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Impact of Formal Seed Sources on Smallholder Farming in India: Evidence from NSS Survey using Propensity Score Matching

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ABSTRACT

This study investigates the impact of formal seed sources on smallholder farming in India using data from the National Sample Survey Office (NSSO). The primary aim is to evaluate how access to formal seed sources affects seed expenses, crop yields, and income. The analysis covers five major crops: paddy, wheat, maize, gram, and arhar. The study employs Propensity Score Matching (PSM) to address selection bias, creating a comparable control group of farmers using informal seed sources. The results indicate that formal seeds significantly enhance productivity and profitability. For instance, formal seed access increases productivity by over 20 per cent for paddy and nearly 50 per cent for arhar. Also, net crop income increases by 23 per cent for paddy, 5 per cent for wheat, 11 per cent for maize, 14 per cent for gram, and nearly 50 per cent for arhar. Key factors influencing farmers' choice of seed sources include access to technical advice, formal training, awareness about Minimum Support Prices (MSP), and the size of the farming operation. Larger farmers and those with better access to information and training are more likely to use formal seed sources. The study underscores the importance of promoting certified seeds to enhance agricultural productivity and food security. Policy recommendations include developing robust seed distribution mechanisms, providing financial support to small farmers, expanding extension services, and ensuring stringent quality control for seeds. These measures can significantly improve the adoption of certified seeds, boosting agricultural productivity and farmer incomes in India.

Keywords: Seed procurement, seed quality, propensity score matching, impact assessment, situation assessment survey

JEL codes: Q10, Q12, Q13, Q16, Q18

I

INTRODUCTION

Poverty alleviation and food security are critical challenges faced by developing countries like India. With rapidly increasing populations and limited cultivable land, technological interventions in agriculture appear to be the only viable solution for feeding the growing population and generating employment. A key aspect of these technological interventions is seed quality. Seeds are the most fundamental and crucial input for sustainable agriculture.

It is estimated that the direct contribution of quality seeds alone to total production is about 15–20 per cent, depending on the crop, and this can be further increased to 40-50 per cent with efficient management of other inputs (Singh, 2013). Seed security is essential for food security, as seeds are the heart of agriculture. Ensuring the availability of quality seeds in adequate quantities, at the right time, and

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at an affordable price is fundamental to increasing food production and productivity (Singh, 2013).

Adopting certified seeds by small and marginal farmers can significantly boost agricultural productivity, which can help reduce poverty and improve household food security (Moyo *et al.*, 2007). To meet the demands of an increasing population, projected to reach 1.7 billion by 2050, we must double our food production (Paroda, 2013). Achieving this goal requires bridging yield gaps through improved productivity and integrated natural resource management (Singh *et al.*, 2019). The Indian seed industry is the fifth-largest globally, valued at over Rs 2500 crores annually ($500 million) (Ali, 2016; Singh *et al.*, 2019). Despite significant progress, only 30-35 per cent of the seeds distributed in the country come from the organized sector. The remainder is supplied through the unorganized sector, mainly farm-saved seeds (GoI, 2016). Seed security hinges on three critical factors, availability, accessibility, and quality, to ensure a robust seed system (Remington *et al.*, 2002).

The importance of quality seeds has long been acknowledged, as reflected in the ancient saying, "Subeejam Sukshetre Jayate Sampada yate" (Manu Smriti), meaning "Good Seed on Good Soil Yields Abundantly." Ensuring the timely availability of quality seeds to farmers is crucial. One major obstacle to improving pulse productivity has been the limited availability of high-quality seeds (Chauhan *et al.,* 2020). In informal seed systems, farmers handle seed production, selection, and storage, using their saved seeds or accessing them through informal networks where seeds are exchanged, gifted, bartered, or purchased from local markets. Critical challenges in informal seed systems include low germination and vigor, disease contamination, and inadequate quantity and diversity of seeds (Louwaars and de Boef, 2012). In contrast, formal seed systems convey improved, certified seeds to farmers (Biemond *et al.*, 2013).

It is important to note that even today, the formal seed sector (including both private and public sector seed organizations/companies) meets only 15-20 per cent of the seed requirement of farmers (MoA, 2012). Over 70 per cent of seed usage in India, particularly for food crops, relies on farm-saved seeds. The private seed industry is well-developed for only a few select crops, and public seed organizations also cater to a limited range of seeds (Ayyappan and Kochhar, 2010). The widespread belief is that formal seed sources account for higher quality seeds than farmer-saved seeds. Farmer-saved seeds are undervalued because they are produced in the same fields as grain and are not certified. Better access to formal seed systems assures better seed quality, leading to higher yields and farmer incomes. Adopting improved seeds has significantly enhanced income and food security (Meles *et al.*, 2009; Louhichi and Paloma, 2014; Tiwari *et al.*, 2010; Hallman *et al.*, 2003). Meles *et al.* (2009) concluded that access to improved seeds enhanced income from cereals, horticultural crops, and non-farm activities directly or indirectly. Ali *et al.* (2015) found that adopting certified seeds can increase wheat yield, boost household incomes, and reduce poverty among small farmers. High-yielding variety (HYV) seeds were a crucial factor in the impressive increase in production from 3.5 million tons to 11 million tons in Bihar over time (Paroda, 2013).

