16-307 than in control varieties (Table 8).

In AICRP multi-location replicated trials conducted at five locations namely Pune, Hisar, Kanpur, Raipur and Deesa, the advanced clone MS/16-307 (51.52 mg/100g

Table 4. Tuber dry matter content (%) of MSP/16-307 at Modipuram, Meerut

Genotypes	Tuber dry matter (%)					
	2019-20		2020-21		Mean	
	75 days	90 days	75 days	90 days	75 days	90 days
MSP/16-307	14.02	16.24	16	18.27	15.01	17.26
Kufri Lalima	15.74	20.61	17.13	20.39	16.44	20.50
Kufri Lalit	14.40	16.63	17.31	19.46	15.86	18.05
Kufri Neelkanth	17.87	18.85	17.11	20.24	17.49	19.54
CD (0.05)	1.43	0.64	0.60	1.06	1.02	0.85

**Table 5. Tuber dry matter content (%) of MSP/16-307 in AICRP trials (pooled over 2021-22 & 2022-23)**

Regions	Locations	75 days			90 days				
		MSP/16-307	Kufri Manik	Kufri Neelkanth	MSP/16-307	Kufri Manik	Kufri Neelkanth		
Northern plains	Hisar	16.54	16.80	15.80	17.68	17.97	16.56		
	Jalandhar	15.59	15.11	14.53	15.88	15.58	15.06		
	Modipuram	14.28	14.87	16.28	14.73	15.57	17.17		
	Mean	15.47	15.59	15.54	16.10	16.37	16.26		
Central plains	Chhindwara	18.70	18.28	17.84	19.25	18.79	18.61		
	Gwalior*	16.49	-	17.80	18.18	-	18.75		
	Deesa	18.30	17.81	18.99	20.54	18.66	19.63		
	Kanpur	16.19	15.13	14.61	17.86	16.19	15.55		
	Raipur	20.16	18.51	18.45	21.39	19.27	19.27		
	Kota	-	-	-	19.69	18.99	20.66		
	Mean	17.97	17.43	17.54	19.49	18.38	18.75		
Eastern plains	Bhubaneshwar	16.57	18.51	16.49	17.74	19.30	18.71		
	Faizabad	17.51	17.52	17.41	18.10	18.10	17.61		
	Jorhat	22.86	22.66	22.69	22.68	22.75	22.78		
	Kalyani	18.64	17.01	19.43	20.23	18.22	20.54		
	Patna	15.08	13.67	16.50	16.42	15.17	18.58		
	Mean	18.13	17.87	18.51	19.03	18.71	19.64		
Overall	Mean	17.46	17.16	17.45	18.60	18.04	18.53		
*2021-22	CD (0.05)	Genotype: 0.14		Year × Location × Genotype: 0.69		Genotype: 0.13		Year × Location × Genotype: 0.67	

**Table 6. Keeping quality of MSP/16-307 at Modipuram, Meerut (2019-20 and 2020-21)**

Genotypes	Dormancy (<or> than 6 weeks)	Sprouting (%)		Weight loss (%) after 75 days of storage			
		At 6 weeks	At 75 days	Rottage	Sprouting	Physiological	Total
MSP/16-307	6-8 weeks	2.87	100.00	0.27	0.58	5.91	6.75
Kufri Lalima	>10 weeks	0.51	45.34	0.72	0.17	5.48	6.37
Kufri Lalit	>10 weeks	13.19	73.39	2.14	0.20	5.94	8.28
Kufri Neelkanth	6-8 weeks	9.48	98.31	0.11	0.64	7.22	7.97
Kufri Manik*	<6 weeks	85.39	97.00	2.44	0.95	11.10	14.60

**Table 7. Keeping quality (Total weight loss) of MSP/16-307 at AICRP Locations (90 days) over 2021-22\* and 2022-23\*\***

Locations	MSP/16-307	Kufri Manik	Kufri Neelkanth
Bhubaneshwar*	29.41	5.82	10.80
Deesa	6.33	18.13	38.15
Faizabad	14.50	14.85	15.65
Hisar**	19.50	15.00	21.50
Kanpur	31.60	17.70	27.70
Modipuram	12.00	15.75	14.20
Mean	18.89	14.54	21.33

**Table 8. Nutritional components in MSP/16-307 at Modipuram, Meerut**

Genotypes	Anthocyanins (mg/100g FW)		Carotenoids (ug/100 g FW)	Ascorbic acid (mg /100 g FW)	Flavouring compounds (AMP+GMP) (ug/g)
	Flesh	Skin	Flesh	Flesh	Flesh
MSP/16-307	42.05	80.66	161.00	42.75	4.68
Kufri Lalima	3.59	8.53	245.25	34.00	2.62
Kufri Lalit	4.36	7.83	296.00	18.00	3.40
Kufri Neelkanth	2.95	18.97	669.50	27.75	2.52

\*Anthocyanins, Carotenoids, Ascorbic acid (means of four years: 2017-18, 2018-19, 2019-20, 2020-21); \*\*Flavouring compounds (AMP+GMP) (means of two years: 2018-19, 2019-20)

fresh weight) exceeded the controls Kufri Manik (37.99) and Kufri Neelkanth (29.04) for ascorbic acid by 35% and 77% respectively. The advanced clone (32.36 mg/100g fresh weight) possessed higher anthocyanin content by 21% over Kufri Manik (26.66). Likewise, carotenoid contents were 64% and 51% higher in MSP/16-307 (163.04 ug/100g fresh weight) as compared to control varieties Kufri Manik (99.20) and Kufri Neelkanth (107.52), respectively (Table 9).

**Micronutrients:** The micronutrient studies at multi location trials revealed that the

advanced clone MS/16-307 (zinc-22.77 ppm and iron-32.23 ppm) was superior to Kufri Manik (17.60 ppm) for zinc content by 29% and Kufri Neelkanth (iron-32.02 ppm) by 1% for iron content in flesh (Table 10)

### Usage

The advanced clone MSP/16-307 released as variety Kufri Jamunia possessing attractive, dark purple, oblong tubers with shallow eyes and purple flesh, adds novelty to various dishes. The tubers are rich in anthocyanins, and micronutrients, especially zinc and iron, prove to be beneficial in enriching health.

**Table 9. Nutritional components in MSP/16-307 at AICRP centers (2022-23)**

Ascorbic acid (mg/100g fresh weight) in flesh						
Genotypes	Pune	Hisar	Kanpur	Raipur	Deesa	Mean
MSP/16-307	50.00	53.80	58.50	48.30	47.02	51.52
Kufri Manik	-	46.90	38.90	-	28.16	37.99
K Neelkanth	27.40	36.30	31.60	25.00	24.90	29.04
Anthocyanins (mg/100g fresh weight) in flesh						
Genotypes	Pune	Hisar	Kanpur	Raipur	Deesa	Mean
MSP/16-307	15.95	69.34	23.16	7.16	46.21	32.36
Kufri Manik	-	69.53	0.79	-	9.65	26.66
K Neelkanth	0.43	1.08	1.96	0.89	1.26	1.12
Carotenoids (ug/100g fresh weight) in flesh						
Genotypes	Pune	Hisar	Kanpur	Raipur	Deesa	Mean
MSP/16-307	185.60	130.80	15.60	298.40	184.80	163.04
Kufri Manik	-	84.00	108.00	-	105.60	99.20
K Neelkanth	37.60	80.40	94.80	235.20	89.60	107.52

**Table 10. Micro-nutrients MSP/16-307 at AICRP Centers (2022-23)**

Zn (ppm) flesh						
Genotypes	Pune	Hisar	Kanpur	Raipur	Deesa	Mean
MSP/16-307	29.76	20.85	15.61	27.17	20.44	22.77
Kufri Manik	-	17.98	17.73	-	17.10	17.60
K Neelkanth	33.42	21.55	17.25	23.28	24.17	23.93
Fe (ppm) flesh						
Genotypes	Pune	Hisar	Kanpur	Raipur	Deesa	Mean
MSP/16-307	35.41	34.50	29.11	30.65	31.48	32.23
Kufri Manik	-	33.53	33.67	-	33.58	33.59
K Neelkanth	34.00	33.78	28.34	33.85	30.12	32.02

This clone reported the least peeling losses due to oblong shape and shallow eyes, easy to cook (15-20 minutes) and possesses a pleasant aroma and mealy texture. Moreover, tubers do not show any deformities like cracking or hollow heart. It is table purpose variety and can serve the value to the meal of the consumers for colourful vegetable curry, parontha, puri, raita etc. The milling of dehydrated form of Kufri Jamunia tubers produces anthocyanin rich daliya, suji and flour. These milled dehydrated products can be successfully used for the preparation of sweet porridge (Daliya), halva, upma, part of dosa batter, and idli (Suji) and roti, paratha, soup, cookies, other bakery items and many more products (potato flour).

The results on organoleptic performance of Kufri Jamunia (sample size of 64 persons, including 11 women) indicated that 91% persons graded Kufri Jamunia between good to excellent for tuber appearance and 90% persons found its flavour between moderate to extreme. Based on texture (mouth feel), 77% persons indicated Kufri Jamunia to have a mealy texture to floury. About 56% people found Kufri Jamunia to have a very good taste, while 41% persons recorded of neutral taste. The overall acceptability analysis indicated that 95% person graded Kufri Jamunia from good to excellent. Owing to its nutritional properties, desirable traits, good keeping quality, and organoleptic taste, the clone will favour its acceptance.

### Disease Resistance

Advance clone MSP/16-307 (AUDPC: 910.63; lesion area: 4.39 cm<sup>2</sup>) showed late blight reactions as compared to Kufri Bahar (AUDPC: 1073.4; lesion area: 7.52 cm<sup>2</sup>), Kufri Neelkanth (AUDPC: 956.84; lesion area: 5.38 cm<sup>2</sup>) and Kufri Manik (AUDPC: 1039.51; lesion area: 4.98 cm<sup>2</sup>) when investigated under field conditions and through standard detached leaf method, respectively (Table 11).

**Table 11. Late blight screening of MSP/16-307 at Modipuram, Meerut**

Genotypes	Year	Field screening		Detached leaf	
		AUDPC	rAUDPC	Lesion area (cm <sup>2</sup> )*	Grading
MSP/16-307	2019-20	748.08	0.416	4.14	MR
	2020-21	1073.17	0.511	4.64	MR
	Mean	910.63	0.46	4.39	MR
Kufri Bahar	2019-20	871.83	0.484	6.27	S
	2020-21	1275	0.607	8.77	S
	Mean	1073.4	0.55	7.52	S
Kufri Neelkanth	2019-20	815.17	0.453	5.12	S
	2020-21	1098.5	0.523	5.63	S
	Mean	956.84	0.49	5.38	S
Kufri Manik	2022-23	1039.51	0.55	4.98	MR

\*Grading: Lesion area (cm<sup>2</sup>): Up to 1.0- Highly resistant (HR); 1.1 to 2.5- Resistant (R); 2.51-5.0- Moderately resistant (MR), > 5.0 -Susceptible(S)

It is moderately resistant to late blight under laboratory conditions; however, it was found susceptible in field conditions.

### Production technology

**Crop management:** The optimum tuber yield of 32-35 t/ha was attained by the advanced clone MSP/16-307 following the recommended package of practices and worked out nutrition doses. Field preparation by ploughing, harrowing, and planking is preferred for better soil status. Planting time in the North Indian plains remains optimum from the second fortnight of October to the first fortnight of November. Tubers for planting must be healthy and free from pests, diseases and any disorders. Potato planting at 20 cm in 60 cm rows for seed size tubers of diameter 30-55mm (40-60g) provides optimum tuber yield and seed rate shall be approximately 35-40 q/ha. Seed tubers from the cold store are to be taken out at least 10 days before planting. Avoid seed bags in direct sunlight as it may result in rotting due to sudden exposure to high temperatures. Spread

the tubers in thin layer under shade 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. A planting depth of 10-12 cm is better for achieving uniform emergence. Nitrogen, phosphorous and potassium levels were 180, 80 and 100 kg/ha, respectively, in trial site at Modipuram. Green manuring before the potato crop is beneficial for crop in several ways, including crop nutrition. At planting 10-15 t/ha well rotten FYM may also be applied to provide the seed bed a better tilth and nutrition to the potato crop. These crop management practices shall reduce approximately one third dose of nitrogen, and half doses of phosphorus and potassium. Thus, half the adjusted dose of nitrogen and full adjusted doses of  $P_2O_5$  and  $K_2O$  should be applied at planting. The remaining half adjusted dose of nitrogen should be applied 20-25 days after planting i.e. at the time of inter-cultivation and earthing. Response to nutrient doses in different agro-ecologies may differ and regional recommendations may be adopted for obtaining optimum productivity. Pre-sowing irrigation is done to ensure uniform emergence. If this is not given then the first irrigation should be done 4-6 days after planting. Post planting irrigations are kept light and applied subsequently at 7-10 days intervals in sandy loam soil and 10-12 days in heavy soil. Potato ridges must not be submerged under water in any case and arrangements for drainage should also be developed, keeping unseasonal rains during crop season (Rawal *et al.*, 2021).

### ***Plant protection measures***

For the management of soil and tuber borne diseases, tubers are treated with boric acid 3% before storage. Planting done after

seed tuber (chitted) treated with pencycuron 22.9% SC @ 0.25% (25g/10 l of water) for 10 minutes can take care of black scurf. The clone is susceptible to late blight under field conditions, therefore, prophylactic spray with mancozeb 75% WP or propineb 70% WP or chlorothalonil @ 0.25% (2.5 g/l of water) as soon as the weather conditions become congenial for late blight or about a week in advance of canopy closure, whichever is earlier. On appearance of the disease in the field, apply any of the systemic/translaminar fungicides viz., cymoxanil + mancozeb or fenamidone + mancozeb @ 0.3% (3 g/l of water) or dimethomorph (0.1%) or ametocradin + dimethomorph (0.2%) or azoxystrobin + tebuconozol (0.1%) fungicides. Apply contact fungicides viz., mancozeb or propineb or chlorothalonil (0.25%) after 8-10 days of 2<sup>nd</sup> spray of systemic fungicides. However, if the weather is highly congenial, repeat application of systemic/translaminar fungicide may be done.

For the management of whiteflies, aphids and thrips in seed crops acting as vectors, dipping sprouted tubers with imidacloprid 200 SL (17.8 w/w) @ 0.04% (4 ml/10 l of water) for 10 minutes can be effective. On 80% crop emergence, first spray of pymetrozine 50WG @ 0.06% (6g/10 l of water) followed by second spray of thiamethoxam (25 WG) @ 0.05% (5g/10 l of water), third spray of flonicamid 50WG @0.04% (4g/10 l of water), fourth of thiamethoxam (25 WG) @ 0.05% (5g/10 l of water), and last spray of flonicamid 50WG @0.04% (4g/10 l of water) or imidacloprid 200 SL (17.8 w/w) @ 0.03% (3 ml/10 l of water) or thiamethoxam (25 WG) @ 0.05% (5g/10 l of water) each done after 10-15 days after every consecutive spray. Placing yellow sticky traps (15x30 cm<sup>2</sup> size) just above the canopy height @ 60 traps/ha at equidistance from each other for mass trapping of white flies/aphids.

**Harvesting:** Withhold irrigation 10-12 days prior to harvesting. Crop harvested after 15-20 days of haulm cutting and at proper soil moisture. After harvest, produce air dried and tubers kept in heaps covered with 25-30 cm thick crop residue/ paddy straw for 10-15 days in shade for curing of skin. All damaged and rotten tubers are removed, followed by grading the produce, packaging in gunny bags and labelling them. Storage in cold storage immediately after post-harvest operations.

### ADAPTABILITY

Advanced clone MSP/16-307 named and released as variety Kufri Jamunia has performed well in multi-location trials conducted under AICRP on Potato and has been recommended for cultivation in North-Indian plains ((Northern, Central & Eastern plains of India) including the states of Haryana, Punjab, Uttar Pradesh, Uttarakhand (plains), Madhya Pradesh, Rajasthan, Chhattisgarh, Gujarat, Orissa, Assam, West Bengal and Bihar. Kufri Jamunia can serve as a better choice for farmers due to its high anti-oxidants (anthocyanins and carotenoids) & ascorbic acid content and at par iron/zinc content. Owing to its purple colour and good organoleptic taste, it will attract growers, traders and consumers, adding novelty in the preparation of various dishes. Its export potential can also be harnessed in the coming time for destinations like Bangladesh, Bhutan, Nepal, Pakistan and Philippines, where red-skinned tubers are traditionally preferred (Pandey *et al.*, 2000 and Luthra *et al.*, 2004).

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### 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

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# CHARACTERIZATION OF POTATO GERMPLASM FOR RESISTANCE TO *GLOBODERA PALLIDA* AND *GLOBODERA ROSTOCHIENSIS*: A STRATEGIC APPROACH TO SUSTAINABLE POTATO PRODUCTION

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**ABSTRACT:** This study evaluates the resistance of 406 potato accessions across different years to potato cyst nematodes (PCNs), *Globodera pallida* and *G. rostochiensis*, a major pest that significantly reduce potato yields. The screening was conducted using a root ball technique in controlled glasshouse conditions over four years (2020-2024) at the ICAR-Central Potato Research Institute (ICAR-CPRI) in Kufri, India. The results revealed a wide range of resistance among the accessions. Notably, accessions such as CP2418, CP1736, CP3641, and JEX/A-15 exhibited high levels of resistance to both PCN species, which showed either immunity or minimal cyst formation. Additionally, accessions such as CP1687 and CP3222 demonstrated moderate resistance. All these highly resistant accessions are potential candidates in breeding for resistance to potato cyst nematode in India. Since major Indian potato varieties used in the current study are susceptible to one or the other species of PCN, the study highlights the importance of continuous screening and the strategic use of resistant germplasm to develop new potato varieties with broad-spectrum resistance, which is crucial for sustainable potato production.

**KEYWORDS:** Potato cyst nematodes, *Globodera pallida*, *Globodera rostochiensis*, resistance, germplasm, susceptibility.

## INTRODUCTION

Potatoes are an essential global food crop, rich in carbohydrates, protein, vitamins, and dietary fiber (Spsychalla and De Jong 2024). In India, it holds significant agricultural importance, being the second-largest producer worldwide. However, potato cultivation is significantly hindered by various plant pathogens, notably potato cyst nematodes (PCN), which represent a substantial production constraint in both developing nations and globally (Sood *et al.* 2023). Potato cyst nematodes are considered

quarantine pests in many countries, including India (Mhatre *et al.* 2019). It comprises two species, *Globodera rostochiensis* and *G. pallida*, and is a significant pest of potato, which causes yield losses ranging from 20% to 70%, if left uncontrolled (Asano *et al.* 2012). These nematodes are soil-inhabiting parasites that attack the roots of solanaceous plants, with five pathotypes identified for *G. rostochiensis* (Ro1 to Ro5) and three for *G. pallida* (Pa1 to Pa3) (Bairwa *et al.* 2023; Mangal *et al.* 2022, 2023, 2025).

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They attack plant roots and form cysts, severely impairing the host plant's ability to uptake essential nutrients and water (Faggian *et al.* 2012). These nematodes are particularly challenging due to their ability to survive in soil for over 20-30 years as dormant cysts (Bachmann-Pfabe *et al.* 2019; Perry 2002).

Potato cyst nematodes have been extensively studied due to their widespread impact on potato production, and genetic resistance has been identified as a crucial strategy to manage these pests effectively (Schultz *et al.* 2012). Traditional control methods, such as long-term crop rotation and pesticide use, are either expensive or environmentally hazardous, which emphasizes the need for breeding resistant varieties (Brodie *et al.* 1991). The genetic diversity present in the different species of potato offers valuable sources of resistance that can be introgressed into commercial cultivars (Gavrilenko *et al.* 2021). For instance, resistance to *G. rostochiensis* has been widely studied and utilized in breeding programs. However, resistance to *G. pallida* is more complex, often involves multiple genes and quantitative trait loci (QTLs) (Gartner 2023). Genetic sources of resistance to this pest exist among various wild and cultivated potatoes (de Jong *et al.* 2001). Both *G. rostochiensis* and *G. pallida* are recognized as quarantine pests, and their management involves strict regulatory measures and concerted research efforts to develop resistant potato cultivars. Breeding for resistance to PCN is a critical component of integrated pest management strategies (Dandurand *et al.* 2019).

The genetic resources or germplasm are crucial for breeding programs aimed at producing nematode-resistant potato varieties, thereby improving crop resilience and productivity (Bradshaw and Ramsay 2005). Host resistance remains a crucial strategy for managing *Globodera* spp. The

*H1* gene provides complete resistance to *G. rostochiensis* pathotypes *Ro1* and *Ro4* and has been successfully introgressed into many commercial cultivars. The first commercial potato cultivar resistant to *G. rostochiensis*, Maris Piper, was registered in 1967. However, with the identification of *G. pallida* as a second PCN species in 1973, subsequent efforts have focused on finding resistance to this species as well (Castelli *et al.* 2003). However, resistance to *G. pallida* is less developed, being polygenic and involves multiple genes that act additively to confer higher resistance levels (Whitworth *et al.* 2018).

Therefore, this study aims to screen diverse potato germplasm and parental lines for resistance to *G. pallida* and *G. rostochiensis*. The goal is to identify new resistant sources to both the species of PCN for the development of new resistant cultivars suitable for the Indian market.

## MATERIAL AND METHODS

In the present investigation, a total of 406 diverse germplasm accessions (Table 1) were tested for resistance to potato cyst nematodes (PCN) using the root ball technique in pots under glasshouse conditions at Kufri. These accessions consisted of germplasm imported from different countries, released Indian varieties, exotic varieties, andigena accessions and advanced breeding clones. The material included in the study is conserved in the National Active Germplasm Repository at CPRI, Shimla and part of the material in field genebank at Jalandhar and Kufri. Potato cyst nematode susceptible varieties i.e. Kufri Jyoti, Kufri Girdhari, Kufri Himalini were used as susceptible checks during all the years. Five tubers from each accession were planted in 15cm diameter earthen pots, with temperature maintained at 20-22°C. The experiment was conducted in three replications over four years (2020-21, 2021-22, 2022-23 & 2023-24).

Table 1. Cultivars and germplasm accessions used for screening

S. No.	Accession Name	S. No.	Accession Name	S. No.	Accession Name	S. No.	Accession Name	S. No.	Accession Name	S. No.	Accession Name	S. No.	Accession Name
1	CP658	60	JEXA215	119	CP2010	178	CP3903	237	CP1974	296	CP1431	355	CP3636
2	Kufri Luvkar	61	JEXA202	120	CP1932	179	CP4224	238	CP1971	297	CP1428	356	CP3247
3	CP1263	62	JEXA197	121	CP1824	180	CP4368	239	CP1926	298	CP1427	357	CP3203
4	CP1218	63	JEXA164	122	CP1571	181	CP4398	240	CP1922	299	CP1426	358	CP2089
5	CP1159	64	JEXA1152	123	CP1420	182	JEXA947	241	CP1889	300	CP1418	359	CP2280
6	CP1140	65	Kufri Anand	124	CP1038	183	JEXA920	242	CP1881	301	CP1414	360	CP2350
7	Kufri Swarna	66	JEXA1092	125	Kufri Sangam	184	JEXA865	243	CP1873	302	CP1411	361	CP2348
8	Kufri Surya	67	JEXA1046	126	JEX-A708	185	JEXA801	244	CP1871	303	CP1402	362	CP2346
9	Kufri Sindhuri	68	JEXA10	127	JEXA26	186	JEXA79	245	CP1869	304	CP1399	363	CP2339
10	Kufri Sadabahar	69	CP4316	128	JEXA918	187	JEXA705	246	CP1854	305	CP2049	364	CP2338
11	Kufri Pushkar	70	CP4311	129	CP1175	188	JEXA683	247	CP1846	306	CP2086	365	CP2336
12	Kufri Megha	71	CP4256	130	CP1242	189	JEXA597	248	CP1833	307	CP3939	366	CP2335
13	Kufri Khyati	72	CP4254	131	CP3896	190	JEXA506	249	CP1806	308	CP3412	367	CP2324
14	Kufri Ashoka	73	CP4242	132	CP3783	191	JEXA45	250	CP1800	309	CP3588	368	CP2292
15	Kufri Kanchan	74	CP4226	133	CP3585	192	JEXA296	251	CP1784	310	CP3587	369	CP2284
16	Kufri Jyoti	75	CP4214	134	CP3529	193	JEXA267	252	CP1771	311	CP3579	370	CP2235
17	Kufri Himalini	76	JEXA316	135	CP3261	194	JEXA22	253	CP1764	312	CP3575	371	CP3201
18	Kufri Girdhari	77	JEXA317	136	CP3182	195	JEXA198	254	CP1544	313	CP3506	372	CP2189
19	Kufri Gaurav	78	JEXA329	137	CP2639	196	JEXA19	255	CP1533	314	CP3505	373	CP2171
20	Kufri Frysona	79	JEXA379	138	CP2283	197	JEXA1081	256	CP2059	315	CP3502	374	CP2167
21	Kufri Chipsona3	80	JEXA93	139	CP2065	198	JEXA1016	257	CP1235	316	CP3486	375	CP2163
22	Kufri Chipsona1	81	JEXA912	140	CP2048	199	CP655	258	CP1367	317	CP3475	376	CP2148
23	Kufri Chandramukhi	82	JEXA907	141	CP1988	200	CP4596	259	CP1348	318	CP3442	377	CP2142
24	Kufri Bahar	83	JEXA877	142	CP1884	201	CP4594	260	CP1335	319	CP3387	378	CP2118
25	CP1326	84	JEXA827	143	CP1864	202	CP4433	261	CP1330	320	CP3222	379	CP2110
26	CP1347	85	JEXA804	144	CP1835	203	CP4179	262	CP1325	321	CP3363	380	CP2093
27	CP1480	86	JEXA763	145	CP1802	204	CP4096	263	CP1319	322	CP3352	381	CP2090
28	CP1564	87	JEXA707	146	CP1767	205	CP659	264	CP1304	323	CP3338	382	CP2354
29	CP2368	88	JEXA668	147	CP1667	206	CP1646	265	CP1302	324	CP3334	383	CP2370
30	CP2347	89	JEXA638	148	CP1662	207	CP1711	266	CP1291	325	CP3329	384	CP2381
31	CP2224	90	JEXA612	149	CP1559	208	CP1710	267	CP1246	326	CP3328	385	CP2385
32	CP2183	91	JEXA595	150	CP1486	209	CP1706	268	CP1225	327	CP3318	386	CP3192
33	CP2149	92	JEXA58	151	CP1442	210	CP1688	269	CP1529	328	CP3295	387	CP3180
34	CP2134	93	JEXA539	152	Kufri Karan	211	CP1687	270	CP1215	329	CP3290	388	CP3153
35	CP2071	94	JEXA513	153	Kufri Deva	212	CP1685	271	CP1202	330	CP3256	389	CP3145
36	CP2061	95	JEXA498	154	CP3183	213	CP1672	272	CP1187	331	CP3602	390	CP3142
37	CP2029	96	JEXA459	155	CP3679	214	CP1664	273	CP1177	332	CP3625	391	CP3124
38	CP1918	97	JEXA457	156	CP3901	215	CP1659	274	CP1157	333	CP3626	392	CP3116

S. No.	Accession Name	S. No.	Accession Name	S. No.	Accession Name	S. No.	Accession Name	S. No.	Accession Name	S. No.	Accession Name		
39	CP1868	98	JEXA42	157	CP3894	216	CP1653	275	CP1151	334	CP3634	393	CP3103
40	CP1829	99	JEXA390	158	CP3881	217	CP1642	276	CP1143	335	CP3917	394	CP3102
41	CP1827	100	JEXA380	159	CP3880	218	CP1538	277	CP1137	336	CP3898	395	CP3096
42	CP1747	101	CP2390	160	CP3853	219	CP1633	278	CP1120	337	CP3891	396	CP3091
43	CP1735	102	CP3098	161	CP3816	220	CP1616	279	CP1012	338	CP3871	397	CP3081
44	CP1700	103	CP4149	162	CP3796	221	CP1602	280	CP1368	339	CP3847	398	CP3079
45	CP1693	104	CP3173	163	CP3788	222	CP1597	281	CP1379	340	CP3809	399	CP3068
46	CP1689	105	CP4052	164	CP3763	223	CP1588	282	CP1390	341	CP3799	400	CP3036
47	CP1674	106	CP3893	165	CP3715	224	CP1584	283	CP1395	342	CP3797	401	CP2927
48	CP1673	107	CP3885	166	CP3652	225	CP1581	284	CP1491	343	CP3795	402	CP2418
49	CP1619	108	CP3738	167	JEXA99	226	CP1555	285	CP1479	344	CP3792	403	CP2413
50	Kufri Badshah	109	CP3632	168	CP3600	227	CP1553	286	CP1470	345	CP3768	404	CP2412
51	Kufri Arun	110	CP3491	169	CP3577	228	CP1545	287	CP1468	346	CP3761	405	CP2409
52	CP2397	111	CP3414	170	CP3549	229	CP1730	288	CP1462	347	CP3718	406	CP2399
53	JEXA15	112	CP3296	171	CP3527	230	CP1736	289	CP1454	348	CP3696		
54	JEXA30	113	CP3274	172	CP3525	231	CP1749	290	CP1453	349	CP3690		
55	JEXA299	114	CP3246	173	CP3439	232	CP1753	291	CP1450	350	CP3681		
56	JEXA298	115	CP3044	174	CP3362	233	CP2030	292	CP1447	351	CP3651		
57	JEXA288	116	Kufri Frysona	175	CP3343	234	CP1990	293	CP1440	352	CP3646		
58	JEXA275	117	CP2285	176	CP3211	235	CP1989	294	CP1435	353	CP3641		
59	JEXA232	118	CP2165	177	CP3189	236	CP1982	295	CP1433	354	CP3639		

In different years, the number of accessions varied due to availability of potato tubers.

The planting soil was mixed with FYM and inoculated with approximate 250-300 cysts (mixed population of *G. pallida* and *G. rostochiensis*) per 100 cc soil, which resulted in approximately 8,000-10,000 eggs and juveniles per test tuber. The volume of planting soil was 650 gm per pot. After 55-60 days, once females were visible on the root balls of the susceptible control plants, the number of females on the root balls of each accession were recorded. Figure 5 demonstrates the root ball of a potato plant, which shows varying resistance and susceptibility to *G. pallida* and *G. rostochiensis* across different accessions. The colour of the developing females was used to distinguish between the two *Globodera* species. *G. rostochiensis* females were distinguished

based on golden yellow colour and *G. pallida* females were characterized based on white/pale colour (Krishna Prasad, 2006). Based on the PCN population the accessions were grouped under 0-4 grade. Immune (0 female/root ball), highly resistant (1-5 females/root ball), resistant (6-20 females/root ball), susceptible (21-50 females/root ball), and highly susceptible accession (>50 females/root ball), following established guidelines (Krishna Prasad, 2006). The ideal resistance level is defined as grade 0-1 (Table 2)

## RESULT AND DISCUSSION

The study assessed the resistance of various potato accessions to *G. rostochiensis* (GR) and *G. pallida* (GP) by counting the number of female cysts per plant from the root ball and subsequently converting these counts into a

**Table 2. Grading Scale for Potato Cyst Nematode (PCN) Resistance**

Grade	Females/root ball	Category
0	None	Immune
1	1-5	Highly Resistant
2	6-20	Moderately Resistant
3	21-50	Susceptible
4	>50	Highly susceptible

0 to 4 grading scale, categorizing them from immune to highly susceptible. The screening results have been presented year wise, with a detailed explanation of the findings.

**Screening Outcomes for the year 2020-21**

The study evaluated the resistance of 275 potato accessions to both PCN species during the year 2020-21 (Table 3). For GR, 21 accessions were immune (Grade 0), 19 were highly resistant (HR, Grade 1), 32 were moderately resistant (MR, Grade 2), 70 were susceptible (S, Grade 3), and 133 were highly susceptible (HS, Grade 4) (Fig 2). For GP, 16 accessions were immune (Grade 0), 8 were highly resistant (HR, Grade 1), 42 were moderately resistant (MR, Grade 2), 83 were

susceptible (S, Grade 3), and 126 were highly susceptible (HS, Grade 4) (Fig 1). Among the 275 accessions evaluated, 148 accessions exhibited common resistance behaviour (same grade response) against both PCN species. Of these, 14 were immune, 2 highly resistant (CP1137 and CP1800), 12 moderately resistant, 33 susceptible and 87 highly susceptible to both species.

**Screening Outcomes for the year 2021-22**

In the current year, 269 potato accessions were systematically evaluated for their response to both the species of PCN (Table 3). For GR, 23 accessions were immune, 14 were HR, 25 were MR, 67 were susceptible and 140 were highly susceptible (Fig 2). For GP, 15 accessions were immune, 14 were highly resistant, 24 were moderately resistant, 71 were susceptible, and 145 were highly susceptible (Fig 1). Among the 269 accessions evaluated during 2021-22, 204 accessions exhibited common resistance behaviour against both PCN species. Of these, 14 were immune, 6 highly resistant (CP1012, CP1581, CP1689, CP1706, JEXA15 and JEXA865), 8 moderately resistant, 46

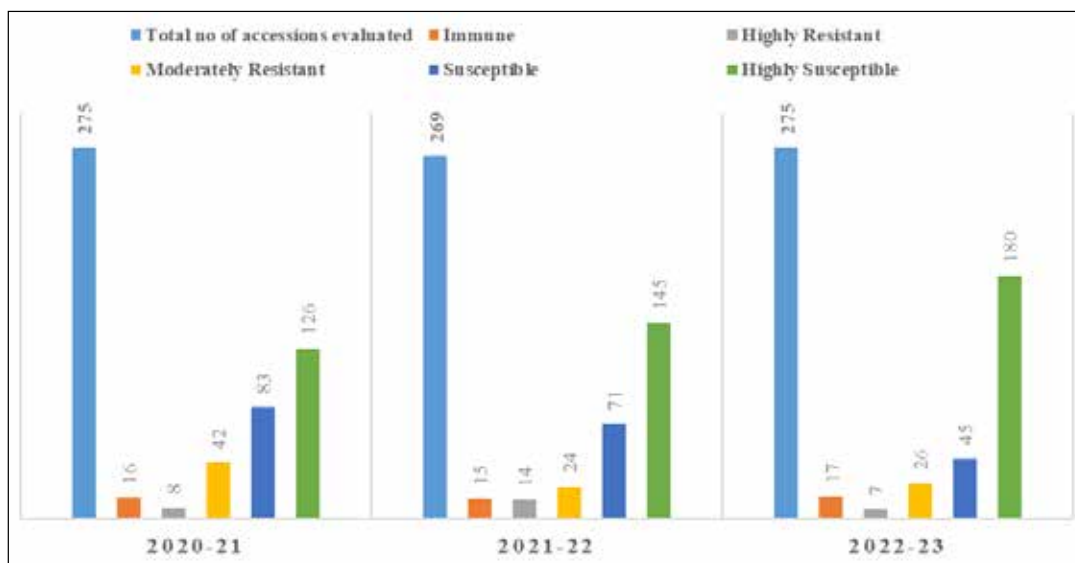


Fig. 1. Summary of potato accession evaluated for *Globodera pallida*

Table 3. Summary and result of potato accession evaluated for *G. pallida* and *G. rostochiensis*

S. No.	Year	Total no of accessions evaluated	<i>Globodera pallida</i>					<i>Globodera rostochiensis</i>				
			Immune	HR	MR	S	HS	Immune	HR	MR	S	HS
1.	2020-21	275	16	8	42	83	126	21	19	32	70	133
2.	2021-22	269	15	14	24	71	145	23	14	25	67	140
3.	2022-23	275	17	7	26	45	180	20	6	17	49	183
4.	Common accessions (over 2020-21 to 2022-23)	125	3	5	12	45	60	3	6	13	39	64
5.	2023-24	10	2	2	3	3	0	2	2	3	3	0

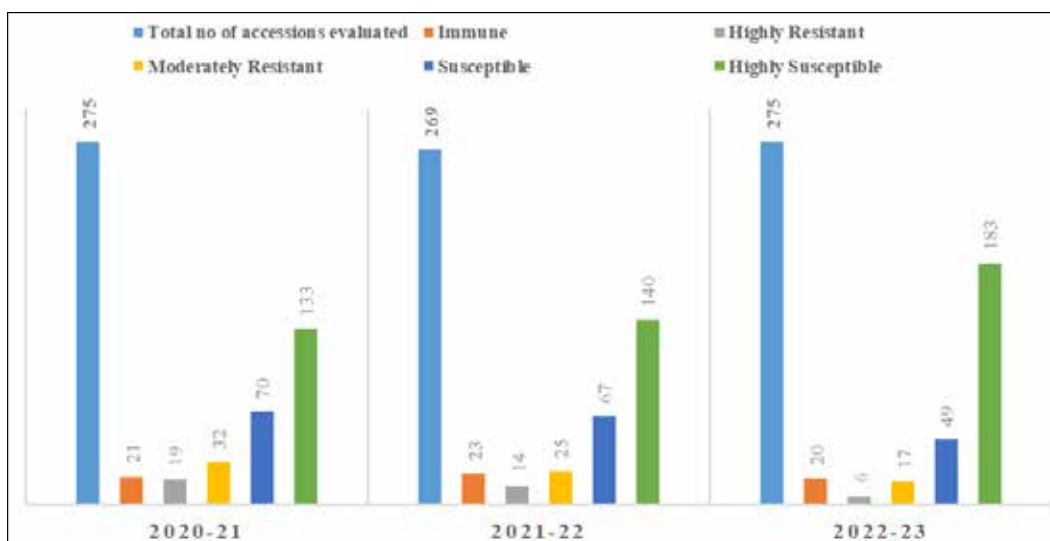


Fig. 2. Summary of potato accession evaluated for *Globodera rostochiensis*

susceptible and 130 highly susceptible to both PCN species.

### Screening Outcomes for the year 2022-23

In this year, 275 potato accessions were evaluated for their response to both species of PCN (Table 3). For GR, 20 accessions were immune, 6 were highly resistant, 17 were moderately resistant, 49 were susceptible, and 183 were highly susceptible (Fig 2). For GP, 17 accessions were immune, 7 were highly resistant, 26 were moderately resistant, 45 were susceptible, and 180 were highly susceptible (Fig 1). Among the 275 accessions evaluated, 227 accessions exhibited common resistance behaviour against both PCN species. Of these, 15 were immune, 1 highly

resistant (CP3939), 9 moderately resistant, 32 susceptible and 170 highly susceptible to both *G. rostochiensis* and *G. pallida*.

Overall, Figure 1 and Figure 2 showed the total number of accessions evaluated in the particular year and their reaction to for *G. pallida* and *G. rostochiensis*, respectively.

### Cumulative Assessment Over Three Years (2020-21 to 2022-23)

The study systematically evaluated the response of 275 potato accessions in 2020-21, 269 in 2021-22, and 275 in 2022-23 to GR and GP at Kufri using root ball techniques, with 125 accessions (Table 4) being consistently assessed across all the three years. For *G. rostochiensis* (GR), three accessions (CP1736,

**Table 4. Reaction of 125 common accessions (2020-21 to 2022-23) for *Globodera pallida* and *G. rostochiensis* (0-4 scale)**

S. No.	Accession Name	Grade (G. <i>pallida</i> )	Grade (G. <i>rostochiensis</i> )	S. No.	Accession Name	Grade (G. <i>pallida</i> )	Grade (G. <i>rostochiensis</i> )	S. No.	Accession Name	Grade (G. <i>pallida</i> )	Grade (G. <i>rostochiensis</i> )
1	CP658	3.67	3.67	43	CP1753	4.00	3.67	85	CP3636	3.67	3.33
2	CP659	3.67	3.33	44	CP1764	3.33	3.33	86	CP3641	1.00	1.33
3	CP1012	2.33	2.00	45	CP1784	2.67	3.67	87	CP3651	4.00	3.67
4	CP1143	3.00	4.00	46	CP1806	4.00	4.00	88	CP3681	3.00	3.33
5	CP1157	3.67	3.67	47	CP1869	2.67	3.00	89	CP3718	2.67	2.33
6	CP1187	3.67	3.67	48	CP1871	4.00	3.67	90	CP3761	2.33	2.33
7	CP1246	3.33	2.67	49	CP1889	3.00	3.67	91	CP3768	3.67	4.00
8	CP1291	3.33	3.33	50	CP1922	3.00	3.33	92	CP3797	3.00	2.67
9	CP1302	3.33	4.00	51	CP1971	3.33	3.67	93	CP3799	1.33	1.33
10	CP1304	3.33	3.33	52	CP1974	3.33	2.00	94	CP3809	1.67	1.33
11	CP1319	2.67	1.33	53	CP1982	3.00	3.67	95	CP3891	1.33	2.33
12	CP1325	3.00	3.67	54	CP1989	3.67	4.00	96	CP4149	3.67	4.00
13	CP1330	2.33	2.67	55	CP2086	4.00	4.00	97	CP4179	3.33	3.00
14	CP1335	3.33	3.67	56	CP2089	3.00	3.00	98	CP4254	3.33	3.67
15	CP1348	4.00	4.00	57	CP2090	4.00	4.00	99	CP4316	3.33	4.00
16	CP1367	4.00	4.00	58	CP2110	3.00	2.67	100	JEXA10	4.00	4.00
17	CP1379	3.33	4.00	59	CP2118	4.00	3.67	101	JEXA1152	4.00	3.00
18	CP1399	2.33	3.00	60	CP2142	3.67	3.67	102	JEXA15	0.33	0.33
19	CP1411	3.33	4.00	61	CP2171	2.67	3.33	103	JEXA197	3.00	3.00
20	CP1414	4.00	4.00	62	CP2189	3.67	4.00	104	JEXA202	4.00	4.00
21	CP1427	4.00	4.00	63	CP2335	3.33	2.67	105	JEXA215	3.33	3.33
22	CP1433	2.67	3.67	64	CP2338	2.00	2.67	106	JEXA275	4.00	3.67
23	CP1450	3.33	2.67	65	CP2346	3.33	3.67	107	JEXA298	3.33	3.33
24	CP1454	3.00	2.67	66	CP2348	3.33	3.33	108	JEXA30	4.00	4.00
25	CP1470	3.33	3.33	67	CP2370	4.00	3.00	109	JEXA316	3.67	3.67
26	CP1479	4.00	4.00	68	CP2418	0.00	0.00	110	JEXA317	1.00	0.67
27	CP1529	4.00	4.00	69	CP3036	2.00	2.00	111	JEXA457	3.67	4.00
28	CP1533	2.00	2.33	70	CP3096	2.67	1.67	112	JEXA459	4.00	4.00
29	CP1538	2.67	2.67	71	CP3103	3.33	3.00	113	JEXA668	3.67	3.33
30	CP1597	3.00	4.00	72	CP3116	3.67	3.67	114	JEXA707	3.67	3.33
31	CP1616	4.00	4.00	73	CP3145	3.67	2.67	115	Kufri Anand	4.00	4.00
32	CP1642	4.00	4.00	74	CP3153	4.00	3.67	116	Kufri Arun	4.00	4.00
33	CP1653	3.00	3.33	75	CP3180	3.67	3.67	117	Kufri Ashoka	3.00	3.00
34	CP1664	1.67	2.33	76	CP3201	3.33	2.33	118	Kufri Chandramukhi	3.67	3.67
35	CP1672	4.00	4.00	77	CP3222	2.33	2.00	119	Kufri Chipsona3	3.33	3.33
36	CP1685	3.67	4.00	78	CP3318	3.67	3.00	120	Kufri Girdhari	4.00	4.00
37	CP1687	1.00	1.00	79	CP3334	4.00	3.67	121	Kufri Kanchan	4.00	4.00
38	CP1688	3.67	4.00	80	CP3486	4.00	4.00	122	Kufri Khyati	4.00	4.00
39	CP1706	2.33	2.33	81	CP3505	3.67	3.33	123	Kufri Megha	3.67	3.67
40	CP1730	3.67	3.33	82	CP3575	4.00	3.33	124	Kufri Pushkar	3.67	3.67
41	CP1736	0.00	0.00	83	CP3588	3.67	3.67	125	Kufri Sindhuri	4.00	3.67
42	CP1749	4.00	4.00	84	CP3634	2.00	2.33				

\*Grade values represent the mean of three years (2020-21 to 2022-23) based on the 0-4 resistance scale described in Table 4.

