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EDITED BY
Pankaj Kumar Arora,
Babasaheb Bhimrao Ambedkar University, India

REVIEWED BY
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Ranjit Kumar,
National Academy of Agricultural Research Management (ICAR), India

*CORRESPONDENCE
Atul P. Kulkarni
a.kulkarni@cgiar.org

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Stress-resilient maize hybrid adoption factors and impact: Evidence from rain-fed agroecologies of Karnataka state, India

Atul P. Kulkarni[1]*, Prakash H. Kuchanur[2], Dayanand G. Satihal[3], P. H. Zaidi[1] and Dil Bahadur Rahut[4]

[1]International Maize and Wheat Improvement Center (CIMMYT), Hyderabad, India, [2]Genetics and Plant Breeding, University of Agricultural Sciences (UAS), Raichur, Karnataka, India, [3]Department of Agricultural Economics, University of Agricultural Sciences (UAS), Raichur, Karnataka, India, [4]Asian Development Bank Institute (ADBI), Tokyo, Japan

Drought is one of the major abiotic constraints that adversely affect maize production in the rain-fed agro-environment in the Asian tropics. In view of the recurrent drought, stress-resilient (SR) maize hybrids were developed and deployed to minimize yield penalties and ensure minimum sustainable production of maize in mild to severe drought conditions. Data were collected from 180 farmers from two districts of northern Karnataka. Findings suggest that the household location, caste, access to credit, number of extension visits, and participation in field days significantly influence the adoption of the SR maize hybrid in the study area. The inverse probability weighting (IPW) estimator revealed that households adopting SR maize hybrid have higher yield and income (23% more yield and $137.86/ha more net income) than the non-adopters. As the SR maize hybrid has considerable scope for improving the livelihood and security of farmers, the agricultural policy should support and scale the stress-resilient maize hybrids in the region.

KEYWORDS

drought, stress-resilient maize hybrid, inverse probability weighting estimator, average treatment effect, Karnataka

Introduction

"Everything can wait but not agriculture" (said by the first prime minister of India), the one sentence very precisely explained the importance of agriculture with reference to global food security, livelihood, employment, a staple for industries, and many more. Maize is one of the major staple foods for developing and underdeveloped countries and basic raw material for food and feed industries. However, climate change is a major impediment to ensuring food and nutritional security for the rapidly growing population. Climate change has been in discussion for the last 3–4 decades, but it has received serious attention in the previous 1–2 decades, as the impact of climate change, such as recurrent drought, heat waves, floods, erratic rainfall, hailstorms, increase global temperature, increase ocean temperature, and sea level has become more visible. Climate risk will continue to become a major threat in the coming decades. For instance, under the business-as-usual scenario, it is forecasted that the temperature will increase by 2.1–3.6°C by 2050 in the tropical and temperate areas (Cairns et al., 2012).

Mean temperature over the last 10 years (2010–2019) peaked across the globe, and in the coming years, it is also expected to increase because of rising greenhouse gas (GHG) emissions (World Meteorological Organization, 2019). South Asia is highly vulnerable to climate alteration because of the high population density, poverty, and limited resources available for adaptation (Ahmed and Suphachalasai, 2014). Climate variation scenarios display that agricultural harvest would be adversely affected and hinder the potential of the many regions to achieve the required gains in food production to ensure future food security (Lobell et al., 2008). According to a new United Nations report on world population prospects 2019, the world population is predicted to reach 9.7 billion in 2050 and nearly 11 billion in 2100, and the population growth will be highest in developing countries (World Population Prospects, 2019). With the present productivity and population growth level, there will be a considerable gap between future demand and production (Cairns et al., 2012). The development of maize hybrid resistance/tolerance to abiotic stresses is crucial for the agricultural sector to adapt to climate risk and ensure food security for the growing population (Easterling et al., 2007).

Rain-fed agriculture, which is highly prevalent in developing countries, is most vulnerable to climate risk. For instance, 95% of farmland in sub-Saharan Africa is rain-fed, and it is 90% in Latin America, 60% in South Asia, 65% in East Asia, and 75% in East and North Africa (Wani et al., 2009). Drought is significant abiotic stress which affects global maize production in rain-fed regions. The occurrence of moisture stress at the asexual and sexual phases of maize diminishes yields by 39.3% (Daryanto et al., 2016). Barron et al. (2003) studied dry spell occurrence in semi-arid locations in Kenya and Tanzania and found that meteorological dry spells of >10 days occurred in 70% of seasons during the flowering stage of maize crop, which is very sensitive to water stress. Maize is particularly susceptible to heat stress during the multiplicative stage (Edreira et al., 2011; Cairns et al., 2012; Mayer et al., 2014; Rezaei et al., 2015). It is reported that a one-degree daily temperature increase beyond 30 °C reduces the final maize yield by 1% under favorable growing conditions and 1.7% under drought-stressed conditions (Lobell et al., 2011).

Globally, India ranks seventh with a maize production of 27.71 million tons in 2019 (FAOSTAT, 2021). Out of the total maize area, 73.4% is under rain-fed agriculture in 2014–2015 (Directorate of Economics and Statistics, 2017). In India, 11.53 million small and marginal maize farmers (<2 ha) are most vulnerable to climate change with low yield and crop loss risk. Although the state of Karnataka is one of the India's leading maize producers, contributing to 12.36% of the total production in 2017–2018, it is frequently affected by drought.