In this context, our study aims to investigate the access to formal and informal seed sources in India. By assuming formal sources as the providers of good quality seed, we have examined the impact of formal seed sources on seed expenses, overall profitability and yield. This study focuses on major cereals and pulses in India, addressing the gaps in previous research, which often concentrated on selective crops and region-specific studies. After providing an overview of the seed scenario, this study also identifies the critical determinants of farmers' choice of seed sources.

II

DATA AND METHODOLOGY

2.1 Data Source

This study is based on the analysis of the unit-level data of the Situational Assessment Survey of Agricultural Households in India, conducted by the National Sample Survey Office (NSSO) during its 77th round (NSSO, 2021). The data collection occurred in two phases: the first phase from July to December 2018, and the second from January to June 2019. The survey identified an agricultural household as the one earning a minimum of Rs 4000 from agricultural activities and having at least one member engaged in agriculture as a self-employed individual during the past year (2017-18). The total number of agricultural households surveyed across both rounds was 44,770.

2.2 Dataset and its Classification

We focused on five crops—paddy, wheat, maize, gram, and arhar—to investigate farmers' access to formal and informal seed sources. The dataset used for impact evaluation comprised 24,961 households for paddy, 15,032 for wheat, 5,693 for maize, 2,470 for gram, and 1,690 for arhar. For each crop, the data were divided into two categories: households that accessed formal seed sources and those that used informal sources. Local markets were defined as those found in small towns or cities where farmers sell their produce to traders at harvest time, and were considered a form of farm-saved seeds, based on the definition by Louwaars and de Boef (2012). These local markets, along with farm-saved seeds, were classified as informal seed sources (control variables). Seeds from informal sources often face several challenges, including poor germination, lower vigor, pest and disease contamination, and inadequate seed quantity and variety. Formal seed sources included Agricultural Produce Market Committee (APMC) markets, input dealers, cooperatives, government agencies, Farmer Producer Organizations (FPOs), private processors, and contract farming companies. Due to limited and unclear information on "other sources" and their small number of observations, they were excluded from the dataset.

2.3 Analytical Framework

We applied propensity score matching (PSM) to assess the impact of formal seed sources on seed expenditure, crop yields, and household income from crop production. In non-experimental studies, controlling for numerous pre-intervention variables and handling dissimilar treatment and comparison groups can make drawing causal inferences challenging. Therefore, we use PSM to address the issue of self-selection bias. This method helps match households using seeds from both formal and informal sources, creating a plausible counterfactual and effectively addressing the selection bias (Dehejia and Wahba, 1999; Diaz et al., 2006; Okello et al., 2017; Wonde et al., 2022). The PSM is based on two primary assumptions: the Conditional Independence Assumption (CIA), which ensures that after controlling for the propensity score, treatment assignment is random ($Y0Y1 \perp D \| X$), and the Common Support Assumption (CSA), which requires that the probability of being in the treatment group falls within the unit interval, i.e., $0 < Pr(Di = 1|Xi) < 1$. These assumptions imply that, conditional on the propensity score, the treatment and control groups are comparable with respect to observable covariates (Cariappa et al., 2021).

The PSM approach follows three main steps. First, the probability, or propensity score, that a household has access to formal seed sources is estimated using either a probit or logit model. In our case, a logit model (0 = informal seed sources, 1 = formal seed sources) was applied to estimate the propensity scores (Rosenbaum & Rubin, 1983). The model is represented as:

$$Pr(Xi)=P(Z=1|Xi)Pr\ (Xi\ )=P\ (Z=1|Xi)Pr(Xi)=P(Z=1|Xi)$$

Where Pr(Xi) represents the propensity score of the i-th household, and P(Z=1|Xi) denotes the probability of treatment given the covariates (X) for the i-th household.

To ensure that there were no significant differences in the covariates between the treated and control groups after matching, we performed a balancing test. The Mean Absolute Standardized Bias (MASB) between the two groups should not exceed 20 per cent (Rosenbaum and Rubin, 1985), and there should be no systematic variation in covariate distribution post-matching. To confirm this, the Pseudo R^2 or p-values of the likelihood ratio test should be insignificant.

The second step involves selecting an algorithm for matching based on the propensity score to calculate the average treatment effect. Finally, the third step calculates the standard errors. We used three different matching algorithms—Nearest Neighbor Matching (NNM), Kernel-Based Matching (KBM) with a bandwidth of 0.01, and Caliper Matching (CM) with a width of 0.01—to ensure robustness in the results. These algorithms differ in how they define the neighborhood of each treated individual, handle common support, and assign weights to the matched control units (Priscilla and Chauhan, 2019). The average treatment effect on the treated (ATT) was then calculated by restricting matches to households with propensity scores within the common support:

ATT=E(Yi1–Yi0)ATT = E(Yi 1 – Yi 0)ATT=E(Yi1–Yi0)

Where ATT is the average treatment effect on the treated, E(Y) represents the expected value of the impact indicator, with "1" referring to the treated group and "0" to the control group.

