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Varietal Turnover in Potato and Its Effect on Yield
Evidence from Household Surveys in India

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ABSTRACT

Potato remains a crucial crop for achieving India's food security goals and generating income for small-scale farmers. But India, the largest potato producer after China, remains behind many of its peers in attaining high yield. A low varietal replacement rate could be one of the major reasons for low yield in India. This critical issue warrants investigation, yet empirical results remain limited in the Indian context. Drawing on data from a comprehensive field survey of 892 potato growing farmers conducted in 2018–19 across five major potato-producing states in India, we find the determinants of the average area-weighted age of potato varieties used, and their impact on potato yield. The instrumental variable regression analysis establishes a negative association between varietal age and yield of potato. It also underscores the importance of access to weather forecast and linkages with agricultural organizations to achieve higher yield. Furthermore, it shows that household size, links to political party, and information about new seeds from friends, progressive farmers and input dealers are associated with lower varietal age. These insights will be instrumental for policymakers and potato breeders in promoting sustainable agricultural practices and boosting food security in India amidst the impending demographic challenges.

Keywords: Potato, Improved variety, Yield, Food security

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ACRONYMS

WAVA	Area Weighted Average Age
MoAFW	Ministry of Agriculture & Farmers Welfare
ICAR	Indian Council of Agricultural Research
CPRI	Central Potato Research Institute
MT	Million tons
Ha	Hectare
KVK	Krishi Vigyan Kendra
FPO	Farmer Producer Organization
NGO	Non-Government Organization
SHG	Self Help Group
MSP	Minimum Support Price
PMKSY	Pradhan Mantri Krishi Sinchayee Yojana
PMFBY	Pradhan Mantri Fasal Bima Yojana
PM-KISAN	Pradhan Mantri Kisan Samman Nidhi

1. INTRODUCTION

Potatoes, in addition to cereals, contribute significantly to food security in India (Rana et al. 2013; Naitam et al. 2017). India has witnessed a tremendous increase in production, yield, and area dedicated to potatoes. Between 1950–51 and 2020–21, potato production increased by more than 32 times, cultivated area expanded by more than 10 times and potato yield tripled, registering a quantum leap (MoAFW 2022).

This impressive growth in potato production and yield is attributed to wide adoption of modern high-yielding varieties, which occupy more than 95 percent of the total area under potato cultivation (Kharumnuid, Devarani, and Singh 2022). The varietal improvement of food crops is estimated to account for 20–50 percent of the yield growth experienced in developing countries (Evenson and Gollin 2003). However, with a projected population increase of about 20 percent by 2050, the pressure on existing resources will intensify enormously. The Indian Council of Agricultural Research Institute-Central Potato Research Institute (ICAR-CPRI) warns that India will be challenged to produce 125 million tons of potatoes on 3.62 million ha by 2050 (CPRI 2015). This implies a compound annual growth rate of 3.2 percent in potato production to meet the country's future demands.

Globally, India is the second largest potato producer after China, but its yield (24,124 kg/ha) is lower than that of many other potato-producing countries, such as New Zealand (50,826 kg/ha), the United States (49,073 kg/ha), Germany (43,794 kg/ha), Canada (41,333 kg/ha), Australia (40,337 kg/ha), South Africa (37,222 kg/ha), Argentina (34,856 kg/ha), Israel (34,734 kg/ha), Brazil (33,099 kg/ha), and Pakistan (25,064 kg/ha) (FAOSTAT 2021). Increasing and sustaining the production of potato, an important part of the Indian food basket that also provides livelihood to large sections of the Indian population, depends on a multitude of factors such as quality seed systems¹, breeding programs, varietal

¹ It is important to note that, in addition to low varietal replacement, low potato yield could also result from poor seed quality (Singh et al. 2019). In case of vegetatively propagated crops, like potato, source material, seed transportation conditions and duration, disease pressure and active monitoring significantly affect the seed quality (Fugile et al. 2006; Gatto et al. 2021; Spielman et al. 2021; Wossen et al. 2024).

replacement and overall production infrastructure including access to irrigation, inputs and storage facility (Scott & Suarez, 2011; Rana & Answer, 2018). While most of these issues are linked with overall development of rural economy and continue to receive policy attention, an aspect worth exploring in the context of low potato yield is slower rate of varietal turnover (Kharumnuid, Devarani, and Singh 2022). Various studies report that older varieties, often referred to as “megastar” varieties, continue to dominate Indian farmers’ preferences (Atlin, Cairns, and Das 2017; Ghimire, Mehar, and Mittal 2012; Krishna, Spielman, and Veettil 2016; Pingali 1999; Singh et al. 2017; Smale et al. 2008). The improved varieties are developed to be resistant to a variety of known and unknown stresses related to pests, diseases and climate change and exhibit higher yield, therefore the continuous release and efficacious diffusion of improved varieties assumes great importance.

Given the crop’s indispensable status, ICAR-CPRI, the country’s dedicated potato research institute, puts concerted effort into the evolution of and advancement in potato production technology to enhance the crop’s yield. Since its inception in 1949, CPRI has developed over 60 genetically improved potato varieties that exhibit earliness in maturity, higher tolerance to externalities such as droughts, pests and salinity, and better suitability to India’s agroclimatic conditions (Table A1 in Appendix). Since the average landholding of an Indian farmer is very small, these developments are critical to ensure greater production per unit area and ultimately contribute to farmers’ welfare. Such efforts are highly warranted, as increased potato yield can have a substantial impact on both food security at the household level and income generation for small-scale farmers, thereby promoting the economic sustainability of agricultural systems in India.