CP2418 and JEXA/15) were immune, six were highly resistant (CP1687, CP1319, CP3641, CP3799, CP3809 and CP3096), 13 were moderately resistant, 39 were susceptible, and 64 accessions were highly susceptible. For *G. pallida* (GP), three accessions were immune (CP1736, CP2418 and JEX-A15), five highly resistant (CP1687, CP3641, JEXA-317, CP3799 and CP3891), twelve moderately resistant, 45 accessions susceptible, and 60 accessions were highly susceptible.

### Validation of promising accessions in the year 2023-24

Promising accessions (CP1012, CP1319, CP2418, CP1687, CP1736, CP3809, CP3641, CP3799, CP3222, and JEX/A-15) identified based on their resistance across three years were reevaluated for their resistance to both the PCN species in the year 2023-24. The accessions demonstrated varying levels of resistance, with some exhibiting high resistance and others showing moderate resistance or susceptibility. Specifically, the majority of the accessions maintained their resistance across the years, with a few showing slight variations. For example, certain accessions had consistently low cyst counts, indicating a high level of resistance,

while others displayed moderate cyst counts, categorizing them as moderately resistant. The mean cyst count per plant over the four years (2020-21 to 2023-24) was calculated, and the accessions were graded based on the predefined scale.

Among the evaluated accessions, two accessions (CP1736 and CP2418) demonstrated an immune response (Grade 0) to both *G. pallida* and *G. rostochiensis* (Table 5, 6 and Fig. 6). These accessions had consistently zero cyst counts across all evaluation years (2020-21 to 2023-24), which indicate their complete resistance to both nematode species. Additionally, two accessions, CP3641 and JEX/A-15, exhibited high resistance (Grade 1) to both species, with cyst counts ranging from 1 to 5. This consistent performance across multiple years and against both nematode species suggests that these accessions possess strong genetic resistance, making them valuable resources for breeding programs aimed at developing potato varieties with enhanced resistance to PCN species.

The heatmap illustrates the resistance of ten promising potato accessions to *both* PCN species from 2020-21 to 2023-24, using

**Table 5. Phenotypic data of ten promising accessions for *Globodera pallida***

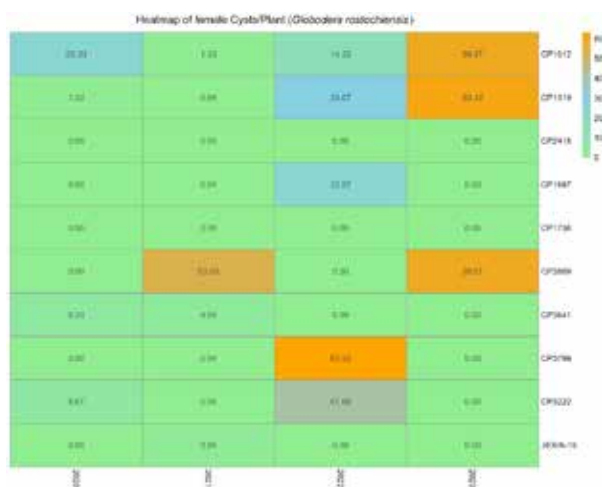
Accession Name	Female cyst/plant ( <i>Globodera pallida</i> )					Grade	Reaction
	2020-21	2021-22	2022-23	2023-24	Mean		
CP1012	41.67	0.33	7.33	59.33	27.17	3	S
CP1319	18.67	9.33	33.00	53.00	28.50	3	S
CP2418	0.00	0.00	0.00	0.00	0.00	0	Immune
CP1687	0.00	0.00	20.33	0.00	5.08	2	MR
CP1736	0.00	0.00	0.00	0.00	0.00	0	Immune
CP3809	0.00	59.00	0.67	64.33	31.00	3	S
CP3641	4.67	0.33	0.00	0.00	1.25	1	HR
CP3799	0.00	0.00	66.67	0.00	16.67	2	MR
CP3222	42.33	0.00	47.67	0.00	22.50	2	MR
JEX/A-15	0.00	1.67	0.00	0.00	0.42	1	HR

**Table 6. Phenotypic data of ten promising accessions for *Globodera rostochiensis***

Accession Name	Female cyst/plant ( <i>Globodera rostochiensis</i> )				Mean	Grade	Reaction
	2020-21	2021-22	2022-23	2023-24			
CP1012	23.33	1.33	14.33	58.67	24.42	3	S
CP1319	1.33	0.00	28.67	60.33	22.58	3	S
CP2418	0.00	0.00	0.00	0.00	0.00	0	Immune
CP1687	0.00	0.00	22.67	0.00	5.67	2	MR
CP1736	0.00	0.00	0.00	0.00	0.00	0	Immune
CP3809	0.00	53.00	0.00	58.67	27.92	3	S
CP3641	6.33	4.00	0.00	0.00	2.58	1	HR
CP3799	0.00	0.00	63.33	0.00	15.83	2	MR
CP3222	6.67	0.00	41.00	0.00	11.92	2	MR
JEX/A-15	0.00	3.00	0.00	0.00	0.75	1	HR

a gradient from light green (high resistance) to orange (low resistance). Accessions CP2418, JEX/A-15 and CP1736 consistently exhibit high resistance with zero cyst counts across all years for golden nematode (Fig 3). In contrast, accessions like CP1012 and CP1319 show low resistance in specific years, indicated by higher cyst counts, particularly in 2023 (58.67 and 60.33). Other accessions such as CP3809 and CP3799 display variable resistance, suggesting possible environmental or genetic influences.

For *G. pallida* accessions CP2418 and CP1736 consistently exhibited high resistance with zero cyst counts across the years (Fig 4). Accessions like CP1012 and CP1319 show low resistance in certain years, indicated by higher cyst counts, especially in 2023. Accessions CP3809 and CP3799 demonstrate variable resistance, with high cyst counts in some years, suggesting potential environmental or genetic influences. This heatmap highlights accessions such as CP1736 and CP2418 as strong candidates for breeding



**Fig. 3. Heatmap of Female Cysts per Plant Across Years (2020-21 to 2023-24) for Potato Accessions Evaluated against *Globodera rostochiensis***



**Fig. 4. Heatmap of Female Cysts per Plant Across Years (2020-21 to 2023-24) for Potato Accessions Evaluated against *Globodera pallida***

programs aiming to enhance resistance to *G. pallida*.

Overall, three accessions, CP2418, JEX/A-15 and CP1736 exhibited highly resistant reaction to both PCN species during four years (2020-21 to 2023-24) and are strong candidates for use in resistance breeding.

## DISCUSSION

Breeding potatoes for resistance to PCN, specifically *G. rostochiensis* and *G. pallida*, require long term sustainable strategy through the identification and introgression of resistant genes (Mangal *et al.* 2025). Incorporating resistance genes from resistant germplasm sources into commercial potato varieties can significantly reduce the impact of nematode infestations, leading to improved yields and reduced reliance on chemical nematicides. By continuously improving and expanding the genetic diversity of resistance germplasm, breeders can create potato varieties that are better equipped to withstand the evolving threats posed by these persistent pests. Therefore, in the present study a diverse set of potato accessions were evaluated to both the species of PCN. The findings from our study align with previous studies on resistance to both the PCN species. Bachmann-Pfabe *et al.* (2019) screened 749 wild potato accessions and identified 78

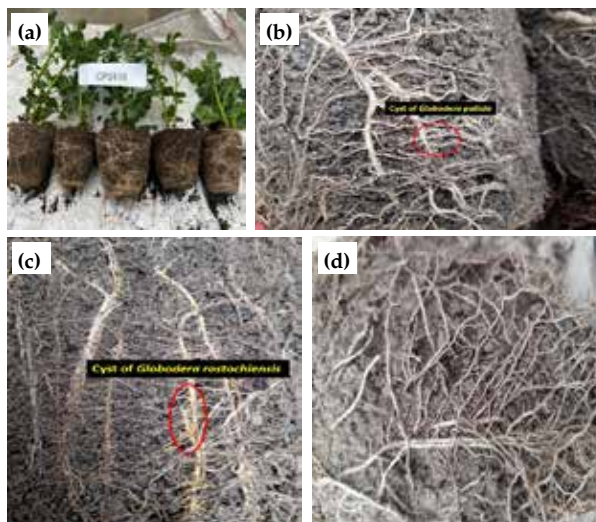


Fig. 5. (a) Root ball of potato plant (b) *Globodera pallida* susceptible accession (c) *Globodera rostochiensis* susceptible accession (d) Resistant accession to both PCN species

accessions resistant to *G. pallida* (Pa2/3), with fewer than five cysts per plant. Our results further corroborate the importance of dual-resistant accessions, as highlighted by Brodie *et al.* (1991) in North American breeding programme and Castelli *et al.* (2003) at Commonwealth Potato Collection (CPC), who emphasized the value of accessions that resist both *G. pallida* and *G. rostochiensis*. The dual-resistant accessions identified in our study are particularly promising, offering potential for developing potato cultivars with broad-spectrum resistance, which is



Fig. 6. Comparative root response of potato accessions CP2418 (a), CP1736 (b) and Kufri Jyoti (c) under both PCN species infestation which shows absence of cysts in CP2418 and CP1736 and high cyst density in Kufri Jyoti.

essential for effective pest management in regions affected by both nematode species. The study conducted by Dalamu *et al.* (2017) supports current investigation on the grouping of potato genotypes based on their resistance profiles. In their work, they identified genotypes such as CP 1843, CP 1879, and JEX/A 267 that demonstrated combined resistance to both species of potato cyst nematode (PCN). Similarly, this study has identified accessions that exhibit strong potential as candidates for breeding programs aimed at pyramiding resistance genes to improve resistance against PCN. These findings are crucial for developing more resilient potato varieties. The resistance patterns observed in our study also resonate with the findings of Faggian *et al.*, (2012), who screened 302 potato cultivars for resistance to *G. rostochiensis* (*Ro1*) and identified a range of resistant, susceptible, and very susceptible cultivars.

Environmental factors may influence resistance expression, as suggested by the varying resistance levels observed in this study across different years. This observation aligns with the work of Silvestre *et al.* (2021), who highlighted the impact of genetic diversity and environmental conditions on PCN resistance. Accessions such as CP2418 and CP1736, which exhibited consistent resistance across multiple years, support the findings of Gartner (2023) and Gavrilenko *et al.* (2021), who also identified genotypes with stable resistance to PCNs. The resistant germplasm identified in this study will be utilized in the development of PCN resistant varieties suitable for regions affected by nematode infestations. The distribution of resistance and susceptibility in present investigation is consistent with the findings of Limantseva *et al.* (2014) and Mangal *et al.* (2023), who reported that while many accessions exhibited resistance to *G. rostochiensis* and *G. pallida*, a

significant proportion remained susceptible. This highlights the necessity of continuous screening and the strategic use of resistant accessions in breeding programs.

Finally, the present study identified new sources of resistance (CP2418, CP1736, CP3641, and JEX/A-15) to both *G. pallida* and *G. rostochiensis*. The resistant accessions identified, particularly with combined resistance to both the species, are valuable for future breeding programs aimed at enhancing potato cultivars' resistance to PCNs, thereby improving potato production and sustainability.

## CONCLUSION

This study systematically evaluated the response of various potato accessions to *G. rostochiensis* and *G. pallida* over multiple years, and identified accessions with varying levels of resistance. Accessions such as CP2418, CP1736, CP3641, and JEX/A-15, which exhibited either immunity or high resistance across the study period, are particularly valuable for breeding programs aimed at the development of potato cultivars with broad-spectrum resistance to PCNs. Accessions such as CP1687, CP3641, CP3799 and JEXA/317 exhibited high resistance (HR, Grade 1) to both *G. rostochiensis* and *G. pallida*. Most of the released varieties (Kufri Anand, Kufri Arun, Kufri Ashoka, Kufri Chandramukhi, Kufri Girdhari, Kufri Kanchan, Kufri Khyati, Kufri Megha, Kufri Pushkar and Kufri Sindhuri) exhibited highly susceptible reaction to both PCN species in the present investigation. Therefore, the identified new sources of resistance can be used for breeding new potato varieties with enhanced resistance to PCN. Overall, the study also highlights the importance of continuous screening and utilization of resistant germplasm in breeding programs. These efforts are essential for the improvement of resilience of potato

against PCNs and sustainable agricultural practices.

## ACKNOWLEDGEMENT

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## 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

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# LAND CHARACTERISTICS AND IMPLEMENTATION OF CONSERVATION AGRICULTURE TO SUPPORT DIVERSITY AND SUSTAINABILITY OF BROMO TENGGER TOURISM

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**ABSTRACT:** Ngadisari Village is located in Bromo Tengger Semeru National Park, Mount Bromo, and has strong natural tourism potential. However, its agricultural practices do not yet follow conservation principles or fully support agro-tourism development. This study has been completed to evaluate the implementation of conservation agriculture in the cultivation of main crops (potatoes, onions, and cabbage) according to conservation agriculture principles. The study was conducted in Ngadisari Village, Sukapura District, Probolinggo, East Java, Indonesia from 2022 to 2023. Located at 1,950 m above sea level, the area has high rainfall (3,577 mm/year), cool temperatures (10–20°C), sloped land, and light-textured soil. Results show that most of the land in Ngadisari is used for agricultural practices that do not fully align with conservation agriculture principles. However, terracing has been implemented, reinforced by annual plants like pine or elephant grass, which has helped reduce soil slope. Land preparation is intensively conducted to a depth of over 30 cm. Most farming is rainfed, leaving fields bare during the dry season. Mixed cropping or two-crop intercropping is more common than monoculture, with potatoes, onions, and cabbage as the most dominant crops.

**KEYWORDS:** Intercropping, Sustainability, Soil Conservation, Terracing

## INTRODUCTION

Conservation agriculture practices refer to efforts aimed at protecting natural resources and promoting environmental sustainability across agricultural landscapes. It focuses on improving soil health, water quality, and biodiversity while ensuring productive and, of course, profitable farming operations. The focused aspects are minimizing soil disturbance through no-till farming, which helps prevent erosion, increases water infiltration, and improves soil health (Busari *et al.*, 2015; Pittelkow *et al.*, 2014).

Conservation agriculture practices play a crucial role in enhancing welfare of farming communities. These practices have been shown to boost crop production by lowering production costs (both inputs and labor), improving and preserving soil fertility (by maintaining plant nutrients, organic matter, and abundant soil microorganisms, as well as a loose soil structure), increasing soil's water retention capacity, and preventing soil erosion and land degradation (McConnell and Burger, 2011; Capmourteres *et al.*, 2018; Burney *et al.*, 2010). Agricultural conservation practices are also key to dealing with climate

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change, both by reducing its causes and by helping farms cope with its impacts. base on mitigation side, they help sequester carbon and lower emissions and energy use. When it comes to adaptation, they lead to better water efficiency and greater crop diversity, which makes farms less vulnerable to changing conditions (Jug *et al.*, 2018; Manale *et al.*, 2016; Su *et al.*, 2021;). In 2018/2019, total area of agricultural land implementing conservation agriculture was 205.4 million ha, equivalent to 14.7% of the global agricultural land area and the distribution of conservation agriculture covers Asia, Africa, and Europe (Kassam, *et al.* 2022).

To make conservation agriculture a success, we need to develop simple and effective practices that help farmers sustain their land while also improving their daily lives. For communities in sensitive areas like the Bromo Tengger Semeru mountains, this approach should ultimately lead to greater food security, better nutrition, and stronger incomes. The nature of Bromo Tengger Semeru mountains is very famous for its natural tourism and in 1982 it was designated as Bromo Tengger Semeru National Park of Indonesia with an area of 50,276.3 ha. This is main destination for tourists when visiting East Java. Rising dramatically from the sea of sand in Tengger Caldera, Mount Bromo is one of Indonesia's most captivating active volcanoes. Standing at 2,329 meters above sea level, its smoldering cone offers visitors a breathtaking glimpse into raw power of nature (Zaennudin, 2011). With a population of 1,461 people in 2023, approximately 76.25% of population have their main job as farmers, and around 2.53% work as farm laborers. Some people other than farmers also work as guides or provide tourism services. The agricultural lands are hilly and mountainous (Ngadisari, 2023).

A preliminary survey revealed that while conservation agriculture practices do exist in Ngadisari Village, they haven't yet been fully adopted. Farmers continue to cultivate land intensively, which raises questions about long-term sustainability. This study therefore aims to evaluate how well conservation agriculture principles are being applied to village's main crops potatoes, onions, and cabbage and whether these practices align with the actual suitability of the land.

## MATERIALS AND METHODS

### Location and Time of research

The research was carried out in Ngadisari Village, part of Sukapura Sub-district in Probolinggo District, East Java, Indonesia (Fig. 1). Covering approximately 1,047.32 hectares, the village is made up of three smaller sub-villages (Wanasari, Ngadisari, and Cemara Lawang). Geographically, research is located at coordinates 112°57'0"E - 112°58'30"E and 7°54'0"S - 7°55'30"S (Fig. 2).

Historically, Ngadisari Village was originally a pine forest located in a highland zone at an altitude of around 1,800 meters above sea level, with an average daily temperature ranging from 10 to 20°C. The research was conducted from September 2023 to 2024. Data analysis was carried out at the



Fig. 1. Research location in agricultural landscapes in three sub-villages (Wanasari, Ngadisari, and Cemara Lawang).

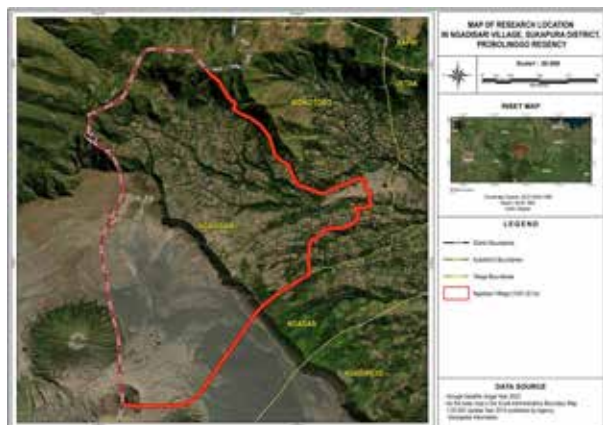


Fig. 2. Research location around the natural tourism of Mount Bromo and the sea of sand as well as some agricultural practices.

Chemistry and Fertility Laboratory of Jember University.

This study was based on three core principles of conservation agriculture: 1) limited soil disturbance (through no-tillage, minimum tillage, or row/ hole planting to reduce erosion), 2) permanent soil cover (using both living and dead mulch), and 3) crop diversification (via crop rotation and intercropping). To assess these principles, map materials were obtained from the Geospatial Information Agency of Indonesia (BIG), and direct field surveys (Table 1) were conducted on agricultural land and with local residents and farmers.



Table 1. Land Quality and Characteristic Parameters

Symbol	Land Quality	Land Characteristics
Tc	Temperature	Average Annual Temperature (°C)
Wa	Water availability	Rainfall (mm) Length of Dry Period (bulan)
Oa	Oxygen availability	Soil Drainage
Rc	Rooting medium	Soil Texture Effective Soil Depth (cm)
Nr	Nutrient	pH (H <sub>2</sub> O) C-Organic (%) N-Total (%)
Xc	Toxicity Hazard	Salinity (dS.m <sup>-1</sup> )
Eh	Erosion	Lereng (%) Erosion hazard
Fh	Flood Hazard	Flood
Lp	Land preparation	Rocks on the surface (%) Rock Outcrop (%)

Source: Djaenudin *et al.*, 2003

## RESULT AND DISCUSSION

### Land Characteristics

Based on the 1:25,000 scale administrative map (BIG) and the 1:50,000 scale soil type map (BBSDLP), soil type in Ngadisari Village is dominated by Typic Hapludands, covering approximately 65.5% of the area. The soil types of research areas are generally Andisols which have a histic epipedon (Soil Survey Staff. 2022). Other types of soil, inceptisol and entisol, distribution and complete area are presented in Figure 3. Land use in Ngadisari

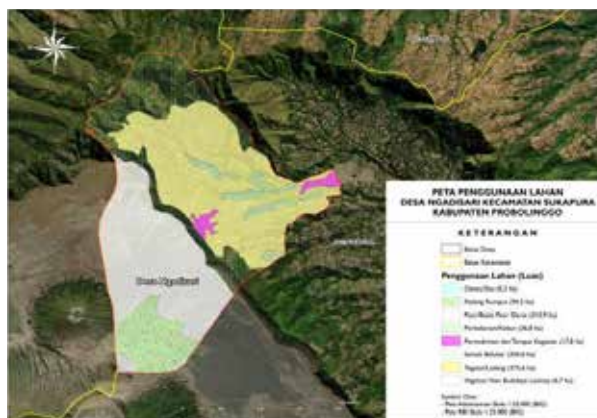


Fig. 3. Soil type and land use map of the research location in Ngadisari Village, Sukapura District, was obtained, covering the area around the Mount Bromo nature tourism site and the sea of sand

village, mostly for fields/dry fields, which is around 456 ha or 58.82% of the total area. Other land uses are bushes, grasslands, plantations, lakes, and settlements.

Agricultural lands in Ngadisari village have slopes with a gradient of more than 15% (slightly steep to steep) as much as 51.8% or 553.7 ha (Fig. 4) and light soil texture and relatively the same between locations, so that it has the potential for landslide hazards. Based on the landslide hazard map on a scale of 1:25,000 (Fig 4) shows that most of the lands in Ngadisari village have high potential (329.2 ha) and medium (204.5 ha) and the rest are low (199.5 ha) and none (314.1 ha). Land management

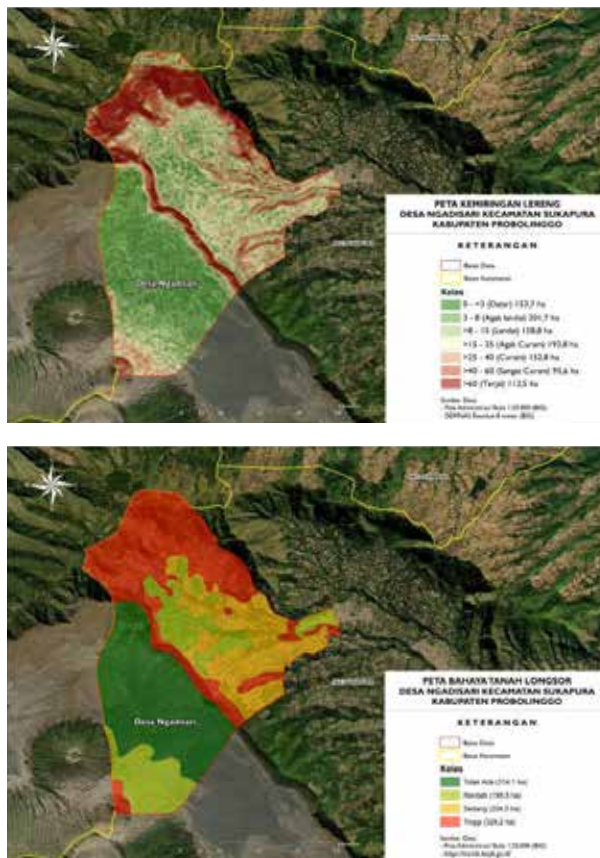


Fig. 4. Map of land slope gradient and landslide hazard at the research location in Ngadisari Village, Sukapura District, around the Mount Bromo nature tourism area and the sea of sand.

practices have transformed the steep terrain through terracing, which lessens the slope within planting areas. The resulting slope gradients range from 0% to 49.73%, and importantly, 60% of the land features slopes under 15% (Fig. 5).

Moreover, based on boxplot, most of the land has a slope of 13%, so that based on a survey of farmers and community in Ngadisari village, landslides have never occurred. In addition, the presence of perennial plants (*Casuarina equisetifolia* or casuarina) between the boundaries of land plots also strengthens land to prevent landslides.

The average land height in Ngadisari village is around 1950 meters above sea level (msl), average annual rainfall is 3577 mm, with an average daily temperature of around 10 – 20°C during the rainy season and 0 – 8°C during dry season. Water availability based on recorded data 2022 – 2023 and the basic data of the Ngadisari village monograph 2023, high rainfall of around 3577 mm, distributed throughout the year as presented in Figure 6.

Based on the picture, it shows that it rains throughout year with a dry period (RF below 60 mm) of only 2 months (August and September). Water conditions based on

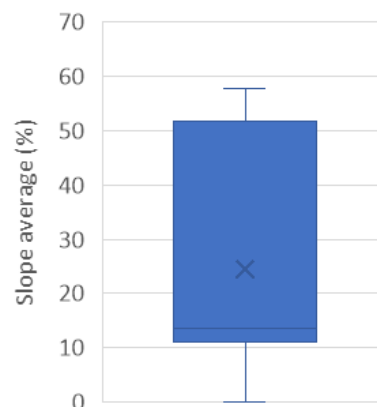


Fig. 5. Diversity of slopes of agricultural land that has been terraced and used for agriculture or vegetable cultivation.

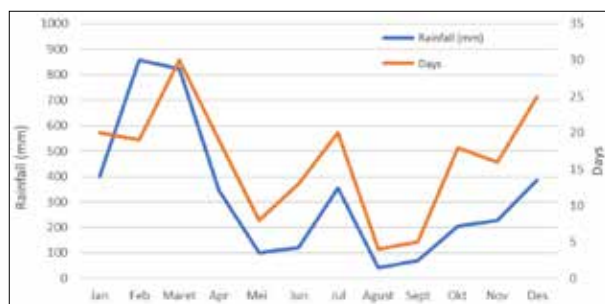


Fig. 6. Number of days and distribution of rainfall in Ngadisari village, Sukapura, Probolinggo in 2023

climate for agriculture are very important, an important factor causing low cropping index. Most of the cropping patterns in Ngadisari village are based on conditions or availability of rainwater during plant growth, so that some land has a cropping index (CI) of 2, it cannot be 3 because there is a time when the land is empty (not planted and open). The availability of oxygen or soil aeration is very good. In addition to light texture, intensive processing, water channels are also made. Most of the water flows as gravity water and also surface water through drainage channels.

The rooting medium is very favorable due to its light texture and intensive cultivation, although organic matter content is generally low to very low (average C-organic 0.99%). This condition contrasts sharply with findings from Nozari and Borůvka (2023) in the Czech Republic, who reported a positive relationship between slope steepness and organic matter content. In their study, soil organic matter ranged from 0.42% to 11.33%, with an average of 2.83%.

The effective soil depth is more than 1 meter. The acidity of the soil pH H<sub>2</sub>O varies between 7.22 to 8.74 with an average of around neutral 7.04 and for KCl pH varies between 6.39 to 7.24 with an average of 5.85. Complete data is presented in Figure 7. Based on Figure 7, salinity, C-organic content (organic matter), and N-total soil are

also explained. Soil salinity based on electrical conductivity (DHL) values, namely the ability of groundwater to carry electric current, cations (Ca<sup>2+</sup>, Mg<sup>2+</sup>, K<sup>+</sup>, Na<sup>+</sup>, and NH<sub>4</sub><sup>+</sup>) and

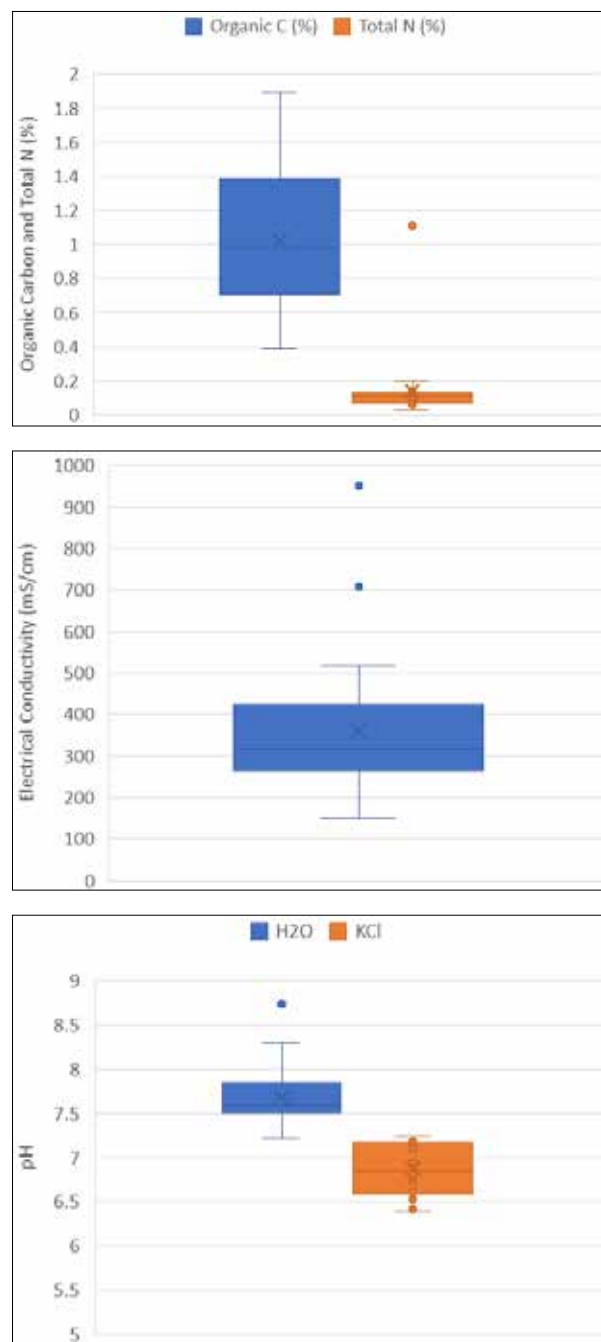


Fig. 7. Variation of Acidity (pH H<sub>2</sub>O and KCl), Electrical Conductivity (EC), C-organic, and N-Total soil in agricultural lands of Ngadisari village, Sukapura, Probolinggo in 2023.

anions ( $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$ ,  $\text{NO}_3^-$ , and  $\text{HCO}_3^-$ ) from dissolved salts in groundwater carry and conduct electric current, varying from not saline to quite saline 150 to 951  $\mu\text{S}/\text{cm}$  with an average of 359  $\mu\text{S}/\text{cm}$ . This average salinity value is based on the Soil Survey Staff salinity class, USDA, including very slightly saline. This DHL value is closely associated with the concentration of nitrogen (N) or nitrate, where an increase in concentration corresponds to a rise in the DHL value (Mirzakhani, *et al.* 2012.).

The perception of farmers and the community in Ngadisari Village is that the risk of erosion is low, despite the slope and potential erosion hazard maps indicating a high risk (Figure 8). The landslide hazard on agricultural land varies from low (199.5 ha), medium (204.5 ha), to high (329.2 ha). However, the implementation of terracing, reinforced with perennial plants such as casuarina trees or elephant grass, has significantly reduced the slope of the agricultural land to about 13% on average, thereby greatly diminishing the potential for landslides. This description is in accordance with the research results of Iskandar *et al.* (2023) on land with deep solum (>90 cm) with low erosion hazard levels. Likewise, based on the results of a survey of 30 farmers, they stated that there had never been a landslide, nor a flood. During land preparation, farmers never encountered surface rocks or rock outcrops, both recorded at 0%.

### Socio-Cultural and Economic Aspects in Supporting the Productivity and Sustainability of the Agricultural Biophysical Environment in Ngadisari

A study by Sejati *et al.* (2023) investigated how the traditional ceremonies of the Tengger tribe contribute to environmental conservation and support the Mount Bromo tourism area.

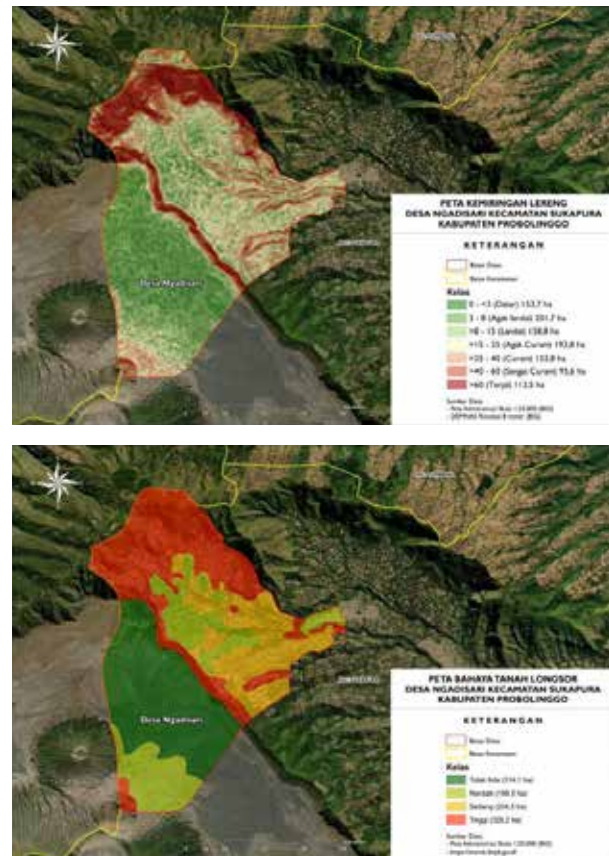


Fig. 8. Map of land slope gradients and landslide hazards Ngadisari Village

The Tengger tribe is a community deeply rooted in tradition and ancestral veneration, expressed through ceremonies like *Pujan Kasanga*, *Pujan Kasada*, and *Unan-Unan*. These rituals embody values of faith, environmental harmony, reverence for the land, and gratitude for its fertility. Beyond their spiritual significance, these ceremonies also serve as cultural attractions that showcase beautiful agricultural landscapes, promote awareness around reducing plastic waste, and demonstrate the harmonious relationship between people and nature. Central to Tengger belief is the principle that humans must live in balance with nature and should never exploit it carelessly.

In general, economy of Ngadisari community is shaped by a combination of

agriculture, tourism, and local trade, largely because the area lies close to Mount Bromo. The presence of this attraction has created economic opportunities in the tourism sector, including homestays, food stalls, and tour guide services. Most farmers in Ngadisari manage their own land, with farm sizes varying considerably ranging from 0.0014 to 3 hectares and an average of 0.99 hectares (Figure 9). In terms of productivity, they achieve average yields of 3.81 tons per hectare for potatoes, 2.45 tons per hectare for spring onions, and 9.1 tons per hectare for cabbage.

Previous research on the socio-economic aspects of the Tengger tribal community reveals that gender roles are generally balanced across various sectors, with no significant difference in the participation

of male and female farmers in planning, implementation, and evaluation. The key factors influencing this balance include the farmers' individual characteristics, ecological environmental support, and economic institutions. Conversely, factors such as the intensity of extension or empowerment programs and the strength of customary traditions were found to have no significant impact on farmer participation (Sudarko, *et al.* 2023).

### Implementation of conservative farming

With light textured land conditions and cool temperatures, Ngadisari farmers implement various vegetable farming. However, almost all farmers still rely on rainwater as their agricultural water source. The rainy season is full of water and humid, making agricultural lands more productive compared to the dry season which lacks water. This condition determines the planting pattern or type of plants or vegetables planted. Evaluation of the implementation of a conservative farming system is very important in supporting the productivity and sustainability of agricultural lands while increasing the attractiveness of Bromo nature tourism in Ngadisari. Conservation agriculture is a cultivation or agricultural practice that combines reduced or no tillage, permanent soil cover, and better crop rotation or diversification. This agricultural practice is also often promoted as a smart practice in climate change (Farooq, 2023) and also to adapt agricultural ecosystems to its impacts, by increasing plant resilience in the face of climate variation (Sanchez *et al.* 2020). However, the research results of Shumba, *et al.* (2023), stated that the impact of conservative agriculture and its three principles on aboveground and belowground soil organic carbon (SOC) stocks and on soil CO<sub>2</sub> emissions in low-input farming systems in sub-Saharan Africa is still limited.

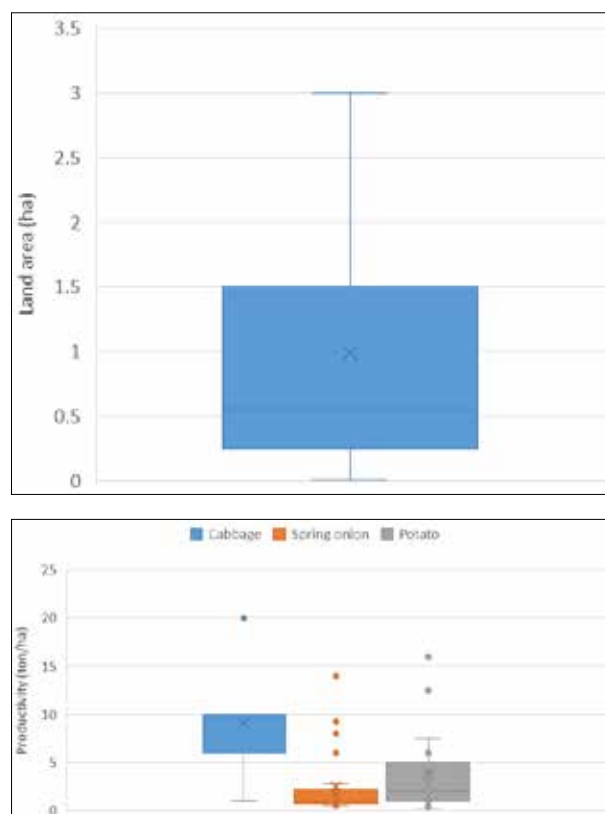


Fig. 9. Diversity of land area ownership cultivated by Ngadisari farmers and land productivity for potatoes, spring onions and cabbage.

The evaluation of the implementation of conservation agriculture in Ngadisari Village indicates that land preparation is carried out thoroughly before planting. Both manual and tractor-based tillage practices disturb the soil intensively, as shown in Figure 5 (post-tillage for planting) and Figure 1 (during crop growth). Most farmers use manual tools, such as hoes, while a smaller proportion utilize hand tractors. Manual tillage allows for deeper soil preparation (>30 cm) compared to tractors (<30 cm). Crop residues are entirely removed, and raised beds are constructed with heights ranging from 15–30 cm.

Many farmers have adopted conservation practices, creating furrows between beds that are perpendicular to the slope or follow contour lines. Intensive soil preparation is preferred by farmers as they believe yields will decline if this is not performed. During tillage, drainage channels are also maintained to prevent waterlogging during the rainy season. However, this practice reduces the soil's water retention capacity, leading to shortages during the dry season.

The land in Ngadisari Village has deep soil profiles, with an average depth exceeding 1 m, which supports agricultural productivity and sustainability. However, the soil organic carbon (SOC) content is very low, averaging 1%, with values ranging from 0.39% to 1.89% (Figure 7). While the soil typically has high organic matter potential, continuous erosion reduces the organic carbon content. These agricultural practices contribute to greenhouse gas (GHG) emissions, exacerbating global warming. The combination of intensive plowing, the use of agricultural chemicals, and the burning of crop residues are the primary agricultural activities contributing to greenhouse gas (GHG) emissions.

Soil tillage is also carried out during the dry season, which is a critical period for CO<sub>2</sub> emissions and water loss from the soil system. Long-term research by Mühlbachová *et al.* (2023) demonstrated that reducing tillage practices and adopting no-tillage with surface mulch decreased CO<sub>2</sub> emissions by an average of 45% and 51%, respectively, over six years. The average CO<sub>2</sub> emissions were 6.1, 3.1, and 2.9 mol CO<sub>2</sub> m<sup>-2</sup>s<sup>-1</sup> for conventional tillage (intensive), reduced tillage, and no-tillage with mulch, respectively. Similarly, Křištof *et al.* (2014) reported that increased tillage intensity leads to higher rates of CO<sub>2</sub> emissions released from the soil into the atmosphere.