III

RESULTS AND DISCUSSION

3.1 Access to Seed Sources

The farmers reported access to ten crop seed sources (Table 1). Over 92 per cent of farmers purchased seeds of major cereals and pulses from informal seed sources such as local markets or farm-saved seed. Some farmers bought seeds from multiple sources (both formal and informal). The proportion of farmers purchasing seed from formal sources such as APMC markets, input dealers, cooperatives, government sources, FPOs, private processors, contract farming, etc., ranged between 6.19 per cent for gram and 11.36 per cent for paddy. Local markets and own farm seed sources indicate convenience and traditional practices (Bal & Douglas, 1992; Almekinders *et al.*, 1994). The seeds from these sources, though cheaper and easily accessible, may not be of high quality and thus lead to continuous lower levels of productivity due to poor germination, susceptibility to insect-pests and diseases, and less vigor (Clayton *et al.*, 2009; Peltonen-Sainio *et al*, 2011). In contrast, formal seed sources ensure better quality, higher productivity, and more returns despite higher seed expenses (Van Gastel *et al*., 2002; Bogdanović *et al.*, 2015).

TABLE 1. SOURCES OF SEED PROCUREMENT FOR VARIOUS CROPS

(*per cent*)

Seed sources (1)	Paddy (2)	Wheat (3)	Maize (4)	Gram (5)	Arhar (6)
Informal seed sources					
Local market	64.54	78.00	63.53	67.35	53.49
Farm-saved	28.10	14.73	29.07	25.04	36.86
Sub-total	92.64	92.74	92.60	92.39	90.36
Formal seed sources					
APMC market	0.71	0.28	0.72	0.77	1.01
Input dealers	4.54	2.94	2.90	2.55	6.86
Cooperatives	2.17	1.40	1.39	0.93	0.59
Government agencies	2.80	1.17	3.46	1.05	1.18
Farmer producer organization	0.09	0.27	0.02	0.00	0.06
Private processor	1.00	0.68	0.51	0.89	0.36
Contract farming	0.07	0.00	0.05	0.00	0.06
Sub-total	11.36	6.74	9.05	6.19	10.12
Other seed sources					
Others	0.98	0.60	1.23	1.98	2.19
Sample size	24,961	15,032	5,693	2,470	1,690

Note: Some farmers purchased seed from multiple sources so that the total may exceed 100%.

The pattern of access to formal and informal seed sources varies considerably across the major producing states in India. While the informal seed sources dominate all the selected crops, the share of formal seed sources varies (Figure 1). In Andhra Pradesh, Karnataka, and Telangana, more than 1/4th of the farmers purchased their paddy seed from formal sources, against an average of about 11 per cent. In Punjab and Haryana, about 13 per cent of farmers purchased wheat seed from formal sources, against an average of about 6.7 per cent. Similarly, the purchase from formal seed sources was much higher (than the all-India average) in Karnataka, Telangana, West Bengal, and Tamil Nadu for maize, in Maharashtra, Andhra Pradesh, and Karnataka for gram, and Maharashtra and Andhra Pradesh for arhar.