At the global level, studies find that farmers’ adoption choices depend on a combination of economic, demographic, socioeconomic, technical, circumstantial, and institutional factors (Kharumnuid, Pandey, and Singh 2018; Ogeto et al. 2019; Toulabi et al. 2022). These include extension services, training and knowledge dissemination about varietal traits; climate suitability (Simtowe et al. 2019); market influence (Abebe et al. 2013; Feleke, Regasa, and Muche 2019; Gairhe, Gauchan, and Timsina 2017; Ogeto, Mohammed, and Bedada 2019; Pradel et al. 2018; Selahkwe et al. 2021; Toulabi et al. 2022);

farming experience (Sehlakwe et al. 2021); source of seeds, both formal (Gairhe, Gauchan, and Timsina 2017; Selahkwe et al. 2021) and informal (Pradel et al. 2018); wealth-related attributes such as a corrugated house, the proportion of land and livestock owned (Abebe et al. 2013; Gairhe, Gauchan, and Timsina 2017), and access to capital through credit (Abebe et al. 2013; Feleke, Regasa, and Muche 2019); farmers' perception of the improved varieties' yield; and gender (Ebrahim 2019; Ogeto, Mohammed, and Bedada 2019; Kimathi et al. 2021).

In the context of India, Prakash et al. (2023) used a sample of 200 farmers from Tamil Nadu and found education, farm income, access to extension services, and regional blocs had a significant impact on adoption of improved Chinese potato variety. However, the rest of the literature in India mainly comprises studies that determine the factors affecting a combination of potato production technologies (including improved varietal adoption as one component). Farmers' age, income, education, experience, social participation, landholding, irrigation facilities, extension contact, mass media exposure, participation in extension activity, economic motivation, risk orientation, and knowledge level were found to have a significant impact on adoption of potato production technologies (Patel et al. 2012; Desai, Thakkar, and Desai 2022). Kharumnuid, Pandey, and Singh (2018) listed lack of credit, heavy incidence of diseases and insects, unavailability of inputs at the right time, and price fluctuations as the major constraints to adoption of potato production technologies.

Another key indicator of farmers' variety adoption behavior is the rate of varietal replacement on-farm, as reflected by the area-weighted average age² (WAVA) of all varieties grown by farmers. Previous studies have indicated that if newer materials do not replace their older counterparts, advancements in genetic improvement become stagnant (Brennan and Byerlee 1991). Consequently, India's average age of improved potato varieties, which stands at around 30 years old, is notably high, despite the consistent development of at least one new variety each year by ICAR-CPRI. As a result, potato growers are missing out on the genetic enhancements—such as increased yield and crucial traits like nutritional

² WAVA is calculated by taking average of the ages of all potato varieties grown by the farmer, weighted by the variety's share in the area under potato cultivation.

enrichment, drought resistance, disease and insect resilience, processing quality, and enhanced storability—that could be beneficial (Kharumnuid, Devarani, and Singh 2022). Even though their study evaluated the weighted average age of varieties across different geographical regions in India and identified constraints to quicker varietal replacement, we found no empirical attempts in the literature to identify the factors affecting this parameter for Indian potato varieties.

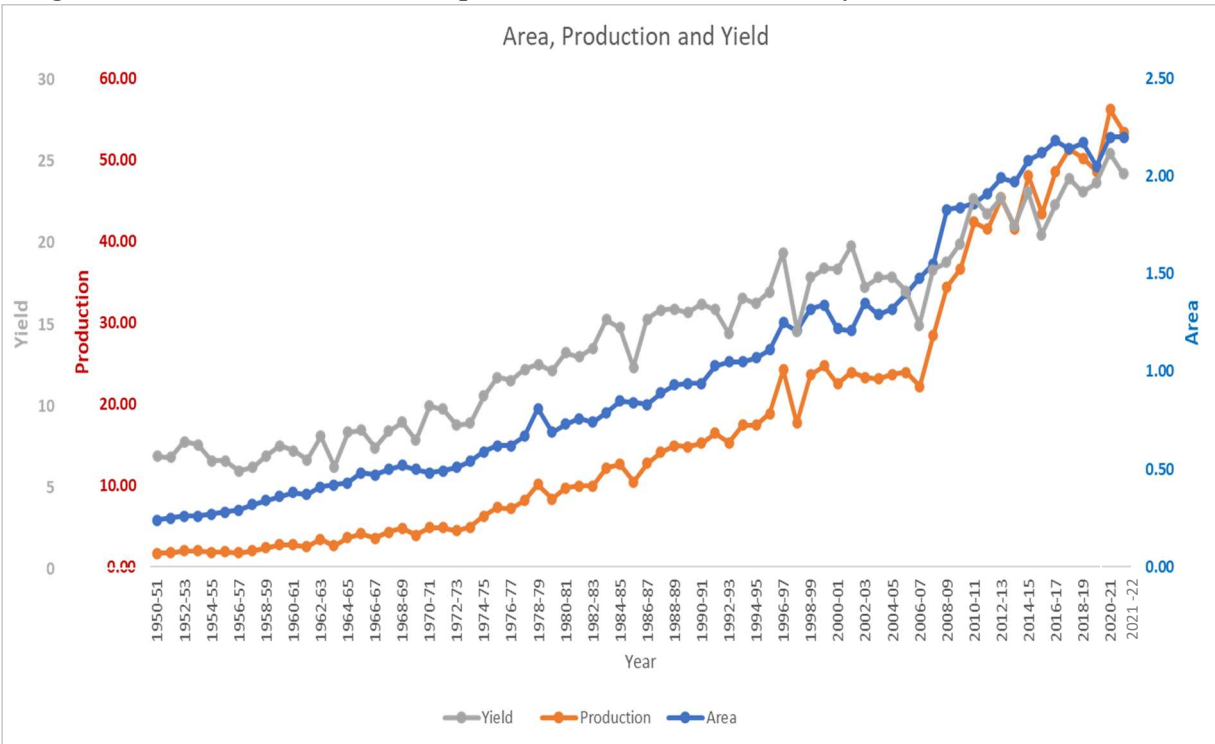
A dearth of literature was also observed in evaluating the impact of an improved varietal adoption/varietal replacement rate. Although Pandey et al. (2009, 2024) and Prakash et al. (2023) established an improvement in yield and/or farmers' income due to adoption of improved potato varieties, their assessments were variety specific. Furthermore, some of these studies followed a qualitative approach and were confined to certain geographical regions. In fact, a lack of comprehensive empirical evidence that identifies the factors affecting potato's improved varietal adoption/replacement rate and its impact on crop yield prevails in India. Hence, our study attempts to fill the research void by using a sample from five top potato-producing states in India and addresses two specific objectives: (1) to determine the factors associated with the average area-weighted age of major varieties used by Indian potato cultivators; and (2) to evaluate the link between varietal turnover, as measured by the average area-weighted age of variety, and potato yield

Section 2 discusses the status of potato cultivators in India. Section 3 describes the data and variables used for the study. Section 4 lays out the conceptual framework and methodology deployed, while Sections 5 and 6, respectively, discuss the results and offer some conclusions and policy implications.