SR maize hybrid is a new climate-smart variety released by the company, and no study has been conducted to quantify the result on the ground. We took this opportunity to conduct a study with 2-fold objectives: first, to examine the factors influencing the adoption of stress-resilient (SR) maize hybrids, and second, to estimate the adoption impact of SR maize hybrids on yield and income. The data collection methods and econometrics analytical framework are provided in Section Data and methodology. The empirical results are presented and discussed in Section Result and discussion. The last section concludes the study and provides the policy implications.

Stress-resilient maize hybrid technology

Climatic variations adversely affect the food security and livelihood of marginal and smallholder farmers; hence, it is crucial to develop and scale climate-resilient technologies. SR maize hybrid is a risk-mitigation technology that is anticipated to maintain yields and income in the incidence of climate risks. A stress-resilient/drought-tolerant (DT) maize variety can produce roughly 30% of its potential yield (1–3 tons per hectare) after suffering water stress for 6 weeks before and through flowering and grain filling (Magorokosho et al., 2008).

Studies on the adoption and impact of DT maize hybrids in Africa indicate a positive effect on the yield and reduction of yield variability (Kassie et al., 2013; La Rovere et al., 2014; Fisher et al., 2015; Holden and Fisher, 2015). A stress-resilient hybrid is considered far superior to normal hybrids under stress conditions, and it has the potential to at least maintain yield at par with normal hybrids under optimal conditions. Although conventional hybrids perform well under optimal climatic conditions, the yield is negatively affected due to climatic stress, such as heat and drought. For instance, the yield of conventional maize hybrids falls drastically if moisture stress occurs at pollination and grain setting time, while the impact is relatively less on SR hybrids. As the stress-resilient maize hybrid ensures good yield under bad weather conditions, they have an advantage in a rain-fed stress-prone agro-environment. Since 2000, Indians have experienced as many as seven widespread severe droughts; thus, SR maize can play an important role in ensuring food security and improving the livelihood of the maize farmers, particularly in a rain-fed stress-prone agro-environment.

International Maize and Wheat Improvement Center (CIMMYT) and University of Agricultural Sciences, Raichur (UAS-R) jointly developed heat and drought stress-resilient maize hybrid, RCRMH2, under the project, Heat Stress-Tolerant Maize for Asia (HTMA) funded by USAID. This hybrid was licensed to Maharashtra Hybrid Seeds Company Private Limited (Mahyco) for harvesting the benefit of the technology by small and marginal farmers of the country. The company deployed the hybrid in the rain-fed areas of the country, including Karnataka, with the commercial name MRM 4070 during Kharif 2018, and they are scaling it up year by year.

Data and methodology

Data sources

The data used for this article are drawn from a primary survey of 180 farm households in two districts of Northern Karnataka from March to April 2019. For data collection, skilled enumerators were selected and systematically trained for 2 days, and questionnaires were pre-tested before the actual survey of respondents. The respondent's participation in the study was voluntary and ensured the concealment of their identity, and the respondent was informed that their identity would not be known in any study report or publications. Respondents were assured that their household information would be kept strictly confidential and would not be shared with any third party. Detailed household information was collected from the head of each household, and in his/her absence, the second most important person in the household was interviewed. A comprehensive questionnaire was drafted to collect information on various aspects of the maize agri-food system, farm-level characteristics, household-level demographic, and socio-economic information. Data were collected through post-graduate agriculture students from Karnataka who were well aware of the local language, conditions, and environment.

Sampled district and sampling procedure

In the study, the districts, blocks, and villages were selected purposively by stratified sampling technique on the basis of the deployment (distribution) of the SR maize hybrid by the Mahyco seed company as the variety is newly released. Gadag and Dharwad districts from northern Karnataka were selected for the study (Figure 1). Although both the districts are in rain-fed environments, Gadag district is drought-prone, and Dharwad has assured rainfall. Shirahatti and Laxmeshwar blocks were selected from the Gadag district, and Dharwad and Hubballi blocks were selected from the Dharwad district. From each district, 11 villages were selected, and 8–9 farmers were selected for the survey from each village. A list of adopters was collected from the dealers and selected purposively, which ranges from two to four adopters in a village, whereas non-adopters were selected randomly from the same and other nearby villages. The study was conducted in the first year of deployment of the stress-resilient maize hybrid, as a result, adopter was scattered and found limited in numbers. In total, 89 maize farmers from Gadag and 91 farmers from Dharwad district formed the basis of this study. The total sample size was 180 (50 adopters and 130 non-adopters) maize growers. The data were collected for the 2018 Kharif season with a pre-design questionnaire.