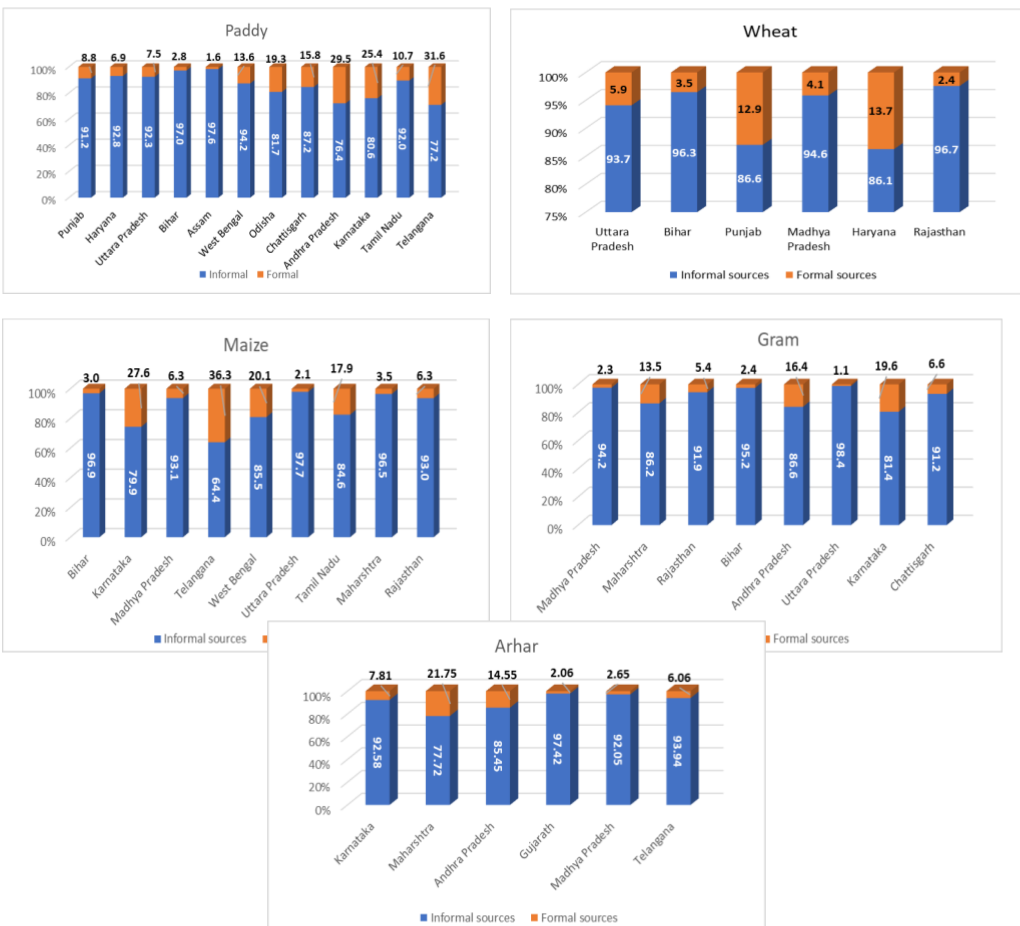

Fig 1. State-wise Distribution of Seed Sources for Major Cereals and Pulses

Apart from the variation in states, the pattern of seed purchases also varied across the land-size categories (Table 2). In general, there has been a clear positive relationship between the land-size category and access to formal seed sources for all five crops in our study (large farmers in maize were an exception). The proportion of medium and large farmers purchasing seed from formal sources was about double or more than that of marginal and small farmers in all the crops (in gram, it was only slightly higher). Such a relationship can have larger implications in the distribution of benefits of new technologies, as we have examined in the following part of our study.

TABLE 2. ACCESS TO FORMAL AND INFORMAL SEED SOURCES FOR VARIOUS LAND-SIZE CATEGORIES

(*per cent*)

Size category (1)	Paddy		Wheat		Maize		Gram		Arhar	
	Informal (2)	Formal (3)	Informal (4)	Formal (5)	Informal (6)	Formal (7)	Informal (8)	Formal (9)	Informal (10)	Formal (11)
Marginal	92.03	9.51	93.76	5.76	91.73	7.98	92.76	5.34	92.30	6.13
Small	89.55	12.20	91.87	7.46	90.50	9.77	92.91	5.37	87.74	11.72
Semi medium	85.40	17.06	90.77	8.25	89.14	11.66	90.41	7.93	86.97	13.64
Medium	79.75	22.76	86.99	11.99	87.85	15.89	91.01	6.88	82.35	15.29
Large	83.61	21.31	90.32	9.68	100.00	0.00	78.26	21.74	72.73	27.27

Note: As some farmers purchased from more than one source, the total may exceed 100%.

3.2 Descriptive Statistics

The descriptive statistics of the variables used in the logit regression are given in Table 3. The average age of the farmer cultivating the selected crops is around 50 years, and their education level is also not very high. About 3-4 per cent of farmers are members of any registered organization, only 1-2 per cent have attended any formal training in agriculture, and 16-23 per cent of households had non-agricultural sources as their major source of income. The average area under cereals, i.e., paddy, wheat, and maize, was 1.3 to 2 acres, and the area under pulses, i.e., gram and arhar was 1.6 and 1.2 acres, respectively. On average, 60-70 per cent of farmers had access to technical advice in agriculture. Another important observation from the data is that a sizable proportion (34-52%) of the farmers had experienced some crop loss in the past. We assume that education, membership in a registered organization, attending a training program, and access to technical advice reflect better awareness, skills, and capacity development and encourage the farmers to adopt modern technologies and practices, including seeds, to improve their agricultural production, productivity, and profitability (Teklewold *et al*.,2013; Ng'ombe *et al*., 2014; Borrás & Edquist, 2015). Access to non-farm income sources may also increase the risk-bearing ability of the farmers and may encourage them to use the new technologies. We also expect age to significantly influence the use of improved seeds in agriculture. However, we don’t set any a priori expectation as young age represents risk-taking capacity, and old age represents the experience. They both may affect the adoption of modern technologies. Chauhan *et al*. (2020) suggested that a price support policy has a higher potential to ensure the availability of quality seed. Building on this idea, we also expect that awareness of MSP reflects the overall awareness of the farmers and may positively impact the purchase of seeds from formal sources because of their superiority. Lastly, we also hypothesize that any incidence of crop loss in the past may compel the farmer to use better seeds to ensure better resilience of the crops and higher productivity.

TABLE 3. DESCRIPTIVE STATISTICS OF VARIABLES USED IN THE LOGIT MODEL

Variables (1)	Description & unit (2)	Paddy (3)	Wheat (4)	Maize (5)	Gram (6)	Arhar (7)
Age	Age of household head in years	51.14 (13.29)	51.18 (13.63)	50.15 (13.73)	52.09 (13.47)	51.05 (13.15)
Education	Education of the household head (##)	2.38 (2.46)	2.48 (2.56)	2.00 (2.26)	2.42 (2.54)	2.09 (2.30)
Social group	ST-1, SC-2, OBC-3, others-9	3.96 (3.07)	4.39 (2.97)	3.44 (2.90)	4.07 (2.96)	3.47 (2.82)
Member of registered organisation	Dummy (1 if yes, 0 otherwise)	0.04 (0.21)	0.03 (0.17)	0.04 (0.20)	0.03 (0.17)	0.04 (0.19)
Formal training attend	Dummy (1 if yes, otherwise)	0.02 (0.14)	0.01 (0.12)	0.02 (0.14)	0.01 (0.12)	0.02 (0.13)
Major income source	Dummy (0 crop production, 1 otherwise)	0.23 (0.42)	0.20 (0.40)	0.27 (0.44)	0.16 (0.37)	0.20 (0.40)
Crop area	Acres	2.01 (2.51)	1.94 (2.71)	1.28 (1.47)	1.61 (2.47)	1.24 (1.62)
Awareness about MSP	Dummy (1 yes, 0 otherwise)	0.36 (0.48)	0.34 (0.47)	0.17 (0.38)	0.28 (0.45)	0.23 (0.42)
Access to technical advice	Access to technical advice from any of the 16 sources, Dummy (1 yes, 0 otherwise)	0.58 (0.49)	0.61 (0.49)	0.59 (0.49)	0.70 (0.46)	0.70 (0.46)
Experienced crop loss	Dummy (1 yes, 0 otherwise)	0.40 (0.49)	0.34 (0.47)	0.41 (0.49)	0.45 (0.50)	0.52 (0.50)

Note: ## The codes for education are: not literate: -01, literate: below primary-02, primary -03, upper primary/middle -04, secondary -05, higher secondary -06, diploma /certificate course (up to secondary)-07, diploma/certificate course (higher secondary)-08, diploma/certificate course(graduation & above) -10, graduate -11, postgraduate and above -12.