2. STATUS OF POTATO CULTIVATION IN INDIA

Area under potato cultivation in India has seen a steady increase since 1950-51 as has production and yield (Figure 1). Over a period of about seven decades, area increased tenfold, from 0.24 million ha in 1951 to 2.20 million ha in 2021; production expanded from 1.66 million tons (MT) in 1951 to 53.39 MT in 2021; and yield went from 6.90 metric tons (MT) per ha to 24.24 MT/ha over the same period.

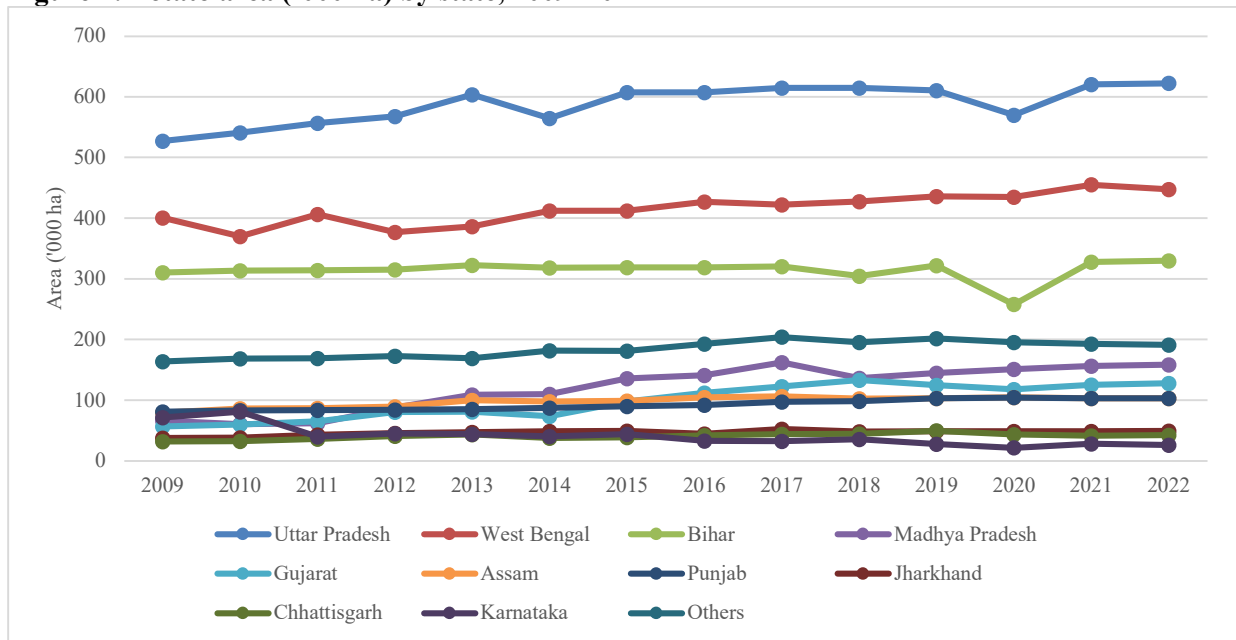
Figure 1: Potato area (million ha), production (million tons), and yield (MT/ha), 1951–2021



Source: Ministry of Agriculture and Farmers Welfare, Govt. of India.

Six major potato-producing states—Uttar Pradesh, West Bengal, Bihar, Gujarat, Punjab, and Madhya Pradesh—constitute 89 percent of India’s total potato production (MoAFW 2022). The area under potato cultivation remained more or less unchanged across all states over the last decade (Figure 2). Uttar Pradesh and Bihar, however, experienced a dip in cultivated area in the pandemic year of 2020, indicating their vulnerability to external shocks. Potato production in Uttar Pradesh and Bihar also dipped then (Figure 3).

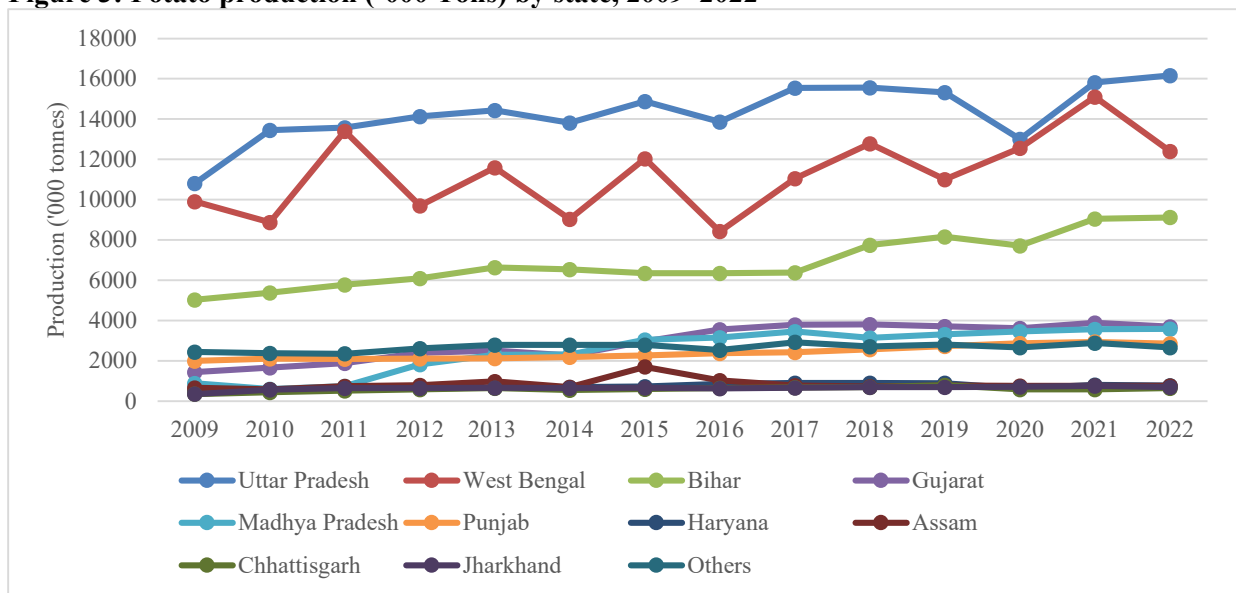
Figure 2: Potato area ('000 ha) by state, 2009–2022