Econometric analysis

Potential outcome framework and average treatment effects

Suppose we observed a sample of subjects, some of whom received treatment and others did not. In the agriculture discipline, a "treatment" could be new fertilizer or pesticide dose, or with adopter farmer of the new variety. We would like to know if a treatment has an effect on an outcome Y. The outcome could be the yield received by a farmer with a conventional maize hybrid or a new hybrid. What we called Y would ultimately be an observed outcome, something we would see. Potential outcomes are the outcomes we would observe under each possible treatment option. The potential outcomes would be observed if we set treatment to certain values, such as treated vs. untreated. For example, we might be interested in the mean difference in the outcome if everybody was treated vs. if no one was treated.

Average treatment effect

Average treatment effect is the mean difference in potential outcomes.

$$E(Y^1 - Y^0) \tag{1}$$

where E–Expected values

Y^1-Potential outcome if population treated with treatment (A) = 1

Y^0-Potential outcome if population treated with treatment (A) = 0

Propensity score

A propensity score is simply the probability of receiving treatment, rather than control, given covariates X (defined by Rosenbaum and Rubin, 1983). Define A = 1 for treatment and A = 0 for control.

We denote the propensity score for subject *i* for π_i.

$$\pi_i = P(A = 1|X_i) \tag{2}$$

So here, the π_i is referring to, a notation for the propensity score for a person *i*. It is really a function of x. So, propensity score as a function of X, but we are indexing it by *i*, because the person *i* has a unique set of covariates Xi. So, this is the probability of treatment, given that person's particular set of covariance.

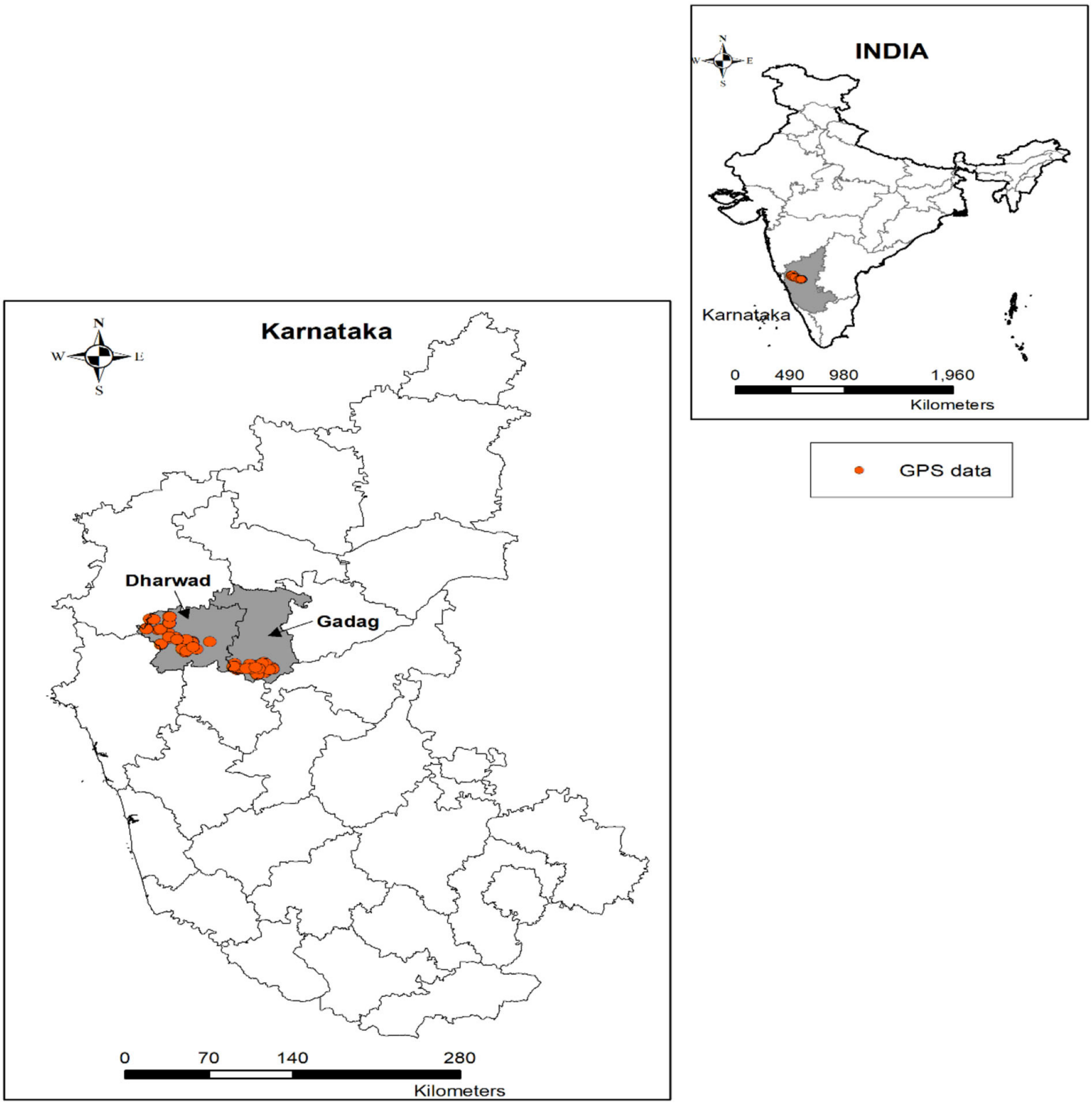

FIGURE 1
Location of the study areas.