Based on the explanation above, effective and continuous education for the community is necessary to achieve high levels of conservation agriculture implementation. This approach can serve as a valuable strategy not only for mitigating climate change but also for preventing and reducing soil erosion, improving soil quality and fertility, and ensuring better water accessibility for crops during the dry season. Establishing well-planned demonstration plots with active community involvement has great potential to yield more effective outcomes.

### **Implementation of permanent closure of agricultural land**

The agricultural lands in Ngadisari Village, Sukapura District, are highly diverse, but the majority rely on rainfed farming (over 95%). During dry season (starting around April and lasting until September, peaking in August and September), most of land is either left bare or the crops receive minimal care. Farmers make significant efforts to cultivate crops year-round but are constrained by water availability, especially from July to September, leading to idle or unproductive land.

The use of mulch, whether plant residues or plastic mulch, remains minimal, and the soil surface is not permanently covered. Typically, the land is bare during tillage, and after planting, the soil surface gradually becomes covered during the growth and production phases, varying from about 70% to nearly full coverage (95%) during the peak vegetative phase until harvest.

The condition of soil surface coverage in agricultural land management practices in Ngadisari Village, Sukapura District, is shown in Figure 1 (during the growth and maintenance phase) and Figure 10 (during the soil preparation phase for planting) above, as well as Figure 11 below. Figure 11 the cropping pattern during the dry season (June-July) in the village. It depicts farmland owned by a farmer nearing harvest, with well-maintained crops that receive irrigation water purchased to address the shortage caused by the absence of rain or insufficient rainfall.

The agricultural practices commonly employed by most farmers result in a depletion of soil nutrients through the use of both inorganic and organic fertilizers. Inorganic fertilizers, such as ZA, NPK (Phonska), and black TSP, still dominate compared to organic fertilizers. This trend contributes to the low average organic matter content in the soil (Figure 7). As a result, the total nitrogen (N) content in the soil is also



Fig. 10. Soil preparation practices before planting in Ngadisari Village



Fig. 11. Cropping patterns in the agricultural land management practices during the dry season in Ngadisari Village, Sukapura District.

low, despite the fact that nitrogen is a crucial nutrient for plants, especially vegetables. Based on this, most farmers apply high-nitrogen fertilizers, such as Phonska (6 tons/ha) and ZA (3 tons/ha).

The evaluation of the relationship between organic carbon (C) and total nitrogen (N-total) in agricultural land management practices in Ngadisari Village shows a very low correlation (Fig. 12), even though the N-total data reflects nitrogen in organic compounds. This is likely due to the main fertilizers being applied in inorganic forms (Phonska and ZA). In addition to the erosion mentioned earlier, which reduces soil organic matter, agricultural

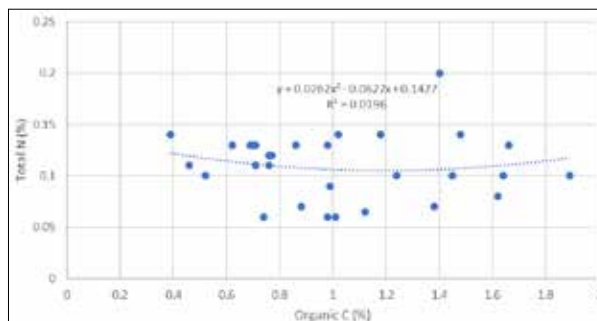


Fig. 12. The relationship between organic carbon (C-organic) and total nitrogen (N-total) in agricultural land management practices in Ngadisari Village

practices do not return crop residues to the soil, either as mulch or composted to create organic fertilizer.

Mulch, both organic and inorganic is an important technique used in crop production to increase yields. It has been proven that mulch regulates soil temperature, reduces fertilizer leaching, helps control weeds, and boosts harvests. Similarly, Demo and Bogale (2024) stated that dryland agriculture requires the efficient use of water resources and natural resources through the application of water-saving technologies. Mulch is a conservation practice used in drylands to maintain soil moisture, regulate temperature, and minimize soil evaporation. Organic mulch reduces soil degradation, improves organic matter, and enhances the soil’s ability to retain water.

Mulch helps maintain moisture in the root zone, allowing plants to access water for longer periods. Under plastic mulch, soluble nutrients such as nitrates (NO<sub>3</sub><sup>-</sup>), ammonium (NH<sub>4</sub><sup>+</sup>), calcium (Ca<sub>2</sub><sup>+</sup>), magnesium (Mg<sub>2</sub><sup>+</sup>), potassium (K<sup>+</sup>), and fulvic acid are released as organic matter decomposes, increasing the availability of soil nutrients.

Application of mulch in agricultural lands in Ngadisari Village could be a solution for water management, as water use in agriculture has become a concerning issue. Utilizing crop residues or harvest leftovers for mulch, or even starting to use plastic mulch while reducing soil tillage, is highly recommended. The use of mulch can be implemented quickly, making it an effective solution to reduce water loss. Mulch offers several advantages for dryland farming, such as reducing soil water loss, erosion, weed growth, the kinetic energy of raindrops, and competition for nutrients and water with nearby fields. The evaluation by Román-Vázquez *et al.* (2023) shows that conservation agriculture practices for annual crops in

Europe, including strip seeding, no-tillage, crop diversification, and cover crops, have been implemented. Shumba *et al.* (2023) stated that Conservation Agriculture (CA), which combines reduced or no tillage, permanent soil cover, and improved crop rotation, is often promoted as a climate-smart practice. The impact of CA and its three principles on soil organic carbon (SOC) stocks, both above and below ground, as well as on CO<sub>2</sub> emissions from the soil in low-input cropping systems in sub-Saharan Africa, is somewhat limited.

### Implementation of crop diversification or rotation in Ngadisari village

Vegetable cropping pattern and rotation implemented by farmers in Ngadisari Village are highly influenced by the seasons, especially rainfall (Table 2). During the rainy season (with ample water), the main crop is potatoes, and the land is always planted. In contrast, during the dry season, crops like cabbage and spring onions are grown around July and August, but land is often left fallow due to water shortages. The implementation of intercropping (two or more crops) or diversification is more common than monoculture. Water availability, particularly in the dry season, is also a key consideration. In intercropping, potatoes are often planted with spring onions, but the latter tends to be overshadowed by the large canopy of the

**Table 2. Seasonal Planting Periods for Potatoes, Cabbage, and Spring Onions**

Plants	Potato and Spring Onion				Cabbage and Spring onion							
	Potato		Cabbage		Spring onion							
	Potato	Potato	Potato	Potato	Spring onion	Spring onion	Spring onion	Spring onion				
Month	J	F	M	A	M	J	J	A	S	O	N	D
Seasons	Rainy season				Dry Season				Rainy season			

potato plants. Spring onions are harvested multiple times, so they are frequently present on the land. Harvesting occurs when there are more than three shoots, leaving two shoots behind to continue growing.

Implementation of crop diversification or rotation in land management in Ngadisari Village is carried out conservatively with the main crops (potatoes, cabbage, and spring onions) being planted according to the principles of conservation agriculture and land suitability. The most common cropping pattern practiced by the majority of farmers in Ngadisari includes potatoes, cabbage, and spring onions, with potatoes being grown during the rainy season and cabbage and spring onions during the dry season.

The planting of crops in Ngadisari has already taken into account conservative agriculture aspects, such as aligning with the contour direction and maintaining perennial trees (like pine) and elephant grass at the boundaries of the land, although it does not yet fully represent all aspects of conservation agriculture. The transition toward conservation agriculture by farmers in Ngadisari is gradual, based on their beliefs and understanding of the meaning and implementation of conservation agriculture.

Research by Mujiyo *et al.* (2022) on land with andisol soil, sloping terrain, and highland areas indicates that the land categories most closely related to soil degradation are slope (0.857\*\*), rainfall (0.595\*\*), and land use (0.415\*). Similarly, Araya *et al.* (2024) evaluated the current practices, challenges, and constraints in the implementation of conservation agriculture in sub-Saharan Africa (SSA). They stated that CA is practiced on only about 1.25% of the total cultivated area, despite efforts to promote it for two decades. This may be due to: i) the lack of locally adaptable

CA systems, especially those integrating livestock production needs; ii) insufficient crop residues available for surface mulch; iii) inconsistent and low harvest yields; iv) the lack of CA equipment for smallholder farmers to implement direct seeding; v) limited availability, high costs, and inadequate knowledge about the proper use of fertilizers and herbicides; and vi) a lack of CA knowledge and training.

## CONCLUSION

In conclusion, the agricultural landscape of Ngadisari Village is characterized by dryland farming on sloped terrain, with over half land featuring inclines greater than 15% and light-textured soils exceeding one meter in depth. While conservation agriculture practices have been partially adopted, most notably terracing reinforced with perennial plants like pine and elephant grass, their implementation remains incomplete. Intensive land preparation is still universally practiced, and soil coverage is inconsistent, with much land left bare during the dry season due to reliance on rain-fed farming and minimal use of mulch. Although farmers predominantly practice intercropping with potatoes, spring onions, and cabbage, they have not integrated perennial crops with vegetable cultivation. Overall, the agricultural practices in Ngadisari reflect a transitional stage, incorporating some conservation elements while still falling short of fully adhering to conservation agriculture principles.

## SUGGESTION

Several key recommendations emerge for advancing conservation agriculture in Tengger tourist area. First, construction of reservoirs or water catchments would enable farmers to store rainwater during the wet season for use during the dry months,

addressing a major limitation of current rain-fed systems. Second, returning plant residues to soil as mulch would help protect against erosion, enhance organic matter content, and improve overall soil health. Finally, reducing intensity of soil cultivation would bring practices closer to conservation agriculture standards by minimizing disturbance and preserving soil structure.

## 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

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# ENHANCING POTATO CROP HEALTH MONITORING USING TWO STAGE CNN BASED DISEASE CLASSIFICATION MODELS

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**ABSTRACT:** Potato is one of the most extensively cultivated crops in India as well as worldwide and serves as a staple food in many regions. Due to its agricultural and economic importance, effective disease management is essential to ensure healthy crop yields. Traditional methods of disease detection rely on manual visual inspection by farmers or agricultural experts, which often lack precision and are prone to misdiagnosis, leading to substantial crop losses. This study proposes a deep learning-based approach for automated disease detection in potato plants using a Convolutional Neural Network (CNN). The novelty of this work lies in developing a two-stage CNN framework that first classifies the potato leaf images as either healthy or unhealthy. Next, the unhealthy leaf images are further classified as either early blight or late blight diseases. The proposed CNN models are optimized using the Adam optimizer with a learning rate of 0.0001. Extensive experimentation on a dataset of 1,500 images demonstrates high classification accuracies of 98.3% and 99% for the two stages, respectively. The results demonstrate that our proposed CNN models are highly effective for automated disease detection and improve decision-making in potato crops.

**KEYWORDS:** Potato Disease, Convolutional Neural Network (CNN), Deep Learning in Agriculture, Early Blight, Late Blight.

## INTRODUCTION

Agriculture is one of the most important aspects of modern-day society as it is used for food, economic development, and global food security. Potato is an important food in human cuisine, which is frequently consumed staple foods. It is the third most important food crop in the world after wheat and rice, as per the Food and Agriculture Organization (FAO), a production of more than 368 million metric tons in the year 2021 (Rashid, *et al.*, 2021). This plant is a combination of carbohydrate, vitamins, and minerals for

hundreds of millions of people. However, potatoes are very vulnerable to disease, i.e., fungal infections like early blight and late blight, that cause unprecedented loss of production.

The development of disease to plant undermines food security, adds to the production cost, and causes financial losses for farmers. Hence, early detection of potato leaf disease is of utmost importance in avoiding such threats and minimize dependence on extensive usage of pesticides (Strange & Scott, 2005). Traditional methods

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involve manual observation by experts, which is time-consuming and prone to human error. Due to these shortcomings, computer vision and machine learning approaches have become useful for automation.

Traditional approaches extract features such as colour and texture from leaf and apply classifier to distinguish between the disease and non-disease plants (Dalal & Triggs, 2005). Other approaches such as Histogram of Oriented Gradients (HOG) and Local Binary Patterns (LBP) have also been used for leaf disease detection with better accuracy (Pujari, Yakkundimath, & Byadgi, 2015). However, with the recent arrival of neural networks, deep learning-based approaches have emerged as a powerful tool for plant disease classification that outperforms traditional approaches by learning more complex patterns from images (Singh & Misra, 2017).

Recent studies have demonstrated the potential of CNNs in the classification of plant diseases. Hence, in this paper, we propose a two stage CNN-based framework for the detection of potato leaf diseases. In the first stage, we classify the leaf image as healthy or unhealthy. Further, the unhealthy image is again classified as early blight or late blight. This hierarchical design simplifies the classification task at each stage and improves the overall model performance. The advantage of using CNN is that it extracts features automatically from raw images and is therefore less sensitive to light variations, noise in the background, and variations in disease patterns (Kamilaris & Prenafeta-Boldú, 2018). It is difficult to distinguish early blight and late blight in their early stage using conventional methods as they exhibit similar texture and patterns. Both diseases cause leaf discoloration, necrotic lesions, and chlorosis, making visual diagnosis difficult (Mohanty, Hughes, & Salathé, 2016). Thus,

the novelty of this work lies in developing a 3 convolutional layers CNN model that distinguishes early and late blight images accurately in its early stage.

We propose same model for classification at both the stages. Each model consists of three convolutional layers, incorporated with max pooling layers, followed by a flattening layer, a fully connected dense layer, and an output layer. A dropout layer with a dropout rate of 0.5 is used after the dense layer to avoid overfitting (Wahabzada *et al.*, 2015). The input images are resized to and normalized in [0, 1] range to ensure training uniformity. A series of experiments are conducted to determine the optimal values for hyperparameters (Chollet, 2017). These are presented in detail in the further sections.

The proposed two-stage CNN model is extensively evaluated on 1,500 potato leaf images using accuracy, precision, recall, and F1-score, that are obtained from the confusion matrices of both stages. In stage 1 (i.e., healthy vs. unhealthy classification), the model achieves an accuracy of 98.3% with minimal misclassifications. Similarly, in stage 2 (i.e., early vs. late blight classification), it achieves an accuracy of 99%. Apart from these, we test on various configurations to decide the optimal values of hyperparameters. The Adam optimizer with a learning rate of 0.0001 and three convolutional layers per stage give the best results. Finally, we obtain the training and validation curves to confirm early convergence without overfitting.

The rest of the paper is structured as follows. The Literature Review section provides a brief summary of previous studies on potato leaf identification. The proposed methodology and the architecture of our two-stage CNN model is discussed in Materials and Methods section. Results and Discussion section presents the experimental results

and its accompanying discussions. Finally, conclusions and future work are provided in the last section.

## LITERATURE REVIEW

In recent years, deep learning has emerged as an important and useful tool for automating disease diagnosis from plant leaf images. It offers high accuracy and scalability as compared to the traditional methods. Thus, in this section, we present a concise review of recent works that focus on potato leaf disease detection using convolutional neural networks (CNNs), transfer learning, hybrid architectures, explainable AI techniques etc.

One prominent approach integrates depth-wise separable convolutions and attention mechanisms. The MDSCIRNet model is enhanced with multi-head attention and tested against both traditional deep learning and ensemble classifiers and achieved up to 99% accuracy when combined with an SVM classifier (Reis & Turk, 2024). Similarly, explainable AI was applied to enhance trust in prediction outputs. One such study employ LIME and SHAP interpretations to ensemble models like CNN, CNN-SVM, DNN. They achieved 99% accuracy while also improving transparency in decision-making (Paul *et al.*, 2024).

Lightweight CNNs like RegNetY-400MF have also shown promise in practical deployments. This model efficiently classified seven types of potato diseases with 90.68% accuracy, supporting real-time use on edge devices (Chang & Lai, 2024). There are many works that have focused on optimizing existing CNNs. An improved version of VGG16 (VGG16S) reduced parameters to one-tenth while achieving 97.87% accuracy (Zhang *et al.*, 2025). Additionally, an ensemble model based on ResNet50V2 and DenseNet201 accurately assessed disease stages beyond classification (Chowdhury *et al.*, 2024). Another modified version of VGG19,

NASNetMobile, and DenseNet169, improved performance by adding additional layers and feature reductions. They demonstrated up to 99% accuracy and high AUC-ROC scores (Lanjewar, Morajkar & Payaswini, 2024).

Custom based CNN architectures have also been proven effective. A new CNN model designed specifically for potato leaves achieved a notable 98.28% accuracy, significantly outperforming prior models (Sofuoğlu & Birant, 2024). Another work combined MDSCIRNet with SEResNet101V2 to attain 99.67% test accuracy (Bajpai, Sahu, & Tiwari, 2025). Furthermore, vision transformer (ViT\_B\_16) models have also been effective, with 99% accuracy on a combined dataset of early blight, late blight, and healthy samples (Adhikari, 2024).

One study highlighted the need for more robust models as VGG19 fail to distinguish healthy leaves (Fuadi, Putri, Nasien, & Oktarina, 2024). The EfficientNetB0 architecture was also tested on a potato leaf dataset, achieving 99.05% accuracy using compound scaling strategies (Upadhyay, Jain, & Prasad, 2024). While most studies focus solely on image-based features, some integrate environmental data. One such work used meteorological features selection algorithms like bGGO to boost the predictive power of traditional ML models, achieving 98.3% accuracy (Radwan, Alhussan, Ibrahim, & Tawfeek, 2024).

In terms of reviews, one comprehensive survey emphasized the importance of CNNs (like ResNet, MobileNet, VGG) in potato disease detection. It also discussed challenges such as generalizability and data scarcity (Gülmez, 2024). Finally, a hybrid deep learning model based on DenseNet-121 and Gaussian filter fusion produced a training accuracy of 99.08% and validation accuracy of 98.37% (Raza, Pitafi, Shaikh, & Ahmed, 2025).

These studies demonstrate that deep learning models are very popular in disease classification. They can produce good results if properly optimized with transfer learning, lightweight architectures, and ensemble strategies. The summary of a few works is presented in the Table 1 below.

## MATERIALS AND METHODS

In this section, we present a detailed overview of the Convolutional Neural Network (CNN)-based model for potato leaf disease classification. This includes dataset description, preprocessing techniques applied to enhance the quality of images, and the design of a robust CNN architecture specifically designed for leaf disease classification. We also present the justification of each architectural choices, parameter tuning strategies, and training configurations used to optimize model performance. This flowgraph is presented in Fig. 1 below.

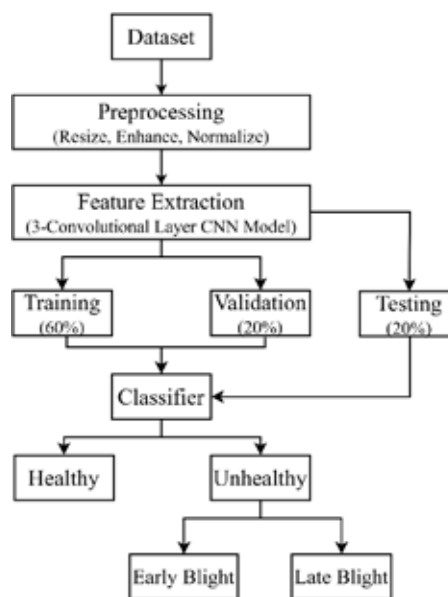


Fig. 1. Flowgraph of proposed two stage CNN based disease classification system.

## Dataset Description

The dataset used in this study is taken from Kaggle, which is the standard public

Table 1.

Sr. No.	Authors	Work Done	Proposed Model	Accuracy
1	(Zhang, et al., 2025)	Designed a full DL pipeline for diagnosing potato leaf diseases.	CNN	97.87%
2	(Bajpai, Sahu, & Tiwari, 2025)	Integrated attention mechanisms and squeeze-and-excitation blocks to enhance detection accuracy.	CNN + SE + Attention	99%
3	(Adhikari, 2024)	Used Vision Transformer for classifying potato leaf diseases.	Vision Transformer	99%
4	(Chang & Lai, 2024)	Developed a lightweight CNN optimized for edge devices and mobile platforms.	Lightweight CNN	90.68%
5	(Chowdhury, et al., 2024)	Employed ensemble deep learning and classified severity levels of diseases.	Ensemble CNNs	Not mentioned
6	(Sofuoğlu & Birant, 2024)	Applied standard DL approach for identifying various potato plant leaf diseases.	VGG16, ResNet50	98.2%
7	(Lanjewar, Morajkar, & Payaswini, 2024)	Introduced modified TL frameworks for better identification using pretrained models.	NasNet	95%
8	(Fuadi, Putri, Nasien, & Oktarina, 2024)	Evaluated various CNNs to find the most effective architecture.	AlexNet, VGG, ResNet	97%
9	(Upadhyay, Jain, & Prasad, 2024)	Targeted early and late blight detection using a pre-trained efficient model.	EfficientNetB0	99%
10	(Radwan, Alhussan, Ibrahim, & Tawfeek, 2024)	Used feature selection and ML optimization for disease classification.	SVM, RF + PCA/GA	98%

repository (Muhammad, 2025). This dataset consists of 1,500 labelled potato leaf images categorized into two main groups: 500 healthy and 1,000 unhealthy leaves. The unhealthy class is further divided into 500 images of Early Blight and 500 images of Late Blight. For this work, the dataset is split into three subsets for model training and evaluation: 60% of the images are used for training, 20% for testing, and the remaining 20% for validation. Table 2 below presents the distribution of samples across the categories and data splits. Furthermore, Fig. 2 below provides the sample images of Normal leaf, early blight leaf and late blight leaf.

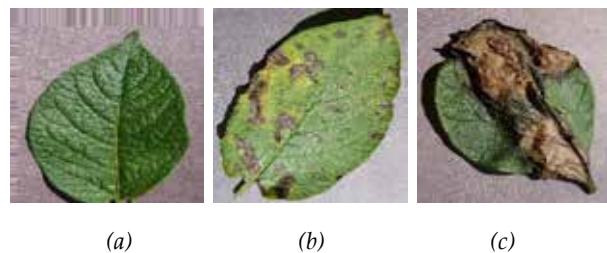
### Data Preprocessing

Data preprocessing is the most important step in classification model to ensure consistent input for the deep learning model and improve its performance. We employed three preprocessing steps to the input image as given below.

- 1. Image Resizing:** All images were resized to pixels. This standardization makes all

**Table 2. Distribution of potato leaf images across health categories and dataset splits (training, testing and validation).**

Category	Early Blight	Late Blight	Healthy	Total
Training	300	300	300	900
Testing	100	100	100	300
Validation	100	100	100	300
Total	500	500	500	1,500



**Fig. 2. Representative sample images of potato leaves: (a) Healthy leaf, (b) Leaf affected by Early Blight, and (c) Leaf affected by Late Blight.**

the images of same size, which is required for efficient processing by the CNN model. This also reduces computational overhead while preserving sufficient detail for accurate classification.

- 2. Colour Image Enhancement:** Image enhancement techniques are required to improve the identification of features relevant to disease detection. There are many image enhancement methods available such as histogram equalization, contrast stretching, and CLAHE (Contrast Limited Adaptive Histogram Equalization). We use the CLAHE that is most commonly used for enhancement (Shastri, Tamrakar, & Ahuja, Density-wise two stage mammogram classification using texture exploiting descriptors, 2018).
- 3. Normalization:** All pixel values are normalized in the range, which is the standard technique to accelerate the training process and contributes to the stability of gradient descent optimization by ensuring uniform input scales across the network. We use the following formula to perform normalization (Shastri, Tamrakar, & Ahuja, Density-wise two stage mammogram classification using texture exploiting descriptors, 2018):

$$I'(x, y) = \frac{I(x, y) - \min(I)}{\max(I) - \min(I)}$$

Where,  $(x, y)$  is the pixel position,  $I'$  is the normalized pixel intensity,  $I$  is the actual pixel intensity,  $\min(I)$  is the minimum intensity over all the pixels, and  $\max(I)$  is the maximum intensity over all the pixels.

### Model Preparation

In this subsection, we present the architecture of our proposed model. As mentioned earlier, we address two binary classification problems using CNN. First, identifying potato leaves as healthy or

unhealthy, and next, further classifying the unhealthy leaves as early blight or late blight. Since both tasks rely on the same type of image input (i.e., potato leaf images), we propose and implement a *single* CNN architecture for both the tasks. This unified architecture is designed in such a way that it is computationally efficient and capable of extracting high quality features capable of discriminating between the different disease classes. This is given in Fig. 2 below.

*First*, the proposed model's architecture begins with an input layer that accepts resized colour images of pixels. As mentioned earlier, this standardizes the input size and is useful in consistent data processing and efficient GPU utilization. The use of three channels (red, green, and blue) ensures that colour-based distinctions are retained in the analysis. This is important for identifying disease patterns such as yellowing, browning, or lesions.

*Next*, the architecture consists of a series of convolutional layers to extract features from the images. In our work, we use three different convolutional layers. The first convolutional layer employs 32 filters of size to capture low-level features such as edges and corners. The filter size of is selected for its efficiency in capturing local patterns without adding any extra computational cost. A second convolutional layer have 64 filters (again of size). This is introduced to enable learning of more complex features by using lower-level information. Finally, a third convolutional layer with 128 filters is introduced to capture high-level hidden features that mostly contributes for distinguishing between early and late blight symptoms. After every convolutional layer, we employ an activation function, specifically the Rectified Linear Unit (ReLU) function. ReLU is crucial for learning complex feature representations by introducing non-linearity to the model. It also improves computational efficiency and solves

the vanishing gradient problem to accelerate convergence during training.

*Furthermore*, to reduce the dimensionality of features and retain only the most critical information, each convolutional block is followed by a max-pooling layer with a window size of. This step reduces computation and contributes to generalization by making the model invariant to small translations and distortions in the input images. The combination of convolution and pooling layers allows the model to progressively extract and condense important image features.

After the final convolution and pooling layers operations, we get a two-dimensional feature map. These maps are given as an input to a flatten layer that converts them into a one-dimensional vector. This transformation is necessary as the next layer is fully connected (dense) layer and it takes single vector as an input. Thus, this flattened vector is then passed into a dense layer containing 128 neurons. Here, 128 neurons are selected to avoid the risk of overfitting to ensure that the model remains generalizable on unseen data. This layer integrates information across the entire image and make informed predictions based on the learned features. We use a dropout rate of 0.5 to further reduce the chances of overfitting and improve generalization<sup>#</sup>.

*Finally*, the output layer consists of a single neuron incorporated with a sigmoid activation function. This function is mostly suitable for binary classification tasks. It generates a probability value between 0 and 1, where a value close to 1 indicates the positive class (in our case, healthy in first

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<sup>#</sup>Dropout rate of 0.5 randomly deactivates 50% of the neurons during training. This prevents the network from becoming overly dependent on specific path, thereby decreasing the chances of overfitting.

stage or early blight in second stage) and a value close to 0 indicates the negative class (again, unhealthy in first stage or late blight in second stage). A threshold of 0.5 is used for decision making. For example, if the predicted probability for a given input instance is less than 0.5, the instance is classified as belonging to the negative class; on the other hand, if the probability exceeds 0.5, it is assigned to the positive class. Fig. 3 below presents the architecture of proposed model with three convolutional layers, followed by flattening and fully connected layers.

The detailed technical overview of the proposed CNN model is given in Table 3 below. This table summarizes the architecture used in both stages of classification. The table includes following columns: the layer type, output shape, number of parameters, and the activation function applied to that layer. The output shape gives the dimensionality of the data and the activation functions indicate how non-linearity is introduced at each stage. This provides a clear understanding of the model’s depth, complexity, and trainable capacity.

To find out the optimal architecture and the values of hyperparameters required for the CNN model, we perform a series of experimentations. For example, the models

**Table 3. Detailed architecture of the proposed CNN model (for both classification stages).**

Layer Type	Output Shape	# of Parameters	Activation Function
Conv2D (32 filters,)	(126, 126, 32)	896	ReLU
MaxPooling2D ()	(63, 63, 32)	0	-
Conv2D (64 filters,)	(61, 61, 64)	18,496	ReLU
MaxPooling2D ()	(30, 30, 64)	0	-
Conv2D (128 filters,)	(28, 28, 128)	73,856	ReLU
MaxPooling2D ()	(14, 14, 128)	0	-
Flatten	(25088)	0	-
Dense (128)	(128)	3,211,392	ReLU
Dense (1)	(1)	129	Sigmoid
<b>Total Parameters</b>		<b>33,04,769</b>	

are trained using three optimizers (i.e., Adam, RMSprop, and SGD), and three different learning rates (0.001, 0.01, and 0.00005). Additionally, we explored architectures with 2, 3, and 4 convolutional layers for both classification stages. The configuration that produced the highest validation performance in each case was selected for final model training. This is discussed in detail in the next section.

## RESULTS AND DISCUSSIONS

In this section, we present the experimental results and corresponding analysis for the

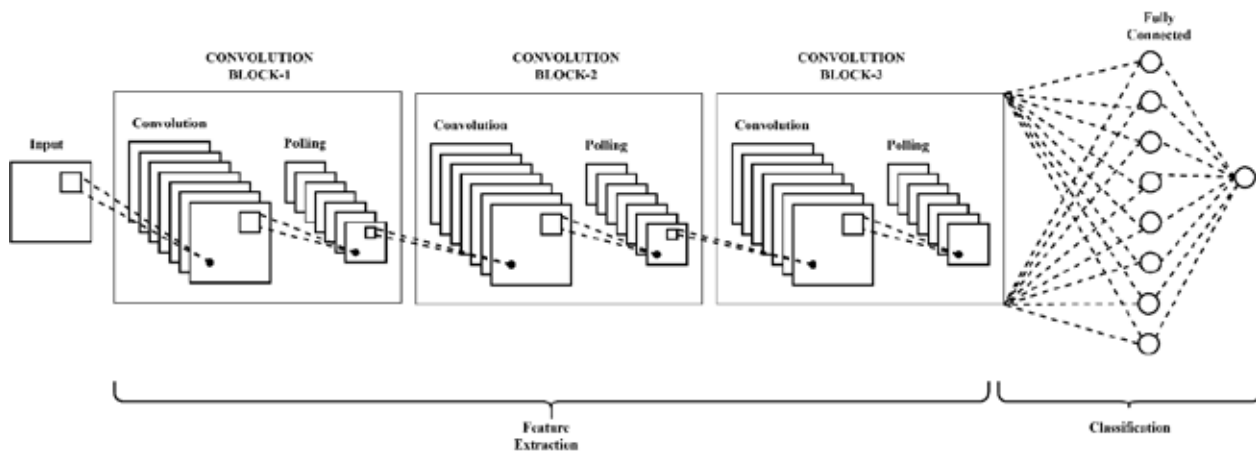


Fig. 3. Architecture of Proposed 3 convolutional layer CNN model.

proposed convolutional neural network (CNN)-based approach for classifying potato leaf diseases. As mentioned earlier, the evaluation is conducted in two stages: (1) classification of leaves as healthy or unhealthy, and (2) classification of unhealthy leaves as early blight or late blight. Furthermore, we also discuss the performance metrics, parameter tuning, and visualizations to validate the effectiveness of the proposed model.

First, to assess the classification performance, we compute four key evaluation metrics; namely accuracy, precision, recall, and F1-score as given by (Shastri, Prajapati, Katariya, Paliwal, & Sabale, 2025). These values are calculated based on the confusion matrix for each stage. All the values presented

in the confusion matrix are obtained by experimenting on a held-out test set (20%) that is not used for training and validation. The confusion matrix for stage 1 is given in Fig. 4, and for stage 2 is given in Fig. 5 below. The confusion matrix gives us true positives (TP: healthy correctly predicted as healthy), true negatives (TN: unhealthy correctly predicted as unhealthy), false positives (FP: unhealthy misclassified as healthy), and false negatives (FN: healthy misclassified as unhealthy).

Using the values from the confusion matrix, the four metrics values are evaluated and given in the Table 4 below.

As evident from this table, the model performs exceptionally well for both stage classifications. Also, the relative low values

**Table 4. Accuracy, Precision, Recall, and F1-Score values for both stages (healthy vs. unhealthy and early blight vs. late blight) classifications.**

Evaluation Metrics	Formula	Healthy vs. Unhealthy	Early Blight vs. Late Blight
Accuracy	$Accuracy = \frac{TP + TN}{TP + TN + FP + FN}$	0.9833	0.9900
Precision	$Precision = \frac{TP}{TP + FP}$	0.9797	0.9900
Recall	$Recall = \frac{TP}{TP + FN}$	0.9700	0.9900
F1-score	$F1 - score = 2 \times \frac{Precision \times Recall}{Precision + Recall}$	0.9748	0.9900

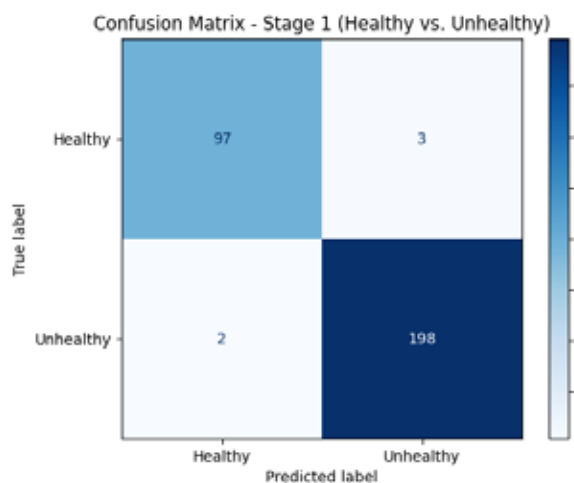


Fig. 4. Confusion matrix for Stage 1 (Healthy vs. Unhealthy)

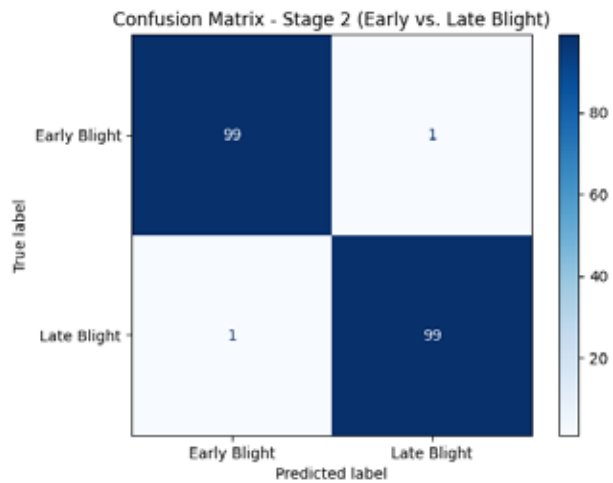


Fig. 5. Confusion matrix for Stage 2 (Early Blight vs. Late Blight)

of false positives and false negatives shows that the model is robust in discriminating the diseases.

Next, as mentioned earlier, to optimize the CNN model's performance, we perform an extensive hyperparameter tuning. For this we evaluate our model using three different optimizers; Adam, RMSprop, and SGD. Among these, Adam optimizer outperformed others in both stages of classification and hence, selected for the proposed model. This analysis is given in Fig. 6 below.

Following this, we investigate the effect of learning rate on the performance of our model. For this, we perform experiments using four different values; 0.01, 0.001, 0.0001, and 0.00005. As evident from Fig. 7 below, 0.0001 performs best as compared with the others as it gives earlier convergence with high accuracy.

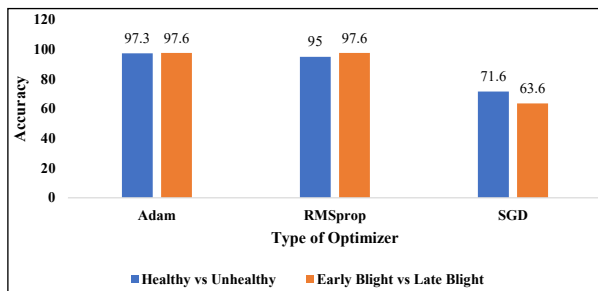


Fig. 6. Comparison of training performances using three different optimizers (Adam, RMSprop, and SGD) for both stage classifications

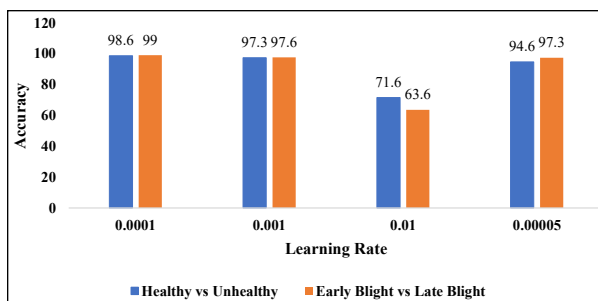


Fig. 7. Comparison of training performances using three different learning rates (0.0001, 0.001, 0.01, and 0.00005) for both stage classifications

Subsequently, to analyse the impact of network depth, we implement CNN architectures with 2, 3, and 4 convolutional layers. It was observed that the model with 3 convolutional layers yielded the most reliable and accurate results for both stage classifications. This provides the best trade-off between the complexity and performance, as large number of layers may capture more complex features but becomes computationally expensive. This analysis is provided in the Fig. 8 below.

To further justify the architecture design choices, we perform an ablation study by varying the number of layers and incorporating dropout regularization. The objective is to evaluate the impact of architectural depth and dropout on the model's performance and feature learning capability. Experiments are performed using one, two, and three layers, both with and without dropout, under identical training conditions. These results are summarized in Table 5 below. The ablation study is presented for healthy/unhealthy classification only, as the other stage classification exhibits analogous trends and consistent performance behaviour.

It is evident from this table that increasing the number of layers improves accuracy up to a certain depth, beyond which the gain becomes marginal. Additionally, the

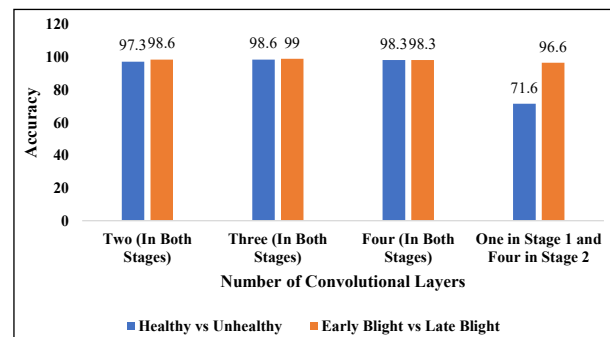


Fig. 8. Comparison of training performances using different convolutional layers for both stage classifications

**Table 5. Ablation study results for varying model configurations (Values in *Italics* are for proposed model).**

Layers	Dropout	Parameters	Accuracy
[32, 0, 0]	Yes	1,62,58,177	0.8100
[32, 0, 0]	No	1,62,58,177	0.9200
[32, 64, 0]	Yes	73,92,449	0.9567
[32, 64, 0]	No	73,92,449	0.9767
[16, 32, 64]	Yes	16,29,473	0.9567
[16, 32, 64]	No	16,29,473	0.9033
[32, 64, 128]	Yes	33,04,769	0.9767
[32, 64, 128]	No	33,04,769	0.9733

inclusion of dropout enhances generalization by reducing overfitting, particularly in deeper configurations. Additionally, the model with 3.3 million parameters is lightweight for deployment, trains fast (converge in 10 epochs), requires low memory and is capable for practical applications.

Thereafter, to qualitatively evaluate the model’s predictions, we present sample outputs showing the actual and predicted labels for various leaf images. Fig. 9 below gives representative cases from each category: healthy, early blight, and late blight. From this figure, it is clear that the model reliably



Fig. 9. Sample images illustrating actual and predicted labels for three categories: Healthy, Early Blight, and Late Blight.

captures promising features, even in the instances where disease identification patterns are visually subtle.

We also illustrate the figures for the training/ validation accuracy and loss curves for both classification stages. The accuracy and loss graphs for stage 1 are given in Fig. 10 and the ones for stage 2 are given in Fig. 11 below. These graphs confirm that the model is able to learn effectively over epochs without overfitting. From both the figures, we observe that the training and validation curves smoothly converge.