Source: Ministry of Agriculture and Farmers Welfare, Govt. of India.

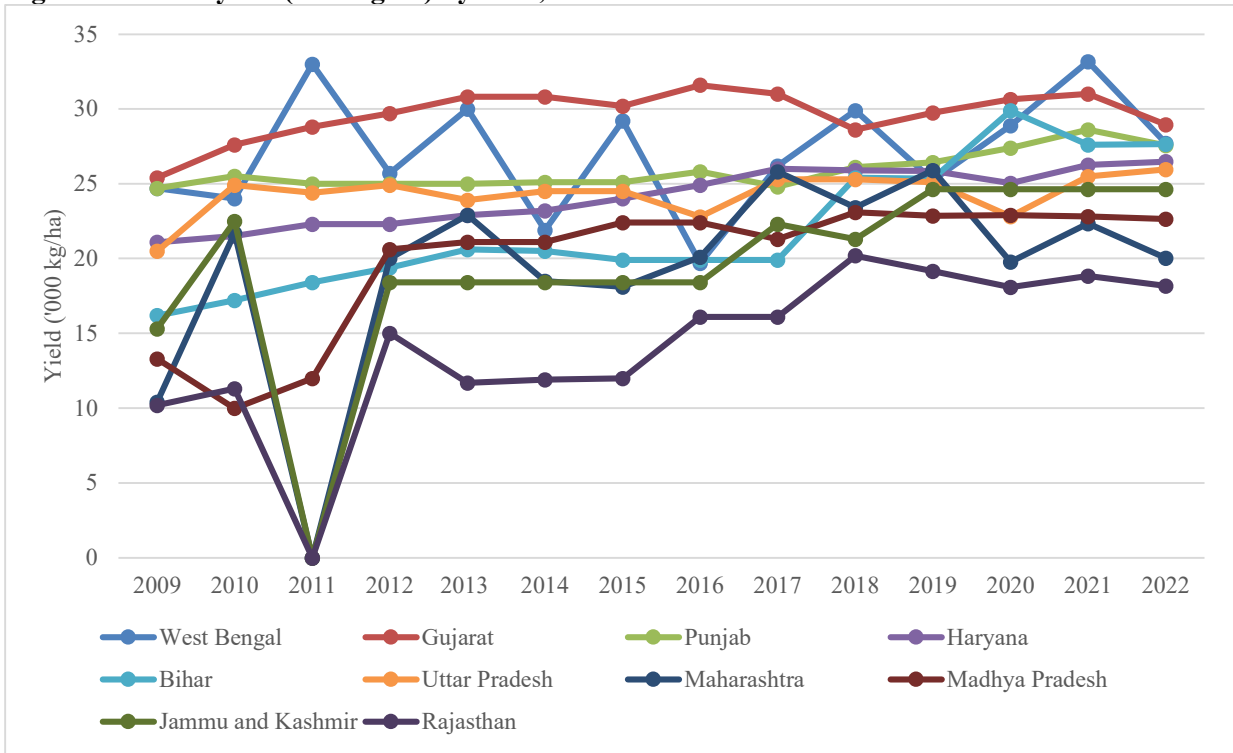
States like Gujarat and Madhya Pradesh enjoyed a steady increase in potato production over the given time period, whereas West Bengal’s production fluctuated. Bihar experienced a slight decline in production in 2020 due to floods in its northern region.

Figure 3: Potato production ('000 Tons) by state, 2009–2022



Source: Ministry of Agriculture and Farmers Welfare, Govt. of India.

Figure 4: Potato yield ('000 kg/ha) by state, 2009–2022



Source: Ministry of Agriculture and Farmers Welfare, Govt. of India.

Much like its production, West Bengal's yield fluctuates highly (Figure 4). Gujarat, Haryana, and Punjab have steady yields throughout the time period. Bihar, on the other hand, shows an upward trend during the same period, with yield peaking in 2020. This may be attributed to the Bihar government's measures including initiatives like supplying seeds at farmers' doorsteps and providing a crop input subsidy (Roy 2022).

3. DATA AND DESCRIPTIVE STATISTICS

3.1 Data

The sampling and data collection were carried out keeping in mind the statistics described above. The study is based on data from a field survey conducted in 2018–19 across five of the six major potato-producing states of India: Bihar, Gujarat, Madhya Pradesh, Uttar Pradesh, and West Bengal, which constitute about 84 percent of India’s total potato production and cover 75 percent of the total area under potato cultivation (MoAFW 2022). From each state, two major potato-producing districts in terms of area were identified. This was followed by a random selection of two to four blocks within each district, from which two villages were selected at random, and, on average, 20 potato-growing households were selected randomly from each village. In accordance with the proposed sampling technique, the number of households chosen from each district was proportional to the area under potato cultivation in that district. One-on-one interviews were conducted with the respondent from every household using a structured questionnaire comprising modules on demography, occupation, farming activity, details of varietal adoption and disadoption, marketing of output, and the role of extension services and government programs in fostering farmers’ welfare. The final sample consisted of 900 potato farmers from these five states. Table 1 depicts the distribution of sample potato cultivators across states and farm-size categories. It is worth noting that most potato farmers are classified as marginal and small (79 percent).