Inverse probability-weighted estimator

Inverse probability weighting removes confounding by creating a "pseudo-population" in which the treatment is independent of the measured confounders. Consider a sample of data from n farmers with treatment indicators (A_i), and individual covariates (X_i) assumed to be independent and identically distributed, i 1, …, n. The propensity score typically is unknown and must be estimated based on the observed covariates and treatment assignments. Denote the estimated propensity score as π_i and *A()* as the treatment indicator function, taking the value 1 if the condition holds and 0 otherwise. The inverse probability-weighted estimate of treatment-specific effect is given by Lunceford and Davidian (2004) with the following estimating equation:

$$ATE(IPW) = \frac{1}{n}\sum_{i=1}^{n}\frac{A_i Y_i}{\pi i} - \frac{1}{n}\sum_{i=1}^{n}\frac{(1 - A_i)\, Y_i}{1 - \pi_i} \tag{3}$$

where,

n = number of people in population
$A_i = 1$ if treated, otherwise 0
Y_i = Output variable

$$\pi_i(Propensityscore) = P(A = 1|X_i) \quad (4)$$

Any type of estimator using the propensity score requires three assumptions: consistency, exchangeability, and positivity. Consistency means that a subject's potential outcome under the treatment received is equal to the observed outcome. Exchangeability, also known as ignorable treatment assignment, is the assumption that there are no unmeasured confounders: that one has measured and has access to all of the variables that affect treatment selection and outcomes. Positivity is the assumption that all subjects have a non-zero probability of receiving each treatment: $0 < \Pr(A = 1) < 1$.

Weights

IPW uses the inverse (reciprocal) of the probability of being in the observed treatment group. These probabilities are obtained by modeling the observed treatment as a function of subject characteristics that determine the treatment group. In the IPW method, for subjects who did receive treatment, the weight is equal to the reciprocal of the predicted probability of treatment. For subjects who did not receive treatment, the weight is equal to the reciprocal of the predicted probability of not receiving treatment; the probability of not receiving treatment is just one minus the probability of receiving treatment. Weight can be defined as Rosenbaum (1987).

$$w_i = \frac{A_i}{\pi_i} + \frac{(1 - A_i)}{1 - \pi_i} \quad (5)$$

Result and discussion

Socio-economic and farm characteristics

The details of the socio-economic characteristics of the households are shown in Table 1. The average age of household heads was 48.81 years. About 57% of households belong to other backward caste (OBC) and 32% from general caste, the remaining 11% from schedule caste and schedule tribe. On average, households comprised 6.96 persons, with adopting households reporting smaller households (6.16 persons) than non-adopters (7.27 persons). The average land holding was 5.74 ha/household, with non-adopter's households having more land (5.85 ha) than adopter's households (5.47 ha), indicating the size medium of the holding. The average land allocated by these households for maize farming accounted for 58.42% (2.79 ha) of the total land holding.

In terms of input use, the average seed rate for maize in these households was 14.73 kg /ha, which is less than the recommended seed rate of 20 kg/ha. The seed rate ranged between 10 kg and 25 kg/ha across the study locations. These large differences are due to the different planting practices followed by farmers. About 55% of households used dibbling method of sowing, 39% of households used tractor-drawn seed drill, and only 6% of households used bullock-drawn seed drill for sowing. Proper seed placement is done in dibbling method, resulting in a low seed rate. Another reason for the low seed rate was as this is a rain-fed agroecology, farmers sometimes double sow because long dry spells after first sowing leads to poor seed germination. The average seed cost was $42.62/ha, with adopter households reporting a significantly (at 1% level) more price ($49.41/ha) than the non-adopters ($40.01/ha). In the study locations, it is observed that maize seed prices ranged from $1.14 to $5/kg, depending upon the type and brand of hybrid. It is noticeable that the price of the stress-resilient maize hybrid (MRM 4070) was lower than the best commercial maize hybrids.

The average seed cost used by non-adopters was low because (i) the seed brought by them included a three-way cross hybrid, a double cross hybrid that was priced lower than the single cross and (ii) and there was a recommended subsidy provided by the state government on hybrids if purchased from government outlets, while this subsidy was not accorded to stress-resilient hybrid. General caste farmers get ₹20 ($0.285)/kg, and schedule caste farmers get ₹30($0.428) /kg subsidy on maize hybrid seed. SR maize hybrid is not yet listed in the government outlet hybrid list. About 18% of farmers purchased seed from government outlets.

Interestingly the study did not find a marked difference between fertilizer usage (Urea, DAP, and Potash), between adopters and non-adopter households. About 94% of adopter's households had access to credit compared to non-adopter's households (67%), with a significant difference at the 1% level. Further, the participation of adopter farmers (36%) in the field day demonstration was significant as compared to the non-adopter households. A significant difference (at a 5% level) was also observed in the average drought encountered frequency of adopter households (2.66 years) with non-adopters households (2.25 years) over the last 10 years. Gadag district (drought-prone) had a significantly higher proportion of adopters than the Dharwad district. With respect to yield and net income, adopter's farmers received an additional yield of 2.56 quintals/ha and an additional net income of $56.71/ha over non-adopter households, but the difference is not significant.