Figures in parentheses are standard errors. *** p<0.01, ** p<0.05, * p<0.1

3.3 Factors Affecting the Choice of Seed Sources

The results of the logistic regressions for major cereals and pulses included in this study are presented in Table 4. The coefficient of age is positive and significant for paddy, wheat, and gram. Although positive, it is not significant for maize and arhar. Social group is positive and significant for wheat and maize but not significant for other crops. Membership in a registered organization is positive and significant for paddy and not significant for all other crops. Attendance of formal training in agriculture is positively significant in paddy, wheat, and arhar but not significant in other crops. Non-agriculture, as a major source of income, significantly affects the purchase of seeds from formal sources, only in wheat but not in other crops. The area under a crop significantly and positively influenced seed purchase from formal sources for all the crops (except arhar). Likewise, awareness of MSP and access to technical information also had a significant positive coefficient for all the crops. The influence of crop loss in the past seed purchase from formal sources is positive and significant only in wheat

TABLE 4: LOGISTIC REGRESSION ESTIMATES OF DETERMINANTS OF ACCESS TO FORMAL SEED SOURCES

Variables	Paddy		Wheat		Maize		Gram		Arhar	
	Logit coefficient	Marginal effect	Logit coefficient	Marginal effect	Logit coefficient	Marginal effect	Logit coefficient	Marginal effect	Logit coefficient	Marginal effect
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Age	0.00310**	0.000282**	0.00460*	0.000273*	0.00491	0.000355	0.0136**	0.000723**	0.00644	0.000485
	(0.00158)	(0.000144)	(0.00246)	(0.000146)	(0.00356)	(0.000257)	(0.00641)	(0.000339)	(0.00675)	(0.000507)
Education	-0.0183**	-0.00167**	0.0129	0.000767	-0.0162	-0.00117	0.0411	0.00219	-0.0102	-0.000766
	(0.00865)	(0.000788)	(0.0130)	(0.000773)	(0.0215)	(0.00155)	(0.0333)	(0.00177)	(0.0389)	(0.00292)
Social group	-0.00108	-9.84e-05	0.0335***	0.00199***	0.0519***	0.00375***	-0.0446	-0.00238	-0.0361	-0.00271
	(0.00692)	(0.000630)	(0.0111)	(0.000658)	(0.0158)	(0.00114)	(0.0308)	(0.00164)	(0.0324)	(0.00243)
Member of registered	0.441***	0.0471***	-0.0716	-0.00413	0.149	0.0114	-1.099	-0.0381**	-0.0440	-0.00325
organisation	(0.0809)	(0.00999)	(0.186)	(0.0104)	(0.212)	(0.0171)	(0.739)	(0.0152)	(0.409)	(0.0297)
Formal training attend	0.651***	0.0758***	0.717***	0.0579***	-0.504	-0.0297*	0.892	0.0704	0.810*	0.0843
	(0.110)	(0.0159)	(0.204)	(0.0215)	(0.360)	(0.0170)	(0.557)	(0.0607)	(0.478)	(0.0655)
Major income source	0.0546	0.00503	0.395***	0.0261***	0.0576	0.00421	0.0448	0.00242	0.0782	0.00600
	(0.0498)	(0.00464)	(0.0777)	(0.00565)	(0.110)	(0.00814)	(0.239)	(0.0131)	(0.211)	(0.0165)
Crop area	0.0514***	0.00469***	0.0413***	0.00245***	0.123***	0.00891***	0.0789***	0.00421***	-0.0111	-0.000831
	(0.00676)	(0.000618)	(0.00869)	(0.000516)	(0.0255)	(0.00185)	(0.0230)	(0.00124)	(0.0584)	(0.00439)
Awareness about	0.542***	0.0527***	0.120*	0.00724*	0.383***	0.0308***	0.638***	0.0389***	1.049***	0.101***
MSP	(0.0426)	(0.00436)	(0.0708)	(0.00435)	(0.113)	(0.01000)	(0.178)	(0.0121)	(0.176)	(0.0208)
Access to technical	0.716***	0.0629***	0.497***	0.0283***	0.948***	0.0647***	0.377*	0.0189**	1.250***	0.0790***
advice	(0.0474)	(0.00390)	(0.0745)	(0.00401)	(0.117)	(0.00721)	(0.207)	(0.00962)	(0.268)	(0.0131)
Experienced crop loss	0.0541	0.00495	0.340***	0.0212***	0.372***	0.0277***	0.0418	0.00223	-0.0263	-0.00198
	(0.0416)	(0.00382)	(0.0671)	(0.00439)	(0.0951)	(0.00725)	(0.172)	(0.00920)	(0.169)	(0.0127)
Constant	-3.075***		-3.732***		-3.815***		-4.016***		-3.715***	
	(0.0962)		(0.153)		(0.220)		(0.422)		(0.449)	
Log likelihood	-8336.10		-3622.80		-1626.10		-547.93		-506.54	
Lrchi2	772.47		168.54		179.97		45.40		85.17	
Prob>chi2	0.00		0.00		0.00		0.00		0.00	
Pseudo R2	0.04		0.02		0.05		0.04		0.08	
Observation	24,782		14,947		5,636		2,422		1,6[illegible]	