Table 1. Distribution of sample farmers by state and farm-size category³

Distribution across states			Distribution across farm-size categories		
State	Number of farmers	% of farmers	Category of farmer	Number of farmers	% of farmers
Bihar	177	19.8	Marginal	577	64.7
Gujarat	83	9.3	Small	126	14.1
Madhya Pradesh	120	13.5	Medium	172	19.3
Uttar Pradesh	294	33.0	Large	17	1.9
West Bengal	218	24.4	Total	892	100
All	892				

Source: Authors’ calculations based on field survey

³ We categorize farmers as Marginal if their net operational land is less than 1 hectare, Small if the operational land is 1 to 2 hectares, Medium if it is between 2 to 4 hectares and Large if the operational land exceeds 4 hectares.

3.2 Adoption practices

Table 2 displays the most popular varieties cultivated by these potato farmers. For the entire sample, major varieties include Kufri Bahar (20 percent), Kufri Badshah (19 percent), Kufri Pukhraj (19 percent), and Kufri Jyoti (12 percent). These four varieties occupy about 70 percent of potato area under cultivation. The popularity of varieties may vary with the size of landholding; for instance, small and marginal farmers find Kufri Pukhraj the most appealing potato variety, medium farmers rely on Kufri Badshah, and large farmers prefer Kufri Bahar. Kufri Pukhraj, as reported by farmers, is preferred due to high yield. Kufri Badshah is preferred due to the higher prices it fetches while Kufri Bahar is preferred due to high demand by consumers. While these were the reasons stated by farmers for preferring a particular variety, the choice may also be driven by the region in which it is being grown. Therefore, we look at the state-wise diffusion in Table 3.

Table 2. Area of a particular variety as a percentage of area under all varieties

Variety	Farm-size category				
	Marginal	Small	Medium	Large	All farmers
Kufri Bahar	21.2	20.9	11.4	70.4	20.0
Kufri Badshah	0.8	4.4	39.8	0.0	19.3
Kufri Pukhraj	28.9	27.9	11.7	0.0	18.8
Kufri Jyoti	11.7	10.8	14.7	4.8	12.4
Chambal-302	10.3	13.6	2.8	23.5	8.4
Kufri Khyati	9.0	5.8	2.3	0.0	4.7
Atlanta	0.9	4.4	5.4	0.0	3.5
Other varieties	17.4	12.1	11.9	1.4	13.0

Source: Same as Table 1.

The popularity of varieties also differs across various states⁴ (Table 3). Interestingly, Kufri Pukhraj features as an important variety in all states. Kufri Jyoti is also highly preferred in three out of five states— Bihar, Madhya Pradesh, and West Bengal—and is the most popular variety in the former two states. Other important varieties include Super 6 in Bihar; Lady Rosetta in Gujarat; Atlanta in Madhya Pradesh; Kufri Bahar, Chambal-302, and Kufri Khyati in Uttar Pradesh; and Kufri Chandramukhi in West Bengal.

⁴ It should be noted that due to budget constraints, DNA finger printing could not be carried out and the varieties listed are based on farmers' responses. However, the enumerators were duly trained to identify varieties to minimize the possibility of error.

Table 3. Popular varieties by state

State	Major varieties	Cropped area (%)	% of farmers
Bihar	Kufri Pukhraj	78.8	51.8
	Kufri Jyoti	11.8	39.4
	Lalgulab	2.4	1.6
	Kufri Ashoka	0.6	2.6
Gujarat	Kufri Badshah	69.0	33.3
	Kufri Pukhraj	12.0	30.8
	Lady Rosetta	9.4	17.5
Madhya Pradesh	Kufri Jyoti	61.3	65.0
	Atlanta	25.8	19.1
	Kufri Pukhraj	6.1	9.2
Uttar Pradesh	Kufri Bahar	49.0	35.2
	Nondscript (Chambal-302)	20.1	15.3
	Kufri Khyati	11.2	14.5
	Kufri Pukhraj	8.7	16.6
West Bengal	Kufri Jyoti	47.2	43.1
	Kufri Pukhraj	33.9	29.7
	Kufri Chandramukhi	17.2	24.6

Source: Same as Table 1.

Next, we explore the critical sources from which farmers procure seeds. Barring large farmers, local shopkeepers and commission agents are a popular choice for obtaining seeds by potato cultivators. Large farmers, although a very small proportion in our sample, appear to rely on farm-saved and/or exchanged seeds, the second most popular preference of all other farmer categories. It is important to note that a very small proportion of farmers from each category turn to government institutions or KVKs⁵ for seed procurement. Reasons could vary from price and quality of seeds from these sources to convenience of procurement. Nevertheless, the issue demands attention of the government and policymakers because it points towards inefficiencies in the functioning of public institutions which perhaps compels the farmers to rely on informal sources.

Table 4. Sources of seeds (% of farmers)

Farm-size category	Farm-saved/ Own seed/ Exchanged	Local shopkeeper/ Commission agent	Private company	seed	Government institutions/ KVKs	Other
Marginal	38.6	46.5	11.5		0.3	3.0
Small	28.8	45.5	22.7		0.8	2.3
Medium	24.6	58.5	10.4		2.7	3.8
Large	61.1	27.8	11.1		0.0	0.0
All farmers	34.9	48.4	12.9		0.9	3.0

Source: Same as Table 1.

⁵ A Krishi Vigyan Kendra (KVK) is an agricultural extension center in India.

It is also worthwhile to determine the most important sources from which farmers derive information about potato varieties. Not surprisingly, for all farmer categories, relatives and friends constitute the top source of information, followed by progressive farmers. Most Indian farmers reside in rural areas constituting well-knit societies; hence the impact of friends, relatives, and progressive farmers is prominent. A small proportion of farmers also find input dealers and shopkeepers to be important sources of information. Once again, not many farmers turn to public sector extension officers, KVKs, and/or agricultural research institutes to obtain information about varieties, reinforcing the need for the government to strengthen the role of such entities.