Finally, we plot the Receiver Operating Characteristic (ROC) curves for both

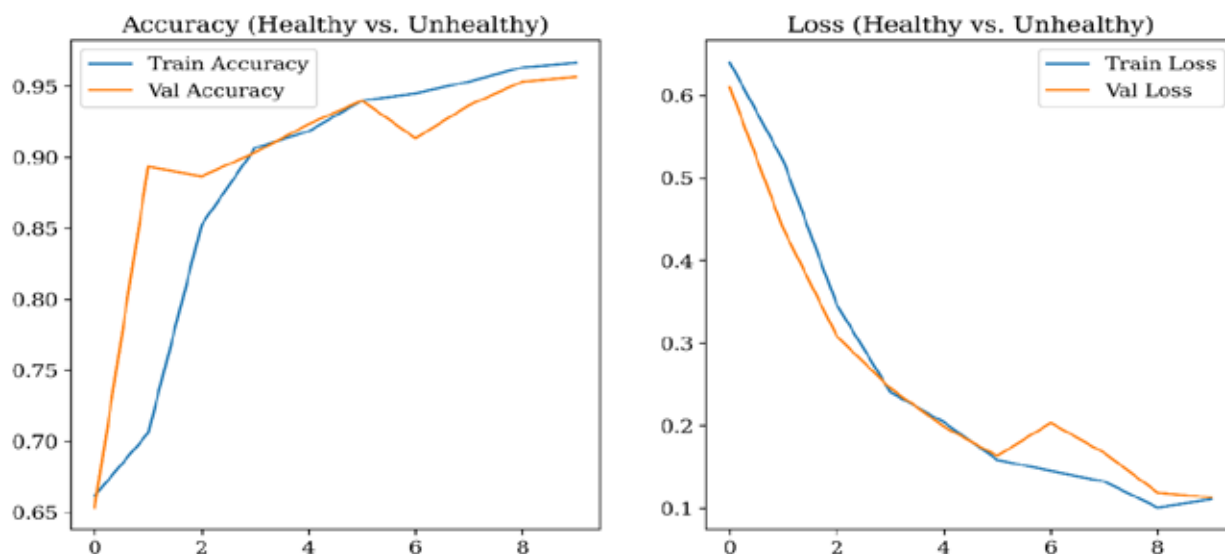


Fig. 10. Training and validation accuracy and loss curves for Stage 1 (Healthy vs. Unhealthy)

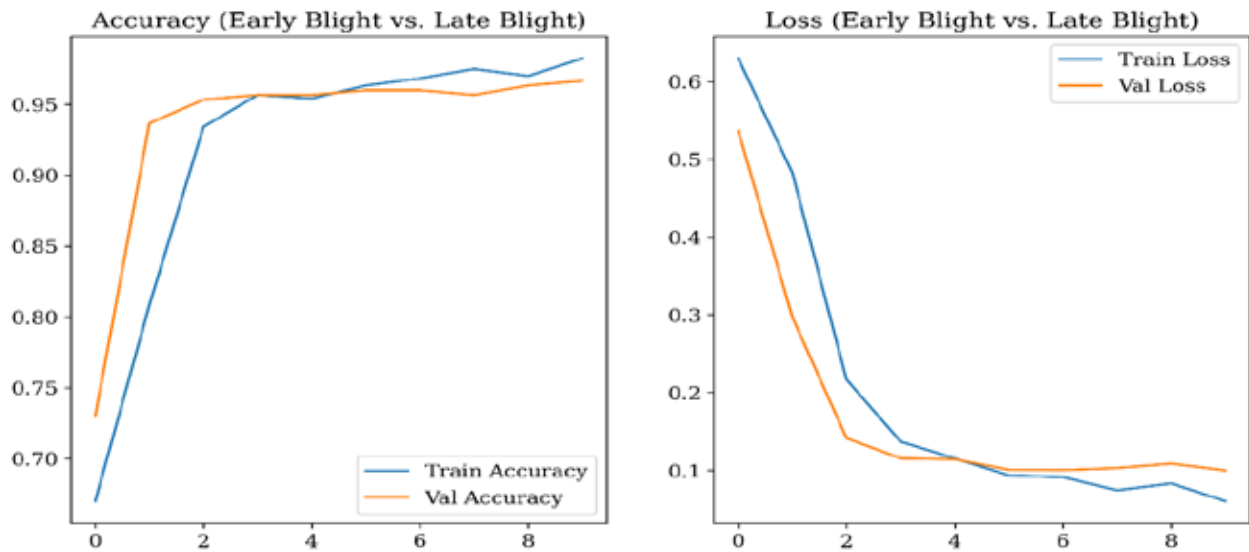


Fig. 11. Training/ Validation accuracy and loss curves for Stage 2 (Early Blight vs. Late Blight)

classification stages. And, the Area Under the Curve (AUC) was calculated to further monitor the discriminative ability of our proposed model. High AUC values in both cases indicate that the models perform well to distinguish between the respective classes. These analyses provide an additional layer of validation to our proposed model. These graphs are given in the Fig. 12 below.

In addition to the above results, a comparative evaluation is performed against two state-of-the-art models, EfficientNet and DenseNet using the same dataset to further establish the robustness of the proposed approach. This evaluation is carried out for both the stages of proposed framework under identical experimental settings, including data preprocessing, augmentation, and training parameters. These results are given in the Table 6 below.

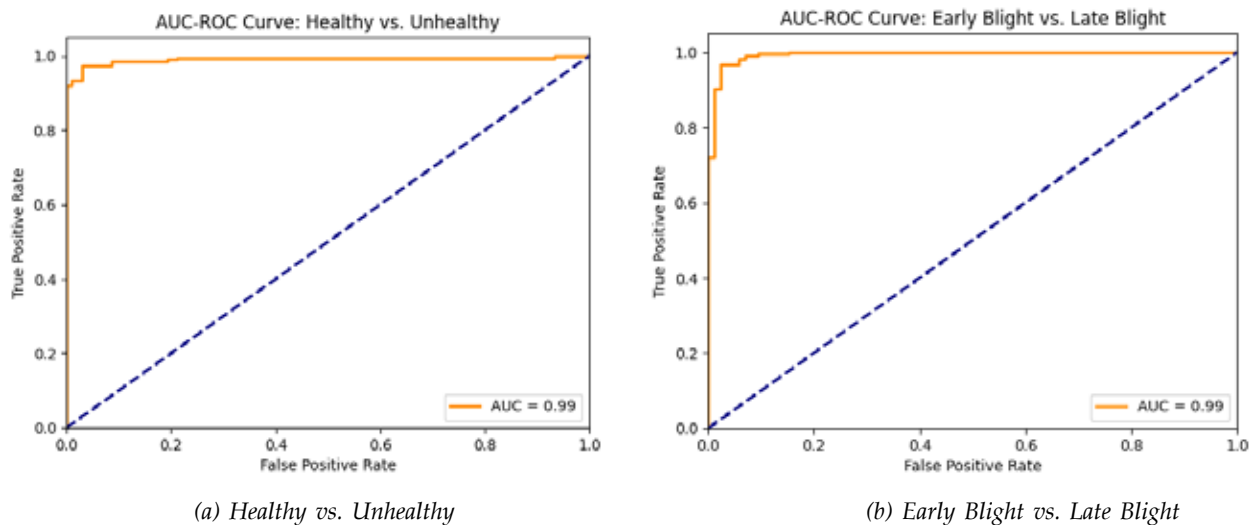


Fig. 12. Receiver Operating Characteristic (ROC) curves with corresponding Area Under the Curve (AUC) values for both Stage 1 (Healthy vs. Unhealthy) and Stage 2 (Early Blight vs. Late Blight) classifications.

**Table 6. Performance comparison of the proposed model with EfficientNet and DenseNet across both stages.**

Stage	Model	Accuracy	Precision	Recall	F1-Score
Healthy vs. Unhealthy	EfficientNet	0.6667	0.4445	0.6667	0.5333
	DenseNet	0.9667	0.9450	0.9555	0.9502
	Proposed	0.9833	0.9797	0.9700	0.9748
Early Blight vs. Late Blight	EfficientNet	0.5000	0.2500	0.5000	0.3334
	DenseNet	0.9611	0.9770	0.9444	0.9604
	Proposed	0.9900	0.9900	0.9900	0.9900

The results demonstrate that the proposed model consistently outperforms both EfficientNet and DenseNet in terms of accuracy and generalization, thereby highlighting its practical advantage and robustness even with a limited dataset.

Due to the limited size of the potato dataset used in this work, the proposed CNN model incorporates various strategies to ensure robustness. As mentioned earlier, we have applied three convolutional layers with increasing filter sizes, max pooling, and dropout layers to prevent overfitting. Additionally, in the preprocessing stage, the images were normalized to improve convergence stability. Furthermore, data augmentation including rotations, shifts, flips, zooming, and shearing is also applied to artificially increase dataset diversity. Learning curves show that training and validation accuracy increase steadily while maintaining a small gap, and loss decreases without divergence, indicating strong generalization beyond the limited training samples. These results demonstrate that the model is robust and capable of accurately classifying potato leaf diseases despite the small dataset size.

## CONCLUSIONS AND FUTURE WORK

In this paper, we present a robust and efficient deep learning-based approach for automatic classification of potato leaf

diseases using a two-stage CNN framework. The novelty of this work involves effective classification between healthy and unhealthy leaves in the first stage and early Blight and late blight in the second stage. Through extensive experimentation on 1,500 potato leaf images, we identify the optimal combination of model parameters; i.e., three convolutional layers, the Adam optimizer, and a learning rate of 0.0001 that give superior classification performance. Evaluation through confusion matrices, standard performance metrics, and ROC curves confirms the reliability and high accuracy of the model. We achieve around 98% accuracy in the first stage and 99% accuracy in the second stage of classification. The proposed system offers a scalable and accurate classification model for disease identification in agriculture, which can aid farmers and agronomists in identifying the diseases at an early stage.

While most of the recent studies focus on classification of leaf images, in future, we plan to localize the abnormality in the leaf using clustering techniques. This can provide more granular insights about the nature of the infection. We propose to explore the unsupervised clustering technique called spectral clustering that is known for its accurate results (Shastri A.A., *et al.*, 2019) Shastri A.A., Ahuja, Ratnaparkhe, & Busnel, 2021). Another future direction that can be explored involve implementation of multi-class classification systems which work for multiple crops types as well. This will make the model more generalize and efficient in real world settings. Finally, we can investigate the integration of CNNs with Internet of Things (IoT) devices, allowing real-time disease monitoring via mobile apps and smart agricultural sensors (Deng *et al.*, 2009).

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## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

## ETHICAL APPROVAL

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

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# COMPARATIVE EVALUATION OF ZERO - TILLAGE CUM MULCHING WITH CONVENTIONAL POTATO PRODUCTION UNDER TRANSPLANTED RICE – POTATO CROPPING SYSTEM

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**ABSTRACT:** Environmental problems such as GHG emissions like carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) emission from rice-residue burning, the over exploitation of underground water, land degradation, and productivity reductions in rice-based agricultural systems is negatively impacting productivity of rice based cropping system and increasing environmental concerns. A field study was conducted at the research farm of ICAR- Central Potato Research Institute RS, Patna (Bihar) during the Rabi seasons of 2022- 23 and 2023-24 with seven treatment combinations having Farmer's practice, zero tillage + mulching, Regional AICRP/ ICAR-CPRI recommendations, Flat-bed planting with slit, Flat-bed planting & mulching, Flat-bed planting & ridging and Flat-bed planting, ridging & mulching. Treatments were replicated thrice. Highest rice grain yield (5.1 t/ha) was recorded with Flat-bed planting, ridging & mulching (T7) which was statistically same compared to other treatments. Highest B:C (1.62) of rice cultivation was recorded with T7 which was statistically same compared to all other treatments. The highest number of total tubers was recorded with Zero tillage + mulching (T2) (624 thousand/ha) which was statistically same with all other treatments. The highest total tuber yield (26.8 t/ha) was recorded with T2 which was significantly higher than all other treatments except T5 and T7. The highest net return (₹114554/ha) of potato was recorded with T5 which was significantly higher than all other treatments except T2. Highest water use efficiency of potato was recorded with T2 (76.63 kg tuber/ha-mm water) which was significantly higher than all other treatments except T5 and T7. The highest rice equivalent yield (14.86 t/ha) was highest with T2 which was significantly higher than all other treatments except T5 and T7. Zero tillage in combination with paddy straw mulch will enhance crop productivity, system sustainability, system vitality, economic profitability, and environmental quality.

**KEYWORDS:** Equivalent yield, mulch, potato, rice, water use efficiency, zero – tillage

## INTRODUCTION

Potato (*Solanum tuberosum* L.) is grown worldwide and is very sensitive to soil and water conditions as it grows and produces better on deep and well-drained soils (Djaman *et al.*, 2021).

Potato is the fourth-largest crop produced worldwide after rice, wheat, and maize (FAOSTAT, 2021). Tillage practices are adopted to create the proper environment for potato growth and yield potential. Tillage is essential for preparing a seedbed

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and for weed control. Potato production is associated with different practices such as planting, diking, cultivation, hilling, and harvest that significantly disturb the soil environment with heavy machinery. Soil and water management in potatoes are therefore critical to assure optimal crop growth and development. Commercial potato production under traditional management practices involves heavy to very heavy machinery and equipment during seedbed preparation and growing season for different operations such as cultivation, herbicide and pesticides application and harvest, exposing the soil to compaction. Compaction before and during planting can restrict root growth (Huntenburg *et al.*, 2021). Soil compaction in combination with decrease plant water availability limit biomass production and potato tuber dry weight (Huntenburg *et al.*, 2021). Larney *et al.*, (2016) reported that integration of conservation management practices led to yield and disease control benefits without negatively impacting tuber quality. Rice - based systems occupy the most important agricultural lands in some of the vastest countries of Asia (Liu *et al.*, 2021). Environmental problems such as carbon emission from rice-residue burning, the overexploitation of underground water table, land degradation, and productivity reductions in rice-based agricultural systems have been reported in Asia (Bhatt *et al.*, 2016). In general, nitrogen recovery in flooded rice is only 30-35% of applied dose, rest nitrogen is either volatilized or leached out beyond root zone. It ultimately reaches to ground water and enhances nitrate content of ground water. On the other hand, there have been significant efforts to adopt sustainability index (SI) in these systems, with substantial results for soil re-carbonization (Jat *et al.*, 2020). In rice - dominant areas, intensification with potato could diversify

diets and create additional incomes. Area's having high moisture content where tillage is not possible after rice harvesting, potato under zero tillage can be planted advancing potato planting 10-15 day before, adopting zero tillage. Similarly, area's having salt problem in soil, Zero tillage in combination with mulching makes micro climate suitable for potato production. Thus, agronomic gain is a current, more inclusive concept related to reducing yield gaps through practices that aim to improve productivity, resource use efficiencies, and soil health. Agronomic gain considers different environments, is socially inclusive, and can easily be framed as a key performance indicator (KPIs) (Saito *et al.*, 2021). There is inconsistent evidence that zero-tillage benefits weed control, but its effectiveness is enhanced by mulching. Even if soil organic matter is increased (+13–33%) and zero-tillage is the main factor driving the reduction in C footprint, no values of kg CO<sub>2</sub> eqha<sup>-1</sup> have been reported in PZTM to date. Agronomic gain, related to productivity, requires a combination of improved agronomic practices that allow for high and stable yields and economic profitability (Saito *et al.*, 2021). The burning of crop residues is a particular issue in Punjab, but it is also increasing in the Eastern States of Indo-Gangetic Plains. Farmers are looking for non-burning alternatives, and mulching is a convenient, sustainable practice in regions where straw resources are locally available. Together with zero-tillage, this can help to reduce burning and, thus, air pollution (Thakur *et al.*, 2018). Farmers burn crop residues because they cannot leave them on the field due to their long decay period and they can spread diseases from the last/previous paddy season, as well as farmers having short sowing period window that does not allow them to manually clear the fields (Bhatt *et al.*, 2021). South India, have a

crop residue production potential of 912 Mt, especially in the rice-wheat system. About 372 Mt residues are surplus. Conservation tillage practices increase soil organic matter of the topsoil and can improve soil structure and soil biological properties following zero tillage along with mulching.

## MATERIALS AND METHODS

A field study was conducted at the research farm of ICAR-Central Potato Research Institute RS, Patna (Bihar) during 2022-23 and 2023-24. Geographically, Patna is located at 25°35'47"N and 85°04'32"E, at an elevation of 76.9 m as per GPS location which lies in the South tract of Bihar. The soil of the experimental site was clay loam with approximately 0.42% organic carbon, EC 0.11 mSm<sup>-1</sup> and pH 6.8, bulk density 1.46 g/cm<sup>3</sup> and available N, P, K were 238.2, 23.4 and 262.4 kg/ha, respectively. Potato cv. 'Kufri Himalini' was grown with seven treatment combinations. Treatments consisted of conservation tillage for potato cultivation *viz* T-1: Farmer's practice: Removing/ Burning of straw from field, tillage, planting, and irrigation afterwards; T-2: Flat planting of seed tubers after FYM & fertilizer application + covering with paddy straw mulch; T-3: Regional AICRP/ ICAR-CPRI recommendations; T-4: Flat-bed planting: Direct planting of potato by opening slit and covering it with soil (Root zone tillage in 10 cm width and 15 cm depth) and no mulching or earthing; T-5: Flat-bed planting & mulching: Direct planting of potato by opening slit and covering it with soil (Root zone tillage in 10 cm width and 15 cm depth) + mulching by chopped straw and no earthing; T-6: Flat-bed planting & ridging: Direct planting of potato by opening slit and covering it with soil (Root zone tillage in 10 cm width and 15 cm depth), earthing after 20-25 days by

tilling soil between rows and no mulching; T-7: Flat-bed planting, ridging & mulching: Direct planting of potato by opening slit and covering it with soil (Root zone tillage in 10 cm width and 15 cm depth) and earthing after 20-25 days by tilling soil between rows + mulching of chopped straw after earthing. Treatments were replicated thrice. Transplanted rice was grown before potato crop. Transplanting was done on 1.7.2022 and 5.7.2023 and crop was harvested on 3.11.22 and 26.10.2023. The crop was fertilized with 120 kg N, 50 kg P<sub>2</sub>O<sub>5</sub> and 40 kg K<sub>2</sub>O/ha. Potato tubers were planted just after harvest of rice as per treatment. Recommended dose of nutrients, *i.e.* 180:80:100 kg/ha of N:P<sub>2</sub>O<sub>5</sub>:K<sub>2</sub>O, respectively were applied as per schedule during crop raising. Half N and full quantity of P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O were applied before planting and the remaining half dose was applied at earthing up. Gross plot size was 4.2 m x 4.0m. Well sprouted potato tubers were planted on 9.11.2022 and 29.10.2023. Four/five irrigations were applied as per requirement in addition to winter rains on 10.12.22, 31.12.2022, 17.1.2023, 8.2.2023 and 7.11.23, 24.11.23, 30.11.23, 15.12.23 23.1.24. The crop was sprayed with herbicide oxyfluorfen 23.5% EC @ 500 ml/ha on 10.11.22 and 1.11.23 for control of weeds. For control of late blight and insects, insecticide imidacloprid 17.8sl was sprayed @ 4ml/10-liter water and dithane M45 and moximate @ 2.5 and 3 kg/ha respectively on 26.12.22, 17.1.23 and 1.2.23 during 2022-23 and 30.12.2023, 10.1.24 and 20.1.2024 respectively during first and second years. Haulm killing of potato was done at 90 days after planting (physiological maturity) on 17.2.23 and 28.2.2024. Potato crop was harvested after haulm killing on 21.2.23 and 28.2.24. To assess the economic viability of different treatments for potato production, both fixed and operating costs were taken into consideration. The economics

of rice, potato and both crops production under variable treatments were calculated. Net returns were estimated as the difference between gross income and total production cost. Gross returns were a product of yield and wholesale market price of potato. The experiment was laid out in a completely randomized block design (CRBD). The data were analyzed statistically by standard analysis of variance (ANOVA). Least significant difference (LSD) test was used to determine whether differences exist between certain comparisons. The probability level for determination of significance was 0.05.

## RESULTS AND DISCUSSION

**Growth and yield attributes and economics of rice cultivation:** Number of ear /plant (16.70) was highest with T7 which was statistically same compared to other treatments. The highest number of tillers/ plant (17.7) was recorded with T7 which was statistically same compared to other treatments. Paddy dry weight (0.10 kg/Plant) was highest with T4. Highest rice grain yield (5.1 t/ha) was

recorded with T7 which was statistically same compared to other treatments. Similarly, the highest straw yield (7.0 t/ha) was recorded with T7 which was statistically same with all other treatments. Cost of cultivation of rice was ₹ 54851/ha. Highest gross return of ₹ 88645/ha of rice was recorded with T7 which was statistically same with all other treatments. Highest net return ₹ 33794 was recorded with T7 which was statistically same compared to other treatments. Highest B:C (1.62) was recorded with T7 which was statistically same compared to all other treatments (Table 1).

**Growth, yield attributes, yield and economics of potato cultivation:** Emergence count (94.2%), stem/plant (3.3), compound leaf/plant (39.3) and fresh haulm weight/plant (10.8 t/ha) were highest with T2 which was statistically same compared to all other treatments. The highest plant height of potato was recorded with T7 (51.4 cm) which was statistically same with all other treatments. The reduced soil temperature is considered

Table 1. Effect of tillage and mulching on growth, yield and economics of rice and growth attributes of potato (mean data of two years)

Treatments	Rice									Potato					
	Tiller/plant	Ear/plant	Paddy straw dry wt /plant (kg)	Weight in (kg/plant)	Rice yield (t/ha)	Straw yield (t/ha)	Cost of cultivation (₹/ha)	Gross return (₹/ha)	Net return (₹/ha)	B:C	Emergence (%)	Plant height (cm)	Stem/plant	compound leaves/plant	fresh Haulm wt t/ha
T1	12.4	12.0	0.1	0.2	4.8	6.6	54,851	82,207	27,356	1.50	93.2	49.6	3.0	34.7	2.7
T2	14.3	13.7	0.1	0.2	4.5	6.5	54,851	81,953	27,102	1.49	95.2	53.5	3.3	39.3	10.8
T3	14.8	14.3	0.1	0.2	5.0	6.1	54,851	85,638	30,787	1.56	93.3	47.3	3.1	36.4	4.1
T4	15.1	14.3	0.1	0.3	4.3	6.0	54,851	79,666	24,815	1.45	92.9	51.9	3.0	34.3	5.3
T5	12.3	11.1	0.1	0.2	4.7	5.8	54,851	84,028	29,177	1.53	92.3	53.5	2.6	32.9	8.4
T6	14.3	14.1	0.1	0.2	4.6	6.5	54,851	87,162	32,311	1.59	93.7	49.5	2.8	35.0	4.6
T7	17.7	16.7	0.1	0.3	5.1	7.0	54,851	88,645	33,794	1.62	94.0	51.4	3.1	36.6	7.3
SE(m)	1.3	1.2	0.0	0.0	0.3	0.3		7,190	7,190	0.13	1.5	2.5	0.4	3.4	0.6
C.D.0.005	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS	1.9

the main factor that improves potato plant development due to mulching. This could be due to the low heat transmissivity, which resulted in a more significant fraction of solar radiation being absorbed at the top of the mulch layer (Kar and Kumar, 2007). Additionally, organic mulching can maintain a higher soil and plant water status over non-mulched soil with only half of the amount of N (60 vs. 120 kg N ha<sup>-1</sup>, respectively), resulting in a water-saving of 40 mm without affecting leaf area index and yield (Acharya and Kapoor, 2001)

**Number of Tubers:** Highest number of <25 g tubers were recorded with T1 (297 thousand/ha) which was significantly higher than T4, T5, T6 and T7 but statistically on par with T2 & T3. The highest number of 25-50 g tubers was recorded with T7 (212 thousand/ha) which was statistically same with all other treatments. The number of 50-75 g tuber was recorded with T3 (115 thousand/ha) which was statistically same with all other treatments. The highest number of >75 g tuber was recorded with T2 (57 thousand/ha) which was significantly higher than all other treatments except T3, T5 and T7. The highest number of total tubers was recorded

with T2 (624 thousand/ha) which was statistically same with all other treatments. The increased tuber rate in the large- and medium-sized tubers and the corresponding weight contributed the most to the increase in the tuber yield in addition to hassle free tuberization and tuber survival.

**Tuber Yield:** Highest tuber yield of <25 g tuber was recorded with T1 (3.0 t/ha) which was statistically same with all other treatments. Yield of 25-50 g tubers was recorded with T7 (7.8 t/ha) which was significantly higher than all other treatments except T1 and T2. David *et al.*, (2022) reported that mulch can mitigate water and heat stresses by increasing soil moisture and reducing soil temperature, respectively, promoting a higher yield (Genger *et al.*, 2018). The yield of 50-75 g tubers was highest with T5 (7.9 t/ha) which was significantly higher than all other treatments except T2, T3 and T7. Highest yield of >75g tubers was recorded with T5 (9.4 t/ha) which was significantly higher than all other treatments except T2. The highest total tuber yield (26.8 t/ha) was recorded with T2 which was significantly higher than T5 and T7 (Table 2). David *et al.*, (2022) reported that combination of mulch

**Table 2. Effect of tillage and mulching on yield attributes, yield and economics of potato cultivation (mean data of two years)**

Treatments	Number of tubers (000/ha)					Tuber yield (t/ha)					Potato			B:C
	0-25	25-50	50-75	>75	Total	0-25	25-50	50-75	>75	Total	Cost of cultivation (₹/ha)	Gross return (₹/ha)	Net return (₹/ha)	
T1	297	200	89	35	621	3.0	7.4	5.2	4.5	20.2	1,45,396	2,01,933	56,537	1.39
T2	252	201	114	57	624	2.7	7.5	7.7	8.9	26.8	1,64,896	2,68,190	1,03,294	1.63
T3	259	167	115	45	586	2.2	5.8	6.8	5.7	20.4	1,45,396	2,04,440	59,045	1.41
T4	197	156	76	42	471	2.2	5.4	5.2	5.4	18.3	1,28,896	1,82,616	53,720	1.42
T5	174	172	113	62	520	1.9	6.5	7.9	9.4	25.6	1,41,896	2,56,450	1,14,554	1.81
T6	228	166	84	28	506	2.4	5.8	5.9	3.6	17.7	1,44,896	1,76,906	32,010	1.22
T7	213	212	105	49	579	2.8	7.8	7.2	7.0	24.8	1,57,896	2,48,260	90,365	1.57
SEm+	22	15	10	4	35	0.3	0.4	0.4	0.6	0.7		7,132	7,132	0.05
CD(P=0.05)	69	NS	NS	13	NS	NS	1.2	1.2	1.9	2.2		22,220	22,218	0.17

and a closer distance (between 30 and 60 cm between plants and rows, respectively) was more appropriate when comparing different plant spacings because the lower soil temperature promoted a better accumulation of carbohydrates in the tubers. Soil water and effective accumulated temperature during the tuber formation stage were the main factors affecting potato total yield, with stronger effect of soil water than that of soil effective accumulated temperature. Therefore, straw mulch could improve soil moisture and heat condition and realize potato yield and income increases (Yang *et al.*, 2023). The increased tuber rate in the large- and medium-sized tubers and the corresponding weight contributed the most to the increase in the tuber yield in addition to hassle free tuberization and tuber survival.

**Economics of potato cultivation:** Highest Cost of cultivation of potato was with T2 (₹ 164896/ha). Although the cost of crop residue for mulching application is higher than that needed for tillage operations, studies have shown that the combination of zero/ minimum tillage with mulching has better gross/net return and monetary efficiency

than conventional tillage practice (Prasad *et al.*, 2014). The highest gross return of potato was recorded with T2 (₹ 268190/ha) which was significantly higher than all other treatments except T5 and T7. The highest net return of potato was recorded with T5 (₹ 114554/ha) which was significantly higher than all other treatments except T2. Highest B:C (1.81) of potato was recorded with T5 which was significantly higher than all other treatments. Tuber yields under mulch increased by 20% or more compared to non-mulched production (Sadawarti *et al.*, 2013). Some other studies have achieved increases of up to 100% and 173%. On an average, mulching increases the benefit–cost ratio (BCR; i.e., revenues per rupee invested) by +10% over no-mulching practice (BCR = 1.55) (Dash *et al.*, 2018).

**Water use efficiency (WUE) of potato production:** Highest water use efficiency of potato was recorded with T2 (76.63 kg tuber/ha-mm water) which was significantly higher than all other treatments except T5 and T7 (Table 3). Huiying *et al.*, (2022) reported that higher water use efficiency was obtained with straw mulch treatments. Some of the reviewed

Table 3. Water use efficiency of potato, rice equivalent and economics of rice-potato sequence (mean data of two years)

Treatment	WUE of potato (kg/ha-mm)	REY (t/ha)	System Economics			
			Cost of cultivation (₹/ha)	Gross return (₹/ha)	Net return (₹/ha)	B:C
T1-Farmer’s practice	57.70	12.06	₹ 2,00,247	2,84,140	83,893	1.42
T2-Zero tillage + mulching	76.63	14.86	₹ 2,19,747	3,50,143	1,30,396	1.59
T3- CPRI recommendations	58.41	12.14	₹ 2,00,247	2,90,078	89,831	1.45
T4-Flat-bed planting	52.18	10.90	₹ 1,83,747	2,62,282	78,535	1.43
T5-Flat-bed planting & mulching	73.27	14.41	₹ 1,96,747	3,40,478	1,43,732	1.73
T6-Flat-bed planting & ridging	50.54	10.95	₹ 1,99,747	2,64,068	64,321	1.32
T7-Flat-bed planting, ridging & mulching	70.93	14.49	₹ 2,12,747	3,36,905	1,24,158	1.58
SEm±	2.04	0.31		7,881	7,881	0.04
CD(P=0.05)	6.35	0.95		24,552	24,554	0.13
CV (%)	5.62	4.11		4	13	4.69

REY-Rice equivalent yield of system, WUE- water use efficiency

studies (29%) combined mulch cover with irrigation schedule treatments, from which mulched crops recorded an increment of 10% in water productivity (WP) over non-mulched crops Sadawarti *et al.*, (2013). The reduction in water evaporation promoted by a low solar energy incidence under organic mulching conditions leads to increased soil moisture conservation in potatoes. However, the data are very variable; for instance, Li *et al.*, (2018) reported an increase in WP by 7.7% at air temperatures ranging from 15 to 20°C without significant effects over 20°C. Li *et al.* 2018 also stated that straw mulching significantly increased potato WP by 8.3% in areas with low water input, but had no significant effect in areas with high water input. When combining zero-tillage and rice-straw mulching, about 200 mm of irrigation (compared with conventional tillage) water can be saved, thereby reducing the water footprint (Sarangi *et al.*, (2020). Li and Hou (2015) reported that straw mulch in potato increased yield and water use efficiency by 37.3%, and 41.2%, respectively, when compared with the conventional tillage treatment.

**Rice equivalent yield and economics of rice – potato sequence:** Highest rice equivalent yield (14.86 t/ha) was recorded with T2 which was significantly higher than all other treatments except T5 and T7. Highest cost of cultivation ₹ 2,19,747/ha of rice - potato sequence was recorded with T2. Highest gross return of rice - potato cropping system was recorded with T2 (₹ 350143/ha) which was significantly higher than all other treatments except T5 & T7. Highest net return was recorded with T5 (₹ 143732/ha) which was significantly higher than all other treatments. Highest B:C was recorded with T5 (1.73) which was significantly higher than T4, T6 & T7. Soil treated with crop residues contained 5–10

times more aerobic bacteria and 1.5–11 times more fungi than soil from which residues were either burned or removed. However, it should be noted that, to obtain a significant improvement in soil health through minimum tillage, a certain set of 3–5 years is required. This could be caused by the reduction in soil water evaporation promoted by soil temperature reduction and moisture retention. Sarangi *et al.*, (2020) state that rice-straw mulching can eliminate weed germination, so there is no need for the intercultural operations required in conventional practices which reduces on cost of cultivation. Singh *et al.*, (2023) reported that zero-tillage was beneficial for potato cultivation under rice – potato sequence.

## CONCLUSION

The adoption of zero-tillage with mulching in potato cultivation resulted in enhanced yield, profitability, and water productivity, alongside a probable elevation in soil organic carbon (SOC) levels. It also achieved complete savings in chemical weed control and machinery costs associated with ploughing and digging. However, this practice entailed additional expenses for paddy straw mulch (requiring 12–15 t/ha), challenges such as rat infestations in mulched plots, disturbances by dogs, and the need for extra labor during mulching. Consequently, while zero-tillage with mulching holds substantial potential to drive agro-ecological transformation, effective management of these challenges- particularly the labor- intensive and costly processes of spreading paddy straw at planting and harvest- is essential.

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## 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

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# STRENGTHENING SEED POTATO AGRONOMY THROUGH ORGANIC AND PHOSPHORUS NUTRITION BASED INTERVENTIONS

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**ABSTRACT:** Punjab contributes significantly to India's seed potato supply, yet its potato productivity remains below expectations. Poor nutrient management, particularly phosphorus, is a key factor in this underperformance. This study, conducted over two years in Ludhiana and Jalandhar, utilized a split-plot design to test three organic treatments (farmyard manure, biofertilizer, control) and five phosphorus fertilizer levels (46.9, 62.5, 93.8, 125, 0 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>). Farmyard manure (FYM) significantly increased plant height, LAI, and tuber and haulm weights at 45 and 75 days after sowing (DAS) compared to other organic treatments. FYM consistently outperformed tuber yield compared to other treatments in both locations and years. Phosphorus application at 125 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> enhanced tuber yield by up to 24% compared to unfertilized plots, with improvements in plant growth attributes. The highest tuber yields were achieved with FYM (50 t ha<sup>-1</sup>) and phosphorus levels up to 125 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>), underscoring the effectiveness of these strategies in optimizing seed potato production.

**KEYWORDS:** Seed potato, Farmyard manure, Biofertilizer, Phosphorus and Fertilizer

## INTRODUCTION

In Punjab, a staggering 85 percent of the country's seed potato demand is met, with seed potato farming occupying about 60 percent of the state's potato cultivation area (Singh *et al.*, 2024). Yet, despite this massive contribution, the region's potato productivity lags far behind, this is notably lower compared to the national average of 241.2 q ha<sup>-1</sup> (Anonymous, 2022). The weak performance of Punjab's seed potato cultivation is largely due to poor nutrient management strategies, with phosphorus nutrient being a key factor. Phosphorus is the second most limiting nutrient after nitrogen, and its effective management is crucial not just for increasing yield but also for improving tuber quality, disease resistance, and overall agricultural efficiency (Rosen and Bierman,

2008). Research has shown that phosphorus significantly boosts tuber numbers and size, which in turn maximizes productivity (Kelling *et al.*, 2020). On the flip side, poor phosphorus management can result in fewer tubers per plant and disrupt key physiological processes like tuber emergence and tuber initiation (Cui *et al.*, 2020). Soratto and Fernandes (2016) reported that higher phosphorus levels increased dry matter accumulation, nutrient uptake, and overall tuber yield. Moreover, efficient phosphorus use is vital to avoid long-term degradation of soil health and to maintain the quality of seed potato production (Hopkins *et al.*, 2008).

For Punjab to truly harness its potential, an integrated approach combining organic, inorganic, and biofertilizer sources is essential. This study is focused on exploring

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the effects of various nutrient sources on seed potato crops. The goal is to revolutionize potato farming practices in subtropical regions, providing solutions that could push productivity beyond current limitations. The future of Punjab's potato farming depends on smarter nutrient management and a commitment to sustainable agricultural practices.

## MATERIAL AND METHODS

### Experimental Area and Climate Overview

The field experiment took place in Autumn 2019 and 2020 at two Punjab locations (School of Organic Farming, Punjab Agricultural University, and Farmer Field, Jalandhar) in subtropical northwest India. Ludhiana [Ldh] (30°56' N, 75°52' E, 247 m) lies in the 'Trans-Gangetic' agro-climatic zone, with temperatures ranging from over 46°C in June to below 5°C in December, and 75% of the 759 mm annual rainfall occurring from July to September. Jalandhar [Jal] (31°32' N, 75°57' E, 228 m) experiences similar conditions, with summer highs exceeding 39.4°C and winter lows below 6°C, averaging 703 mm of rainfall annually. Ludhiana's soil (0-15 cm depth) is loamy sand with a pH of 7.20, 0.50 percent organic carbon, and higher nitrogen (288 kg ha<sup>-1</sup>), phosphorus (26 kg ha<sup>-1</sup>), and potassium (335 kg ha<sup>-1</sup>). Jalandhar's soil, sandy loam with a pH of 6.85, has slightly lower organic carbon (0.43 percent), nitrogen (263 kg ha<sup>-1</sup>), phosphorus (21.6 kg ha<sup>-1</sup>), and potassium (305 kg ha<sup>-1</sup>).

### Treatments and Experimental Design

The experiment employed a split-plot design with three replications. Main plot treatments comprised three organic sources: farmyard manure (FYM) at 50 t ha<sup>-1</sup>, biofertilizer [Biof] consortium at 10 kg ha<sup>-1</sup>, and a control. Subplots included five phosphorus levels: 46.9 (P<sub>75</sub>), 62.5 (P<sub>100</sub>), 93.8 (P<sub>150</sub>), 125 (P<sub>200</sub>), and 0

(P<sub>0</sub>) kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>. FYM was applied during seedbed preparation, while phosphorus and biofertilizer were administered at sowing time. Statistical analyses followed Cochran and Cox's guidelines, assessing normality, variance homogeneity, and treatment interactions. Significant effects (P < 0.05) were analyzed using Fisher's protected LSD test. Data analysis was conducted using the "Doebioresearch" package in R Studio.

### Crop Raising and Data Collection

The experimental field underwent two disc harrow cultivations, followed by two rounds of plowing with a tractor-drawn cultivator, producing a finely prepared seedbed, finalized by planking. The short-duration potato cultivar '*Kufri Pukhraj*' was selected for experimental trials at both locations. Medium-sized tubers (35-45 cm) were planted mid-autumn (Ludhiana: October 9, 2019, and October 16, 2020; Jalandhar: October 28, 2019, and November 13, 2020) in 3.25 m x 4.05 m plots, with 65 cm row spacing and 15 cm plant spacing, at a seed rate of 4.5 t ha<sup>-1</sup>. Irrigation was immediately applied after sowing, with five total irrigations until harvest. Standard seed potato production practices recommended by Punjab Agricultural University, Ludhiana, were followed. Nitrogen (187.5 kg ha<sup>-1</sup>) and potassium (62.5 kg ha<sup>-1</sup>) were supplied through urea and muriate of potash, with half the nitrogen and all potassium applied at sowing and the remaining nitrogen top-dressed 30 days after sowing (DAS). Dehaulming of tubers occurred on January 3, 2019, and January 11, 2020, in Ludhiana, and on February 1, 2019, and February 15, 2020, in Jalandhar. Plant height and leaf area index (LAI) were measured at haulm cutting from five randomly selected plants in each treatment. Plant height was recorded using a measuring tape, and LAI was calculated as the ratio of leaf area to

ground area, reflecting the canopy structure. Tuber and haulm weights were recorded by uprooting two randomly selected plants per treatment. The fresh weights of both tubers and haulms were measured separately using an electronic balance to ensure accuracy. The total yield of tubers was measured from a net plot size of 7.89 m<sup>2</sup>. All tubers and haulms within the experimental area were harvested and weighed to assess the overall yield under each treatment plot.

## RESULT AND DISCUSSION

### Plant height

At both Ludhiana and Jalandhar, plant height increased significantly with the application of FYM at 45 and 75 DAS during both years of the study (Table 1). In Ludhiana, FYM treatment recorded plant heights of 35.3 cm and 56.2 cm at 45 and 75 DAS in 2019-20, and 36.8 cm and 59.6 cm in 2020-21. Similarly, in Jalandhar, FYM consistently resulted in higher plant heights than other treatments at the same crop stages. Biof also performed

better than the unfertilized control at both locations, while the lowest plant heights were observed in the control plots without fertilization. Among phosphorus treatments, P<sub>200</sub> resulted in the higher height of seed crop, with P<sub>150</sub> statistically at par with P<sub>100</sub> and P<sub>200</sub>, while P<sub>0</sub> recorded the lowest heights at Ldh and Jal locations. The enhanced plant height with FYM treatment aligns with the findings of Jaipaul *et al.* (2011), who reported increased height due to the improved nutrient availability from FYM. The phosphorus response is consistent with Kumar *et al.* (2007) and Manorama *et al.* (2017), who noted higher potato plant heights with increased phosphorus rates, which may be attributed to better carbohydrate accumulation and cell growth, as highlighted by Abbasian *et al.* (2018).

### Leaf area index

At both Ludhiana and Jalandhar, FYM significantly increased the leaf area index (LAI) at 45 and 75 DAS during both years of the study (Table 2). In Ludhiana, FYM

Table 1. Effect of organic sources and phosphorus nutrition on plant height of seed potato

Treatment	Plant height (cm)							
	Ldh				Jal			
	45 DAS		75 DAS		45 DAS		75 DAS	
	2019	2020	2019	2020	2019	2020	2019	2020
	Organic source							
Control	28.2	29.5	43.7	46.2	32.6	25.2	49.3	41.1
Biof	30.2	31.5	48.4	51.5	35.1	26.9	55.8	45.1
FYM	35.3	36.8	56.2	59.6	40.9	31.1	64.4	51.9
LSD (p=0.05)	1.6	1.7	3.2	3.3	1.9	1.3	3.4	2.6
	Fertilizer phosphorus							
P <sub>0</sub>	28.2	29.4	43.8	46.3	32.6	25.1	50.0	41.4
P <sub>75</sub>	30.3	31.7	48.2	51.4	35.1	26.7	55.0	44.6
P <sub>100</sub>	31.2	32.6	49.6	52.7	36.1	27.7	56.6	46.1
P <sub>150</sub>	32.6	34.0	51.8	54.9	37.9	29.0	59.3	48.3
P <sub>200</sub>	33.9	35.2	53.7	57.0	39.3	30.0	61.6	49.9
LSD (p=0.05)	1.6	1.8	3.3	3.4	2.1	1.4	3.8	2.7

Table 2. Effect of organic sources and phosphorus nutrition on LAI of seed potato

Treatment	LAI							
	Ldh				Jal			
	45 DAS		75 DAS		45 DAS		75 DAS	
	2019	2020	2019	2020	2019	2020	2019	2020
	Organic source							
Control	1.43	1.51	2.51	2.62	1.65	1.25	2.75	2.24
Biof	1.63	1.75	2.85	3.02	1.94	1.43	3.24	2.56
FYM	2.02	2.16	3.54	3.76	2.38	1.78	4.00	3.19
LSD (p=0.05)	0.14	0.11	0.20	0.18	0.15	0.12	0.22	0.21
	Fertilizer phosphorus							
P <sub>0</sub>	1.46	1.56	2.57	2.70	1.70	1.28	2.84	2.31
P <sub>75</sub>	1.61	1.72	2.81	2.96	1.89	1.40	3.15	2.52
P <sub>100</sub>	1.68	1.80	2.94	3.12	1.98	1.48	3.31	2.66
P <sub>150</sub>	1.80	1.92	3.15	3.33	2.12	1.57	3.55	2.82
P <sub>200</sub>	1.91	2.05	3.35	3.56	2.26	1.68	3.79	3.00
LSD (p=0.05)	0.14	0.15	0.22	0.24	0.18	0.11	0.28	0.20

recorded the highest LAI at 45 DAS and 75 DAS compared to all other organic treatments, with biof also performing better than the unfertilized control, which had the lowest LAI. Similarly, in Jalandhar, FYM consistently resulted in significantly higher LAI at 45 and 75 DAS, with biof outperforming the control. Among phosphorus treatments, P<sub>200</sub> achieved the highest LAI at these stages at Ldh and Jal, with P<sub>150</sub> statistically at par with P<sub>100</sub> and P<sub>200</sub>. The lowest LAI was recorded with P<sub>0</sub> at 45 and 75 DAS across both years. These findings are consistent with Koireng *et al.* (2018), who reported increased LAI with FYM, and Kumar *et al.* (2007), who observed a positive correlation between phosphorus levels and LAI due to enhanced cell elongation and division.