Farmer's perception and demand for the stress-resilient maize hybrid

The result shows that 40 and 27% of farmers from the Gadag district reported having experienced drought three and four times in the past 10 years, respectively (Figure 2A). In the Dharwad district, 40% of farm households experienced

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TABLE 1 Social and economic status of sampled farmers.

Variables	Full sample ($n = 180$)		Adopters ($n = 50$)		Non-Adopters ($n = 130$)		Mean difference
	Mean	SE	Mean	SE	Mean	SE	
Age of household head (years)	48.8	13.01	50.4	13.27	48.19	12.91	2.21
Caste (general) (1 = yes, 0 = otherwise)	0.32	0.47	0.28	0.45	0.34	0.48	−0.06
Caste (OBC) (1 = yes, 0 = otherwise)	0.57	0.5	0.66	0.48	0.54	0.5	0.12
Household size (numbers)	6.96	4.2	6.16	4.4	7.27	4.1	−1.11
Education of household head (years)	6.74	4.85	7.06	5.22	6.62	4.72	0.44
Farm size (ha)	5.74	6.03	5.47	5.53	5.85	6.23	−0.38
Maize area (ha)	2.79	3.54	2.52	2.67	2.89	3.83	−0.38
Proportionate of maize area to farm size (%)	58.42	30.23	57.88	29.81	58.63	30.5	−0.75
Family members work in agriculture (numbers)	2.97	1.78	2.8	1.63	3.03	1.84	−0.23
Associated with any farmers group (1 = yes, 0 = no)	0.40	0.49	0.36	0.48	0.42	0.49	−0.06
Seed rate (kg/ha)	14.73	0.29	14.57	0.55	14.8	0.34	−0.22
Seed cost ($/ha)	42.62	1.21	49.41	1.95	40.01	1.43	9.40***
Urea (kg/ha)	189.5	7.79	193.15	16.27	188.1	8.82	5.05
DAP (kg/ha)	121.3	3.18	117.82	8.84	122.64	2.82	−4.82
Potash (kg/ha)	15.71	2.95	13.34	5.06	16.63	3.61	−3.29
Irrigation (1 = yes, 0 = no)	0.17	0.03	0.18	0.05	0.17	0.03	0.01
Number of irrigation given	0.37	0.07	0.38	0.14	0.36	0.07	0.02
Owned bullock (1 = yes, 0 = otherwise)	0.67	0.47	0.66	0.48	0.68	0.47	−0.02
Owned tractor (1 = yes, 0 = otherwise)	0.34	0.48	0.28	0.45	0.37	0.48	−0.09
Access to credit (1 = yes, 0 = otherwise)	0.74	0.44	0.94	0.24	0.67	0.47	0.27***
Extension visits (Nos/years)	1.4	1.77	1.18	1.69	1.48	1.81	−0.3
Field day participation (1 = yes, 0 = otherwise)	0.17	0.37	0.36	0.48	0.09	0.29	0.27***
Distance to seed input shop (km)	8.85	5.47	8.55	5.61	8.96	5.44	−0.41
Distance to grain market (km)	10.49	8.37	9.82	10.02	10.75	7.67	−0.93
Drought encounter frequency (in last 10 years)	2.36	1.28	2.66	1.1	2.25	1.34	0.41**
District (1 = Gadag, 0 = otherwise)	0.55	0.5	0.72	0.45	0.48	0.5	0.24***
Yield (tons/ha)	3.06	0.15	3.25	0.31	2.99	0.16	0.26
Cost-C ($/ha)	616.42	147.45	633.96	21.30	609.68	12.82	24.28
Gross income ($/ha)	771.42	37.83	829.92	78.42	748.92	42.87	80.99
Net income ($/ha)	154.99	33.91	195.95	69.89	139.23	38.59	56.71

***, **indicates statistically significant at 1 and 5% respectively. SE stands for stand error.

drought two times over the last 10 years, while 14% reported that they did not experience drought. The study conducted by Fisher et al. (2015) found that the average frequency of drought occurrence was 1–3 years of the last 10 years reported by the Zimbabwean farmers. In Dharwad, most farm households experienced drought in the previous 3–4 years, and in Gadag, many farmers reported having experienced drought in recent years. Similar types of drought patterns experienced by adopters and non-adopters are shown in Figure 2C. The respondents were also asked to list the top criteria considered while choosing the maize variety. The district-wise maize hybrid choosing criteria are shown in Figure 2B.