Table 5. Sources of information about varieties (% of farmers)

Source of information	Farm-size category				
	Marginal	Small	Medium	Large	All farmers
Relative/friends	67.0	52.6	53.2	47.1	61.8
Public sector extension officers/KVKs/ Agricultural research institutes	0.3	0.0	1.9	5.9	1.6
Progressive farmers	28.3	42.2	30.5	41.2	31.0
Input dealers/Shopkeepers	4.2	3.7	6.8	5.9	4.7
Other (includes Internet and private sector extension officers)	0.2	1.5	2.1	0.0	1.0

Source: Same as Table 1.

Table 6 gives an overview of the key variable of our interest—area-weighted average age of varieties—depicting how its mean value varies across states and farm-size categories. Among the top five potato-producing states, Gujarat and Uttar Pradesh exhibit a much better average varietal age than the other three states. Madhya Pradesh and West Bengal—where Kufri Jyoti, released in 1968, dominates as a popular variety—lag in varietal replacement (Table 6). Across farm-size categories, marginal and small farmers can be seen to adopt relatively newer varieties, indicating smallholder farmers seek newer varieties to achieve better yields.

Table 6. Average area-weighted age of varieties by state and farm-sizes category⁶ (in years)

Average age of varieties by state		Average age of varieties by farm-size category	
State		Category of farmer	
Bihar	32.7	Marginal	32.1
Gujarat	26.4	Small	32.2
Madhya Pradesh	45.0	Medium	39.5
Uttar Pradesh	26.3	Large	43.8
West Bengal	40.2	Total	33.8
All	33.8		

Source: Same as Table 1.

3.3 Socio-economic characteristics of sample households

Table 7 presents descriptive statistics of the data used in the analysis. The average farmer is 49 years old and has 25 years of farming experience. Nine out of 10 (91 percent) of the sampled households cite farming as a primary occupation, with an average net operational land size of 1.94 ha, of which almost one-half (48 percent) is used for the cultivation of horticulture crops. We calculated the average area-weighted age of variety by taking the average of the ages of three major varieties grown by each farmer, weighted by the variety's proportion in total cropped area. The overall average value of 34 indicates the slow rate of adoption of new varieties, reinforcing the purpose of this study.

Table 7 includes a variable on the source of procuring seeds that takes a value of 1 if the seed is farm-saved/exchanged and 0 if it is obtained from any other source, such as government institutions, private seed companies, or local shopkeepers. About 94 percent of sampled farmers derive information about improved varieties from their relatives and friends or progressive farmers. The role of public and private sector extension officers and even KVKs appears to be limited in this respect.

The next few variables in the table summarize respondents' participation in and awareness of ongoing government programs such as the Pradhan Mantri Krishi Sinchayee Yojana, Pardarshi Kisan Yojana, and Pradhan Mantri Fasal Bima Yojana, among others. The final set of variables captures the extent of farmers' networking. For example, these binary variables indicate if the farmer has links with one or more entities

⁶ Calculated only for varieties whose release year is available on CPRI's official website; these constitute 81 percent of the observations.

such as cooperatives, Farmer Producer Organizations (FPOs), nongovernmental organizations (NGOs), self-help groups (SHGs), or farmers' associations.

Table 7. Descriptive statistics of key variables

Variable	Variable	Label used in analysis	Mean	Standard deviation
Household characteristics	Age	-	49.16	11.5
	Gender (1=male; 0 otherwise)	-	0.99	0.06
	Education (years)	Education	8.23	4.25
	Farming experience (years)	Experience	24.70	10.96
	Family size (no.)	HH size	7.07	3.72
	Migration (1=yes; otherwise, 0)	Migration	0.12	0.33
	Weaker class- belonging to Scheduled Caste, Scheduled Tribe or Other Backward Classes (1=yes; otherwise, 0)	Weaker class	0.55	0.50
Farming characteristics	Net operational land (ha)	L	1.94	3.02
	% share of area under horticulture crops	Horticulture share	47.68	22.56
	Average area-weighted age of variety	WAVA	33.77	14.38
	Yield (quintal/ha)	Y	292.62	99.74
Access to information about seeds	Info. from relative/friends or progressive farmers (1=yes; otherwise, 0)	I1	0.94	0.24
	Info. from input dealers and shopkeepers (1=yes; otherwise, 0)	I2	0.05	0.21
Awareness and access to development programs/ networks	Aware of Pradhan Mantri Krishi Sinchayee Yojana (1=yes; otherwise, 0)	PMKSY	0.25	0.43
	Beneficiary of Pradhan Mantri Fasal Bima Yojana (1=yes; otherwise, 0)	PMFBY	0.28	0.45
	Beneficiary of Jan Dhan Account (1=yes; otherwise, 0)	JDA	0.28	0.45
	Beneficiary of PM-KISAN Yojana (1=yes; otherwise, 0)	PM-KISAN	0.38	0.48
	Has Kisan Credit Card (1=yes; otherwise, 0)	KCC	0.51	0.50
	Has Soil Health Card (1=yes; otherwise, 0)	SHC	0.11	0.32
	Access to weather forecast (1=yes; otherwise, 0)	WF	0.56	0.50
	Links (1=has links with cooperatives/farmer associations or groups/NGOs/SHGs/FPOs; otherwise, 0)	Link	0.26	0.44
	Political party (1=member; otherwise, 0)	PP	0.12	0.32

Source: Same as Table 1.

4. CONCEPTUAL FRAMEWORK AND METHODOLOGY

We used both primary and secondary sources of data to conduct this research. While the latter afforded a preliminary understanding of the issues, we used the former to create a cross-sectional dataset for our empirical analysis, as already described.