### Tuber and haulm weight

The application of FYM resulted in markedly higher tuber and haulm weights compared to other organic treatments (Table 3 and 4), with bio significantly surpassing the unfertilized control, which exhibited

the lowest tuber and haulm weights. The increased tuber and haulm weights with FYM can be attributed to the enhanced plant height and leaf area index (Table 4). Similar findings were reported by Asghari *et al.* (2016) and Alemayehu *et al.* (2020), who observed greater tuber and haulm weights under FYM application compared to control other organic manures. Statistical analysis revealed that P<sub>200</sub> phosphorus application yielded the highest tuber and haulm weights among the phosphorus treatments in both Ludhiana and Jalandhar, except for the P<sub>150</sub> phosphorus level, which showed comparable results for tuber weight and haulm. The lowest tuber and haulm weights were recorded with unfertilized phosphorus. The superior tuber and haulm weight with P<sub>200</sub> could be attributed to enhanced cell elongation and division in the root zone, which led to increased biomass accumulation per plant. These results are consistent with Teshome *et al.* (2018) and Fernandes *et al.* (2016), who also reported higher tuber and

**Table 3. Effect of organic sources and phosphorus nutrition on tuber weight per plant of seed potato**

Treatment	Tuber weight (g plant <sup>-1</sup> )							
	Ldh				Jal			
	45 DAS		75 DAS		45 DAS		75 DAS	
	2019	2020	2019	2020	2019	2020	2019	2020
Organic source								
Control	43.1	45.3	232.6	238.8	48.5	38.6	246.2	218.9
Biof	47.1	50.4	254.9	267.1	54.9	43.1	280.9	246.1
FYM	54.4	58.3	296.8	311.9	62.9	50.1	324.6	283.7
LSD (p=0.05)	2.7	3.3	16.2	16.5	3.4	2.5	19.3	14.7
Fertilizer phosphorus								
P <sub>0</sub>	43.2	45.4	233.9	239.3	48.8	39.0	248.8	222.1
P <sub>75</sub>	46.8	50.0	253.6	265.8	53.8	42.7	276.3	242.9
P <sub>100</sub>	48.1	51.4	261.1	273.2	55.4	44.0	284.5	249.9
P <sub>150</sub>	50.4	53.9	273.4	286.5	58.3	46.1	299.1	261.7
P <sub>200</sub>	52.6	56.1	285.1	298.3	60.6	47.9	310.9	271.4
LSD (p=0.05)	3.3	3.5	18.3	19.9	4.4	3.0	22.6	17.4

**Table 4. Effect of organic sources and phosphorus nutrition on haulm weight per plant of seed potato**

Treatment	Haulm weight (g plant <sup>-1</sup> )							
	Ldh				Jal			
	45 DAS		75 DAS		45 DAS		75 DAS	
	2019	2020	2019	2020	2019	2020	2019	2020
Organic source								
Control	48.8	52.2	87.2	94.8	53.4	44.5	96.1	79.4
Biof	55.8	61.4	104.4	114.1	64.1	51.4	120.1	94.3
FYM	68.1	73.7	126.8	137.8	76.2	62.4	142.1	113.9
LSD (p=0.05)	4.1	4.4	9.1	8.5	4.3	3.3	8.2	7.2
Fertilizer phosphorus								
P <sub>0</sub>	50.1	54.4	90.4	98.6	55.3	45.8	100.1	81.9
P <sub>75</sub>	54.1	59.3	100.0	109.8	61.4	49.8	114.4	91.0
P <sub>100</sub>	57.4	62.2	105.8	115.3	64.2	52.3	119.5	95.5
P <sub>150</sub>	61.3	66.2	114.0	123.7	68.9	56.2	127.8	102.4
P <sub>200</sub>	65.0	70.3	120.5	130.5	73.0	59.7	135.2	108.6
LSD (p=0.05)	3.9	4.6	8.3	8.9	5.5	3.9	9.8	7.8

haulm weights with increased phosphorus application in potatoes.

**Total tuber yield**

Tuber yield is a critical metric for evaluating the effectiveness of various treatments and

selecting the best strategy for enhancing seed potato production. The pooled data presented in Table 5 reveal that farmyard manure (FYM) significantly increased tuber yields, with up to a 30 percent increase compared to the control at Ludhiana and Jalandhar. This

**Table 5. Effect of organic sources and phosphorus nutrition on total tuber yield**

Treatment	Total tuber yield (q ha <sup>-1</sup> )			
	Ldh		Jal	
	2019-20	2020-21	2019-20	2020-21
	Organic source			
Control	265.0	269.2	277.6	251.6
Biof	290.5	299.5	315.1	281.0
FYM	339.8	349.7	363.3	322.6
LSD (p=0.05)	17.9	18.8	22.0	17.7
	Fertilizer phosphorus			
P <sub>0</sub>	266.9	269.2	280.1	255.3
P <sub>75</sub>	289.6	298.0	309.6	277.1
P <sub>100</sub>	298.1	306.4	318.9	285.0
P <sub>150</sub>	312.2	321.5	335.6	298.5
P <sub>200</sub>	325.5	334.9	349.0	309.5
LSD (p=0.05)	21.2	22.4	25.8	20.2

improvement is attributed to better nutrient availability and soil conditions provided by FYM, which aligns with findings by Moore *et al.* (2011) and Koroto (2017), who also reported enhanced tuber yields with FYM. In addition to organic sources, phosphorus application also played a significant role in increasing tuber yields. Phosphorus levels up to P<sub>200</sub> resulted in up to a 24 percent higher tuber yield compared to unfertilized plots (P<sub>0</sub>). The P<sub>150</sub> phosphorus level showed similar results to P<sub>100</sub> and P<sub>150</sub>. Increased tuber yield with higher phosphorus levels is attributed to enhanced cell division, elongation, and photosynthesis, leading to greater starch synthesis and tuber development. This observation is consistent with Kumar *et al.* (2007) and Nyiraneza *et al.* (2017), who noted that phosphorus promotes above-ground biomass growth and starch accumulation, thereby boosting tuber productivity. Overall, the results underscore the effectiveness of both FYM and phosphorus nutrition in increasing tuber productivity, highlighting their importance in optimizing seed potato production strategies.

## CONCLUSION

The study confirms that farmyard manure (FYM) and phosphorus nutrition substantially improved plant growth and tuber yield in seed potatoes. FYM increased plant height, leaf area index (LAI), tuber and haulm weights significantly at 45 and 75 days after sowing (DAS) at both Ludhiana and Jalandhar. The application of FYM resulted in up to 30 percent higher tuber yields compared to the control, supported by better nutrient availability and soil conditions. Phosphorus application further enhanced tuber yield, with 125 kg/ha showing up to a 24 percent increase compared to unfertilized plots. The observed improvements in tuber yield with higher phosphorus levels are linked to enhanced cell division, elongation, and photosynthesis. The study also highlights that while FYM and phosphorus fertilization are effective individually, their interaction did not significantly affect growth attributes. These findings emphasize the importance of both FYM and phosphorus in optimizing seed potato production.

## 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

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# A COMPARATIVE STUDY OF POTATO FARMERS' EARNINGS IN CONTRACT FARMING AND OPEN MARKET OPERATION

Abhijit Das<sup>1\*</sup>, Antonio Richard<sup>2</sup> and Debjani Das<sup>3</sup>

**ABSTRACT:** Contract farming has gained attention as a market mechanism to stabilize farm incomes and reduce risks, yet its effectiveness remains debated. This study examines the economic differences between contract and open-market potato farmers in Punjab, focusing on profitability, yield, and market dynamics. Using primary data collected over two years, the analysis applies Propensity Score Matching (PSM) and Difference-in-Differences (DID) to assess financial outcomes. The findings indicate that while contract farming offers stability and input support, open-market sales may provide higher price flexibility. Policy recommendations emphasize the need for balanced contract terms, better price transparency, and institutional support to enhance farmers' economic benefits.

**KEYWORDS:** Contract farming, Farmers' earnings, Market price, Open-market sales, Sustainable agriculture

## INTRODUCTION

Agriculture continues to play a central role in the economy of Punjab, where potato cultivation represents an important commercial activity contributing significantly to farm income and rural employment. In the 2023–24 agricultural season, Punjab recorded potato production of approximately 3.24 million tonnes over an area of about 117,066 hectares, with major production concentrated in districts such as Jalandhar, Hoshiarpur, Kapurthala, Ludhiana, Amritsar, Bathinda, and Fatehgarh Sahib (PAU, 2024). Despite the expansion of cultivated area and improvements in productivity, potato farmers frequently face challenges related to market price volatility, uncertain demand conditions, and fluctuating input costs, which often lead to unstable farm incomes.

Contract farming has emerged as an institutional marketing arrangement intended

to address these risks by providing assured procurement, access to quality inputs, and technical advisory support (Tripathi *et al.*, 2005; Khan *et al.*, 2019). Such arrangements are expected to enhance production efficiency while reducing marketing uncertainty. However, the actual economic outcomes of contract participation remain debated. While some farmers benefit from reduced production risk and organized supply chains, others express concerns regarding limited bargaining power, restricted price flexibility, and the possibility of receiving lower output prices compared to open-market sales (Das and Mishra, 2019). Empirical evidence across regions also presents mixed conclusions, suggesting the need for localized assessments that consider both production efficiency and income dynamics over time.

While several previous studies have examined the economic implications of

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contract farming, most analyses rely on cross-sectional comparisons that do not adequately control for selection bias or time-varying income dynamics. The present study contributes new empirical evidence by combining Propensity Score Matching with a panel-based Difference-in-Differences framework using two-year primary data from major potato-growing districts of Punjab. This integrated approach enables simultaneous correction of selection bias and estimation of dynamic income effects, providing district-level empirical insights that remain limited in existing literature.

In this context, a systematic comparative evaluation of contract and open-market potato farming systems becomes essential to understand whether contractual participation generates measurable economic advantages for farmers. The present study therefore examines the differences in cost of cultivation, yield performance, market price realization, and net income between contract and non-contract farmers in Punjab using panel data collected over two agricultural years. By integrating Propensity Score Matching (PSM) to address selection bias and a Difference-in-Differences (DiD) framework to measure income changes over time, the study aims to provide a robust empirical assessment of the income and productivity implications of contract farming. The findings are expected to support evidence-based policy design aimed at improving contractual market systems, strengthening farmer bargaining capacity, and enhancing income stability in the potato sector.

## MATERIALS AND METHODS

### Study Area and Sampling

The study is conducted in five districts of Punjab: Jalandhar, Ludhiana, Amritsar, Patiala and Bathinda selected based on

potato production and market structure. A stratified random sampling method was used, with a total sample of 400 farmers: 200 contract farmers and 200 open-market farmers, approximately proportionally distributed across districts according to regional potato cultivation intensity. A comprehensive list of potato growers was obtained from district agriculture offices, farmer producer organizations, and contracting firms operating in the selected districts. Contract farmers were verified through company procurement records and farmer agreements, while open-market farmers were confirmed as non-contract participants through cross-verification with procurement agencies and self-reported marketing channels. The same farmers were surveyed in both years, thereby forming a balanced panel dataset. Data on cost of cultivation, yield, and prices were collected through structured interviews supported by farm records wherever available, while recall information was limited to the most recent production season to minimize recall bias.

### Data Collection

Primary data is collected over two years through structured surveys and interviews, covering input costs, yield levels, price realization, and income variability.

### Analytical Framework

**Propensity Score Matching (PSM):** Because farmers self-select into contract farming, simple comparison between contract and open-market farmers may produce biased estimates. Therefore, Propensity Score Matching (PSM) was employed to construct a comparable control group of open-market farmers based on observable pre-treatment characteristics. Nearest-neighbour matching with replacement was employed using one-to-one matching within the region of common

support. Matching quality was assessed through standardized mean difference reduction and t-tests of covariate balance before and after matching. Bias reduction (%) was calculated as the percentage decline in standardized mean differences following matching.

The probability of participation in contract farming was estimated using a logistic regression model, where the dependent variable took the value 1 for contract farmers and 0 for open-market farmers. Explanatory variables included farm size, education level, access to credit, input cost per acre, and yield level. Based on the estimated propensity scores, nearest-neighbor matching was performed within the common support region to match each contract farmer with a statistically similar open-market farmer, and the matched sample was used for subsequent impact analysis. Das *et al.*, 2024; Munshi *et al.*, 2024 also adopted PSM for impact analysis.

$$\log (P_i / 1-P_i) = \beta_0 + \beta_1 (Farm\ Size_i) + \beta_2 (Education_i) + \beta_3 (Credit\ Access_i) + \beta_4 (Input\ Cost_i) + \beta_5 (Yield_i) + \epsilon_i$$

Where:

$P_i$  represents the probability of a farmer adopting contract farming.

$\beta_0$  is the intercept.

$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$  are coefficients estimating the effect of explanatory variables.

$\epsilon_i$  is the error term.

**Difference-in-Differences (DID):** To measure the dynamic income impact of contract farming, a Difference-in-Differences (DiD) framework was employed using panel data collected over two agricultural years. The DiD method compares the change in income of contract farmers (treatment group) before and after participation with the corresponding change observed among open-market farmers (control group). This approach helps isolate

the effect of contract participation by removing time-specific shocks that may simultaneously influence both groups, such as climatic variations, price fluctuations, or macroeconomic changes.

The empirical specification is represented as:

$$Y_{it} = \alpha + \beta_1 D_i + \beta_2 T_t + \beta_3 (D_i T_t) + \epsilon_{it}$$

Where:

$Y_{it}$  = farm income of farmer  $i$  in period  $t$

$D_i$  = Contract farming dummy (1 = contract, 0 = open-market)

$T_t$  = Time dummy (1 = post-contract, 0 = pre-contract)

$D_i T_t$  = Interaction term capturing contract impact

## RESULTS AND DISCUSSION

### Sample Distribution

The study was conducted across five major potato-producing districts in Punjab: Jalandhar, Ludhiana, Amritsar, Patiala, and Bathinda. A total of 400 farmers were selected using a stratified random sampling approach, ensuring equal representation of contract and open-market farmers (Table 1).

Jalandhar and Ludhiana had the highest number of respondents, given their prominence in contract farming and well-established market linkages. Amritsar and Patiala were chosen to represent regions with both contract and open-market sales, while

**Table 1. Sample Distribution Across Districts**

District	Total Farmers	Contract Farmers	Open-Market Farmers
Jalandhar	90	45	45
Ludhiana	85	42	43
Amritsar	75	38	37
Patiala	80	40	40
Bathinda	70	35	35
Total	400	200	200

Bathinda was included for its dominance in open-market transactions. The sample was structured as follows:

The selection of these districts ensures regional diversity in the study, capturing variations in farming practices, market access, and pricing mechanisms. Data collection spanned two years, allowing for a comprehensive assessment of both seasonal and annual trends in contract and open-market sales.

### Propensity Score Matching (PSM) analysis

The Propensity Score Matching (PSM) Balance Test ensures comparability between contract and open-market farmers by minimizing selection bias. Before matching, significant differences existed in farm size, education, credit access, input costs, and yield. After matching, these differences became statistically insignificant, confirming a reliable comparison (Das *et al.*, 2024).

From the Table 2 it is evident that before matching, contract farmers had 1.25 acres larger farms ( $p = 0.022$ ), 2.4 more years of education ( $p = 0.003$ ), and 18.5% higher credit access ( $p = 0.007$ ). Post-matching, differences reduced to 0.18 acres ( $p = 0.496$ ), 0.5 years ( $p = 0.267$ ), and 2.1% ( $p = 0.362$ ), achieving bias reductions of 85.6%, 79.2%, and 88.6%, respectively. Similarly, the input cost difference of ₹3,200 ( $p = 0.014$ ) dropped to ₹450 ( $p = 0.385$ ), and yield disparity of 16.8 quintals ( $p = 0.004$ ) declined to 2.3 quintals ( $p = 0.351$ ), ensuring an unbiased impact evaluation.

Table 2. PSM Balance Test Results

Variable	Before Matching (Mean Difference)	t-Statistic (Before)	p-Value (Before)	After Matching (Mean Difference)	t-Statistic (After)	p-Value (After)	Bias Reduction (%)
Farm Size (Acres)	1.25	2.31	0.022	0.18	0.68	0.496	85.6%
Education (Years)	2.4	3.05	0.003	0.5	1.12	0.267	79.2%
Credit Access (%)	18.5	2.74	0.007	2.1	0.91	0.362	88.6%
Input Cost (₹/Acre)	3,200	2.48	0.014	450	0.87	0.385	85.9%
Yield (Quintals)	16.8	2.89	0.004	2.3	0.93	0.351	86.3%

The common support zone analysis (Fig.1) further validates the matching process by illustrating the density distribution of propensity scores for both contract and open-market farmers. The graph shows that before matching, contract farmers had a higher likelihood of being in structured farming agreements, while open-market farmers had lower propensity scores. After matching, both distributions overlap significantly within the common support range, marked by the vertical dashed lines, ensuring that only comparable farmers were included in the impact analysis. The common support zone eliminates outliers who could have biased the results, making the findings more robust and reliable (Munshi *et al.*, 2024).

### Cost, Yield, Market Price, and Net Income Comparison

A comparative analysis was conducted to evaluate the differences in cost of cultivation,

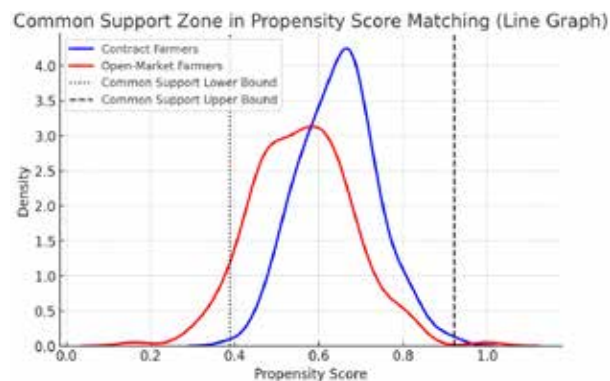


Fig. 1. Common Support Zone

yield, market price, and net income between contract and open-market potato farmers (Table 3). The results indicate statistically significant differences in cost, yield, and market price, while the net income difference was not statistically significant. Mishra *et al.*, 2018 also reported similar finding in their research.

**Cost of Cultivation:** The cost of cultivation per acre was significantly lower for contract farmers (₹45,500) than for open-market farmers (₹48,700) ( $p = 0.038$ ,  $p < 0.05$ ). This 6.6% cost reduction can be attributed to bulk procurement discounts, technical guidance, and reduced input price fluctuations for contract farmers. Open-market farmers faced higher input costs due to fragmented purchases and exposure to market volatility.

**Yield:** Contract farmers achieved a higher yield of 195 quintals per acre, compared to 178 quintals per acre for open-market farmers ( $p = 0.014$ ,  $p < 0.05$ ). This 9.6% yield advantage is primarily due to access to superior seed varieties, recommended agronomic practices, and timely input supply under contract agreements. In contrast, open-market farmers faced yield variability due to inconsistent input quality and limited technical support.

**Market Price:** Contract farmers received a lower average market price of ₹1,200 per quintal, whereas open-market farmers secured ₹1,350 per quintal ( $p = 0.071$ ,  $p < 0.10$ ). This 11.1% price difference reflects the trade-off in contract farming, where price stability and

assured sales come at the cost of slightly lower prices. Open-market farmers, while benefiting from potentially higher prices, were more vulnerable to market fluctuations and price uncertainty.

**Net Income:** The net income for contract farmers (₹1,89,000 per acre) was slightly lower than for open-market farmers (₹1,92,300 per acre), but this difference was not statistically significant ( $p = 0.364$ ). The cost savings and higher yields in contract farming compensated for the lower market price, leading to comparable profitability. However, open-market farmers, despite earning a slightly higher income, faced greater financial risk due to unpredictable price variations.

The statistical significance in cost, yield, and market price differences confirms that contract farming enhances production efficiency and reduces cost burdens, while the insignificant difference in net income suggests that both systems can be financially viable depending on risk tolerance and market conditions. Net income per acre was calculated as the difference between gross revenue and total cost of cultivation. Gross revenue was obtained by multiplying yield per acre by the average realized market price.

The pattern of higher yields but relatively lower output prices among contract farmers reflects a commonly observed trade-off in contract farming systems. Previous studies have shown that contracting firms often provide improved seed varieties, extension

Table 3. Cost, Yield, Market Price, and Net Income Comparison

Category	Contract Farmers (Avg. per Acre)	Open-Market Farmers (Avg. per Acre)	Difference (%)	t-Statistic	p-Value	Significance Level
Cost of Cultivation (₹)	45,500	48,700	-6.6%	-2.10	0.038	$p < 0.05$ (Significant)
Yield (Quintals)	195	178	+9.6%	2.48	0.014	$p < 0.05$ (Significant)
Market Price (₹/Quintal)	1,200	1,350	-11.1%	-1.82	0.071	$p < 0.10$ (Moderately Significant)
Net Income (₹)	1,89,000	1,92,300	-1.7%	-0.91	0.364	Not Significant

support, and timely input supply, which enhance productivity and reduce production risk, leading to higher yields (Mishra *et al.*, 2018; Khan *et al.*, 2019). However, procurement prices under contracts are typically pre-determined, limiting farmers' ability to benefit from peak market prices. Similar evidence has been reported in developing-country contract farming contexts where productivity gains compensate for reduced price flexibility. The present findings therefore align with existing empirical literature while providing localized evidence from Punjab's potato sector.

### Logistic Regression Analysis

A logistic regression model was applied to estimate the probability of adopting contract farming, considering key socio-economic and farm-specific factors.

The logistic regression model estimates the probability of a farmer adopting contract farming based on key factors (Table 4). The intercept is negative (-1.562,  $p = 0.017$ ), indicating that without considering other factors, the likelihood of contract farming adoption is low.

Farm size has a significant positive effect on contract farming participation, with a coefficient of 0.865 ( $p = 0.021$ ). This means that for each additional acre of land, the odds of adopting contract farming increase by 2.38 times. Larger farms may provide

better economies of scale, making contract agreements more viable.

Education level also plays a crucial role, with a coefficient of 0.195 ( $p = 0.006$ ), meaning that an additional year of schooling increases the odds of contract farming participation by 1.22 times. Educated farmers are more likely to comprehend contract terms, manage risks, and engage with contracting firms effectively. Similar findings reported by Trey and Brindal, 2015.

Credit access positively influences adoption, as shown by the coefficient of 0.029 ( $p = 0.026$ ). Farmers with better access to credit are 1.03 times more likely to enter contract farming. This suggests that financial support reduces liquidity constraints, allowing farmers to meet contract requirements.

Input cost per acre negatively impacts contract farming participation, with a coefficient of -0.00048 ( $p = 0.011$ ). Though small, this suggests that higher input costs reduce the likelihood of contract adoption, possibly because some contracts require farmers to purchase specific inputs at fixed prices. The odds ratio of 0.99 indicates a slight decline in participation as costs increase. Kawsar *et al.*, 2013 also reported parallel findings.

Yield levels have a positive and significant impact, with a coefficient of 0.071 ( $p = 0.011$ ). This means that for every additional quintal of yield, the odds of adopting contract farming increase by 1.07 times. Higher yields may make contract farming more attractive by ensuring stable production and profitability. Das and Mishra, 2020 reported similar trend in their research on tea.

Overall, the results highlight that farm size, education, credit access, and yield positively influence contract farming adoption, while higher input costs act as a deterrent. Addressing cost concerns and

**Table 4. Logistic Regression Analysis**

Variable	Coefficient (β)	Standard Error	p-Value	Odds Ratio
Intercept	-1.562	0.654	0.017	-
Farm Size (Acres)	0.865	0.374	0.021	2.38
Education (Years)	0.195	0.071	0.006	1.22
Credit Access (%)	0.029	0.013	0.026	1.03
Input Cost (₹/Acre)	-0.00048	0.00019	0.011	0.99
Yield (Quintals)	0.071	0.028	0.011	1.07

improving credit accessibility could further encourage participation in contract farming models.

**Long-Term Impact Using Difference-in-Differences (DID)**

The Difference-in-Differences (DiD) approach was employed to examine whether income changes over time differed significantly between contract and open-market farmers after controlling for baseline differences. This method isolates the net income effect attributable to contract participation by comparing the change in income of the treatment group with the corresponding change observed in the control group (Nguyen *et al.*, 2015).

The estimates presented in Table 5 indicate that although open-market farmers recorded slightly higher income levels in both years, the magnitude of income growth during the study period was nearly similar for the two groups. Contract farmers experienced an income increase of ₹60,000, while open-market farmers reported an increase of ₹62,000 over the same period. The DiD estimator therefore indicates a marginal differential change of ₹2,000 in favour of open-market farmers, which was statistically insignificant.

The results imply that participation in contract farming did not generate a statistically significant additional income gain over time compared to open-market sales. Nevertheless, the relatively stable income growth observed among contract farmers

reflects the role of contractual arrangements in reducing marketing uncertainty and income variability, even when price advantages occasionally favour open-market transactions (Khan *et al.*, 2019; Mishra *et al.*, 2018).

**CONCLUSION**

The study compared the economic performance of contract and open-market potato farmers in Punjab using Propensity Score Matching and Difference-in-Differences approaches based on two-year panel data. The empirical results demonstrate that contract farming significantly reduces cultivation costs and improves yield performance, reflecting the role of input support, technical guidance, and organized production practices provided under contractual arrangements. However, contract farmers received relatively lower output prices compared with open-market farmers, which offset the gains achieved through higher productivity and lower costs. The analysis shows that differences in net income between contract and open-market farmers were statistically insignificant. Difference-in-Differences estimates further indicate that income growth over time was similar across both groups, suggesting that contract participation did not generate an additional measurable income advantage during the study period. These findings provide statistical evidence that contract farming improves production efficiency but does not necessarily enhance farm income under existing pricing structures. From an interpretive perspective, contract farming appears to function primarily as

**Table 5. Difference-in-Differences Analysis**

Year	Contract Farmers (₹/Farmer)	Open-Market Farmers (₹/Farmer)	Difference (DID Impact, ₹)	t-Statistic	p-Value	Significance Level
Year 1	3,20,000	3,30,000	-10,000	-1.48	0.139	Not Significant
Year 2	3,80,000	3,92,000	-12,000	-1.67	0.097	<i>p</i> < 0.10 (Moderately Significant)
Change	+60,000	+62,000	-2,000	-0.55	0.584	Not Significant

a risk-management and market-assurance mechanism rather than a guaranteed income-enhancing strategy. The relative stability offered through assured procurement and input access may still be valuable for farmers facing price uncertainty, even when average income gains remain comparable to open-market participation. Policy efforts should therefore focus on improving transparency in contract pricing, incorporating flexible price-linking mechanisms with market trends, and strengthening institutional monitoring to ensure equitable agreements between farmers and contracting firms. Enhancing farmer awareness and bargaining capacity may further improve the long-term effectiveness and sustainability of contract farming systems in the potato sector.

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## 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.

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# IMPACT OF NANO-FERTILIZERS ON TUBER YIELD AND MORPHOLOGICAL TRAITS OF POTATO VAR. SPIRIT IN SEMI-ARID CONDITION

Mojtaba Nouraein<sup>1\*</sup> and Mohsen Janmohammadi<sup>1</sup>

**ABSTRACT:** In recent years, the use of nano-fertilizers has gained attention for increasing agricultural productivity, especially in potato cultivation. This study aimed to evaluate the effects of nano, bio, and conventional fertilizers on tuber yield and key agronomical traits of the Spirit potato variety. The experiment was performed using a randomized complete block design with three replicates. Six nutritional treatments were tested: control, NPK, Mog biofertilizer, nano-chelated calcium (Nano-Ca), nano-chelated zinc + boron (Nano-Zn+B), and a complete nano-chelated fertilizer. An effective biplot approach (treatment trait) was used to visualize interactions and assess relationships among treatments, traits, and their combined effects. The first and second principal components explained 92% of the total variance. Among the measured traits; tuber weight per plant, leaf number per plant, mean tuber weight, total tuber yield, number of tubers per plant, days to flowering, dry matter content, and starch content, the complete nano-chelated fertilizer showed the highest performance. Based on the ideal treatment biplot model, this fertilizer was closest to the ideal position, performing best across all traits. It proved to be the most effective treatment for maximizing tuber yield, followed by NPK, Nano-Zn+B, and Nano-Ca treatments. This study highlights the potential of nano-fertilizers as an efficient and environmentally friendly approach to improving potato yield in semi-arid regions. The results suggest that using complete nano-fertilizers can significantly enhance agricultural practices in such areas, leading to higher yields and more efficient resource use.

**KEYWORDS:** nano-B, nano-Ca, nano-Zn, tuber yield, yield components

## INTRODUCTION

Potato is one of the major food crops of world, grown on about 17 million hectares with a total production of 383 million *tons*. In Iran, potato cultivation spans 80,000 hectares, producing roughly 2.5 million tons annually (FAOSTAT 2023). However, potato yields are often limited by several factors, particularly low soil fertility, which is linked to poor organic matter content and restricted availability of essential nutrients. These conditions lead to declining productivity. According to Alkharabsheh *et*

*al.* (2021), such challenges also contribute to soil erosion as well as soil degradation. To address these issues, replenishing nutrients and improving soil quality through fertilizer application is necessary (Dimkpa *et al.*, 2023). Conventional bulk fertilizers have shown limited effectiveness in maintaining high yields, as they are often associated with increased soil acidity, nutrient leaching, and deterioration of soil physical properties (Agegnehu *et al.*, 2021).

Repeated use of bulk fertilizers can further worsen soil health. As a result, alternative

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fertilization strategies, such as bio-fertilizers and the newly developed nano-fertilizers, have gained increasing attention. Studies indicate that nano-fertilizers can deliver essential nutrients more efficiently while enhancing soil quality (Sabaghnia 2015; ul Ain *et al.*, 2023). Avila-Quezada *et al.* (2022) reported that nano-fertilizers supply key nutrients; nitrogen, phosphorus, and potassium, in amounts comparable to mineral fertilizers, with added advantages over conventional bulk fertilizers.

The introducing of nanotechnology in agriculture has been relatively slow, but nano-fertilizers offer great potential to improve nutrient use efficiency. Their uptake by plants can occur through complexation, endocytosis, or ion channels, allowing more effective nutrient delivery due to their nanoscale size. This small size enables nano-fertilizers to access plant surfaces and internal transport pathways more efficiently than conventional fertilizers (Janmohammadi *et al.*, 2017b; Babu *et al.*, 2022). Silica nanoparticles have successfully delivered cargo into plant cells (Niazian *et al.*, 2021), suggesting that nano-fertilizers may have higher solubility and reactivity than their bulk counterparts. The development of nano-sized fertilizer formulations is expected to enhance fertilizer efficiency rather than hinder it. In major potato-producing regions, nutrient management is intensive and heavily reliant on chemical fertilizers (Xu *et al.*, 2022). This dependence has reduced the emphasis on crop rotation, which is important for maintaining soil fertility and nutrient balance. However, information on the interactive effects of potato cropping systems on nutrient dynamics remains limited. Among fertilizers, NPK formulations are the most widely used to increase potato yield (Xu *et al.*, 2025). Phosphorus application has been shown to improve tuber yield (Qiu *et al.*, 2022), while insufficient nitrogen results in

reduced productivity (Shrestha *et al.*, 2023). Micronutrients like boron and zinc are also essential, and their deficiency can significantly lower yield (Sarkar *et al.*, 2024). Commercial application of micronutrients should focus on minimal, optimal, and efficient amounts. Nano-fertilizers have used as an alternative, providing nutrients in sufficient quantities to meet crop requirements effectively (Avila-Quezada *et al.*, 2022).

Current research aimed to assess the reaction of the Spirit potato cultivar to various fertilizer types, including conventional bulk fertilizers, biofertilizers, and nano-sized fertilizers. The main objectives were to identify the most effective fertilizer and to determine the key traits that respond most positively to fertilization. The study was based on the hypothesis that nano-fertilizers can enhance potato yield more effectively than conventional fertilizers.

## MATERIAL AND METHODS

The trial was conducted at the experimental field in Sarab, northwest of Iran in 47°53' East, and 37°93' North coordinates with elevation 1650 m. The region has a steppe climatic property, with mean yearly min and max temperatures of 2°C and 17°C, respectively. The soil of filed was classified as silty clay loam (Table 1), with a pH of 7.8 and an EC of 1.3 dS m<sup>-1</sup> in the topsoil (0-0.3 m depth). The study was conducted using the Spirit potato variety, a late-medium maturity cultivar. Cultivation was done in early April and potatoes were harvested late August. Each experimental plot covered 36 m<sup>2</sup>, consisting

**Table 1. Some soil properties of experimental field (Sarab, Iran)**

P (mg kg <sup>-1</sup> )	K (mg kg <sup>-1</sup> )	Fe (mg kg <sup>-1</sup> )	Cu (mg kg <sup>-1</sup> )
23	517	5.8	2.3
Zn (mg kg <sup>-1</sup> )	Mn (mg kg <sup>-1</sup> )	TNV (%)†	OC (%)‡
1.59	7.62	6.61	1.12

†TNV, Total Neutralizing Value; ‡OC, organic carbon

of eight 6-m length rows, with 0.75 m as row distance and an intra-row distance of 0.25 m between seed pieces. Irrigating of plots was performed weekly to replenish soil humidity decrease regarding the evapotranspiration of region.

The trial followed a randomized block scheme using three replicates. Six nutritional treating were evaluated: (1) control (no fertilizer application), (2) NPK chemical bulk fertilizer (20:10:5), (3) Mog biofertilizer (2 L ha<sup>-1</sup>), (4) Nano-form calcium (Ca, 2 kg ha<sup>-1</sup>), (5) Nano-form zinc and boron (Zn+B, 1 kg ha<sup>-1</sup>), and (6) Nano-complete fertilizer (Com, 1 kg ha<sup>-1</sup>). At chemical bulk fertilizer, 200 kg ha<sup>-1</sup> routine NPK was used: half as a pre-plant application and the remaining half as a post-emergence in the tuber formation stage. the remained treatments were utilized via irrigation water at sowing and during the tuberization stage. Equalization is done by calculating the kg/ha of each nutrient provided by each fertilizer and adjusting the dose so all treatments supply roughly the same total nutrient amount, allowing fair comparison of nutrient source effects. The nano-chelated complete fertilizer contained 11 essential macro- and micronutrients, including nitrogen (5%), phosphorus (3%), potassium (3%), iron (5%), zinc (8%), calcium (6%), magnesium (6%), manganese (0.7%), copper (0.7%), boron (0.1%), and molybdenum (0.7%). The physicochemical properties of the Mog organic fertilizer included nitrogen (4%), potassium oxide (4%), iron (0.4%), copper (0.2%), and some enzymes (13%).

The following agronomic traits were measured: number of tubers per plant (NTP), number of leaves per plant (NL), mean tuber diameter (MTD), tuber weight per plant (TWP), mean tuber weight (MTW), tuber yield (TY, t ha<sup>-1</sup>), days to tuber initiation (DIT), days to row closure (DRC), days to flowering (DF), dry matter content (DM),

starch content (ST), and number of stems per plant (NS). The biplot model based on treatment-trait interaction was generated following the method of Yan (2024), with all biplots produced directly using the GGEbiplot software (Yan, 2001). This analysis visualizes the interactions between genotypes and traits, where each genotype is shown as a vector and each trait as a point. The angle between a genotype vector and a trait vector reflects the strength and direction of the interaction: smaller angles indicate a strong positive association, while larger angles indicate a weaker or no association.

## RESULTS

### Treatment performance in traits

The model explained 92% of the variation in the tester-standardized data, with the first and second components accounting for 80% and 12% of the variation, respectively (Figure 1). The biplot was divided into five

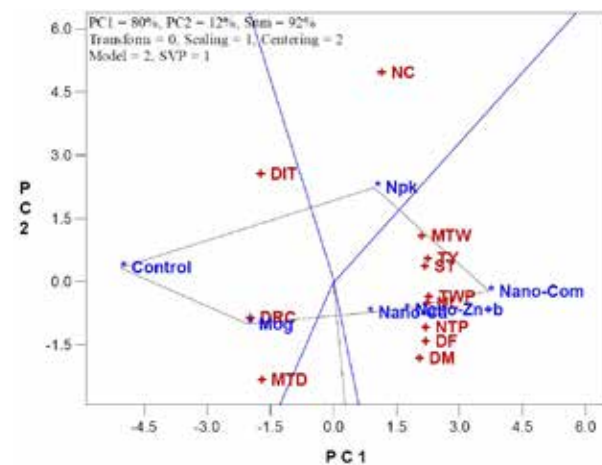


Fig. 1. Polygon-view of TT biplot showing which nano, bio and bulk fertilizer treatment had the highest values for which traits of potato.

Traits: NL, number of leaves per plant; MTD, mean tuber diameter; MTW, mean tuber weight (g); TWP, tuber weight per plant (g); TY, tuber yield (t ha<sup>-1</sup>); NTP, number of tubers per plant; DIT, day to initiation of tuberization; DRC, number of the days to row closure; DF, number of days to flowering; DM, dry matter content (%); and NS, number of stems; ST, percent of starch content.

sections by five rays, with twelve traits distributed across three sections. Vertex treatments in each quadrant represented the highest-performing treatments for the respective traits. NPK treatment showed the highest performance for the number of stems (NS), while Control treatment excelled in days to tuber initiation (DIT), days to row closure (DRC), and mean tuber diameter (MTD). Nano-chelated complete fertilizer (Nano-Com) outperformed other treatments in number of leaves per plant (NL), mean tuber weight (MTW), tuber weight per plant (TWP), tuber yield (TY), number of tubers per plant (NTP), days to flowering (DF), dry matter content (DM), and starch content (ST) (Figure 1). Also, Nano-Ca and Nano-Zn+B exhibited the lowest performance across all twelve traits.

### Trait correlations

Based on the angles of trait vectors in the biplot, two major correlation groups were identified (Figure 2), as Group 1 consist on

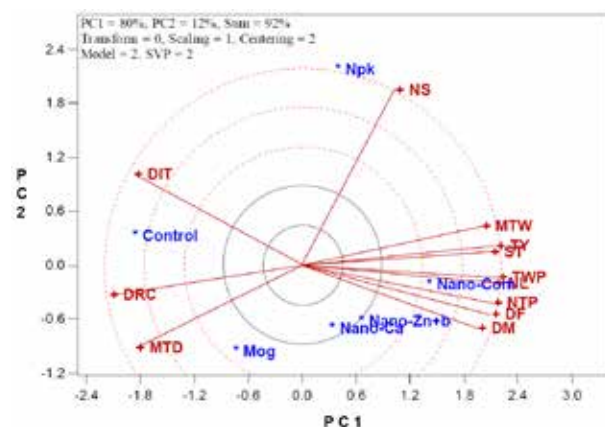


Fig. 2. Vector view of TT biplot showing the interrelationship among measured traits of potato under different nano, bio and bulk fertilizer treatments.

Traits: NL, number of leaves per plant; MTD, mean tuber diameter; MTW, mean tuber weight (g); TWP, tuber weight per plant (g); TY, tuber yield ( $t\ ha^{-1}$ ); NTP, number of tubers per plant; DIT, day to initiation of tuberization; DRC, number of the days to row closure; DF, number of days to flowering; DM, dry matter content (%); and NS, number of stems; ST, percent of starch content.

NL, MTW, TWP, TY, NTP, DF, DM, and ST were positively correlated with each other but negatively associated with DRC and MTD. These traits had no significant association with NS. Also, Group 2 including DRC and MTD were positively correlated, while DIT was negatively associated with Group 1 traits. These relationships can be explained by source-sink dynamics. Carbon fixed during photosynthesis is either metabolized to generate energy and structural carbon for cellular growth or exported, primarily as sucrose, to other organs for development and storage compound synthesis (Janmohammadi *et al.*, 2018). Increased leaf number and leaf area index enhance the ability of plant to supply photo-assimilates, which are essential for growth. Beyond supporting actively growing sink tissues, photo-assimilates contribute to the production of growth-promoting phytohormones (Janmohammadi *et al.*, 2017a). Enhanced flow of photo-assimilates into stolons can accelerate tuberization, reducing DIT. These findings align with previous studies: Das *et al.* (2021) reported positive associations between tuber yield and NL, NTP, MTW, and DM; Asnake *et al.* (2023) indicated a strong positive correlation between tuber yield and MTW; and Gebreselassie *et al.* (2022) demonstrated that both tuber number and weight contributed to final yield, with tuber number having a greater influence.

### Treatment correlations

Analysis of treatment vectors revealed that Nano-Com exhibited a significant negative correlation with the Control, while NPK showed no distinct association with either (Figure 3). Nano-Com, which contains macronutrients (NPK) and micronutrients, appears sufficient to meet the nutritional requirements of potatoes, potentially eliminating the need for other fertilizers. Other treatments showed weak or non-significant

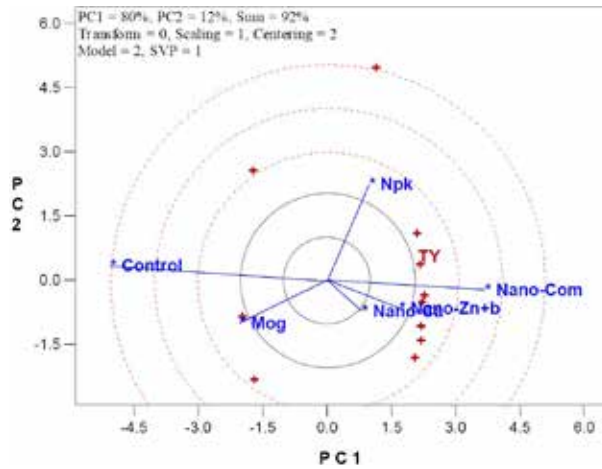


Fig. 3. Vector view of TT biplot showing the interrelationship among fertilizer treatments. TY is tuber yield ( $t\ ha^{-1}$ ).

correlations due to their short vector lengths (Ebrahimi *et al.*, 2023).