Most frequently considered maize traits by farmers while selecting the maize seed were grain size, grain yield, drought and heat tolerance, fodder quality and quantity, and cob size. Farmers consider the drought and heat tolerance trait in the climate change scenario, which assures minimum yield in bad weather years. About 82% of farmers consider drought

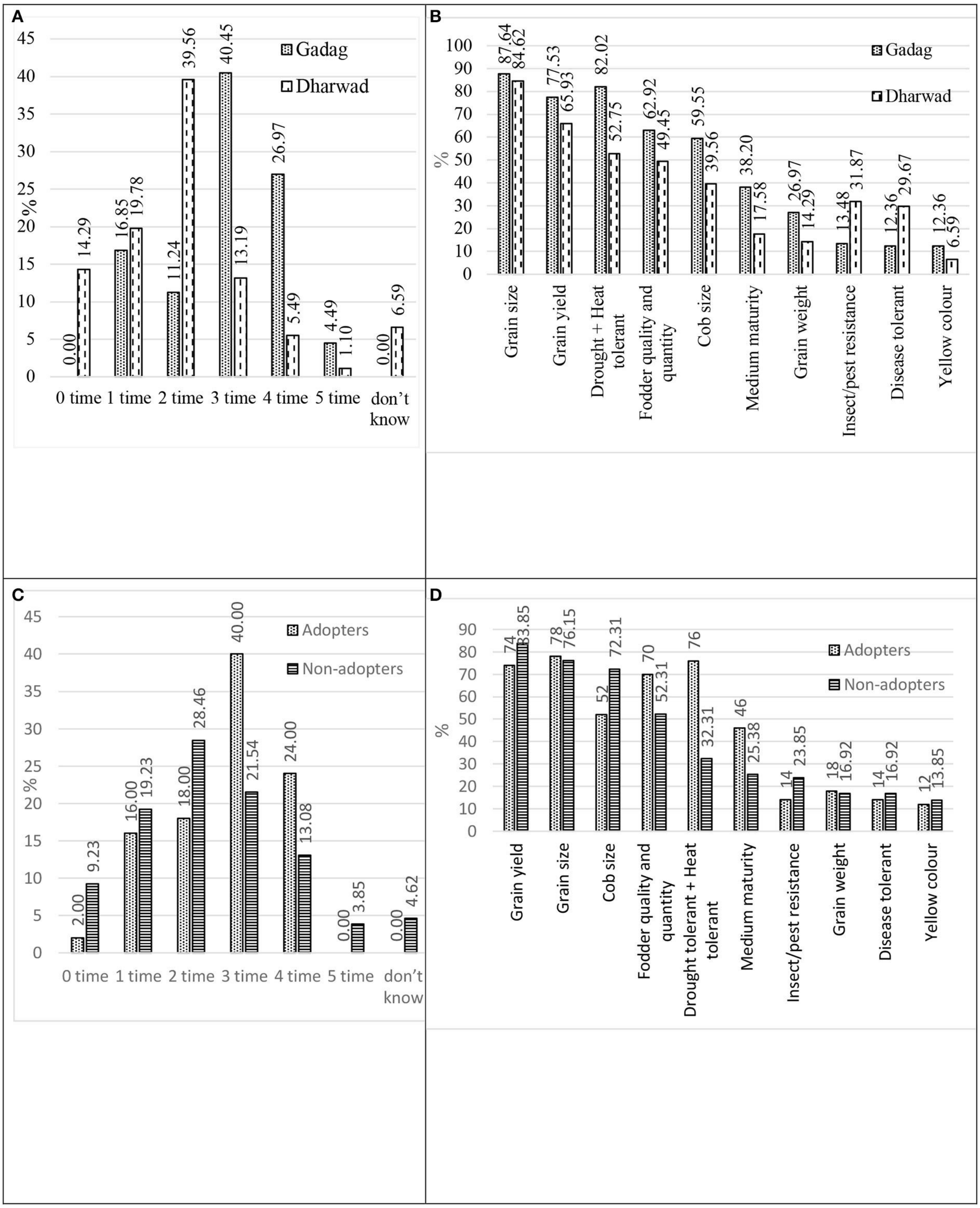

FIGURE 2
Farmer's perception of drought frequency and criteria of the selection of maize hybrid in the study location. **(A)** Farmer's perception of drought frequency in the last 10 years, by sample districts. **(B)** Criteria for the selection of maize hybrid by sample districts. **(C)** Adopter and non-adopter farmer's perception of drought frequency in the last 10 years. **(D)** Criteria for the selection of maize hybrid by adopters and non-adopter farmers in the study location.

and heat-tolerant traits when selecting maize hybrid in Gadag (stress-prone) district. For variety selection, along with yield criteria, adopter farmers also consider drought + heat-tolerant trait and fodder quality and quantity compared to non-adopter farmers (Figure 2D). While interacting with farmers during the survey, it was found that farmers expect a minimum yield of 2 tons/ha under stressful weather conditions to adopt new SR maize varieties. As farmers struggle to feed their livestock during a bad year, drought and heat-tolerant maize hybrid could be one option to tackle fodder shortage. More than 90% of the farm household reported their intentions to grow stress-resilient maize hybrids in the coming years in the study area.