Note: Figures in parentheses are the standard errors.
*** p<0.01, ** p<0.05, * p<0.1

and maize and not in other crops. While education had no significant effect on the source of seed purchase for four crops (out of five), it had an unexpectedly negatively significant coefficient for paddy.

Describing the direction and significance of the above variables and their implications for purchasing seed from formal sources is crucial, as they may significantly affect crop productivity and income. The area under crop, awareness of the farmers (as reflected from awareness of MSP), access to technical advice, and participation in formal training programs have the most widespread influence on the farmers' choice to purchase seed from formal sources. As education was not significant for most crops (except paddy, where it is negatively significant), it seems that the awareness and capacity building of the farmers make them more inclined to use new technologies such as seeds. With relatively lower education levels, farmers are either indifferent or reluctant to adopt better seeds. Crop area reflects the size of the operation and risk-taking ability and thus the choice of better seeds to realize better gains. Membership of registered organizations, non-agriculture as a major source of income, and incidences of crop losses have some influence on farmers' decisions, though not as widespread as the earlier factors (awareness, training, area, etc.).

3.4 Balancing Test of the Covariates and the Models

Before discussing the effects of purchasing seeds from formal sources, we provide the balancing tests for individual covariates and the models applied in our analysis. These tests were conducted using Nearest Neighbour Matching (NNM), Caliper Matching (CM), and Kernel-Based Matching (KBM). The covariate tests are outlined in Table 5, showing that the bias for all covariates reduced to less than 20 per cent after applying propensity score matching. This indicates that differences between the treatment and control groups were effectively minimized, which is a highly desirable outcome (Rosenbaum and Rubin, 1985). Without properly balancing the covariates between the groups, the results might be unreliable.

To evaluate the quality of matching, three tests were used: median absolute bias, R^2 value, and the joint significance of covariates before and after matching. Table 6 illustrates the adequacy of the models. For paddy, the Pseudo R^2 decreases significantly to 0.002 per cent, 0.003 per cent, and 0.001 per cent for NNM, CM, and KBM, respectively, after matching, compared to 0.045 per cent before matching. For all major cereals, the p-values are not significant after matching. The Median Absolute Standardized Bias (MASB) for paddy drops from 16.7 per cent before matching to 3.4 per cent, 3.5 per cent, and 2.5 per cent for NNM, CM, and KBM, respectively. For wheat, MASB declines from 13.2 per cent to 3.8 per cent, 3.8 per cent, and 1.9 per cent, and similar reductions are seen for maize. In the case of pulses, the Pseudo R^2 and mean biases show significant declines after matching, and the p-values of the likelihood ratio tests are insignificant. These outcomes confirm that the models are satisfactorily balanced in terms of the covariate distribution between farmers in the control and treated groups concerning access to seed sources.

TABLE 5: BALANCING TEST FOR INDIVIDUAL COVARIATES USED IN THE STUDY

Variables	Matched/ Unmatched	Paddy % bias			Wheat % bias			Maize % bias			Gram % bias			Arhar % bias		
		NNM	CM	KBM	NNM	CM	KBM	NNM	CM	KBM	NNM	CM	KBM	NNM	CM	KBM
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Age	U	10.8	10.8	10.8	8.6	8.6	8.6	15.1	15.1	15.1	15	15	15	12.7	12.7	12.7
	M	-2.8	-3	0.6	-4.3	-4.3	0.9	0	-0.3	-0.1	-5.7	-4.5	1.2	2.9	4.6	4.2
Education	U	4.1	4.1	4.1	10	10	10	5.8	5.8	5.8	13.6	13.6	13.6	11.3	11.3	11.3
	M	7.6	7.5	2.6	7.5	7.8	1.2	4	4.1	-0.2	15.4	16.4	-0.6	8.5	9	-0.8
Social group	U	7.6	7.6	7.6	14.9	14.9	14.9	24.4	24.4	24.4	-2.6	-2.6	-2.6	-0.6	-0.6	-0.6
	M	1.8	2	0.9	-1.5	-1.7	2	-0.1	-0.1	1.2	-0.9	-0.9	0.2	7.9	7.2	1.4
Member of registered organisation	U	17.8	17.8	17.8	0.9	0.9	0.9	5.9	5.9	5.9	-11.7	-11.7	-11.7	6.2	6.2	6.2
	M	0.9	0.6	3.7	2.8	2.8	0.4	-4.6	-5.5	-0.1	-4.5	-4.6	-0.2	3	3	3.1
Formal training attend	U	16	16	16	11.9	11.9	11.9	-0.3	-0.3	-0.3	9.7	9.7	9.7	17.1	17.1	17.1
	M	4.1	4.3	2.6	-2.8	-2.8	3	5.6	5.6	3.6	0	0	-3.5	7.2	0	9.5
Major income source	U	-2.4	-2.4	-2.4	12.4	12.4	12.4	-4	-4	-4	-1.4	-1.4	-1.4	-1.9	-1.9	-1.9
	M	3.9	3.9	0.1	-2.4	-2.4	1.8	2.2	2.2	-0.2	7.1	7.2	-1.8	7.3	7.4	2.3
Crop area	U	24.3	24.3	24.3	16.6	16.6	16.6	32	32	32	29.4	29.4	29.4	-0.1	-0.1	-0.1
	M	3.8	4.5	6.1	8	7.7	6.6	4.4	4.7	14.2	13	8.8	14	-5	-2.1	1
Awareness about MSP	U	36.6	36.6	36.6	14.4	14.4	14.4	25.2	25.2	25.2	37.4	37.4	37.4	57.8	57.8	57.8
	M	3	2.9	3.5	-0.2	-0.2	0.9	5.3	5.3	3.2	-16.6	-16.8	-2.5	-1.3	-1.3	-0.6
Access to technical advice	U	42	42	42	26.7	26.7	26.7	49.8	49.8	49.8	19.7	19.7	19.7	56.6	56.6	56.6
	M	-4.6	-4.7	-4.5	3.2	3.2	0.4	-3.9	-3.9	-3.7	7.5	6.1	0.3	0	1.5	-1.9
Experienced crop loss	U	5.1	5.1	5.1	15.5	15.5	15.5	19.5	19.5	19.5	2.3	2.3	2.3	-7.5	-7.5	-7.5
	M	-1.5	-1.8	0.1	-5.5	-5.5	1.7	3.5	3.6	0.2	-15.7	-15.9	1.2	-10.6	-12	1.5