### Ideal Fertilizer

The ideal treatment, represented at the center of concentric circles (Figure 4), corresponds to the combination of superior performance across multiple traits. Nano-Com was closest to this ideal point, followed by Nano-Zn+B, Nano-Ca, NPK, and Control. While the effects of NPK and certain micronutrients (Mg, Zn, Mn) are well-

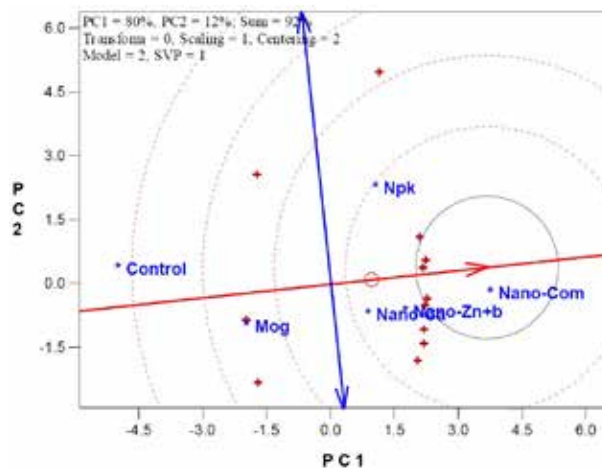


Fig. 4. Ideal entry view of TT biplot, showing the relationships of different nano, bio and bulk fertilizer treatments with ideal entry (treatment) in potato.

documented, data on Fe, Mo, Ca, B, and Cu remain limited (Singh and Maiti, 2022).

### Tuber Yield

The treatment trait biplot (Figure 5) highlighted Nano-Com as the optimal treatment for maximizing TY, followed by NPK, Nano-Zn+B, and Nano-Ca. Nano-Com not only enhanced tuber yield but also promoted other morphological traits associated with tuber development. Combined application of nano zinc plus nano boron, nano calcium, and the three primary macronutrients (N, P, and K) could further optimize productivity, suggesting that while Nano-Com is the most effective standalone treatment, integration of specific nano-fertilizers may enhance results.

### Mechanistic of nano-fertilizers

Nanotechnology in agriculture offers innovative strategies to increase productivity while minimizing environmental impact. Nano-fertilizers increased efficiency of nutrients uptake and decreased nutrient loss by optimizing delivery, maintaining soil structure, and mitigating pollution (Babu *et al.*, 2022). The biplot method proved valuable

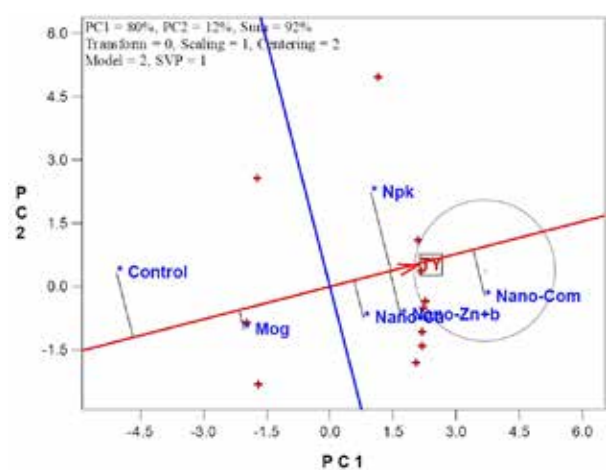


Fig. 5. Vector view of TT biplot, showing the relationships of different nano, bio and bulk fertilizer treatments with tuber yield (TY) of potato. TY is tuber yield ( $t\ ha^{-1}$ ).

for assessing treatment trait interactions, allowing simultaneous evaluation of multiple traits (Yan and Rajcan 2002). In semi-arid regions, such as northwest Iran, low soil fertility makes balanced nutrition critical. Soils are often inadequate for meeting crop nutrient requirements using only macronutrients or micronutrients, and biological/enzymatic fertilizers tend to underperform due to insufficient nutritional thresholds (Nikitin *et al.*, 2022). A complete nano-fertilizer, providing all essential nutrients in nano-sized forms, demonstrated superior performance by enhancing vegetative growth, increasing source strength, and stimulating photoassimilate production.

### Physiological considerations

The higher performance of Nano-Com can be attributed to its ability to supply a broad spectrum of macro- and micronutrients critical for photosynthesis, protein synthesis, stress response, and tuber development (Noulas *et al.*, 2023). Nutrient synergy, particularly the interaction of NPK with Fe, Zn, and B, likely improved nutrient uptake, metabolic processes, and yield (Fan *et al.*, 2021). Nitrogen increases vegetative growing and photosynthesis, while phosphorus maintains root developing and energy transfer process, but potassium controls water balance and stress tolerance, while Zn and Fe enhance enzyme activity, cell wall stability, and hormone regulation (Dhaliwal *et al.*, 2022). Nano-Ca and Nano-Zn+B also improved specific traits such as tuber weight, dry matter, and starch content, but their effects were less pronounced than Nano-Com due to a more limited nutrient profile (Seleiman *et al.*, 2020; Vera-Maldonado *et al.*, 2024).

### Practical advises

The results indicated that Nano-Com is the most promising fertilizer for improving

potato yield and quality, particularly in nutrient-poor, semi-arid soils. Complete nano-fertilizers offer a sustainable strategy for increasing crop yield performance, reducing nutrient losses, and mitigating environmental pollution. Adoption of a holistic nutrient management approach, emphasizing nutrient synergy and balanced nutrition, can improve crop performance not only for potatoes but also for other nutrient-sensitive crops. Next investigations should focus on improving application rates and extending evaluations to other crops to maximize agricultural sustainability and productivity.

### DISCUSSION

In semi-arid regions, such as the test site in northwest Iran, low soil fertility makes balanced nutrition a critical factor for crop production. The inherent properties of these soils are often insufficient to meet crop nutrient requirements with only macronutrients or micronutrients. Furthermore, the unfavorable physical and chemical conditions of semi-arid soils limit the effectiveness of biological and enzymatic fertilizers, as microbial activity depends on minimum nutrient thresholds that are frequently absent in these environments (Nikitin *et al.*, 2022). The application of a complete nano-fertilizer; providing all essential macronutrients and micronutrients in nano-sized forms, demonstrated superior performance. This indicates that in semi-arid regions, supplying a full complement of nutrients is crucial, as synergistic interactions among them can enhance overall nutrient efficiency. The superior effect of the complete nano-fertilizer in this study is likely due to its ability to strengthen source-sink relationships, promoting vegetative growth, increasing sink capacity, and enhancing the production of photo-assimilates.

This study aimed to evaluate the impact of various fertilizers on the growth and yield of the Spirit potato variety, with a particular focus on nano-fertilizer applications. Results revealed significant effects of fertilizer treatments on key growth traits, including tuber yield, dry matter content, starch content, and several morphological characteristics. Among all treatments, the complete nano-fertilizer; containing nanoparticles of essential macro- and micronutrients, produced the most substantial positive effect on tuber yield. These results highlight the importance of balanced nutrition in promoting high crop productivity, especially in semi-arid regions with prevalent nutrient limitations. The observed increase in tuber yield under complete nano-fertilizer treatment can be attributed to more efficient nutrient uptake facilitated by the nano-sized particles. Previous researches have reported that nano-fertilizers enhance nutrient use efficiency by enhancing uptake through plant roots, particularly under conditions where traditional fertilizers are less effective (Pudhuvai *et al.*, 2024; Shoukat *et al.*, 2025). The tiny size and great surface area of nanoparticles allow them to penetrate plant cell walls and interact more efficiently with plant tissues, preparing a more balanced nutrient supply.

The superior performance of the complete nano-fertilizer also stems from its ability to supply a broad spectrum of nutrients needed for several physiologic processes, like photosynthesis, protein synthesis, and stress response. Balanced nutrient provision is particularly critical in semi-arid areas, where soil fertility is low and nutrient imbalances can limit optimal plant growth (Noulas *et al.*, 2023). By delivering a complete range of nutrients in nanoparticle form, the treatment stimulated vegetative growth, enhanced photosynthesis, and increased tuber formation and yield. An important finding of current

research is the role of nutrient synergy in the complete nano-fertilizer. Nutrients interact with one another in complex ways rather than acting in isolation. The synergistic effects of macronutrients (NPK) with micronutrients like iron, zinc, and boron likely contributed to the improved plant performance. This synergy enhances nutrient uptake, metabolic activity, and ultimately, yield (Fan *et al.*, 2021). The addition of micronutrients such as zinc and iron further enhances metabolism, increases stress resilience, and boosts overall productivity (Dhaliwal *et al.*, 2022). Supplying all these nutrients in nanoparticle form ensures a well-rounded nutritional profile, translating into improved tuber yield.

Although, the complete nano-fertilizer was the most effective, other treatments such as Nano-Ca (nano chelated calcium) and Nano-Zn+B (nano chelated zinc and boron) also improved tuber yield and related traits, albeit to a lesser extent. Nano-Ca enhanced the number and weight of tubers, likely due to its role in strengthening cell walls and promoting root development (Seleiman *et al.*, 2020). Nano-Zn+B improved dry matter and starch content, reflecting the importance of zinc and boron in enzyme activity, cell wall stability, and hormone regulation (Vera-Maldonado *et al.*, 2024). However, these single-nutrient applications could not match the effectiveness of the complete nano-fertilizer. The biplot analysis for treatment trait interactions proved valuable for visualizing fertilizer performance across multiple traits. It highlighted that the complete nano-fertilizer consistently outperformed other treatments in key traits such as leaf development, tuber weight per plant, and starch content. Current findings indicated the capability of complete nano-fertilizers to increase potato yield and quality, particularly in nutrient-poor, semi-arid soils.

The obtained results have significant implications for semi-arid regions like northwest Iran, where soil fertility limits crop productivity. Complete nano-fertilizers offer a sustainable strategy for increasing yields while minimizing nutrient loss and environmental impact. By ensuring efficient nutrient uptake and balanced nutrition, their application could improve potato yields, food security, and farmer livelihoods. Current study emphasized the importance of a fertilizer managing that considers nutrient interactions. Traditional fertilization often focuses on individual nutrients, whereas the complete nano-fertilizer demonstrates that balanced, synergistic nutrient delivery yields the best results. This approach can benefit not only potatoes but also other crops grown in nutrient-limited environments. Supplying a full complement of nutrients in nanoparticle form presents a promising solution to the challenges of low soil fertility and environmental stress. Future research should optimize nano-fertilizer application rates and explore their potential across other crops to further enhance agricultural sustainability and productivity.

## CONCLUSION

The study demonstrated that fertilizer type influences growth, tuber yield, and quality of the Spirit potato variety under semi-arid conditions. The complete nano-chelated fertilizer, containing macro-(N, P, K) and micronutrients (Zn, Fe, B, Ca, Mn, Cu) in nanoparticle form, performed better than the other fertilizers across important traits, like leaf number, tuber weight per plant, tuber yield, dry matter, and starch content. The enhanced performance of above treatment is attributed to its balanced nutrient provision, improved source-sink relationships, and synergistic interactions between macro- and

micronutrients, which collectively increase nutrient uptake, photosynthesis, and tuber development. Nano-Ca and Nano-Zn+B also improved specific traits such as tuber weight, dry matter, and starch content, but their effects were less pronounced due to their limited nutrient profiles, while NPK improved stem number but was less effective than Nano-Com in enhancing tuber yield and quality. Based on the results, the recommended quantity for effective nano-fertilizer application is 150 kg ha<sup>-1</sup> of the complete nano-chelated fertilizer, split into three equal applications at vegetative, flowering, and tuber initiation stages. This regimen ensures balanced nutrient supply throughout the growth cycle, maximizing tuber yield and quality while minimizing environmental nutrient losses. Finally, complete nano-chelated fertilizer provided a sustainable and efficient nutrient management strategy for potato cultivation in nutrient-poor, semi-arid soils. Its application can improve productivity, support food security, and serve as a model for integrating complete nano-fertilizers in other nutrient-sensitive crops.

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## 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

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# OPTIMIZING WARE POTATO LONGEVITY AND SPROUT SUPPRESSION VIA NUTRITION MANAGEMENT DURING NON-REFRIGERATED STORAGE

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**ABSTRACT:** In regions with subtropical climates, where farmers often cultivate small and marginal quantities of ware potatoes, storage at ambient temperatures is common, necessitating the use of various storage techniques to prolong shelf life. Employing external substances that stimulate growth is one such method utilized to positively influence the quality of potato tubers during storage. A two-year field experiment conducted in Punjab, India, assessed the effects of farmyard manure (FYM), biofertilizer (Biof), and phosphorus levels on stored ware potato tubers. Results revealed that FYM (50 t/ha) application led to substantially lower weight loss (24.0-26.6%), rotting loss, and sprouting percentages (ranging from 86.0% to 91.1% in Ludhiana and 87.5% to 93.4% in Jalandhar) compared to biofertilizer (10 kg/ha), and the control. Additionally, although not statistically significant, phosphorus levels displayed a consistent trend, with P<sub>200</sub> (125 kg/ha P<sub>2</sub>O<sub>5</sub>) demonstrating the lowest weight loss and rotting loss values. These findings underscore the efficacy of FYM (50 t/ha) in enhancing tuber storage quality and market viability, highlighting the importance of organic amendments and phosphorus management in optimizing storage protocols for potato farming practices.

**KEYWORDS:** Potato storage, Farmyard manure, Biofertilizer, Phosphorus, Shelf life and quality

## INTRODUCTION

Efficient storage is essential for maintaining the marketability and usability of ware potatoes. In regions where affordable refrigerated storage is unavailable, post-harvest losses due to market surpluses, financial setbacks, and food waste become major challenges (Singh *et al.*, 2023). Several physiological factors contribute to quality deterioration during storage, including sprouting, greening, decay, transpiration, and respiration, all of which impact tuber weight, marketability, and nutritional value (Suttle, 2003). Among these, sprouting is particularly detrimental, leading to increased

weight loss, reduced consumer appeal, and nutrient degradation. To enhance food security and minimize storage losses, maintaining optimal storage conditions is critical. While technologies such as refrigeration and surface coatings can extend potato shelf life, their high cost and limited accessibility make them impractical for small-scale farmers. In such cases, on-farm storage emerges as a viable alternative, enabling farmers to store potatoes over extended periods while reducing post-harvest losses (Marwaha, 2011). Various sprout suppression techniques, including chemical inhibitors (Foukaraki *et al.*, 2016), hot water treatment (Hu *et al.*, 2011), and

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packaging modifications (Clark *et al.*, 2002), have been explored to prolong storability.

However, nutrition management has gained attention as a cost-effective and sustainable approach, offering an alternative to synthetic inhibitors and refrigerated storage (Kumar *et al.*, 2020). Nutritional interventions influence key storage-related characteristics, such as physiological weight loss, total weight loss, decay, and sprouting behavior in stored tubers (Kumar *et al.*, 2011). Potatoes hold global significance in agriculture due to their high nutritional value and culinary versatility, with quality attributes such as tuber dry matter content, phenolic compounds, and starch composition playing crucial roles in determining market demand. Phosphorus fertilization enhances these attributes by increasing ascorbic acid concentration (Klein *et al.*, 1980) and promoting starch synthesis (Stark and Love, 2003). Research by Karim (2007) further highlights phosphorus's involvement in starch metabolism, significantly improving starch content. Additionally, Mohamed *et al.* (2021) reported that phosphorus application enhances phenolic compounds, including chlorogenic acid, which contribute to tuber quality. Similarly, farmyard manure (FYM) has been found to improve protein and starch content in potatoes, reinforcing its value as an organic nutrient source (Asghari and Fard, 2016). Given the importance of nutrient management in optimizing post-harvest potato quality, this study aimed to assess the effectiveness of different nutritional strategies in reducing storage losses and enhancing tuber longevity. The findings provide insights into sustainable approaches for improving potato storability, ultimately benefiting market value and sales.

## MATERIAL AND METHODS

A field experiment was conducted in Autumn 2019-20 and 2020-21 at two locations in

Punjab, India: Punjab Agricultural University, Ludhiana, and a farm in Jalandhar. The soil at Ludhiana (loamy sand) and Jalandhar (sandy loam) had EC of 0.30 and 0.32 dS/m, pH 7.20 and 6.85, and organic carbon of 0.50% and 0.43%, respectively. Available N, P, and K were 288 & 263 kg/ha, 26 & 21.6 kg/ha, and 335 & 305 kg/ha, analyzed using standard methods. Using a split-plot design with three replications, the main plot treatments included farmyard manure (50 t/ha), Biof (10 kg/ha), and a control. Subplots had five phosphorus levels: 46.9, 62.5, 93.8, 125, and 0 kg/ha P<sub>2</sub>O<sub>5</sub>. FYM was applied during seedbed preparation; phosphorus fertilizer and Biof at sowing. The 'Kufri Pukhraj' potato cultivar was planted mid-autumn in 3.25 m × 4.05 m plots with 65 cm row spacing and 15 cm plant spacing, using 4.5 t tubers/ha. After sowing, irrigation and recommended cultivation practices were followed. Nitrogen (187.5 kg/ha) and potassium (62.5 kg/ha) were supplied through urea and muriate of potash, with nitrogen split between sowing and 30 days after sowing.

To evaluate the keeping quality of ware-sized potato tubers (those larger than 45 mm), researchers selected a 5-kilogram sample from each growth regulation treatment. These clean tubers underwent a curing process lasting 15 days at a controlled temperature of 25°C to promote proper skin set and healing of surface wounds. Following curing, the samples were placed in storage conditions that mimicked a typical farmer's setup, maintained at ambient temperatures averaging 27°C (with daily highs up to 33°C and lows down to 19°C), for a full period of 120 days. Ample ventilation and air circulation were ensured throughout the storage to prevent moisture buildup and rot. At the conclusion of the 120-day storage duration, detailed records were taken of

any post-harvest losses, including weight reduction, sprouting, rot, or greening.

- a) Total weight loss - The total weight loss (percentage) of each sample, including both physiological and rot loss, was measured by comparing the initial weight of the tubers to their weight after 120 days of storage (Singh *et al.*, 2023).
- b) Rottage loss - The percent tuber rottage was calculated at 120 d using the following formula (Kumar *et al.*, 2023):

$$\text{Rottage (\%)} = \frac{\text{Weight of rotted tubers}}{\text{Weight of unrotted tubers}} \times 100$$

- c) Sprouting - The sprouting percentage was calculated by dividing the number of sprouted tubers by the total number of tubers in the sample and multiplying by 100. The sprout length (mm) was measured for each tuber, and the average length was calculated (Singh *et al.*, 2023).

**Statistical analysis** - All parameters were measured in triplicate (n=3), and the results

were presented as the mean. The data underwent one-way analysis of variance (ANOVA), and significant differences between treatments were assessed using Fisher’s protected least significant difference (LSD) at a significance level of  $P < 0.05$ , utilizing RStudio software (Doebioresearch package).

**RESULT AND DISCUSSION**

**Total weight loss**

Over both study years, the total weight loss at 120 days of storage (DOS) showed significant differences among nutritional treatments (Table 1). FYM consistently ( $P < 0.05$ ) resulted in the lowest weight loss across both study years and locations. In contrast, Biof and the Control treatment exhibited higher weight loss values compared to FYM with values ranging from 25.9% to 36.4% across different years and locations. Percentage data indicated that FYM treatments led to approximately 24.0- 26.6% lower weight loss compared to the Control. Overall, FYM contributed to reduced

**Table 1. Impact of organic inputs and phosphorus availability on the tuber total weight loss and rottage of ware potato cv Kufri Pukhraj during storage at 27°C. The experiment was carried out during 2019-20 and 2020-21 at two locations (Ludhiana and Jalandhar) and presented separately. DOS-Days of storage at 27°C.**

Treatment	Total weight loss (%)				Rottage loss (%)			
	120 DOS				120 DOS			
	Ldh		Jal		Ldh		Jal	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Organic source								
FYM	33.5	29.9	25.9	36.4	8.03	7.17	6.22	8.74
Biof	35.7	33.1	27.7	40.1	8.58	7.94	6.64	9.61
Control	44.1	41.1	34.4	49.6	10.58	9.87	8.26	11.91
LSD (p=0.05)	3.9	3.6	3.5	2.8	0.95	0.85	0.84	0.70
Fertilizer phosphorus								
P <sub>0</sub>	39.9	36.6	30.9	43.8	9.57	8.78	7.42	10.51
P <sub>75</sub>	39.2	36.0	30.4	43.1	9.41	8.63	7.30	10.34
P <sub>100</sub>	37.9	34.8	29.4	42.5	9.10	8.36	7.06	10.19
P <sub>150</sub>	36.8	33.9	28.7	41.4	8.84	8.12	6.88	9.95
P <sub>200</sub>	35.0	32.2	27.2	39.4	8.39	7.73	6.54	9.45
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

weight loss in stored ware potato tubers. Phosphorus levels exhibited a consistent pattern, with P<sub>200</sub> demonstrating the lowest weight loss, although the difference was not statistically (P<0.05) significant. Farmyard manure (FYM) application significantly reduced weight loss in stored ware potato tubers, recording the lowest percentage compared to biofertilizer (Biof) and control treatments. Its organic carbon and nutrient buffering enhanced periderm integrity, minimizing transpiration, desiccation, and shriveling, aligning with Singh et al. (2018) findings on organic amendments. FYM's microbial consortium, including PGPR, likely provided bioprotection by suppressing pathogens and stabilizing tuber metabolism.

### Rottage loss

FYM consistently resulted in the lowest rotting loss (Table 1) across both years and locations (P<0.05). In contrast, Biof and the Control treatment exhibited higher rotting

loss values. Overall, FYM markedly reduced rotting loss in stored-ware potato tubers. Although phosphorus levels followed a consistent pattern with P<sub>200</sub> showing the lowest rotting loss, the differences were not statistically significant (P<0.05). Farmyard manure (FYM) application significantly reduced rotting losses in stored ware potato tubers, demonstrating its superior efficacy in maintaining post-harvest quality. The organic matter in FYM likely strengthened tuber periderm resilience, suppressing microbial rot and shriveling, consistent with Kumar et al. (2020) on organic amendments. Beneficial microbes within FYM further contributed by antagonizing pathogens and stabilizing physiological processes during storage.

### Sprouting attributes

Table 2 unveils the organic inputs and phosphorus availability's blunt impact on seed potato sprouting. Diverse organic sources wielded contrasting effects on

**Table 2. Impact of organic inputs and phosphorus availability on the tuber sprouting and sprout length of ware potato cv Kufri Pukhraj during storage at 27°C. The experiment was carried out during 2019-20 and 2020-21 at two locations (Ludhiana and Jalandhar) and presented separately. DOS-Days of storage at 27°C.**

Treatment	Sprouting (%)				Sprouting length (mm)			
	120 DOS				120 DOS			
	Ldh		Jal		Ldh		Jal	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
	Organic source							
FYM	91.1	86.0	87.5	93.4	11.38	10.76	10.93	11.67
Biof	94.0	89.7	90.3	96.4	11.75	11.22	11.29	12.04
Control	96.5	93.6	92.7	98.9	12.07	11.70	11.59	12.37
LSD (p=0.05)	3.1	5.6	3.0	3.2	0.38	0.69	0.38	0.38
	Fertilizer phosphorus							
P <sub>0</sub>	94.7	91.3	90.9	97.0	11.84	11.42	11.37	12.12
P <sub>75</sub>	94.0	90.5	90.2	96.4	11.74	11.31	11.29	12.04
P <sub>100</sub>	93.9	89.9	90.1	96.2	11.73	11.24	11.27	12.03
P <sub>150</sub>	93.8	89.4	90.0	96.1	11.70	11.19	11.27	12.01
P <sub>200</sub>	93.1	87.7	89.4	95.4	11.63	10.97	11.17	11.92
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

sprouting. FYM emerged as the ultimate suppressor of sprouting ( $P < 0.05$ ), recording meager percentages across both years and locations, plummeting between 86.0% to 91.1% in Ludhiana and 87.5% to 93.4% in Jalandhar. Biof and the Control treatment, on the other hand, boasted elevated sprouting percentages in contrast to FYM. Regarding fertilizer phosphorus levels,  $P_0$  showcased the pinnacle ( $P < 0.05$ ) sprouting percentages, while  $P_{200}$  lagged with insignificantly lower values. The sprouting decline with FYM ranged approximately from 3.3% to 6.2% in comparison to Biof and Control treatments. These revelations starkly propose that FYM application potentially curtails sprouting during seed potato tuber storage relative to Biof and Control treatments. Additionally, a parallel trend was observed in sprouting length, corroborating the findings delineated above. FYM application consistently demonstrated a pronounced suppression of sprouting length, further reinforcing its efficacy in mitigating sprouting during seed potato tuber storage. Hence, the integration of FYM into potato cultivation methodologies presents a promising avenue for elevating tuber storage quality and bolstering market viability. This discovery echoes the earlier work of Kumar et al. (2020), who noted diminished sprouting in tubers receiving higher nutritional inputs compared to lower doses. The presence of potassium (K) in FYM, as proposed by Havlin et al. (2005), may account for its impact on enzymatic activities within sprouting tuber eyes, thus elucidating the observed decline in sprouting with nutritional supplementation. In essence, these findings underscore FYM's potential in attenuating sprouting within stored seed potato tubers, offering invaluable insights for refining storage protocols and augmenting tuber quality and longevity.

## CONCLUSION

Farmyard Manure (FYM) application significantly reduced weight loss and rotting loss in stored ware potato tubers compared to Biof and the Control treatment. Among the treatments, FYM consistently results in the lowest weight loss and rotting loss percentages, highlighting its superior effectiveness in preserving tuber quality during storage. Furthermore, FYM proves to be a strong suppressor of sprouting, with significantly lower sprouting percentages observed compared to Biof and the Control. While phosphorus levels did not show statistically significant differences,  $P_{200}$  (125 kg/ha  $P_2O_5$ ) consistently exhibited the lowest weight loss and rotting loss values. These findings emphasize the critical role of FYM as an organic amendment in improving tuber storage quality and extending shelf life. Further research is needed to elucidate the mechanisms behind FYM's beneficial effects and optimize its use in practical potato farming systems.

## 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

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# EVALUATION OF POTATO VARIETIES FOR RESISTANCE TO MAJOR INSECT PESTS IN WEST GODAVARI, ANDHRA PRADESH (RABI 2018)

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**ABSTRACT:** A field experiment was conducted during the rabi season of 2018 at the College of Horticulture, Venkataramannagudem, to evaluate the response of eight potato (*Solanum tuberosum* L.) varieties—Kufri Surya, Kufri Badshah, Kufri Chandramukhi, Kufri Chipsona-3, Kufri Jyoti, Kufri Pukhraj, Kufri Khyathi and Kufri Himalini (sourced from CPCRI, Jalandhar)—to major insect pests. The experiment was laid out in a Randomized Block Design (RBD) with three replications. The occurrence of sucking pests, namely whitefly and leafhopper, was first observed during the 41<sup>st</sup> Standard Meteorological Week (SMW), whereas foliage-feeding pests such as tobacco caterpillar and gram pod borer appeared during the 42<sup>nd</sup> SMW. Pest population gradually increased and crossed the Economic Threshold Level (ETL) during the first and second weeks of November in most varieties; however, in Kufri Badshah and Kufri Surya, ETL was reached during the fourth week of November. Peak pest incidence was recorded during the third and fourth weeks of December. Among the varieties, Kufri Khyathi was highly susceptible, recording the highest populations of whitefly (21.44 no./plant), leafhopper (21.97 no./plant), epilachna beetle (20.38 no./plant) and tobacco caterpillar (21.53 no./plant). In contrast, Kufri Badshah exhibited the lowest pest infestation with whitefly (5.36 no./plant), leafhopper (3.27 no./plant), epilachna beetle (4.66 no./plant) and tobacco caterpillar (5.80 no./plant), indicating tolerance to major insect pests. Yield performance revealed that Kufri Badshah ranked second, next to Kufri Surya. Based on pest incidence and yield, Kufri Badshah was found to be suitable for cultivation under the prevailing agro-climatic conditions.

**KEYWORDS:** Potato varieties, Screening, Insect pests, kufri Badshah, kufri khyati.

## INTRODUCTION

Potato, *Solanum tuberosum* L. belonging to the family Solanaceae, originated from north America and now has been distributed throughout the universe and is one of the main food sources around the world (Nazari and tamara, 2025). Potato is often highlighted as the 'King of Vegetables' because of its wide range of uses and versatility. Globally, potato ranks as the fourth most important food crop, following maize, wheat, and rice.

(Haverkort *et al.*, 2009). It contains substantial energy of edible protein (1.60g), carbohydrate (22.60g), minerals (0.60g), crude fiber (0.40g), fat (0.10g) and vitamin C (25.00mg) per 100 g fresh weight of tubers (Patel *et al.*, 2024). China ranks first in production (95.50 MT), followed by India (46.4 MT), Russia (31.50 MT), Ukraine (23.70 MT) and USA (20.10 MT) (Anonymous, 2021a). In India, Uttar Pradesh ranks first in terms of area (603.7ha) and production (14,430.2 MT/year) and occupies

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second place in productivity (23 q ha<sup>-1</sup>). West Bengal occupies second rank in area (386.6 ha) and production (11,591.30 t ha<sup>-1</sup>) and first in productivity (29 q ha<sup>-1</sup>). Potato accounts for about 2% of the total cultivated area in Andhra Pradesh (Anonymous, 2021b).

Review of literature revealed that potato crop is being attacked by more than 100 arthropods and 156 species of plant parasitic nematodes that belong to 52 genera all over the world (Lodaya *et al.*, 2017). Out of these, 80 arthropods and 93 species of nematodes reported from India alone (Pandey, 2007).

Among the various insects, Aphids (*Myzus persicae* Sulzer), Thrips, (*Thrips palmi* Karny); Leaf hopper, (*Amarasca biguttula biguttula* Ishida); White fly, (*Bemisia tabaci* Gennadius); and soil insects like Cut worm, (*Agrotis ipsilon* Hufnagel); Potato tuber moth, (*Pthoromea opercullela* Povolny) have significant influence on potato yield (Nag *et al.*, 2018). Among the sap feeders, Potato leaf hopper, (*Empoasca devastans* Distant) is the most important species, prolonged feeding by which causes a condition known as “hopper burn”, manifested in the form of brown triangular lesions at the tips of the leaves (Amlari, 2021). Whitefly, *Bemisia tabaci* is a newly emerging vector in Central India transmitting apical leaf curl disease in potato crop (Anand *et al.*, 2023). The nymph and adult population of whiteflies will feed and excrete honeydew that promotes the growth of sooty mold, which in turn, adversely affect plant photosynthesis, leading to a reduction in yield (Naik *et al.*, 2022).

The foliage feeding insects like Tobacco caterpillar, Epilachna beetle and Leaf miner also causing substantial damage to the potato crop. Tobacco caterpillar, (*Spodoptera litura*) cause damage by feeding on the leaves and cause holes on the leaves, (Shigwan, 2022).

Epilachna beetle is a significant pest of potato crops, with both grubs and adults feeding on the foliage. The grubs remove chlorophyll by scraping the leaf surface, leaving only the veins intact. In cases of severe infestation, yield losses may reach up to 70% (Nayak *et al.*, 2022).

Various control measures can be followed to control insect pest infestations below the Economic Threshold Level (ETL). Among these, chemical control is the most commonly used method; however, it poses significant risks to human health (Landge *et al.*, 2022). An alternative sustainable approach is the screening of insect-resistant potato varieties. Identifying and cultivating resistant varieties is one of the most economical and environmentally friendly strategies for effective insect pest management.

Despite the availability of substantial information on insect pest complexes of potato from major potato-growing regions of India, such studies are predominantly restricted to traditional cultivation belts of northern and eastern India. In contrast, information on the incidence and severity of major insect pests of potato under the coastal agro-climatic conditions of Andhra Pradesh is scanty. The recent introduction of potato cultivation in the East Godavari district has exposed the crop to a distinct ecological environment, which may significantly influence pest composition, abundance, and crop response.

Further, the performance of potato varieties against key insect pests such as whiteflies, leaf hoppers, tobacco caterpillar, and epilachna beetle under these non-traditional growing conditions has not been systematically evaluated. Existing studies largely emphasize chemical control measures, while region-specific information on host plant

resistance as a sustainable pest management strategy remains inadequate. The absence of varietal screening for insect resistance in conjunction with yield performance limits the development of effective IPM strategies and varietal recommendations for this region. Therefore, there is a clear need for systematic screening of potato varieties to identify high-yielding and insect pest-resistant genotypes suitable for cultivation under the coastal agro-climatic conditions of Andhra Pradesh.

## MATERIALS AND METHODS

An experiment was conducted during *Rabi* season (2018) to evaluate the resistance or susceptibility levels of potato varieties against different insect pests at the College of Horticulture, Venkataramannagudem (Situated at 16.305° N latitude 80.047° E longitude above Mean Sea Level). The experiment was laid out in Randomized Block Design (RBD) with three replications including eight potato varieties, *i.e.* Kufri Surya, Kufri Badshah, Kufri Chandramukhi, Kufri Chipsona-3, Kufri Jyoti, Kufri Pukhraj, Kufri Khyathi and Kufri Himalini (Source institute: CPCRI-Jalandhar).

Sowing was done on 46<sup>th</sup> SMW on a uniform sandy loamy soil with medium fertility. Field was divided into different plots. Plot size was 6m × 2m with 60cm inter-row and 30cm intra row spacing. All standard agronomic practices were strictly followed for ensuring good crop growth, except application of any insecticides. Five plants were randomly selected from twenty-five plants in one plot. A small sample size of five plants was used because random selection ensures unbiased representation of the 25-plant population, while minimizing time and resource requirements without significantly affecting reliability. The selected plants were tagged from each plot for recording

observations at weekly interval. From each plant three leaves, one each from the top, middle and bottom leaves were selected to record the observations and average pest population per plant was calculated the population counts were recorded based on visual observation. Basic statistical analysis was carried out using OPSTAT software by using Randomized Block Design as a statistical model. Significant differences among treatments were determined at 5% level of significance.

## RESULTS AND DISCUSSION

The data on incidence of insect pests *viz.*, Whitefly, Leaf hopper, Epilachna beetle & Tobacco caterpillar on all eight varieties was presented in Table 1, 2, 3 and 4, respectively. Among the eight varieties none of the variety showed immune response. Three varieties *viz.*, Kufri Badshah, Kufri Surya, Kufri Chandramukhi were found to be resistant and Kufri Chipsona-3, Kufri Jyoti, Kufri Himalini found moderately resistant. Whereas Kufri Pukhraj and Kufri Khyati displayed moderately susceptible and highly susceptible reactions, respectively.

Infestation of whitefly was observed on all the varieties of potato. Data on mean population of whitefly revealed that the highest population count was recorded in the variety Kufri Khyati (21.44/plant). The next cultivars in the descending order of population counts were Kufri Pukhraj (19.50), Kufri Himalini (15.48), Kufri Jyoti (12.72), Kufri Chipsona-3 (10.69), Kufri Chandramukhi (8.44) and Kufri Surya (6.30). The lowest mean population of whitefly was recorded for Kufri Badshah (5.36/plant) (Table 1).

Minimum leafhopper infestation was observed in the variety Kufri Badshah (3.27 adults/plant), followed by Kufri Surya (5.41), Kufri Chandramukhi (7.96), Kufri

**Table 1. Screening of potato varieties against whitefly at COH, Venkataramannagudem**

S. No	Treatments	SMW 41	SMW 42	SMW 43	SMW 44	SMW 45	SMW 46	SMW 47	SMW 48	SMW 49	SMW 50	SMW 51	SMW 52	SMW 1	Avg
1	T1 - Kufri Surya	1.67 (1.63)	3.6 (2.14)	8.6 (3.10)	9.27 (3.20)	13.07 (3.75)	9.53 (3.24)	5.6 (2.55)	6.2 (2.67)	5.9 (2.61)	4.6 (2.36)	4 (2.23)	3.6 (2.17)	2.53 (1.87)	6.30
2	T2- Kufri Khyati	8.33 (3.05)	16.27 (4.14)	26.13 (5.20)	27.47 (5.32)	35.86 (6.06)	26.4 (5.22)	21.93 (4.79)	21.93 (4.79)	21.53 (4.75)	18.4 (4.40)	17.8 (4.33)	15.2 (4.02)	14.47 (3.93)	21.44
3	T3 - Kufri Chipsona-3	2.33 (1.82)	8.73 (3.11)	11.73 (3.57)	13.87 (3.85)	17.8 (4.33)	13.93 (3.86)	13.6 (3.82)	12.93 (3.73)	9.07 (3.17)	8.3 (3.05)	8 (2.30)	8 (3.00)	7.73 (1.82)	10.69
4	T4 – Kufri Chandramukhi	1.93 (1.71)	5 (2.45)	9 (3.16)	11.4 (3.52)	14.93 (3.99)	10 (3.32)	9.53 (3.24)	11.8 (3.57)	8 (2.30)	7.47 (2.91)	6.8 (2.78)	5.47 (2.54)	5.4 (2.53)	8.44
5	T5-Kufri Badshah	1.42 (1.56)	3 (1.99)	6.2 (2.68)	8.5 (3.07)	12.12 (3.61)	8.12 (3.01)	5.6 (2.55)	5.2 (2.48)	4.9 (2.42)	3.6 (2.14)	3 (1.99)	2.6 (1.88)	2.2 (1.77)	5.36
6	T6 - Kufri Pukhraj	6.53 (2.74)	15.07 (4.01)	24.27 (5.03)	26.2 (5.21)	34.07 (5.92)	24.2 (5.02)	20.4 (4.62)	20.4 (4.62)	19 (4.47)	15.27 (4.03)	15.13 (4.01)	13.47 (3.80)	12.2 (3.63)	19.50
7	T7- Kufri Jyoti	3.67 (2.17)	9 (3.16)	12.24 (3.61)	14.73 (3.96)	18.4 (4.40)	17.4 (4.29)	16.87 (4.23)	13.67 (3.83)	15.77 (4.09)	11.33 (3.51)	10.6 (3.40)	8.93 (3.15)	8.57 (3.09)	12.72
8	T8 - Kufri Himalini	4.6 (2.36)	11.33 (3.51)	13.67 (3.83)	18.33 (4.40)	24.93 (5.09)	21.4 (4.73)	18.93 (4.46)	18.27 (4.39)	16.87 (4.22)	13.27 (3.77)	12.73 (3.70)	11.4 (3.52)	10.9 (3.45)	15.48
9	SE (m)	0.06	0.130	0.16	0.15	0.13	0.10	0.12	0.08	0.11	0.10	0.10	0.09	0.105	
10	C.D. at 5%	0.19	0.40	0.49	0.47	0.41	0.31	0.36	0.24	0.33	0.30	0.31	0.29	0.321	
11	C.V. (%)	4.93	7.34	7.39	6.54	4.95	4.31	5.43	3.63	5.25	5.27	5.60	5.47	6.258	

Figures in parentheses are square root transformed values.

**Table 2. Screening of potato varieties against leafhopper at COH, Venkataramannagudem**

S. No	Treatments	SMW 41	SMW 42	SMW 43	SMW 44	SMW 45	SMW 46	SMW 47	SMW 48	SMW 49	SMW 50	SMW 51	SMW 52	SMW 1	Avg
1	T1 - Kufri Surya	1.67 (1.63)	3.07 (2.07)	7.93 (2.99)	9.53 (3.41)	14.07 (3.88)	6.87 (2.80)	6.67 (2.75)	4.27 (2.28)	3.60 (2.14)	3.33 (2.08)	3.27 (2.06)	3.13 (2.03)	2.87 (1.97)	5.41
2	T2- Kufri Khyati	5.67 (2.57)	16.67 (4.20)	27.27 (5.32)	32.87 (5.82)	35.47 (6.04)	28.67 (5.44)	22.87 (4.88)	22.93 (4.89)	21.73 (4.77)	18.87 (4.46)	17.60 (4.31)	17.53 (4.30)	17.40 (4.29)	21.97
3	T3 - Kufri Chipsona-3	2.20 (1.77)	4.60 (2.34)	11.47 (3.53)	12.73 (3.70)	18.27 (4.43)	14.13 (3.89)	11.93 (3.66)	12.13 (3.62)	10.80 (3.43)	8.60 (3.09)	6.20 (2.67)	6.00 (2.63)	7.30 (2.88)	9.72
4	T4 – Kufri Chandramukhi	1.93 (1.71)	4.40 (2.32)	8.80 (3.12)	10.67 (3.24)	15.60 (4.05)	10.67 (3.42)	11.93 (3.60)	9.27 (3.20)	8.67 (3.11)	6.47 (2.73)	6.20 (2.67)	4.60 (2.36)	4.33 (2.30)	7.96
5	T5-Kufri Badshah	1.47 (1.57)	2.47 (1.86)	3.67 (2.16)	6.00 (2.64)	8.93 (3.15)	3.33 (2.08)	3.07 (2.02)	2.80 (1.95)	2.60 (1.89)	2.43 (1.85)	2.07 (1.75)	2.00 (1.73)	1.73 (1.65)	3.27
6	T6 - Kufri Pukhraj	4.20 (2.28)	13.40 (3.79)	21.13 (4.70)	26.93 (5.28)	31.20 (5.67)	24.73 (5.07)	20.80 (4.67)	20.40 (4.62)	18.60 (4.43)	15.80 (4.10)	14.80 (3.97)	13.27 (3.78)	12.67 (3.70)	18.30
7	T7- Kufri Jyoti	3.67 (2.16)	8.00 (2.30)	10.73 (3.42)	16.87 (4.22)	18.67 (4.39)	17.80 (4.34)	17.00 (4.24)	15.87 (4.10)	13.80 (3.84)	11.87 (3.59)	10.93 (3.45)	8.80 (3.13)	8.43 (3.07)	12.50
8	T8 - Kufri Himalini	4.13 (2.26)	8.40 (3.06)	12.87 (3.72)	18.00 (4.36)	24.80 (5.08)	20.53 (4.64)	19.13 (4.49)	18.40 (4.40)	17.00 (4.24)	14.20 (3.90)	14.00 (3.87)	11.33 (3.51)	10.70 (3.42)	14.88
9	SE (m)	0.08	0.13	0.09	0.11	0.18	0.05	0.10	0.09	0.08	0.08	0.13	0.09	0.08	
10	C.D. at 5%	0.24	0.39	0.29	0.35	0.54	0.16	0.31	0.29	0.26	0.26	0.39	0.28	0.25	
11	C.V. (%)	6.68	7.76	4.56	4.81	6.63	2.35	4.65	4.48	4.25	4.55	7.16	5.33	4.95	

Figures in parentheses are square root transformed values.