Climatic conditions in the study area

Maize plants may respond differently to drought stress at different crop stages. Among various crop stages, the reproductive stage, especially 3–4 weeks bracketing male flowering (anthesis), is the most critical stage of the crop (Claassen and Shaw, 1970; Grant et al., 1989). Female reproductive structures are more seriously affected than male flowers (tassels). Extreme sensitivity seems confined to the period 2–22 days after anthesis, with a peak at 7 days, and complete infertility can occur if maize plants are stressed in the period from just before tassel emergence to the lag-phase of grain filling (Grant et al., 1989; Zaman-Allah et al., 2016). Hence stress at reproductive stages causes severe damage to the yield. The rainfall distribution and temperature range in the surveyed districts are shown in Figures 3, 4, respectively. The normal mean rainfall in the Gadag district is reported as 641 mm, whereas for the Dharwad district, it is 792 mm (Open Government Data Platform India, 2019; Government of India, 2019) from January to December. However, the actual rainfall received in 2018 in Gadag was merely 455.9 mm and in Dharwad was 720.75 mm from January to December 2018 (Karnataka State Natural Disaster Monitoring Centre, 2017) (Figure 3). Gadag had more rainfall deficit (185 mm) than Dharwad (71.25 mm) compared to normal mean rainfall. The reproductive stage begins 55–60 days after sowing (most probability) if sowing commences in mid-June (normal practice), the crop flowers in August.

In August, the rainfall received in the Gadag district was less than in the Dharwad district, whereas the maximum temperature in Gadag was 35.3°C at the reproductive stage. During the flowering of the optimal planted crop at Dharwad, the maximum temperature was 31.2°C, which is optimal for a good pollination shed (Figure 4). The low rainfall and high temperature at the reproductive stages of maize, particularly in the Gadag district, could be the reason for reported lower yields than in the Dharwad district. In addition, few farmers opted for late sowing (in mid-July) and had their crop exposed to high temperatures (37.7°C in September), resulting in severe yield

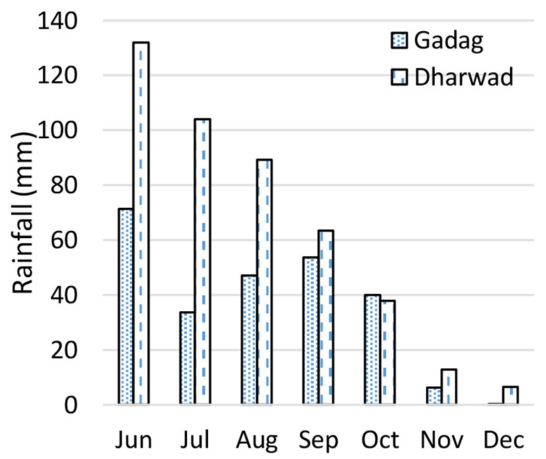

FIGURE 3
Rainfall distribution in 2018. Source: KSNDMC, Government of Karnataka, 2018.

losses. The losses could be attributed to improper pollination and grain setting. The observed weather parameter clearly indicates that the main season crop planted by farmers of Gadag was severely stressed and had drought + heat stress conditions at the reproductive stage than the Dharwad district. These had also resulted in the government of Karnataka declaring Gadag as a drought-hit district in 2018.

Performance of stress-resilient hybrid under stress and optimal condition (cost-return)

Table 2 presents a comparative analysis of adopters and non-adopters of the stress-resilient maize hybrid in relation to cost, productivity, and income. The adopters received 0.26 tons/ha additional yield and additionally net income of $56.72/ha as compared to non-adopter farmers but not significant. The cost of production for adopter farmers was less by $8.84/ha than for non-adopters. The average total cost (cost-c) of $558.60/ha was recorded among the surveyed farmers in the Gadag district. The adopter's cost was significantly more ($615.30/ha) than the non-adopters ($526.20/ha). Differences in the cost were due to the significant differences in the seed price, higher labor cost, threshing cost, and interest on the working capital of adopters and non-adopters. The total cost of the cultivation of maize estimated in this article is similar to the earlier studies conducted by Chowti and Basavaraja (2015) in the Haveri district and Hamsa et al. (2017) in the Tumakuru district of Karnataka.

Grain yield was the primary trait of interest for all the farmers in the study. Results in the Gadag district indicated that adopter's households recorded an average yield of 2.94