As it adjusts for the area over which each variety is grown, the area-weighted average age of variety provides a relatively more accurate picture of the extent of varietal replacement than simply relying on information about adoption of specific varieties. A lower value indicates that the varieties being cultivated by farmers are relatively recent releases, on average. The area-weighted average age of variety (WAVA) is calculated as:

$$WAVA_i = \sum \left(\frac{Area_p}{TCA} \right)_i * (Y - T_p)$$

where for every farmer $i=1, 2, 3, \dots$ and so on,

p = potato variety

$Area_p$ = area under potato variety 'p' for farmer i

TCA = total cropped area of all potato varieties

Y = the reference year against which varietal age is calculated; here it is 2019 (i.e., the year of our survey)

T_p = year of release of variety 'p'

For greater accuracy, we calculated the WAVA only for varieties whose release year is available on CPRI's official website.

Table 8. Potato varieties' release year and age

Variety name	Release year	Variety age (in 2019)
Kufri Arun	2005	14
Kufri Ashoka	1996	23
Kufri Bahar	1980	39
Kufri Chandramukhi	1968	51
Kufri Chipsona-2	1998	21
Kufri Chipsona-4	2010	9
Kufri Jyoti	1968	51
Kufri Khyati	2008	11
Kufri Pukhraj	1998	21
Kufri Sindhuri	1967	52
Kufri Badshah	1979	40

Source: Central Potato Research Institute (CPRI).

4.1 Determinants of Varietal Turnover and its association with potato yield

Multivariate OLS regression may yield biased results due to a possibility of endogeneity. We, therefore, investigate the factors associated with the WAVA and the latter's relationship with Yield using the two-stage least squares (2SLS) instrumental variable regression method with state fixed effects. This is because $WAVA_i$ may be determined within the system of equations.

We look at whether and how the area-weighted average age, among other factors, is associated with the yield of potato farmers. The proposed relationship between the variables for i^{th} farmer is given as:

$$Y_i = \alpha + \beta_1(WAVA_i) + \beta_2(Education_i) + \beta_3(Experience_i) + \beta_4(HH\ size_i) + \beta_5(Migration_i) + \beta_6(Horticulture\ share_i) + \beta_7(Weaker\ class_i) + \beta_8(L_i) + \beta_9(PMKS Y_i) + \beta_{10}(PMFB Y_i) + \beta_{11}(JDA_i) + \beta_{12}(PM-KISAN_i) + \beta_{13}(KCC_i) + \beta_{14}(SHC_i) + \beta_{15}(WF_i) + \beta_{16}(Link_i) + \beta_{17}(PP_i) + \beta_{18}(State_i) + \varepsilon_i \quad (1)$$

Where $i=1,2,\dots$, Y_i is a continuous variable as defined in Table 7. α and β_i are the coefficients to be estimated and ε_i represents the error term. The explanatory variables carry their usual meanings.

The first stage gives the estimates for factors associated with the WAVA, the endogenous variable, and is specified as:

$$WAVA_i = \delta + \beta'_1(I_{1i}) + \beta'_2(I_{2i}) + \beta'_3 X_i + \beta'_4(State_i) + u_i \quad (2)$$

Here, $WAVA_i$ is a continuous variable as defined in Table 7. δ and β' represent the coefficients and X represents the vector of all other explanatory variables. It should be noted that I_1 , and I_2 serve as the

instrument variables in our instrumental variable regression system, where they represent information about the new seed from various sources and impact the farmers' choice of seeds, and thereby the weighted average age of varieties used by the farmer. The instrument variables do not directly impact the yield variable Y_i .

5. RESULTS AND DISCUSSION

Table 9 presents the outcome of 2SLS instrumental variable regression⁷. We report the determinants of WAVA and Yield in adjacent columns as seen.

Discussing the first stage results, it can be observed that a larger household size is associated with lower WAVA (i.e., greater usage of newer varieties). This could be a result of greater social networking and awareness. Alternatively, bigger households may use newer varieties to achieve higher production per unit cultivable land and meet higher self-consumption demand in comparison to smaller families.

Table 9. Association between farmers' average area-weighted age of variety and yield

Variable	WAVA	Yield
WAVA		-5.559*** (1.845)
Education	-0.165 (0.120)	-1.124 (0.950)
Experience	-0.067 (0.042)	-1.028*** (0.378)
HH size	-0.255* (0.141)	1.327 (1.205)
Migration	0.949 (1.603)	22.538 (13.762)
Horticulture share	0.019 (0.023)	0.472** (0.215)
Weaker class	0.925 (1.078)	-14.449 (10.349)
L	-0.024 (0.142)	-2.840** (1.436)
PMKSY	-0.589 (1.134)	-1.280 (10.045)
PMFBY	-1.740 (1.069)	-16.655 (10.133)
JDA	-1.103 (1.042)	2.786 (9.050)
PM-KISAN	-1.261 (1.091)	-30.363*** (10.107)
KCC	0.518 (0.990)	10.294 (8.204)
SHC	-0.981 (1.501)	-16.544 (13.119)
WF	1.849*	28.714***

⁷ The Durbin-Wu-Hausman test for endogeneity confirmed the presence of endogeneity. We also conducted the Sargan test for over-identification for testing the validity of the instruments.

Variable	WAVA	Yield
	(0.992)	(9.188)
Link	2.823***	16.804*
	(1.072)	(9.154)
PP	-3.070**	-0.283
	(1.413)	(13.637)
I1	-9.113***	
	(1.843)	
I2	-8.925***	
	(2.526)	
Constant	43.876***	411.338***
	(3.063)	(68.541)
State Fixed Effects	Yes	Yes
Observations	802	802
R-squared	0.283	.

Note: Robust standard error in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

Access to weather forecast is associated with higher WAVA, implying farmers equipped with weather related information may not feel the need to switch to newer varieties. Similarly, farmers that have links with farmer cooperatives and similar organizations may have access to other better-quality inputs that help them achieve their desired outcome without the need for transitioning to newer varieties. However, the role of such organizations in such a case may need rethinking. In contrast, farmers who are members of a political party have a lower WAVA, possibly due to better access to improved variety seeds and higher levels of awareness. Farmers with access to information about new seeds from friends and relatives/ progressive farmers have significantly lower WAVA as compared to others. A similar outcome is also observed in cases where information from input dealers and shopkeepers emphasize the role of social networks and different stakeholders in encouraging the adoption of newer varieties.