TABLE 6: BALANCING TEST OF THE MODELS FOR DIFFERENT CROPS

Test	Paddy			Wheat			Maize			Gram			Arhar		
	Pseudo R2	LR chi2	Mean Bias	Pseudo R2	LR chi2	Mean Bias	Pseudo R2	LR chi2	Mean Bias	Pseudo R2	LR chi2	Mean Bias	Pseudo R2	LR chi2	Mean Bias
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Before matching		785.46***			171.46***			185.52***			46.12***			85.56***	
	0.045	(0.00)	16.7	0.023	(0.00)	13.2	0.054	(0.00)	18.2	0.04	(0.00)	14.3	0.078	(0.00)	17.2
NNM		17.76			8.74			3.98			8.37			4.16	
(1)	0.002	(0.06)	3.4	0.003	(0.56)	3.8	0.003	(0.95)	3.4	0.02	(0.60)	8.6	0.009	(0.94)	5.4
CM		19.71			10.08			4.3			8.55			4.08	
(0.01)	0.003	(0.04)	3.5	0.004	(0.43)	3.8	0.003	(0.93)	3.5	0.02	(0.58)	8.1	0.009	(0.94)	4.8
After KBM		10.57			2.68			5.67			1.61			1.06	
matching (0.01)	0.001	(0.4)	2.5	0.001	(0.99)	1.9	0.004	(0.84)	2.7	0.004	(0.99)	2.6	0.002	(1.00)	2.6

Note: Figures in the parentheses are p-values *** p<0.01

3.5 Impact of Seeds from Formal Sources

The impact assessment has been carried out using the propensity score matching and presented in Table 7. Firstly, access to quality seeds led to an increased expenditure on seeds, which is obvious. While the expenditure increase was statistically significant with all the three matching criteria (Nearest Neighbour Matching (NNM), Caliper Matching (CM), and Kernel Based Matching (KBM)) for paddy, wheat, and gram, it was significant with KM only for maize and arhar. Similarly, all three matching criteria showed significantly higher productivity for paddy and arhar with improved seeds. The productivity of wheat and maize was higher only through Kernel Matching, and there was no impact of improved seeds on the productivity of wheat crops. Finally, the crop profitability was significantly higher by all three matching criteria for paddy and arhar and only by one criterion (KM) for wheat, maize, and gram. The results reveal that the use of improved seeds by the farmers caused an initial increase in the farmers' expenditure. Fuglie *et al*. (2006) also highlighted that quality seed costs three to four times more than seed procured from informal sources. The expenditure on seeds increased by more than 40 per cent for paddy, about 25 per cent for wheat, more than $3/4^{th}$ for gram, 24 per cent for maize, and $1/3^{rd}$ for arhar. This is a major constraint in adopting certified seeds because the financial condition of small farmers doesn't permit them to adopt (Baglan *et al*., 2020). Improved seeds yield better than other informally procured seeds (Ali *et al*., 2015; Manjunatha *et al*., 2015; Wimalasekera, 2015). The improved seeds raised the productivity of paddy by more than 20 per cent and that of arhar by almost half or even more. The productivity enhancement for maize and gram was 12-13 per cent. There was no impact on the productivity of wheat. The NSS unit-level data does not estimate net income from individual crops. Thus, we could not assess the impact of formal seed sources on individual crop income. However, we estimated that the net crop income of the farmers using seed from formal sources and growing paddy, wheat, and maize increased by about 23 per cent, 5 per cent, and 11 per cent, respectively. Likewise, the net crop income of the farmers growing gram increased by about 14 per cent, and that of the farmers growing arhar rose by almost half. Taking net farm income as a weak proxy for the individual crop income, we may conclude that despite spending more on quality seeds, farmers could realize higher profitability due to an increase in crop productivity and, in some cases, a reduction in some other costs (such costs are not examined in our study).