Chipsona-3 (9.72), Kufri Jyoti (12.50), Kufri Himalini (14.80), and Kufri Pukhraj (18.30), in ascending order. The maximum infestation was recorded in Kufri Khyati (21.97 adults/plant), as shown in Table 2.

Data on mean population of *Epilachna* beetle revealed that the highest mean population (20.38/plant) was observed in Kufri Khyati. The next varieties in descending order of mean population of Tobacco caterpillar were Kufri Pukhraj (18.06), Kufri Himalini (14.80), Kufri Jyoti (13.01), Kufri Chipsona-3 (10.04), Kufri Chandramukhi (7.91), Kufri Surya (5.65) and Kufri Badshah (4.66 adult/plant) (Table 3).

Observations on population counts of *Spodoptera litura* on different potato varieties indicated that the highest mean population were recorded on Kufri Khyati (21.53/plant), followed by Kufri Pukhraj (18.16), Kufri Himalini (14.96), Kufri Jyoti (12.76),

kufri Chipsona-3 (9.71), Kufri Chandramukhi (8.28) and Kufri Surya (6.82). The lowest mean population of Tobacco caterpillar was observed in Kufri Badshah (5.80 adult/plant).

Konar and Paul (2008) conducted an experiment on the population build-up of aphids on different potato genotypes in the Gangetic plains of West Bengal. Their findings indicated significant variation among genotypes in resistance or susceptibility on aphid infestation. Results were in accordance with the finding of raj *et al.* (2014), who evaluated heat tolerant potato genotypes and varieties against leaf hopper and mite. Kahar and Konar (2024) reported results similar to those of the present investigation in their study on screening aphid incidence among various potato germplasm in the plains of West Bengal. Sarjan and Nikmatulla (2020) also reported a population occurrence

**Table 3. Screening of potato varieties against *Epilachna* Beetle at COH, Venkataramannagudem**

S. No	Treatments	SMW 42	SMW 43	SMW 44	SMW 45	SMW 46	SMW 47	SMW 48	SMW 49	SMW 50	SMW 51	SMW 52	SMW 1	Avg
1	T1 - Kufri Surya	3.13 (2.03)	4.33 (2.31)	9.13 (3.17)	11.13 (3.48)	8.80 (3.12)	6.60 (2.74)	5.13 (2.47)	4.33 (2.31)	4.23 (2.27)	4.07 (2.23)	3.53 (2.13)	3.33 (2.07)	5.65
2	T2- Kufri Khyati	6.40 (4.17)	18.40 (4.40)	31.07 (5.66)	33.60 (5.88)	23.80 (4.97)	22.20 (4.81)	21.80 (4.77)	21.20 (4.71)	17.47 (4.29)	17.20 (4.26)	16.60 (4.19)	14.77 (3.97)	20.38
3	T3 - Kufri Chipsona-3	5.10 (2.45)	6.33 (2.71)	10.53 (3.40)	15.53 (4.05)	14.27 (3.91)	14.20 (3.90)	11.53 (3.54)	10.93 (3.44)	8.80 (3.13)	8.40 (3.06)	7.47 (2.89)	7.37 (2.89)	10.04
4	T4 – Kufri Chandramukhi	4.07 (2.25)	5.33 (2.51)	8.73 (3.12)	14.93 (3.99)	10.13 (3.33)	11.93 (3.60)	8.80 (3.13)	7.60 (2.92)	6.40 (2.69)	6.13 (2.66)	5.87 (2.59)	5.03 (2.41)	7.91
5	T5-Kufri Badshah	2.90 (1.96)	3.40 (2.06)	8.12 (3.01)	9.20 (3.15)	6.90 (2.80)	5.60 (2.55)	4.90 (2.40)	3.90 (2.18)	3.50 (2.08)	3.00 (1.95)	2.50 (1.86)	2.00 (1.71)	4.66
6	T6 - Kufri Pukhraj	12.00 (3.58)	16.73 (4.21)	23.27 (4.92)	30.67 (5.62)	21.20 (4.71)	20.40 (4.63)	19.27 (4.50)	18.47 (4.41)	15.67 (4.08)	17.40 (4.27)	13.00 (3.74)	8.60 (2.96)	18.06
7	T7- Kufri Jyoti	7.93 (2.98)	10.33 (3.36)	15.00 (4.00)	19.33 (4.50)	18.07 (4.36)	17.60 (4.31)	15.53 (4.06)	13.67 (3.83)	11.60 (3.55)	11.00 (3.45)	8.60 (3.09)	7.50 (2.91)	13.01
8	T8 - Kufri Himalini	8.80 (3.13)	12.13 (3.6)	15.47 (4.06)	22.40 (4.84)	18.80 (4.45)	18.27 (4.39)	17.93 (4.35)	16.47 (4.17)	13.00 (3.74)	12.67 (3.69)	11.33 (3.51)	10.30 (3.36)	14.80
9	SE (m)	0.15	0.13	0.12	0.20	0.11	0.13	0.12	0.16	0.17	0.19	0.17	0.29	
10	C.D. at 5%	0.47	0.40	0.37	0.61	0.34	0.41	0.38	0.49	0.51	0.57	0.52	0.89	
11	C.V. (%)	9.37	7.22	5.36	7.82	4.89	6.02	5.95	8.00	9.01	10.08	9.78	17.98	

Figures in parentheses are square root transformed values.

Table 4. Screening of Potato varieties against tobacco caterpillar at COH, Venkataramannagudem

S. No	Treatments	SMW 42	SMW 43	SMW 44	SMW 45	SMW 46	SMW 47	SMW 48	SMW 49	SMW 50	SMW 51	SMW 52	SMW 1	Avg
1	T1 - Kufri Surya	2.10 (1.75)	4.93 (2.41)	8.66 (3.06)	12.64 (3.66)	10.42 (3.34)	9.20 (3.15)	8.13 (3.01)	7.42 (2.87)	6.81 (2.78)	4.92 (2.41)	3.50 (2.11)	3.10 (1.98)	6.82
2	T2- Kufri Khyati	16.40 (4.17)	18.87 (4.46)	33.73 (5.89)	34.73 (5.97)	24.47 (5.04)	23.60 (4.95)	21.47 (4.73)	21.33 (4.72)	17.60 (4.31)	16.53 (4.18)	15.20 (4.02)	14.37 (3.92)	21.53
3	T3 - Kufri Chipsona-3	3.00 (1.95)	6.33 (2.70)	10.33 (3.36)	15.93 (4.11)	13.07 (3.75)	12.00 (3.61)	11.53 (3.54)	10.67 (3.41)	10.07 (3.33)	9.53 (3.24)	8.13 (3.02)	5.95 (2.54)	9.71
4	T4 – Kufri Chandramukhi	2.53 (1.88)	5.47 (2.54)	9.67 (3.26)	14.40 (3.92)	11.40 (3.52)	10.60 (3.40)	8.47 (3.07)	8.27 (3.04)	8.07 (3.01)	8.07 (3.01)	7.30 (2.88)	5.13 (2.46)	8.28
5	T5-Kufri Badshah	1.93 (1.71)	2.40 (1.83)	7.10 (2.81)	11.15 (3.46)	9.50 (3.23)	8.90 (3.14)	7.60 (2.90)	6.50 (2.70)	5.60 (2.52)	4.30 (2.27)	2.53 (1.86)	2.13 (1.75)	5.80
6	T6 - Kufri Pukhraj	12.33 (3.65)	17.40 (4.29)	20.47 (4.63)	28.60 (5.44)	23.33 (4.93)	19.67 (4.54)	18.80 (4.45)	19.47 (4.52)	17.20 (4.25)	14.33 (3.91)	13.67 (3.83)	12.63 (3.69)	18.16
7	T7- Kufri Jyoti	7.93 (2.98)	9.43 (3.23)	15.00 (3.98)	18.13 (4.37)	17.27 (4.27)	15.67 (4.08)	15.40 (4.05)	13.07 (3.75)	11.93 (3.60)	10.87 (3.44)	9.40 (3.22)	9.03 (3.16)	12.76
8	T8 - Kufri Himalini	9.60 (3.25)	12.20 (3.63)	16.13 (4.12)	22.00 (4.80)	17.33 (4.27)	17.27 (4.27)	17.27 (4.27)	17.20 (4.26)	15.87 (4.08)	13.27 (3.77)	11.27 (3.52)	10.10 (3.33)	14.96
9	SE (m)	0.13	0.17	0.21	0.16	0.14	0.17	0.14	0.18	0.21	0.16	0.01	0.23	
10	C.D. at 5%	0.40	0.12	0.65	0.51	0.46	0.53	0.42	0.56	0.65	0.50	0.27	0.71	
11	C.V. (%)	8.40	6.59	9.46	6.51	6.36	7.67	6.37	8.64	10.55	8.62	4.97	14.14	

Figures in parentheses are square root transformed values.

pattern similar to that observed in the present study.

Among the eight potato varieties evaluated, Kufri Badshah was found to be highly resistant to major insect pest infestation. This variety is characterized by a semi-compact canopy, green stems with scattered red-brown pigmentation, and ovate-lanceolate leaflets. The foliage has medium green color with a moderately dense structure, which may contribute to its lower susceptibility to insect pests. In contrast, Kufri Khyati, an early maturing variety, showed severe insect pest infestation. It has a semi-compact foliage structure with dark green leaves, large oval-shaped leaflets on a green rachis, and typically grows tall and erect. The plant also exhibits moderate flowering with white flowers, which, along with its growth habit, may favor higher pest incidence.

The biophysical, biochemical, and weather parameters were evaluated to determine their relationship with pest population per plant among the different varieties. Among the biophysical (quantitative) characters studied, trichome density exhibited a significant negative correlation with pest population per plant. The remaining biophysical parameters, namely plant height, internodal length, and number of leaves, showed non-significant negative correlations with pest population per plant.

With respect to biochemical characters, leaf phenol content demonstrated a significant negative correlation with pest population per plant. In contrast, sugar content, protein content, and moisture content showed significant positive correlations with pest population per plant.

Weather parameters such as temperature, rainfall, and humidity were recorded at

standard weekly intervals. The results indicated that maximum temperature was positively correlated with pest population, whereas rainfall exhibited a negative correlation with pest population.

## CONCLUSION

Kufri Badshah, exhibiting the highest resistance to major insect pests screened, can be recommended for cultivation in the agro climatic zones of coastal Andhra Pradesh, whereas Kufri Khyati, being highly susceptible, is not suitable for pest-prone regions.

## FUTURE SCOPE

1. Documentation of pests scenario along with natural enemies on potato crop in Andhra Pradesh over a period.
2. Identification of potential natural enemies in all categories *i.e.*, insects, viruses, bacteria, fungi, predators *etc.*, on potato pests to explore biological control measure as a part of IPM.
3. Finding of threshold levels of potato pests in different regions of Andhra Pradesh.
4. Development of most suitable and sustainable IPM modules to protect potato crop from different pest.
5. Latest pest control aspects on potato crop
6. Further germplasm screening to find out best suitable varieties to other regions of Andhra Pradesh also.

## 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

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# EFFICIENT *IN VITRO* MICROTUBER INDUCTION IN POTATO (*SOLANUM TUBEROSUM* L. CV. KUFRI CHANDRAMUKHI) USING HIGH-SUCROSE MS MEDIUM UNDER DARK CONDITIONS

Satabdi Ghosh<sup>1\*</sup>

**ABSTRACT:** The present study aimed to standardize an efficient protocol for *in vitro* microtuber induction in *Solanum tuberosum* L. cv. Kufri Chandramukhi. Nodal explants were cultured on Murashige and Skoog (MS) medium supplemented with 10.0 mg l<sup>-1</sup> benzyladenine (BA) and 80.0 g l<sup>-1</sup> sucrose to promote microtuber development under dark conditions at 20 ± 1°C. Microtubers were harvested after 6 weeks, and their number, average weight, and diameter were recorded. Results demonstrated successful induction of morphologically uniform microtubers from *in vitro* grown microplants. The average number of microtubers per plantlet was 2.2 ± 0.4, with an average weight of 0.460 ± 0.042 g and a diameter of 6.24 ± 0.78 mm. This protocol offers a reproducible and scalable system for rapid microtuber production, with potential applications in seed potato propagation, germplasm conservation, and pre-breeding programs. The study highlights the amenability of cv. Kufri Chandramukhi to *in vitro* tuberization, contributing to the advancement of potato biotechnology and seed systems in India.

**KEYWORDS:** Microtuberization, *Solanum tuberosum*, Kufri Chandramukhi, *In vitro* culture, MS medium, Sucrose, Cytokinin, Potato biotechnology

## INTRODUCTION

Potato (*Solanum tuberosum* L.) is the fourth most important food crop globally after rice, wheat, and maize, and plays a significant role in ensuring food and nutritional security (Scott and Suarez, 2012). In India, it is a vital component of the agricultural economy, contributing to both rural income and urban consumption. Among the several improved Indian cultivars, *Kufri Chandramukhi* is a widely adopted early-maturing variety, developed by the Central Potato Research Institute (CPRI), Shimla. It is appreciated for its short dormancy, light skin, and good culinary qualities (CPRI, 2005).

Traditional methods of potato seed production rely heavily on tuber multiplication under field conditions, which is time-consuming and prone to systemic disease accumulation, particularly viral and bacterial infections. As a vegetatively propagated crop, potato is highly susceptible to seed degeneration under tropical and subtropical climates (Gildemacher *et al.*, 2009). This challenge has intensified the demand for clean, high-quality seed tubers, leading to the development and deployment of *in vitro* techniques for disease-free seed multiplication.

*In vitro* microtuber production provides a highly efficient and controlled approach

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to producing pathogen-free mini tubers. Microtubers are small, physiologically functional tubers that are induced and matured in artificial media under controlled laboratory conditions (Donnelly *et al.*, 2003). They serve as planting materials in seed production programs or for germplasm conservation, international exchange, and rapid multiplication (Ranalli, 2007).

The induction of microtubers is influenced by several factors, including genotype, explant source, culture medium composition, carbon source, phytohormonal balance, and environmental conditions such as photoperiod and temperature (Naik and Sarkar, 1998; Hoque, 2010). Among these, sucrose concentration and dark incubation have been reported to be crucial in initiating and enhancing microtuber formation (Struik and Wiersema, 1999). Plant growth regulators like BAP (6-benzylaminopurine), kinetin, and CCC (cycocel) are frequently used to manipulate endogenous hormonal levels, promote shoot growth, and initiate tuber formation (Kumar *et al.*, 2007).

*Kufri Chandramukhi*, owing to its genetic makeup and early bulking trait, has shown a favourable response to *in vitro* culture and micro tuberization (Pandey *et al.*, 2011). However, genotype-specific standardization of media and culture conditions is essential to standardize protocols for large-scale production. The efficient use of microtuber technology for *Kufri Chandramukhi* can potentially reduce dependence on traditional seed tubers, enhance disease control, and enable year-round production in tissue culture facilities.

This study aims to optimize the protocol for *in vitro* microtuber induction in *Kufri Chandramukhi* by evaluating the effects of sucrose concentration, growth regulators, and dark incubation on tuber

initiation and development. The findings are expected to contribute significantly to the micropropagation-based seed system and support clean seed potato production in India.

## MATERIAL AND METHODS

### Plant Material and *In vitro* Culture Initiation

Certified tubers of *Solanum tuberosum* L. cv. *Kufri Chandramukhi* were procured from the Central Potato Research Institute (CPRI), Shimla, Himachal Pradesh, India. Surface sterilization of sprouted tuber explants was carried out using 0.1% (w/v) mercuric chloride ( $\text{HgCl}_2$ ) for 3–5 min followed by three to four rinses with sterile distilled water, as this treatment provided high aseptic culture establishment (>90%) with minimal tissue injury compared to preliminary trials using 1–2% sodium hypochlorite (10–15 min) or 70% ethanol (30 s), which showed higher contamination (25–40%) or were insufficient to eliminate endophytic microbes.  $\text{HgCl}_2$  was selected because field-derived potato explants often harbor persistent surface and sub-surface contaminants, and its strong antimicrobial efficacy and rapid penetration help ensure reliable culture initiation; however, recognizing its toxicity and environmental hazards, all procedures were performed inside a laminar airflow cabinet using appropriate personal protective equipment (gloves, lab coat, eye protection) and minimal working volumes. Used  $\text{HgCl}_2$  solutions were collected separately in labeled hazardous waste containers, chemically neutralized with excess sodium thiosulfate ( $\text{Na}_2\text{S}_2\text{O}_3$ ) to reduce  $\text{Hg}^{2+}$  ions, stored securely, and disposed of through the institution's authorized hazardous chemical waste management system in accordance with national environmental safety regulations, with no discharge into sinks or municipal drains. Despite its effectiveness,  $\text{HgCl}_2$  use

represents a limitation due to increasing regulatory restrictions and ecological concerns; therefore, safer alternatives such as optimized sodium hypochlorite–ethanol combinations.

Sprouted eyes were excised and cultured on Murashige and Skoog (MS) medium containing 3% (w/v) sucrose and solidified with 0.8% agar. The pH of the medium was adjusted to 5.8 prior to autoclaving at 121°C for 15 minutes. Cultures were maintained in a growth chamber under a 16-hour photoperiod at 25 ± 2°C, with a light intensity of 40–50 μmol m<sup>-2</sup>s<sup>-1</sup> provided by cool-white fluorescent lamps. Healthy *in vitro* plantlets obtained from these cultures were maintained through periodic subculturing and served as mother stock cultures for microtuber induction.

### ***In vitro* Microtuber Induction**

For microtuberization, uniform microplants derived from *in vitro*-maintained mother stock cultures were selected and transferred to liquid MS medium supplemented with 10.0 mg l<sup>-1</sup> 6-Benzylaminopurine (BA) and 80.0 g l<sup>-1</sup> sucrose. The cultures were incubated under complete darkness at 20 ± 1°C to promote tuber initiation and development. The high concentration of sucrose served both as a carbon source and an osmotic agent, while BA functioned as a cytokinin to facilitate tuberization.

After six weeks of incubation, microtubers were harvested from the 50 ml culture tubes. Data were recorded on the number of microtubers produced per plantlet, the average fresh weight of individual microtubers (in grams), and their average diameter (in millimetres). For microtuber induction, each treatment consisted of three independent biological replicates. Each replicate comprised 10 culture vessels, with one microplant per vessel, resulting in 30 explants per treatment (n = 30).

Microplants were cultured in 250 mL sterile glass culture bottles containing 40 mL liquid MS medium supplemented with 10.0 mg l<sup>-1</sup> BA and 80.0 g l<sup>-1</sup> sucrose. The culture density was therefore one explant per 40 mL medium per vessel, ensuring adequate aeration and nutrient availability while minimizing competition effects.

After six weeks of incubation, all microtubers produced per plantlet within each replicate were counted. Fresh weight was recorded individually using an analytical balance immediately after harvest, and diameter was measured using a digital vernier caliper. Data were expressed as mean ± standard error (SE). Means were calculated using the formula:

$$\text{Mean} = \sum X/n$$

where *X* represents individual observations and *n* represents the total number of explants per treatment (n = 30).

Standard error (SE) was calculated as:

$$\text{SE} = \text{SD}/\sqrt{n}$$

where *SD* is the standard deviation of the observations.

Statistical comparisons between control and regenerated plant groups were performed using Student's *t*-test at *P* ≤ 0.05. All analyses were conducted using standard statistical procedures.

## **RESULTS AND DISCUSSION**

### ***In vitro* Microtuber Induction in Kufri Chandramukhi**

The *in vitro* regenerants derived from the ZR-free ASR system were evaluated for their microtuberization capacity (Ghosh *et al.*, 2014) under standardized induction conditions (Fig. 1). Both the control (C) and the regenerated (P) plants of *Solanum tuberosum* L. cv. Kufri Chandramukhi showed



Fig. 1. *In vitro* microtuber formation in *Solanum tuberosum* L. cv. Kufri Chandramukhi

successful microtuber formation in liquid MS medium supplemented with 10.0 mg l<sup>-1</sup> BA and 80.0 g l<sup>-1</sup> sucrose under dark conditions at 20 ± 1°C.

Quantitative assessment revealed minor variations in microtuber traits between control and *in vitro*-derived plants. The number of microtubers per plant in the control was 2.2 ± 0.4, while the regenerated plants produced slightly more, averaging 2.4 ± 0.5. The average fresh weight of microtubers in control plants was 0.460 ± 0.042 g, compared to 0.440 ± 0.035 g in regenerated plants. The microtuber diameter was also slightly higher in the control (6.24 ± 0.78 mm) than in the regenerated group (5.06 ± 0.25 mm). The detailed statistical comparison of microtuber number, fresh weight, and diameter between control and regenerated plants is presented in Table 1.

(A) Induction of microtubers on a single-node explant cultured in liquid MS medium

supplemented with 10.0 mg l<sup>-1</sup> BA and 80.0 g l<sup>-1</sup> sucrose under dark conditions at 20 ± 1°C. (B) Mature microtubers excised from *in vitro*-grown plants after 6 weeks of culture.

Unpaired two-tailed Student's t-tests analysis indicated that there were no significant differences ( $P \leq 0.05$ ) in microtuber number, weight, or diameter between control and regenerated plant groups, indicating phenotypic stability in the regenerated plants with respect to tuberization traits.

The present study demonstrated the successful induction of microtubers in *Solanum tuberosum* L. cv. Kufri Chandramukhi under *in vitro* conditions using liquid MS medium supplemented with 10.0 mg l<sup>-1</sup> BA and 80.0 g l<sup>-1</sup> sucrose. Both control and *in vitro*-regenerated plants (Ghosh *et al.*, 2014) showed a consistent response, indicating that plantlets derived from the zeatin-free adventitious shoot regeneration system retained their microtuberization potential without significant variation. The distribution and variability of raw data for microtuber number, fresh weight, and diameter in control and regenerated plants are graphically represented in Fig. 2, further confirming the absence of statistically significant differences between the two groups.

Sucrose plays a dual role as a carbon source and osmotic agent, with concentrations above 5% being critical for triggering tuberization *in vitro* (Naik and Sarkar, 1998).

Table 1. Comparative microtuberization traits of *in vitro*-grown control plants of Kufri Chandramukhi

Parameter	Group	N	Mean ± SE	Test Used	t value	df	Exact P value
Microtubers per plant	Control	30	2.2 ± 0.4	Unpaired t-test	1.68	58	0.098
	Regenerated	30	2.4 ± 0.5				
Average fresh weight (g)	Control	30	0.460 ± 0.042	Unpaired t-test	1.98	58	0.052
	Regenerated	30	0.440 ± 0.035				
Diameter (mm)	Control	30	6.24 ± 0.78	Unpaired t-test	1.12	58	0.267
	Regenerated	30	5.06 ± 0.25				

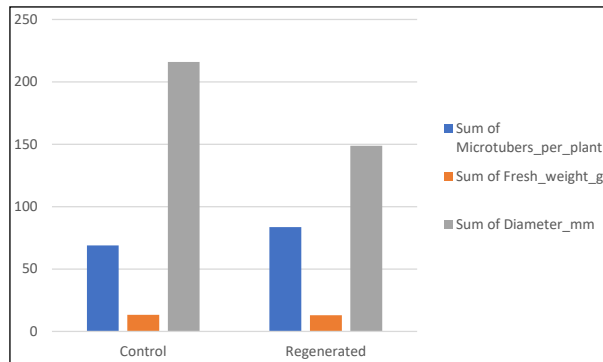


Fig. 2. Raw data summary plots

The 8% sucrose used in this study aligns with earlier findings where high sucrose concentrations significantly enhanced tuber induction by mimicking stress conditions favorable to sink development (Yamazaki *et al.*, 2001; Donnelly *et al.*, 2003). Moreover, the dark incubation at  $20 \pm 1^\circ\text{C}$ , a condition known to inhibit gibberellin synthesis and promote tuberization, was found to be effective for *Kufri Chandramukhi*, as also reported by Ranalli (2007) and Struik and Wiersema (1999).

The hormonal regulation of tuberization is complex, with cytokinins such as BA known to promote cell division and differentiation at the axillary buds, leading to microtuber initiation (Kumar *et al.*, 2007). In this study,  $10.0 \text{ mg l}^{-1}$  BA induced successful microtuberization without callus formation or morphological abnormalities, suggesting its optimal concentration for *Kufri Chandramukhi* under liquid culture conditions.

A comparison of tuberization traits between control and regenerated plants revealed no significant differences ( $P \leq 0.05$ ) in terms of microtuber number, average fresh weight, and diameter. This phenotypic stability confirms that the *in vitro* regeneration process via zeatin free adventitious shoot regeneration did not alter the tuber-forming capacity of the cultivar. This is particularly

important for clonal fidelity and genetic stability in tissue culture-derived seed production pipelines (Pandey *et al.*, 2011).

Interestingly, although *Kufri Chandramukhi* produced fewer microtubers per plant compared to other high-yielding cultivars such as *Kufri Jyoti* in earlier studies (Naik *et al.*, 1999), the average tuber size and uniformity in our protocol are advantageous for direct use in minituber production and germplasm conservation. Further improvement involving additives like CCC (chlormequat chloride) or activated charcoal could potentially improve yield and tuber size (Al-Hussaini and Mahasneh, 2009).

In summary, the findings validate a reliable and genotype-specific microtuber induction protocol for *Kufri Chandramukhi*, offering a promising strategy for disease-free seed production and storage. The consistency of traits between regenerated and parent lines supports the use of this protocol for commercial-scale micropropagation programs.

## CONCLUSION

The present study successfully established an efficient *in vitro* protocol for microtuber induction in *Solanum tuberosum* L. cv. *Kufri Chandramukhi* using liquid MS medium supplemented with  $10.0 \text{ mg l}^{-1}$  BA and  $80.0 \text{ g l}^{-1}$  sucrose under dark conditions at  $20 \pm 1^\circ\text{C}$ . The findings demonstrate that this genotype is responsive to *in vitro* tuberization, producing morphologically uniform microtubers with consistent average weight and diameter. No significant variation was observed between control plants and those regenerated via the ZR-free ASR system, indicating the genetic and phenotypic stability of the micro propagated lines.

This optimized micro tuberization protocol holds promise for rapid, year-round

production of disease-free planting material, particularly in seed potato multiplication systems. Moreover, it offers a valuable tool for germplasm conservation, genetic transformation, and breeding programs targeting tuber traits. Future work may focus on refining the protocol using additional growth regulators or biotic elicitors to enhance microtuber yield and size.

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## 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

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# SCOPE FOR FOOD PROCESSING INDUSTRIES TO BOOST GLOBAL ECONOMY BY MEANS OF POTATO VALUE ADDITION: A REVIEW

M. Selvamuthukumaran<sup>1\*#</sup>

**ABSTRACT:** Potato, an important agricultural crop grown mainly for domestic consumption as well as for variety of uses. The consumption of fresh potato accounts for 50% in worldwide, and the remaining is being processed into variety of food products as well as food ingredients for its use in food processing industries. The waste generated from potato processing industries, which is being fed to various livestock's and poultry, it can also be used for production of starch. Value added products produced from potato, which is being highly liked and consumed to a greater extent especially frozen potatoes like crisp and French fries especially in UK restaurants. The fuel grade ethanol can also be even manufactured by fermenting the liquid extract obtained from potato processing waste, so there is an ample scope for the various food processing industries to add value to this crop in order to boost the economy of the nation.

**KEYWORDS:** Potato, chips, French fries, flour, starch

## INTRODUCTION

Potato, one of the essential agricultural crops, which are being cultivated in several countries. India stands second place in the production of potato after China, both the countries significantly lead to produce around 38% of total global potato production. The consumption of potato at global level accounts to around greater than a billion (FAO, 2008). By using this crop, several processed products can be prepared, which can further enhance the economic potential of the country. The crop had significant level of protein, which possesses more biological value, when compared to cereals and dairy products and therefore, it can be considered as a major vegetable ascribed to the source of energy as well as protein (King and Slavin, 2013). Potato and its processed products

were consumed widely, which form the part of breakfast, lunch as well as dinner. With respect to production aspects, more amount of dry matter cum nutrients like starch as well as proteins was produced in minimum duration, when compared to production of other agricultural crops like cereals (Rajiv and Kavar, 2016). The nation's nutritional security can be achieved by growing potato at huge extent.

The technology is widely available for exploring postharvest handling and value addition of potato in tropical parts of the world (Dhumal *et al.*, 1991). There is a lot of demand for value added products from potato viz. French fries, especially in fast food industries. In the early hood years, the usage of potato products has tremendously enhanced because of scientific existence of

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new innovative products, to name a few which includes potato flour, flakes, French fried products and also extraction of chemical components like chaconine, lactic acid, and solanine and many more products (Salunkhe and Kadam, 1991).

In UK, most of the fast food outlets and restaurants serve frozen potatoes in the form of French fries, which is deeply fried in oil, and it will be liked by most of the consumers. The global scenario is changing from utilizing potatoes in the fresh form to several value added products (FAO, 2008). Globally around 7 million tons of French fries were processed annually to cater the need of a consumer at global level (DHC, 2016). The global market growth of popularly consumed potato products were given in Table 1. The U.S manufactured and marketed potato crisp in the form of chips, which is also produced by several other developed countries. The starch obtained from potato is being used by multisector industries like paper, pharmaceutical, textile etc. Its usage in respective industries seems to be more, it can be used as a filling, binding, texturing and adhesive agents (Stearns *et al.*, 1994). One can use the starch obtained from potato as an alternative for manufacturing plastics and polystyrene products, it can be used in biodegradable cups, dishes, plates etc.

Good quality alcohol can be produced by using waste product obtained from peels of potato. Starch from these wastes can be effectively utilized for fermentation to further

yield alcohol (Dimitrios *et al.*,2010). Therefore, the global economy can be boosted by adding value to this crop into the form of various innovative processed potato products.

Therefore, in this review the various processing techniques adopted for manufacturing several potato based products were highlighted, which may further help the entrepreneur to start the industry, which can provide employment generation on one side and income generation on another side, which may help in boosting the global economy to a greater extent.

**Potato value addition**

*French fries*

Frozen potatoes in the form of French fries were the popular processed product consumed widely irrespective of the age. Majority of the consumption goes to this product only. The consumer choice for this product is long fry, which is being fried in vegetable oils, for this purpose long variety potatoes should be used for processing (Stearns *et al.*, 1994). It occupies not only as the evening snacks but also used as a startup during dinner in most of the hotel food industries. The color quality of the potatoes can be enhanced by choosing the potato varieties with lesser reducing sugar content, so that browning can be reduced during frying (Tzia *et al.*, 2016). The crop is of course seasonal in nature; therefore proper post-harvest handling and storage practices should be adopted to cater the need

**Table 1. Market growth of popularly consumed potato products.**

Name of the product	Maket size (2019) US Billion \$	Forecasted market size (2019-2024) US Billion \$	Top leading manufacturers	Challenges faced by firms
Potato Chips	30	35	PepsiCo, Kraft Foods, Nestle, Diamond, General Mills	Low fat, Low calorie
Frozen Potato Products	52	72	MccainFoods, Nomad Foods, Aviko Group, Kraft Heinz, Lamb Weston	Low fat

of consumer demand (Talburt *et al.*, 1987; Kadam *et al.*, 1991). To manufacture frozen fries, one has to consider selecting tubers with higher solids content with good texture; this is because the higher solid content has lesser moisture content compared to potato varieties of lesser solids (Stearns *et al.*, 1994). Selection of species with greater specific gravity also produces crispy, mealy with reduced oil absorption capacity. More specific gravity potato variety yields richer taste with slight tenderness (Kadam *et al.*, 1991).

### Manufacturing of French fries

#### *Receiving of raw materials, washing and peeling*

The flow sheet for production of French fries was given in Fig.1. The potato is received, screened for its defect; malformed, greenish and infected potatoes were removed and send for washing. The potatoes were subjected to washing with the help of drum washer, during washing the solid particles

adhere to the potato get dissolved in water and they were washed, after that they were send to the peeling section. The potatoes were peeled by steam peeling process, the potatoes were subjected to steam pressure, the product surface layer is exposed to steam and after some minutes the pressure is quickly released, during this time the potato cell moisture begins boiling and the cell wall is being rubbed, making the skin looser, so that peeling can be effectively carried out and the adhering microorganisms will be killed during the steaming process, which render the product devoid of microbes for further processing. The loose peels were removed by using brush machines and this waste is utilized as an efficient feed for various cattle's. Once again the peeled potatoes were subjected for washing to remove the last traces of starch dirt's followed by manual inspection for efficient and quality processing.

#### *Cutting, sorting and blanching*

The slices were prepared with the help of hydro cutting system, especially for producing the French fries; one has to assure that slices should be of either square shape with straight cuts. The major advantages of this cutting are slice damage that will be minimized during cutting with reduced oil uptake during frying. Then the slices enter into blanching process in two stages, in first stage, where the blanching is done by treating cut slices with hot water around 90°C for a time period of 2 min, wherein the second stage the slices were exposed to a lesser temperature of 70°C with exposing time duration of 40 min.

#### *Drying*

The product quality sounds well if it has uniform color, for this the slices needs to be dipped in hot water at 80°C for a period of 45-60 sec. The slices were drained

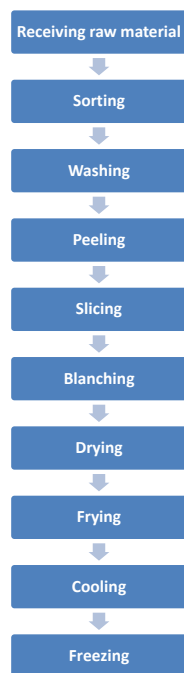


Fig. 1. Flow sheet for production of French fries.

and spread on the dryer belt for removal of some moisture before frying, which will definitely enhance the crispiness of the final product, on the other side it will reduce the oil absorption capacity during frying process and frying time will also be minimized to a greater extent. During drying the hot air will be travelling in upward as well as downward direction, which efficiently removes the moisture content by reducing the weight to 20%. The assurance of internal moisture equilibrium is very much important before frying process.

### ***Frying***

Frying is carried out in fryer equipment with filled oil. The oil is filled with the help of pump circulatory system; it also contains heat exchanger system for controlling heat with belt filter for removing dirt's. The pan is maintained at temperature of 180 °C during frying process with the exposure time duration of 1-2 min. De-fatting vibrator is placed near fryer to remove surface fat from the product.

### ***Cooling and freezing***

The cool air is blown from cooling tunnel towards the product for reducing the temperature from 90°C to 5°C, in this tunnel the products were exposed for 4 min after that the products were send for freezing with the help of freezer belt. The freezing is carried out rapidly with the help of commercial freezer by maintaining the temperature of -18°C for 10 min time duration.

### **Potato chips**

This product, which is quiet popular snack product in US and it is also consumed by different age groups. The major challenges attached with this product are incorporation of spicy flavor, which has significant effect towards organoleptic characteristics.

This is a typical product served to the different sorts of people (McMath, 1990). It's a widely consumed food product especially among youngsters. The product, which is highly preferred because of its crispness texture, salt taste and fat mouth feel.

### ***Production of potato chips***

The potatoes were received in the manufacturing industries, they were stored properly preferably under cold atmosphere, if the processing time delays or immediately it can be washed to remove the adhering surface microorganism, and also to remove stones, dirt and they were peeled with the help of potato peeling machine assuring that without causing any damage to the potatoes. The pleasant color and chips texture will be affected if we utilize damaged tubers. After peeling once again the peeled one is again washed with potable water to prevent discoloration. One has to evaluate the quality checks during peeling like evaluation of potato for identification of green and dark patches, contaminated parts, bruises if any and also for trimming of eyes in order to assure the sound quality product. The very larger potatoes were chopped before the process of slicing, as they crumble as a result of frying. Slicing is an important operation to ensure crispiness quality because of uniform texture and it should be in the range of 0.7 to 1.8 mm. Sliced potatoes were also further washed to remove adhering carbohydrates like starch, sugars in order to prevent them from browning during frying (Tzia *et al.*, 2016). The uniform and consistent colored product can be retained by washing slices.

It was observed that for improving the color appearance the slices were blanched using plain potable water or by adding salt or chemical like sodium bisulfite at temperature of 65°C–95°C for time duration

of 1 min has significantly improved the color appeal (Tzia *et al.*, 2016). The slices should be partially dried before frying and after blanching period to reduce more oil absorption capacity.

After blanching and before frying, partial drying of slices should occur to avoid excessive oil absorption by the product. In bigger and continuous potato processing unit the chips were continuously dried before frying, the temperature utilized during frying is around 175°C- 190°C with a frying time of less than 3 min to achieve good quality product. Once the product is fried, the adhering oil can be easily removed from chips with incorporation of salt cum desired flavors (Tzia *et al.*, 2016). The products were cooled as such and send to the packaging section through conveyor. In the meantime, broken and burnt chips were removed, packed in laminated films, heat sealed and transported to the storage go downs until marketing (Vorria *et al.*, 2004).

### **Fried potato skin**

It's a product, which can be prepared from Russet potatoes, peels can be easily fried or baked. The product will have minimum oil absorption capacity.

### **Mashes potatoes**

The potatoes can be sorted, washed, steam blanched, peeled, mashed and seasoned with garlic and onion to be marketed as seasoned mashed potatoes, which is a quiet popular product in United States.

### **Potato cuisine microwaveable mini potatoes**

In Canada, a product known as Potato Cuisine Microwaveable Mini Potatoes, which are being marketed with 5 different kinds of spices viz. garlic, smoked paprika, sundried

tomato, Maple Butter, Caribbean Jerk. This product were packed in trays and they can be easily cooked less than 7 min in microwave

### **Precooked frozen potato specialities**

It's a product from Agristo firm; a Belgium based company successfully produces this product. The frozen potato specialities can be precooked using virgin sunflower oil, which is s source for 90% monounsaturated and polyunsaturated fatty acids. Precooking the products in such oil may remove bad cholesterol in the body, due to low oil intake during deep fat frying of such product, thereby preventing lifestyle diseases especially heart related diseases. The precooked, frozen and fried potato products taste well as like deep fat fried potato products

### **Potato flakes**

It is one of the dehydrated potato products, which are available in the form of pellets, granules, powder, shredded and sliced forms. It is prepared by subjecting cooked potatoes into a drum drier to give a thin sheet, which is further grounded into a specific form of a product (NPCS, 2012; Milan *et al.*, 2023). During processing the cells were disintegrated, which will yield a mealy textured product ascribed to addition of monoglyceride as an emulsifier and as well as cooking of potatoes (Willard *et al.*, 1987). The short potato pieces during production of French fries can also be used for manufacturing potato flakes by means of grading as per the size (Willard *et al.*, 1987). It has got excellent application; it can be used in manufacturing other products on large scale like pasta, croquettes, instant mashed potatoes etc. It can be used as a thickening agent in chocolate milk, gravies and frozen desserts (NPCS, 2012).

## Potato flour

It is one of the widely used potato products and it is being commercially used in bakery industries especially bread (Ezekiel and Singh, 2011). The incorporation of solids from source of potato may enhance organoleptic qualities especially product fresh appeal, pleasant flavor as well as for improvement of toasting qualities. The flour can be obtained by feeding the dehydrated and cooked potatoes into drum drier with applicator rolls attachment. Desired product fineness can be achieved by pulverizing sheets of potato solids (NPCS, 2012).

Snack kind of crackers can be prepared with the help of this flour, fabricated potato chips as well as frankfurters can also be manufactured by using potato flour (Ezekiel and Singh, 2011). The potato processed product industry can be further extended by adopting various new techniques and processes (Willard and Hix, 1987).

## Minor Products

There are several commercial by products that can be manufactured by using potato (Milan *et al.*, 2023). The waste generated from potato industries can be utilized as cattle feed and even it's a source for extraction of various chemical components (Kadam *et al.*, 1991).

## Potato starch

Starch is a major carbohydrate and it's a precious raw material for several food processing industries (Carvalho, 2008). It is being utilized for either food or feed purpose. The sub quality potatoes accounts for around 10% of the entire crop production, it will be difficult to further process such produce because of either damaged or malformed or any other defects, such crop can be utilized for manufacturing of starch. The starch can also be even manufactured from culled as

well as potatoes which are meant for cattle feed (Treadway, 1987).

The industrial demand stands in the production of starch from especially corn sources, which has got wide utility, production cost is also less for starch obtained from corn sources compared to potato (ERS, 1993). Even though the corn starch price is low, but potato starch is widely used in industries because of its functional properties (Phadnis and Jadhav, 1991). The functional properties for potato starch are excellent binding capacity, film forming ability, higher consistency etc.

## Potato starch applications

For most of the products usage, the starch needs to be modified and they can be modified either by physically or chemically or enzymatically to cater specific use (Phadnis and Jadhav, 1991). The applications of starch for various industries obtained from source of potato are given in Fig.2.