Next, coming to our assessment of the relationship between WAVA and farmers' yield, we observe the WAVA has a negative association with yield at the 1 percent significance level. More specifically, a one-year reduction in the WAVA improves yield by over 5.6 quintal/ha, indicating that adoption of genetically superior varieties is beneficial for farmers. Less experienced farmers perform better than their counterparts in terms of yield, perhaps because younger farmers deploy newer cultivation techniques, rather than relying on traditional methods. Farmers cultivating a larger share of horticulture crops also display higher potato

yield. The net operational land is also inversely proportional to yield, perhaps because smaller farmers are quicker to adopt high-yielding varieties. This outcome is in line with the findings of Gairhe, Gauchan, and Timsina (2017). Farmers who availed the benefits of PM-KISAN, displayed significantly lower yields. Generally, the beneficiaries of such schemes include poor and needy farmers, who lack access to the right information and inputs to achieve high yield. These schemes act as a safety net against major financial losses during an unfavorable agricultural year. Access to information about the weather is seen to help the farmers in realizing higher yield. In fact, links with cooperatives, farmer organizations and similar bodies also support farmers to perform better in terms of the yield.

6. CONCLUSIONS AND POLICY IMPLICATIONS

The emergence of improved potato varieties has been a mammoth step in the development of suitable technologies for smallholder potato farmers in India. Although several adoption studies continue to indicate several socioeconomic and institutional/organizational variables as important factors influencing varietal replacement in many parts of the world, this study attempted to determine how these factors play out in the context of India. The results gave detailed insights into the factors associated with the area-weighted average age of potato varieties sown by farmers in five major potato-producing states in India, thereby filling a gap in the existing literature. The empirical exercise stressed that association with political parties can provide the means to access newer varieties. Furthermore, access to information about the new seeds from relatives, progressive farmers and shopkeepers/input dealers can go a long way in achieving a lower average age of variety for potato farmers. Drawing on the importance of information, the role of extension services, agricultural demonstrations, and trainings cannot be emphasized enough, especially since the proportion of farmers participating in these was found to be very low among the surveyed households. Such activities would equip farmers with critical knowledge about disease resistance, yield, quality, pricing, and other features of new varieties, enabling improved decision making. Policies that foster collaboration among different market stakeholders can help bridge the information gap between seed markets and farmers. Involving farmers in the development process of varieties will help scientists better meet their needs. The study, using two-stage least squares (2SLS) instrumental variable regression, also established that adoption of improved varieties—as implied by the lower average age of varieties—is linked to higher crop yield. This paper provides the first empirical evidence based on a representative sample of Indian potato farmers, contributing to informed policymaking on this important crop in the future.

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APPENDIX

Table A1. List of potato varieties developed by ICAR-CPRI, Shimla since inception during 1949-2020

Sr. No.	Variety	Year of release	Yield (tons/ha)
1	Kufri Kisan	1958	-
2	Kufri Kuber	1958	15-20
3	Kufri Kumar	1958	15-20
4	Kufri Kundan	1958	15-20
5	Kufri Red	1958	20-25
6	Kufri Safed	1958	20-25
7	Kufri Neela	1963	20-25
8	Kufri Sindhuri	1967	20-25
9	Kufri Alankar	1968	20-25
10	Kufri Chamatkar	1968	20-25
11	Kufri Chandramukhi	1968	20-25
12	Kufri Jeevan	1968	15-20
13	Kufri Jyoti	1968	25-30
14	Kufri Khasigaro	1968	20-25
15	Kufri Naveen	1968	20-25
16	Kufri Neelamani	1968	-
17	Kufri Sheetman	1968	20-25
18	Kufri Muthu	1971	25-30
19	Kufri Lauvkar	1972	20-25
20	Kufri Dewa	1973	20-25
21	Kufri Badshah	1979	30-35
22	Kufri Bahar	1980	30-35
23	Kufri Lalima	1982	20-25
24	Kufri Sherpa	1983	15-20
25	Kufri Swarna	1985	30-35
26	Kufri Megha	1989	25-30
27	Kufri Jawahar	1996	25-30
28	Kufri Sutlej	1996	30-35
29	Kufri Ashoka	1996	25-30
30	Kufri Pukhraj	1998	35-40
31	Kufri Chipsona-1	1998	30-35
32	Kufri Chipsona-2	1998	30-35
33	Kufri Giriraj	1998	20-25
34	Kufri Anand	1999	35-40
35	Kufri Kanchan	1999	25-30
36	Kufri Arun	2005	30-35
37	Kufri Pushkar	2005	30-35
38	Kufri Shailja	2005	30-35
39	Kufri Surya	2006	25-30
40	Kufri Chipsona-3	2006	30-35
41	Kufri Himalini	2006	30-35
42	Kufri Himsona	2008	15-20
43	Kufri Sadabahar	2008	30-35
44	Kufri Girdhari	2008	30-35
45	Kufri Khyati	2008	25-30
46	Kufri Frysona	2009	30-35
47	Kufri Neelima	2010	25-30
49	Kufri Garima	2012	30-35
50	Kufri Gaurav	2012	30-35
51	Kufri Lalit	2013	30-35
52	Kufri Mohan	2016	35-40
53	Kufri Ganga	2018	35-40
54	Kufri Lima	2018	30-35
55	Kufri Neelkanth	2018	35-40
56	Kufri Chipsona-4	2019	30-35
57	Kufri FyroM	2019	30-35

Sr. No.	Variety	Year of release	Yield (tons/ha)
58	Kufri Karan	2019	22-25
59	Kufri Manik	2019	22-25
60	Kufri Sahyadri	2019	30-35
61	Kufri Sangam	2019	35-40
62	Kufri Thar-1	2019	30-35
63	Kufri Thar-2	2019	35
64	Kufri Thar-3	2019	45

Source: Central Potato Research Institute (CPRI)

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