TABLE 7: IMPACT OF ACCESS TO FORMAL SEED SOURCES ON EXPENDITURE, YIELD, AND CROP INCOME

Crop	Matching algorithm	Seed Expenses			Yield			Crop Income		
		Treatment	Control	Impact/ Difference	Treatment	Control	Impact/ Difference	Treatment	Control	Impact/ Difference
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Paddy	NNM (1)	2820.0	1966.1	854.0*** (43.4)	1874.0	1546.7	327.3*** (21.2)	33356.4	26912.0	6444.5*** (23.9)
	CM (0.01)	2787.1	1939.9	847.3*** (43.7)	1874.1	1545.4	328.7*** (21.3)	33360.1	26878.1	6482.0*** (24.1)
	KBM (0.01)	2820.0	1951.2	868.9*** (44.5)	1874.0	1561.5	312.5*** (20.0)	33356.4	26943.6	6412.8*** (23.8)
Wheat	NNM (1)	3438.5	2655.0	783.5*** (29.5)	1237.1	1200.6	36.5 (3.0)	24971.9	24072.0	899.9 (3.7)
	CM (0.01)	3298.7	2657.6	641.1*** (24.1)	1236.5	1200.6	35.9 (3.0)	24961.9	24073.7	888.2 (3.7)
	KBM (0.01)	3438.5	2724.6	713.8*** (26.2)	1237.1	1219.9	17.2 (1.4)	24971.9	23636.6	1335.3*** (5.6)
Maize	NNM (1)	2673.7	2544.3	129.4 (5.1)	1260.4	1234.4	26.1 (2.1)	21927.1	21426.7	500.4 (2.3)
	CM (0.01)	2636.1	2510.2	125.9 (5.0)	1261.3	1232.7	28.6 (2.3)	21943.0	21415.3	527.7 (2.5)
	KBM (0.01)	2673.7	2155.4	518.4** (24.0)	1260.4	1124.0	136.5** (12.1)	21927.1	19742.2	2184.9** (11.1)
Gram	NNM (1)	3401.4	1707.9	1693.5*** (99.2)	461.3	410.6	50.8 (12.4)	19599.5	17363.8	2235.7 (12.9)
	CM (0.01)	3025.9	1664.3	1361.6*** (81.8)	455.1	410.0	45.1 (11.0)	19303.5	17370.1	1933.5 (11.1)
	KBM (0.01)	3401.4	1986.3	1415.1*** (71.2)	461.3	407.2	54.1** (13.3)	19599.5	17137.4	2462.1** (14.4)
Arhar	NNM (1)	998.9	897.9	101.0 (11.2)	430.7	270.0	160.7*** (59.5)	21455.5	13954.6	7501.0*** (53.8)
	CM (0.01)	1000.7	901.4	99.3 (11.0)	431.2	273.7	157.5*** (57.5)	21480.1	14151.1	7329.0*** (51.8)
	KBM (0.01)	998.9	747.6	251.2** (33.6)	430.7	298.0	132.7*** (44.5)	21455.5	14949.2	6506.3*** (43.5)

Note: Figures in parentheses denote the % difference between treatment and control.
*** p<0.01, ** p<0.05, * p<0.1

V

CONCLUSIONS AND POLICY IMPLICATIONS

We utilized data from the 77th round of surveys conducted by the National Sample Survey Office (NSSO) to assess farmers' access to formal seed sources and their effects on crop yields and income levels. The analysis reveals that over 92% of farmers relied on informal channels for obtaining seeds for key cereals and pulses. Formal seed sources were available to a smaller segment of farmers, with access rates varying from 6.19 per cent for gram to 11.36 per cent for paddy. The pattern of seed procurement differed significantly across states and farm sizes. States such as Andhra Pradesh, Karnataka, and Telangana showed higher formal seed use for paddy, while Punjab and Haryana had more significant usage of formal seeds for wheat. Larger farms tended to rely more on formal seed sources compared to small and marginal farms, suggesting a positive correlation between farm size and access to formal seeds.

Key factors influencing access to formal seed sources included technical advice, formal training, awareness of Minimum Support Prices (MSP), and the scale of farming operations. Raising awareness and building capacity are essential to promoting the use of improved seeds. Although accessing formal seeds increased seed-related expenses, it resulted in substantial gains in productivity and profitability. For example, productivity improved by over 20 per cent for paddy and nearly 50 per cent for arhar. Farmers also experienced increases in net crop income, with paddy farmers seeing a 23 per cent rise, wheat farmers 5 per cent, maize farmers 11 per cent, gram growers 14 per cent, and arhar growers almost 50 per cent.

The study highlights the need to encourage the adoption of seeds from formal sources. There is a clear necessity to raise awareness about the advantages of formal seeds and to offer financial support to small and marginal farmers to help them access these seeds. Developing an efficient seed distribution system, particularly in rural areas, could enhance access to quality seeds. Strengthening the seed supply chain will ensure the timely availability of seeds at reasonable prices. Furthermore, expanding extension services and providing regular training on modern agricultural techniques, including seed management, can build farmers' skills and increase the advantages of improved seeds. Such policy measures would drive the adoption of certified seeds, leading to higher agricultural productivity, better farmer incomes, and greater food security in India.

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