## Paper industry

The application of starch in paper industry is surface coating for manufacturing paper of high quality, for sizing of beater, here the fibres i.e. cellulose fibres, which can be

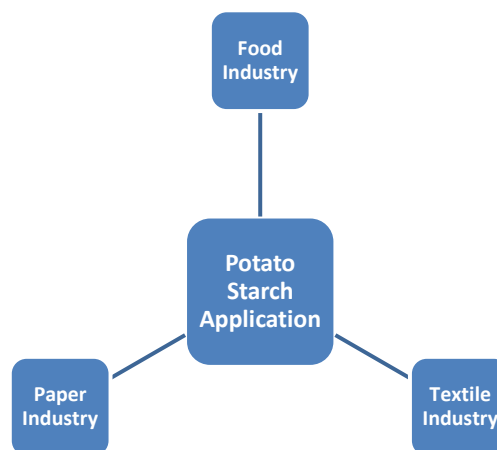


Fig.2. Application of starch obtained from potato.

cemented jointly ahead of forming sheets; tub sizing, here the sheet is send through dilute solution and finally calendar sizing, here the glossy finishing is obtained. The dextrin's and starches obtained from the source of potatoes were used for fabrication of boxes especially for fabricating laminated and corrugated fibre boxes (Treadway, 1987; Phadnis and Jadhav, 1991).

### ***Textile industry***

In textile industry the starch can be utilized for cotton sizing, as well as for spun rayon warps (Stearns *et al.*, 1994). The loose fibers can be binded by means of warp sizing, which can further prevent the warp during weaving process by means of abrasion. The greater flexibility and toughness can be obtained when potato starch is especially used, which further permit the sized warps from potato can be woven at lesser humidity when compared to wraps sized by using corn starch (Stearns *et al.*, 1994).

### ***Food industry***

In food industry, the starch obtained from potato is being used for baking industry (Stearns *et al.*, 1994). Its utility as a soup and gravy thickener, the pellets were used in the preparation of instant puddings, ascribed to jellying consistency (Stearns *et al.*, 1994). In confectionery processing, it can be utilized for molding purpose especially during processing cast candies. It can be a bodying agent, which can add softness to marshmallows and caramels, as a thickener in jellies, as a dusting ingredient along with crushed sugars for chewing gums (Treadway, 1987).

A product known as Perfect amyI Gel MB, which is a starch derived product from potato, which can be used for substituting casein protein @ of 20% in imitation cheese formulations with reduced product

production cost to 10 to 15%. The starch can be used successfully as a ingredient in various food processing industries because of its various properties like good viscosity and clarity with clean taste, lower gelatinization temperature etc. (Dairy Foods, 1991).

### ***Adhesives***

The dextrans can be manufactured by roasting of starch with the acid as a catalytic agent. The films made out of potato starch are having more flexibility with greater resistance power compared to dextrans obtained from cereal starch. They can be further used as a binding agent in manufacturing sandpaper, manufacturing abrasive cloth, for binding books etc. (Stearns *et al.*, 1994). The United States were using lot of adhesives which accounts for greater than 40%, which are from the source of potatoes (Morris and Ahmed, 1992).

### ***Minor uses***

The starch obtained from potato can be utilized as a additives in baking powder, for fermentation of raw materials, as a tablet binder, sausage extender, soap builder, dry cell battery separator, one of the raw material source for manufacturing nitro-starch, insecticidal attractant mixers, as a treating agent in boiler feed water, water clarifiers in mining industries, as a drilling muds in oil well etc. (Stearns *et al.*, 1994).

### ***Waste products***

There are two different kinds of wastes that can be obtained from potato processing first one is liquid waste ascribed to total soluble solids and other one is solid waste obtained as a result of potato tissues. On the other side the enormous volume of water used for frying potatoes, especially during washing raw material as well as during production of

starch powders enhance the generation of more liquid waste, which can be effectively recycled for further use (Anbuselvi and Reji, 2018). The other solid waste like immature potatoes, culled one can be recycled for manufacturing several byproducts (Natu *et al.*, 1991).

### ***Recovery of proteins***

The protein present in potato is lysine and the limiting amino acids in potato were cysteine and methionine. The protein of potato source is quite well comparable with animal protein i.e. egg, ascribed to its quality (Friedman, 1996). Therefore, the waste obtained from potato processing plants can be used as a food, feed and several useful by products. The European starch processing plants were manufacturing protein concentrates from potato, which can be used as an animal feed (Natu *et al.*, 1991).

### ***Animal feed***

Animal feed can be manufactured by efficiently utilizing peels obtained from potato source, culled potatoes and other waste obtained during potato processing can be recycled for manufacturing excellent animal feed. It's an excellent feed for especially ruminant animals because of plenty of nitrogen sources. It was estimated that around processing waste obtained from potatoes accounts for around 1.3 million tons in United States (Natu *et al.*, 1991).

The composite livestock feed can be prepared by using potato protein sources, which is a quite common practice. The meal prepared from potato waste can be used for feeding broiler chicken and other livestock's and it's one of the main carbohydrate sources for such livestock animals (Natu *et al.*, 1991).

### **Other applications**

The waste obtained from potato processing plant is biodegradable (Stearns *et al.*, 1994).

It contains low phosphorus content and it can be used for efficient cleaning and washing purposes. The waste residues can be prepared in either granular or bar form for various specific applications. The waste can be further incorporated with wheat starch milk and used as an adhesive (Stearns *et al.*, 1994). The treatment of potato waste residues with hot water to remove residual starch, which can be further treated with enzyme glucoamylase to yield pectin, which has got extensive industrial applications. From potato peels the phenolic component like Chromogenic acid can be manufactured, which is a good antioxidant as like butylated hydroxyanisole (BHA), which has got good health properties (Rodriguez de Sotillo *et al.*, 1994). As like Chromogenic acid, L-ascorbic acid can be obtained from potato processing waste and it is widely used in agar gel. The starch obtained from potato can be transformed into glucose, further to lactic and citric acids, which can help in biodegradable plastic construction (Coleman, 1990; ERS, 1993).

### ***Potato peel***

It's a byproduct of potato processing industry, which is one of the cheap source for developing several value added by products like biopolymers, dietary fibres, antioxidants and food additives (Chiellini *et al.*, 2004). The method of peeling plays a significant role with respect to its application, adopting steam method of peeling exerted higher dietary fibre content with lesser starch content during production of dehydrated potato products and its better compared to abrasion method of peeling, usually the chips producing industries adopt (Camire *et al.*, 1997).

The dietary fibre obtained from source of potato exhibited hypocholesterolemic effect

demonstrated in animal model (Lazarov and Werman, 1996). The feeding of potato peel along with routine diet had significantly reduced cholesterol content in the plasma to 40% and while hepatic fat cholesterol was reduced to 30% pronouncing significant hypocholesterolemic activities, it also further minimized the glucose content in blood.

For bakery products development the dietary fibre obtained from potato peel can be incorporated to exert health benefits for the consumers (Table 2). The peel obtained from potato processing accounts for around 50%, when it is incorporated into flour, it exhibited good water holding capacity with lesser starch content, only issue is during incorporation it will produce end product with musty odour, which can be nullified by utilizing potato peel obtained by using extrusion process (Alonso *et al.*, 2006). Incorporation of potato peel during biscuit preparation @ of 5-10% lead to produce good quality acceptable product with smaller stack weight (Abd-El-Magied, 1991; Al-Weshahy and Rao, 2012).

The peel as a substrate can be successfully employed for producing variety of enzymes (Shukla and Kar, 2006). The peel obtained from potato serves as a carbon source for mannase production by utilizing microorganisms i.e. *Bacillus amyloliquefaciens*. As like mannase, and other enzymes like amylase, cellulose can also be prepared by using potato peel, and these enzymes have wide food industrial applications.

**Table 2. Proximate composition of potato peel.**

Parameter	Content (%)
Moisture	82.34
Carbohydrate	57.20
Protein	7.16
Fat	2.20
Ash	6.13

Potato peel, a rich source of antioxidants especially polyphenols, which exert preservative effects in various food applications. The freeze dried extract obtained from potato peel can be used @ of 1000 ppm for preserving beef patties as a substitute for synthetic antioxidants, the use of such peel extracts pronounced more antioxidant power, noticed at selective pH of 5-6 (Mansour and Khalil, 2000). It is also used in oil products to control rancidity (Rommi *et al.*, 2016).

## CONFLICT OF INTERESTS

The author declare that they have no conflict of interest

## ETHICAL STATEMENT

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

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# POTATO TUBER DRY MATTER: A CRITICAL TRAIT FOR BREEDING, PROCESSING AND PRODUCTIVITY

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**ABSTRACT:** Potato (*Solanum tuberosum* L.) is a globally important staple crop valued for its versatility and high carbohydrate content. Tuber dry matter content (TDM) typically comprising 20% of freshly harvested tubers, is a critical trait influencing processing quality, nutritional value and marketability. TDM is closely associated with specific gravity and varies significantly across cultivars and is shaped by genetic and environmental factors, including agronomic practices and storage conditions. High TDM is essential for processing industries particularly chips, French fries and dehydrated products due to higher product yield, lower oil uptake and better texture. While 18–20% TDM is adequate for canning, levels exceeding 20% are optimal for most fried and dried products. Despite its importance, breeding for high TDM presents challenges due to its quantitative inheritance and strong genotype- by-environment interactions. Moreover, increased TDM may compromise other traits, such as tuber yield and culinary quality, including disintegration during boiling. These trade-offs complicate breeding decisions and demand a balanced approach that integrates genetic, physiological and agronomic strategies. This review critically examines the significance of TDM in potato breeding and processing, explores its genetic and environmental determinants and highlights current challenges and future opportunities in developing high-TDM cultivars. By enhancing our understanding of this complex trait, we can better align breeding goals with industry needs and consumer preferences, ultimately improving potato productivity and value across the supply chain.

**KEYWORDS:** Potato, Tuber Dry Matter, Specific Gravity, Processing Quality, Breeding

## INTRODUCTION

Potatoes are among the most highly consumed food crops worldwide, with high per capita consumption across many regions. As the fourth most important food crop after rice, maize and wheat, the potato holds the distinction of being the world's most important vegetable. Its high nutritional value, favorable harvest index and good yield potential make it an ideal crop for addressing global challenges related to population

growth, food security and nutritional needs.

Following its global dissemination during the colonial era, the potato gained widespread acceptance as a calorie-dense food. Historians have highlighted its critical role in influencing demographic patterns, famine events and mass migration.

The “potato influence” of the medieval period played a transformative role in shaping global population dynamics and political

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history. Over time, significant efforts have been made to improve the crop's adaptability to diverse agroecological zones, enhance its yield potential and expand its end-use applications. Although potato yields increased by about 50% between 1966 and 2016, this gain is relatively modest compared to those achieved in maize, rice and wheat over the same period. However, when yields are compared on a dry weight basis, potato production increase (3.92 t/ha) is quite comparable to that of maize (4.79 t/ha), wheat (2.90 t/ha) and rice (3.94 t/ha) (Bradshaw 2021). Yield improvements have been driven by advances in crop improvement, the use of modern fertilizers, disease-free seed, plant protection chemicals and agricultural mechanization.

Potato tubers consist of 75–85% water and 15–25% tuber dry matter (TDM). Despite their high moisture content, potatoes yield more edible energy, protein and dry matter per unit area and time than cereal crops (Wassu, 2017). However, tuber dry matter content has received comparatively less attention in potato breeding programs, as high TDM is often viewed primarily as a requirement for specific processing purposes such as chip and fry production. In general cultivation, varieties with higher overall yield are typically preferred by growers, unless specific traits such as disease resistance, stress tolerance, or industrial applications like starch extraction are prioritized. In India, for instance, potato varieties with TDM of 18–20% are considered suitable for table purposes (boiling/baking), while those with TDM above 20% are recommended for processing into chips, French fries and flakes (Souza and Silva 2003).

It also reflects the cumulative nutritive content of the tuber, including starches, carbohydrates, fats, proteins, minerals and vitamins. Its high correlation with starch

content, offer higher caloric density. While the average potato provides approximately 70 kcal per 100 g fresh weight (Trawczyński 2016), tubers with higher TDM provide substantially greater calorific value. This has important implications across multiple dimensions, enhanced nutritional productivity per unit land area, improved input-use efficiency (irrigation, harvesting and transport) and economic benefits throughout the value chain.

Besides, TDM also significantly affects texture, taste, resistance to mechanical damage and the overall processability of tubers (Thygesen *et al.*, 2001; Tarn *et al.*, 2010) which influence consumer preferences, culinary suitability and market acceptance.

Given these considerations, it becomes imperative to focus on this important characteristic of potatoes at various levels ranging from breeders and agronomists to growers and consumers. This review aims to comprehensively examine the importance of TDM in potatoes, a trait of critical relevance across breeding, cultivation, storage, processing and consumption. It synthesizes current knowledge on the physiological, genetic, agronomic and environmental factors influencing TDM, discusses methods of its estimation and highlights recent advances in molecular and genomic tools for improving this trait. Furthermore, the review explores TDM's role in determining processing quality, nutritional value and economic efficiency. By consolidating these diverse aspects, the review advocates for the strategic integration of TDM into breeding and crop management programs to meet evolving industry and consumer demands.

## POTATO TUBER AS A STORAGE ORGAN

Potato tubers, the edible part of the plant, are metabolically active, specialized

stem structures that serve not only as storage organs but also support vegetative propagation. These storage organs significantly influence the tuber's physical characteristics and chemical composition. Being rich in metabolically active plastids, tubers synthesize a variety of compounds through plastidic pathways ranging from primary metabolites to complex secondary metabolites. These compounds contribute not only to the organoleptic properties of the tubers but also provide physiological advantages in terms of tuberization and environmental adaptation (Katan and De Roos 2004; Navarre *et al.*, 2009). TDM, specific gravity and starch content in potato increase progressively from planting to maturity. This rise stabilizes upon physiological maturity, which is marked by the senescence of aerial plant parts leading to a decline in photosynthetic activity and, consequently, TDM accumulation (Kumlay *et al.*, 2002). Physiological maturity is marked by a peak in TDM indicating full tuber development (Sabba and Lulai, 2002; Bussan *et al.*, 2009). Mature tubers are also characterized by lower levels of reducing sugars which is beneficial for both storage and processing quality (Driskill *et al.*, 2007). Furthermore, tubers with higher concentrations of dry matter, starch and calcium exhibit increased resistance to mechanical stress, a trait linked to specific structural attributes of their cells. Calcium in particular has been shown to enhance cell wall integrity by strengthening the bonds between cell wall polymers, thereby stabilizing the overall structure (Koch *et al.*, 2019).

## ESTIMATION OF DRY MATTER

Estimating TDM is a fundamental step in all potato breeding and evaluation programs due to its close association with processing quality and nutritional content. A common method involves selecting five randomly

drawn tubers from each variety. These tubers are sliced horizontally and half of each tuber is finely chopped and homogenized. A 50 g sample from each variety, in triplicate, is then dried in a hot air oven at 80°C for 72 hours until a constant weight is reached, indicating complete moisture removal (Luthra, 2003). Although direct TDM estimation can be time-consuming, it is highly correlated with specific gravity, enabling indirect assessment using a 3–5 kg tuber sample (Tawfik *et al.*, 2002; Kumar *et al.*, 2005). This method, widely used for large-scale evaluations, typically employs the specific gravity measurement technique outlined by Storey and Davies (1992), in which tuber weight is measured in air (x) and underwater (y) to calculate specific gravity using the formula  $SG = x/(x-y)$ . A specific gravity value of 1.095 generally corresponds to a TDM of approximately 24%. The measurements can be expressed as a percentage of total fresh weight or as a ratio of dry to fresh mass, as described by Mostofa *et al.*, (2019). Commercial specific gravity balances with capacities up to 10 kg are also used for this purpose.

In recent years, advancements in analytical tools have enabled the development of more precise and industry-friendly methods for TDM estimation. Processing industries now widely employ equipment specifically designed to assess specific gravity. Additionally, near-infrared (NIR) spectroscopy has gained popularity for its rapid and non-destructive estimation capabilities. In this method, NIR spectra in the 700–1100 nm range are acquired and analyzed using partial least squares (PLS) regression to build predictive models for specific gravity estimation (Scanlon *et al.*, 1999). VIS–NIR spectroscopy coupled with a 1D-convolutional neural network

(1D-CNN) for online prediction of potato dry matter content has been evaluated by Guo et al. (2024) for TDM estimation. The model automatically extracted spectral features without manual preprocessing and demonstrated high prediction accuracy, robustness, and rapid processing, making it suitable for industrial applications. While non-destructive assessment techniques offer several advantages, they also present important limitations. These include the need for handling and analyzing large and complex datasets, frequent calibration for changes in setup, high costs associated with purchase, maintenance and repair. Additionally, their performance can be affected by physical and environmental factors such as lighting conditions, cultivar, seasonal variation, optical alignment, sample size and temperature (Wang *et al.*, 2023).

Non-destructive techniques, such as imaging and spectroscopy, are less accurate than the direct dry matter assessment carried out in lab, enable rapid, high-throughput comparative quality inspection of large seed lots received from the field and storage and are suitable for high end processing industries. Breeding pipelines may rely on simpler dry matter estimation methods in the early generations and direct dry matter based or specific gravity based estimations to ensure development of the desirable potato varieties.

## TUBER DRY MATTER CONTENT GOVERNS POTATO USE

The quality of potatoes is a critical factor in determining market acceptance. Consumer perception is primarily influenced by external attributes such as appearance, colour, size, shape, and the presence or absence of defects. In addition, texture, flavour, and nutritional value are critical internal quality parameters that significantly influence consumer preference and overall marketability. TDM is closely associated with internal quality attributes like texture and the end-use suitability of potato varieties (Table 1). A mealy texture corresponds to high TDM levels, whereas a waxy texture is associated with lower TDM.

TDM is the most important criterion for processing potatoes, significantly influencing both product recovery and quality. High TDM varieties yield better outputs for dehydrated products such as flakes, starch and cubes compared to those with low TDM which are suitable for boiling and salads. Additionally, it affects multiple processing traits, including crispiness, color, oil absorption, flavor and final product texture (Marwaha *et al.*, 2008). Low-TDM tubers absorb more oil during frying, leading to greasy and sticky-textured products. Since oil constitutes a major cost in fried product manufacturing, selecting varieties with optimal TDM can substantially reduce processing expenses. Desirable traits

**Table 1. Relationship between tuber dry matter and optimum use (Mosley and Chase 1993)**

Specific gravity	Dry matter %	Texture	Typical uses
Below 1.060 (very low)	Below 16.2	Very soggy	Pan frying, salads, canning
1.060-1.069 (low)	16.2-18.1	Soggy	Pan frying, salads, boiling, canning
1.070-1.079 (medium)	18.2-20.2	Waxy	Boiling, mashing, fair to good for chip processing and canning
1.080-1.089 (high)	20.3-22.3	Mealy, dry	Baking, chips, frozen French fry, some cultivars tend to slough when boiled
Above 1.089 (very high)	Above 22.3	Very mealy or dry	Baking, frozen French fry, chip, tendency to produce brittle chips and to slough when boiled

for processing-grade potatoes include high specific gravity, elevated TDM, low reducing sugars and high starch content (Kumar *et al.*, 2009; Wassu 2017).

In recent years, there has been a marked increase in breeding efforts aimed at developing processing-specific cultivars. In India, a series of cultivars such as Kufri Chipsona-1, Kufri Chipsona-2, Kufri Chipsona-3, Kufri Chipsona-4, Kufri Chipsona-5, Kufri Himsona, Kufri Frysona, Kufri FryOM and Kufri Sangam have been developed to meet the specific needs of the processing industry.

Nutritional quality is further influenced by the composition of starch fractions, namely rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS). These fractions influence the glycemic response and digestion rate (Englyst *et al.*, 1992), underscoring the importance of not only evaluating the quantity but also the quality of TDM to breed nutritionally enriched varieties with specific health benefits.

## **TUBER DRY MATTER DISTRIBUTION WITHIN A TUBER**

Tuber dry matter (TDM) content varies not only between tubers on the same plant but also within different regions of an individual tuber. The highest concentration of TDM is found in the outer cortex, apical and stem end regions, while the central pith typically contains the lowest levels (Pritchard and Scanlon 1997). According to Iritani and Weller (1973) moisture stress during the growing season contributes significantly to this non-uniform distribution. Moreover, TDM and sugar distribution within tubers can shift during storage. While the flesh of the tuber is rich in TDM and total soluble solids, the peels are more concentrated in

protein, fiber, ash and minerals with the exception of magnesium. Varieties with uniform starch distribution are preferred for the development of processing cultivars, as they ensure uniform colour and quality in the final processed products.

## **FACTORS AFFECTING TUBER DRY MATTER**

**Genotypic Variation:** TDM exhibits a strong genotypic influence, although it remains susceptible to environmental conditions (Tsegaw, 2011). Variation in intra-tuber TDM distribution is also genotype-dependent (Grewal and Uppal 1989; Pritchard and Scanlon 1997; Marwaha *et al.*, 2010; Wayumba *et al.*, 2019; Kajunju *et al.*, 2022; Islam *et al.*, 2022). As a highly heritable trait, TDM demonstrates stability over multi-year evaluations with values ranging from <16% to >22% depending on the variety. It is essential to select appropriate cultivars for specific uses such as processing. Diploid pre-breeding populations have been reported to show wider variation in total dry matter and glucose content due to their higher genetic diversity and limited selection as compared to advanced tetraploid lines which are more uniform as they have already undergone multiple cycles of selection for desirable quality traits (Bonierbale *et al.*, 2003). Early-maturing genotypes generally have lower TDM due to a shorter photosynthate accumulation period, while very late types may sometimes display poor TDM allocation between foliage and tubers (Haverkort and Kooman 1997). The released potato processing varieties having higher TDM are mostly of late maturing type.

Gupta *et al.*, (2015) reported TDM in 44 Indian potato varieties, ranging from 16% in Kufri Khyati and Kufri Pukhraj to 24% in Kufri Kundan, Kufri Himsona and Kufri

Frysona. Floury texture and flavor showed positive correlations with TDM ( $r = 0.33^*$ ,  $r = 0.32^*$ ). Similar ranges have also been reported by Luthra *et al.*, (2018).

**Environmental Variation:** TDM is influenced by genotype-environment interactions. Mthembu *et al.*, (2022) noted the combined impact of genotype, water availability and growth stage on TDM, yield and tuber size. Spring-grown tubers usually show higher TDM and starch but lower reducing sugars and polyphenols than autumn-grown ones (Freitas *et al.*, 2012). In Peru, potatoes grown at 3273 masl exhibited higher TDM and better TDM partitioning than those at 230 masl (Victorio *et al.*, 1986).

Mazurczyk *et al.*, (2009) found that cooler, more humid conditions with low radiation supported better TDM accumulation. TDM content in the same variety fluctuated across years, seasons and locations due to planting time, temperature and soil moisture. In India, longer durations are needed for achieving suitable TDM and low reducing sugars in potatoes grown in the north-western and west-central plains (Gupta *et al.*, 2024). Salej *et al.* (2022) in the varietal evaluation of varieties released over time (Era trials) for quantifying realized genetic progress in Indian potato varieties reported that mean dry matter was high in the Eastern plains and West-Central plains whereas, the highest dry matter was observed in the hilly regions. Whereas the Eastern plains and West-Central plains of India depict cool night temperatures (8–14 °C), bright sunshine, low humidity, and controlled irrigation during tuber bulking which are important climatic factors promoting high total dry matter accumulation in potato. The high dry matter reported in hilly regions is merely on account of the long growing periods.

**Temperature:** Air temperature significantly affects both total and tuber-specific TDM.

Studies on Bintje and Désirée show that rising air temperature reduces tuber TDM with distinct responses from stolons and secondary growth (Struik *et al.*, 1989). High day/night temperatures (31°C/29°C) reduce TDM and harvest index compared to lower regimes (19°C/17°C) (Lafta and Lorenzen 1995). Transient heat stress (>7 days) has been reported to increase TDM and reducing sugars, causing defects such as stem-end chipping (Busse *et al.*, 2019). While, Indian regions with mild night temperatures (>10°C) tend to produce high TDM and low reducing sugar content (Pandey *et al.*, 2009; Gupta *et al.*, 2024).

**Radiation:** Solar radiation better expressed as RUE (radiation use efficiency) plays a critical role in TDM accumulation by enhancing photosynthetic activity, translocation of photosynthates to the developing tubers thereby promoting early tuber initiation and efficient tuber bulking (Goudriaan and Monteith, 1990; Burstall and Harris, 1983; Ewing and Struik, 2010). TDM has been defined as the product of intercepted radiation (IR, MJ m<sup>-2</sup>), radiation use efficiency (RUE, g MJ<sup>-1</sup>) and the harvest index (HI, g g<sup>-1</sup>) (Sandana *et al.*, 2023). TDM is both dependent of area of cultivation as well as the genotype (plant canopy and leaf architecture). Persistent cloud cover and frost reduce photosynthesis, moisture levels and TDM (Darabi and Mohammadi 2015). Elevated ozone has been reported to reduce starch content (Vandermeiren *et al.*, 2005), while increased CO<sub>2</sub> enhances TDM accumulation (Wheeler *et al.*, 1991).

**Soil Type:** Soil characteristics such as water-holding capacity, structure and fertility influence TDM directly or in combination with other factors. Drier soils may enhance TDM concentration but limit yield. Loamy

soils with optimal moisture and temperature conditions support both yield and TDM. Clay loams support better TDM accumulation in wet conditions as compared to sandy soils on account of higher nutrient retention promoting growth. Loamy soils have been reported to offer highest productivities in potato and therefore the TDM on account of their optimum moisture and temperature relationships. While pH has no direct effect on TDM, it may affect yield and TDM per hectare. Generally, a pH range of 5.5 to 6.2 is considered optimal for potato growth and tuber development, as it promotes the uptake of essential nutrients. Deviations from this ranges create imbalances in nutrient uptake leading to reduction in tuber yield, quality and reduced dry matter.

**Planting Date and Maturity:** Early planting enhances TDM by maximizing photosynthetic activity during tuber initiation. Nevertheless, actual emergence date may be a more reliable indicator. In Meghalaya, mid-November planting resulted in the highest TDM in winter potatoes (Gogoi and Ray 2019). Mature tubers generally contain less reducing sugar and TDM but offer improved storage and lower susceptibility to damage (Driskill *et al.*, 2007).

**Fertilizers:** Increased soil fertility tends to reduce TDM (Vos 1997; Mazurczyk and Lis 2000; Bélanger *et al.*, 2001). Nitrogen application often boosts vegetative growth at the expense of TDM, particularly when extending maturity periods. El-Hadidi *et al.* (2017) reported that excessive nitrogen application delays tuber initiation, diminishes specific gravity, and decreases yields in certain cultivars. Splitting nitrogen does not significantly affect TDM (Sun *et al.*, 2012). Studies report no significant nitrogen effect on TDM (Sun *et al.*, 2012), while others

show positive responses to calcium addition (Banerjee *et al.*, 2014) or variety-fertigation interactions (Bandana *et al.*, 2018). Potassium influences starch synthesis via activation of starch synthase. Xie and Wang (2022) reported available potassium showed the strongest positive correlation, followed by soil nitrate content, electrical conductivity, water content and available phosphorus. Similar observations also reported by Panique *et al.* (1997) and Koch *et al.* (2020). Arsenic contamination has been reported to lower TDM and starch levels (Haque *et al.*, 2018). Among the different forms of supplied Potash, Polyhalite followed by Sulphate of Potash reportedly increases TDM, while Muriate of Potash reduces it (Panique *et al.*, 1997; Roy *et al.*, 2017). Increased P availability in soils has also been correlated with high TDM, besides lowering total sugar content and higher contents of both starch and proteins (Leonel *et al.*, 2017). Nutrient uptake at 40 days after planting shows a strong positive correlation with total dry matter content, as it determines the plant's capacity for assimilate production and efficient partitioning to tubers (Da Carlos *et al.*, 2020). The second half dose of nitrogen is generally recommended for application at this critical stage in potato to enhance tuber bulking. Organic fertigation supplemented with N and P reportedly has no effect on TDM (Prakash *et al.*, 2024; Alexopoulos *et al.*, 2019).

**Chemical Applications:** Biostimulants such as Green OK-Universal Pro and Asahi SL, alone or with herbicides like Avatar 293 ZC, enhance TDM and starch accumulation (Baranowska 2018). Gypsum and boron foliar spray applications have been reported to significantly improve TDM at optimized doses (Shirur *et al.*, 2021).

**Irrigation Regime:** Irrigation method and regime reportedly plays a profound effect

on potato TDM, as it is a shallow root plant whose roots are mainly distributed in the soil surface and extremely sensitive to water stress. Reduced irrigation post-tuberization enhances starch and TDM but can lower yield (Carli *et al.*, 2014; Banerjee *et al.*, 2016). Drip irrigation is superior to furrow systems in increasing TDM and chip recovery (Sinha *et al.*, 2021). Irrigating up to 50% of tuber development has been reported to boost TDM and nutritional traits (Ierna and Mauromicale, 2022). In recent reports by Li *et al.* (2023) water deficit reduced flowering, tuber yield, dry matter and tuber size.

**Biochemical Factors:** Starch, constitutes upto 75% of TDM which enhances processing quality (Lister and Munro 2000; Bandana *et al.*, 2016; Burke 2012). Strong positive association of TDM have been reported with soluble protein ( $r = 0.76^{**}$ ) and ascorbic acid ( $r = 0.51^*$ ) (Luthra *et al.*, 2018). High TDM also negatively correlates with low reducing sugars and lower glycemic index (Kumar *et al.*, 2009). High TDM varieties like Agria, Aula, Herta, Aziza and Sante also feature favorable specific gravity and processing traits (Hassanpanah *et al.*, 2006). These are already being considered for improving potato quality and nutritional status of potato varieties.

### Effect of Storage on Tuber Dry Matter (TDM)

Potatoes are a semi-perishable commodity that require proper storage to ensure a continuous supply during the offseason. Under controlled conditions of 2–4 °C and 95% relative humidity, tubers can be stored for over six months. Storage at low temperatures (2–4 °C) slows enzymatic and metabolic processes, thereby retarding starch degradation and minimizing TDM loss. However, extended low-temperature storage also increases sugar accumulation, which negatively affects processing quality.

Long term low-temperature storage leads to sugar accumulation, a phenomenon known as cold-induced sweetening, which imparts an undesirable sweet taste in table potatoes and causes darkening and poor-quality chips during frying (Freitas *et al.*, 2012; Kaaber *et al.*, 2001). This is caused due the breakdown of starch stored in the amyloplasts through the phosphorolytic pathway involving phosphorylase and the hydrolytic pathway involving amylase into sugar phosphate compounds. These can be further converted into suberin for wound healing or into additional starch compounds during wound periderm formation (Geigenberger *et al.*, 2004). It is estimated that TDM losses over a seven-month period range from 1.6% to 4.3% under optimal storage conditions (Kaaber *et al.*, 2001).

Conversely, when tubers are stored at higher temperatures, they tend to lose moisture through respiration and evaporation, leading to a relative increase in TDM as a result of tuber shrinkage on account of reduced moisture content (Kaaber *et al.*, 2001). Further, as tubers break dormancy and begin to sprout, respiration rates further increase, enhancing the conversion of starch into reducing sugars, which are consumed during metabolic activity, contributing to a net reduction in TDM over time. Temperatures, around 8–12°C reportedly help maintain processing quality by reducing cold-induced sweetening and have been shown to slightly increase TDM content.

During storage, several physiological and biochemical changes affect tuber TDM content. As storage progresses, Improper storage conditions, such as poor ventilation, immature or damaged tubers, or excessively humid environments, can enhance respiration losses that exceed evaporative water loss, ultimately causing a decline in TDM (Heltoft

*et al.*, 2016). Humidity levels during storage also play a critical role; maintaining optimal humidity around 95% helps reduce moisture loss and stabilize TDM content, whereas low or fluctuating humidity accelerates desiccation and respiration, resulting in variable effects on TDM.

## GENETICS AND BREEDING FOR TDM

TDM in potato is a complex quantitative trait governed by multiple genes and significantly influenced by environmental conditions. Despite this complexity, TDM shows high heritability, making it a promising target for genetic improvement through both conventional and molecular breeding methods.

TDM is primarily controlled by general combining ability (GCA) rather than specific combining ability (SCA), indicating the predominance of additive gene effects. Bradshaw *et al.*, (2000) found that GCA variance for specific gravity (high correlation with TDM) was significantly higher than SCA variance. Additionally, narrow-sense heritability of TDM is high, enabling effective selection using full-sib family breeding strategies. TDM is also positively associated with essential processing traits such as fry color, making it a critical component in breeding programs targeting processing-quality potatoes (Islam *et al.*, 2022).

In breeding programs, high TDM is an important selection criterion alongside yield, disease resistance and agronomic performance. In breeding for processing varieties, parental lines are selected based on their dry matter potential and field performance. Screening for TDM is typically initiated in the early generations, such as F<sub>1</sub>C<sub>1</sub>, to identify elite clones, which are then multiplied in advanced generations to carry out replicated trials (Luthra *et al.*, 2020). The TDM is generally

attributed a 10% score in the varietal score card for selecting a variety for release. The analysis by Salej *et al.* (2023) revealed very low and occasionally negative genetic gain for total dry matter content (TDM) in the Indian potato breeding programme over the last fifty years, indicating limited selection progress for this trait. This observation differs from Bradshaw (2021), who reported measurable genetic improvement in dry matter content in potato breeding, possibly reflecting differences in breeding objectives, germplasm base, and selection intensity between breeding programmes. This trend highlights the historical orientation of Indian potato breeding programmes toward improving yield, early maturity and late blight resistance, while total dry matter content (TDM) has received relatively less direct selection pressure and has largely been treated as a secondary quality attribute.

Considerable genetic variability in TDM exists among cultivated potato varieties (Johansen *et al.*, 1967; Ruttencutter *et al.*, 1979) reflecting its polygenic inheritance. Due to strong genotype environment interactions, multi-location evaluations are necessary for accurate selection. Quantitative trait loci (QTL) mapping has facilitated the identification of genomic regions associated with TDM and related traits like starch content. Several studies have reported allelic variants influencing tuber starch accumulation and quality (Li *et al.*, 2013; Schonhals *et al.*, 2016) and multiple QTLs associated with TDM have been mapped (Park *et al.*, 2021). However, the tetraploid nature of cultivated potato complicates marker-assisted selection (MAS) for TDM on account of its complex quantitative inheritance.

Genomic selection (GS) offers a more effective approach for improving TDM. Unlike MAS, GS utilizes genome-wide marker

data to predict breeding values without the need to identify individual QTLs (Meuwissen *et al.*, 2001; Busse *et al.*, 2019). GS involves estimating genomic estimated breeding values (GEBVs) from a training population with known genotypic and phenotypic data, then using these GEBVs to select superior individuals in a test population based solely on genotypic information. This approach reduces breeding time and costs by minimizing field trials (Heffner *et al.*, 2010; Slater *et al.*, 2017). Prediction accuracies of 0.56 for starch content have been reported using cross-validation, which were observed to drop significantly in the range of 0.30–0.31 in independent test populations (Sverrisdóttir *et al.*, 2017, 2018). GS has also been successfully applied to predict traits such as chipping quality and starch content using genotyping by sequencing and statistical models (Endelman *et al.*, 2018; van Eck 2007; Li *et al.*, 2008; Fischer *et al.*, 2013; Schreiber *et al.*, 2014).

Exotic germplasm, including wild species and *Solanum tuberosum* ssp. *Andigena*, serves as a valuable source of genetic variation for enhancing TDM and incorporating resistance to traits like late blight. Chimote *et al.*, (2008) emphasized the value of such genetic resources in expanding the breeding base for high TDM varieties. Several studies related

to TDM breeding have been summarized in Table 2.

The candidate gene approach has been widely used to explore genes involved in carbohydrate metabolism, starch biosynthesis and water regulation which are the key component characters determining TDM. Since starch constitutes the largest component of TDM, genes regulating starch biosynthesis are particularly important. ADP-glucose pyrophosphorylase (AGPase) catalyzes the first committed step in starch biosynthesis and plays a pivotal role in starch accumulation (Sun *et al.*, 2020). Starch branching enzymes (SBEs) have been reported to influence the architecture of amylopectin which affects starch quality and quantity (Yu *et al.*, 2021), while starch synthases contribute to the elongation of glucan chains during amylose and amylopectin synthesis (Nazarian-Firouzabadi and Visser 2017).

Genetic variations in several key biosynthetic genes including *BMY-8/2* (a  $\beta$ -amylase gene), *PHO1b* (plastidic starch phosphorylase) and the large  $\beta$ -subunit of AGPase have been associated with differences in starch content and yield (Schreiber *et al.*, 2014). However, limited understanding of the regulatory mechanisms and enzymatic functions of these genes restricts their broader

**Table 2. Genetic studies related to dry matter in potato**

Freyre and Douches 1994	Diploid mapping population in three different locations and mapped ten putative QTL on chromosomes 1, 2, 3, 5, 7 and 1. Highest R <sup>2</sup> QTLs explained 39-40% of variation
Schäfer-Pregl <i>et al.</i> , 1998	Eighteen Specific gravity QTL detected on all 12 potato chromosomes in segregating generations.
Li <i>et al.</i> , 2008	Loci linked to this trait on chromosomes 2, 3, 5, 7, 8, 9, 10 and 11 through candidate genes- or known loci-association mapping in tetraploid potato population
Li <i>et al.</i> , 2019	Specific gravity QTL on chromosomes 1, 2 and 8 after analyzing a Chinese tetraploid mapping population at three different locations for 2 years.
Schönhals <i>et al.</i> , 2016	The 450 genes observed to harbour markedly distinct SNPs and deemed primary functional candidates for regulating the inherent variability in tuber yield and starch content. 89 SNPs corresponding to 72 genes were proposed as primary targets for the development of diagnostic markers and breeding applications.
Park <i>et al.</i> , 2021	QTL analysis for russet family for tuber shape and TDM 11 significant QTL were reported specific gravity, appeared on chromosomes 1 and 5

application in breeding programs. This limits the practical utility of candidate gene based selection and transgenic approaches aimed at enhancing TDM in potato.

## **FUTURE PERSPECTIVES**

Improvement of total dry matter (TDM) content in potato requires an integrated approach combining targeted breeding, advanced phenotyping, and alignment with evolving industry requirements. Future breeding efforts should prioritize the development of high-TDM genotypes with stable performance across diverse environments, while simultaneously maintaining high yield, early maturity, and resistance to major biotic and abiotic stresses. Broadening the genetic base through the incorporation of diploid germplasm, wild relatives, and pre-breeding populations will be critical to enhance genetic gain for TDM and processing quality traits.

Advances in phenotyping technologies, particularly non-destructive tools such as near-infrared spectroscopy (NIRS), hyperspectral imaging, and sensor-based high-throughput phenotyping platforms, offer significant potential to improve selection efficiency. These technologies enable rapid, accurate, and large-scale assessment of dry matter and related physiological traits, thereby accelerating breeding progress. Integration of phenomics with genomics-assisted breeding approaches, including marker-assisted and genomic selection, will further enhance the precision and efficiency of TDM improvement.

From an industry perspective, increasing demand for processing-grade potatoes necessitates the development of varieties with consistently high dry matter, low reducing sugars, and suitability for mechanized production and long-term storage. Future breeding programmes must therefore adopt

a market-oriented approach, focusing on improving dry matter stability, processing quality, and adaptability to climate variability. Collectively, these efforts will be essential to meet the growing demand for high-quality potato raw material and ensure sustainable productivity and profitability across the value chain.

## **CONCLUSION**

TDM is a fundamental quality parameter that affects the suitability of potato cultivars for diverse uses, including table consumption and industrial processing. The development of varieties with optimal TDM levels is therefore critical, especially for the processing industry where high TDM ensures improved frying quality, reduced oil uptake and enhanced end-product texture. Suitable choices for optimizing dry matter based on end use and consumer preference can be excised on account of genotype, planting region, elevation, soil type, harvesting dates, nutrient management etc. This offers immense opportunities for the stakeholders.

Higher tuber dry matter is directly linked to improved nutritional value and processing quality in potatoes. Globally, there is growing emphasis on breeding early-maturing potato varieties due to their environmental sustainability and their ability to evade various biotic and abiotic stresses compared to long-duration cultivars. Enhancing dry matter content in these early varieties is therefore crucial for enhancing both nutritional security and processing potential. Moreover, high tuber dry matter content is a fundamental requirement for processing grade potatoes as it directly influences product yield, texture, oil absorption and overall quality. With the rapid expansion of the potato processing industry driven by rising consumer demand for products, the

ratio of processed to fresh potato use has increased significantly in recent years. This shift underscores the growing importance of developing varieties specifically tailored for processing, where elevated dry matter content not only enhances industrial efficiency but also aligns with economic and nutritional objectives.

This review emphasizes the various genetic, physiological, environmental and post-harvest factors that collectively influence TDM in potatoes. Multiple factors interact in a complex and interdependent manner to influence plant physiology and total dry matter (TDM) accumulation. These factors do not operate in isolation, rather their effects are integrative and synergistic, collectively determining the overall dry matter production and its partitioning within the plant. Consequently, no single factor can be identified independently as the sole determinant of TDM, as its accumulation is the outcome of the combined influence of genetic, physiological, and environmental components. To summarise among various traits, the duration and rate of tuber bulking, along with photosynthetic efficiency and assimilate partitioning efficiency (affected by the influencing factors), are the most critical determinants of total dry matter accumulation in potato. These traits directly regulate assimilate production, translocation, and storage in tubers, thereby exerting the strongest influence on final dry matter content.

A deeper understanding of the genetic control of TDM, including its polygenic inheritance and interactions with environmental variables, is crucial for accelerating the development of improved potato varieties. While traditional selection has yielded some progress, modern breeding approaches incorporating candidate gene

analysis, quantitative trait locus (QTL) mapping and genomic selection offer new avenues for efficient cultivar development. Strategic selection of superior parental lines, integration of molecular tools and optimized agronomic practices can enable targeted improvement of TDM content. This integrated approach will ultimately benefit processors, consumers and producers by delivering cultivars with enhanced quality and market value.

### Statements & Declarations

Authors certify by submitting a work to the journal that the submission is the authors' original study that has not been published elsewhere or is not currently under review by another journal.

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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

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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

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E-Views (2006) E-Views quantitative software. <http://www.eviews.com>, 28 September 2006

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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

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#### **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

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Gram	g	Minute	min
Hectare	ha	Nanometre	nm
Kilogram	kg	Second	s
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