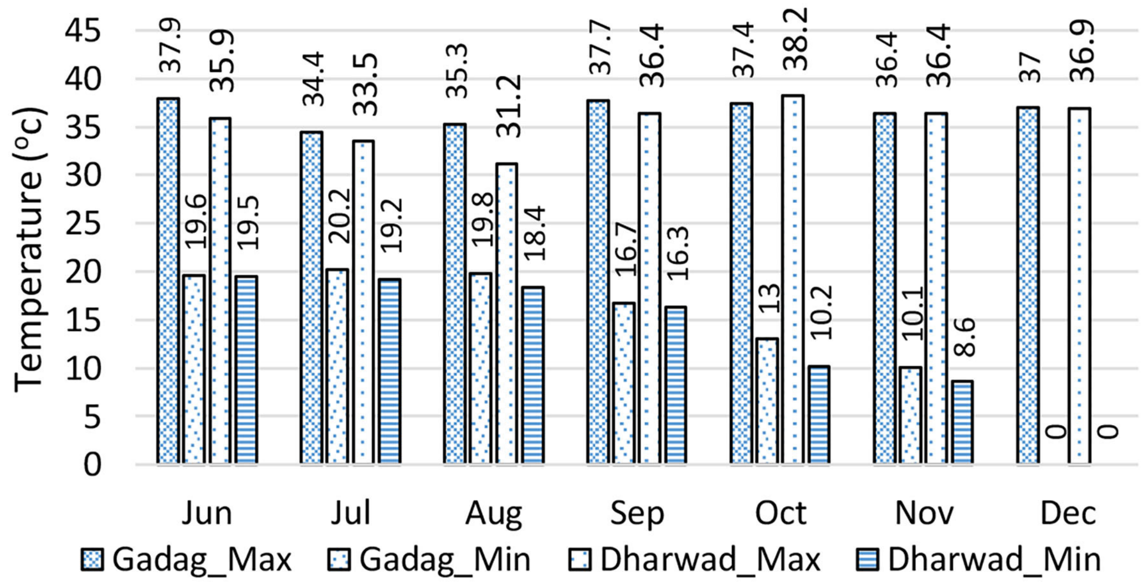

FIGURE 4
Temperature range in study locations in 2018.

tons/ha, and non-adopter households reported 1.98 tons/ha. It shows that adopter farmers had a significant addition of 0.96 tons/ha compared to non-adopters ($P \leq 0.05$). It clearly reveals that a stress-resilient maize hybrid gives a cushion to farmers under severe climatic conditions than cultivating a non–stress-resilient maize hybrid. In addition, in the Gadag district, the average selling price of the grains by adopters was $215.60/tons, whereas non-adopters received only $205.67/tons. The smaller maize grain size of non-adopter farmers due to high moisture stress at the grain filling stage compared to the stress-resilient hybrid was the reason for this disparity. In total, the adopter households received significant additional income from primary produce ($226.63/ha) and an additional $41.92/ha as byproduct income. It is worth noting that adopter households received $179.45/ha additional net income over non-adopter households in a drought year. The average cost of production for adopter households was $209.17/ton, which is less by $56.23/ton than the non-adopters household income ($265.39/ton) in the Gadag district. In summary, a dollar invested in a non–stress-resilient maize hybrid resulted in a $0.94 return during a drought-prone climate, while the stress-resilient maize hybrid gave a $1.24 return on investment. In the Dharwad district, under the optimal climatic condition, the stress-resilient maize hybrid performed at par with presently available hybrids in the market.

Multi-location evaluation trial (MLT) of CAH-153 (MRM4070) in a larger plot size of 10 m^2 was conducted by CIMMYT with other maize hybrids (checks) to compare the performance in Kharif 2017 (Table 3). Grain yield of the hybrids was recorded in kgs on a plot basis and converted to tons/ha at the standard moisture of 12.5%. MLTs were conducted in high input/optimal and rain-fed environments, and the yield mentioned in Table 3 is a potential yield of hybrids. MLTs elaborated that the performance of CAH-153 (MRM4070) was much better than or at par with checks in all locations in Kharif (rainy) 2017. Even in the rain-fed locations, MRM4070 performed better than the checks.

Factors affecting the adoption of the stress-resilient maize hybrid

We estimated determinants through a probit model where the dependent variable was categorical, indicating the adopters and non-adopters of the stress-resilient maize hybrid in a stress-prone agro-environment. We used a model to estimate the factors affecting the adoption of the SR maize hybrid in a drought-prone agro-environment. Results in Table 4 indicate that location (district), caste (OBC), access to credit, extension visits, and field day participation in the demonstration were significantly associated with the probability of adopting the stress-resilient maize hybrid in the study location. The significance of location (district dummy variables) (with Dharwad district as reference) likely reflects unobservable differences in terms of resources and weather patterns. A farm household in the Gadag district has a 0.174 higher probability of adopting new maize varieties than the farmers in the Dharwad district. Generally, general category respondents are the early adopters of new innovation/technology, but we found

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TABLE 2 Comparison of adopters and non-adopters of the stress-resilient maize hybrid in study locations (values in $/ha).

	Overall					Gadag district							Dharwad district						
	Adopters		Non-Adopters		Diff#	Gadag		Adopters		Non-Adopters		Diff#	Dharwad		Adopters		Non-Adopters		Diff#
	Mean	SE	Mean	SE		Mean	SE	Mean	SE	Mean	SE		Mean	SE	Mean	SE	Mean	SE	
Cost-A1 ($/ha)	424.61	15.96	410.84	8.08	13.77	385.47	9.85	430.12	18.97	359.96	9.81	70.16***	450.35	9.6	410.46	30.3	458.69	9.55	−48.23**
Cost-A2 ($/ha)	450.01	18.49	431.33	9.18	18.68	404.84	11.12	454.95	21.72	376.2	10.88	78.75***	475.25	11.42	437.34	36.37	483.18	11.45	−45.83
Cost-B ($/ha)	553.72	20.17	530.95	11.29	22.77	497.89	12.76	553.26	24.18	466.26	13.09	87.00***	585.42	13.79	554.93	37.8	591.79	14.71	−36.86
Cost-C ($/ha)	633.96	21.3	609.67	12.82	24.28	558.6	13.77	615.3	25.93	526.2	14.41	89.10***	687.11	14.25	681.97	34.77	688.18	15.74	−6.21
Yield (tons/ha)	3.25	0.31	2.99	0.16	0.26	2.33	0.18	2.94	0.36	1.98	0.19	0.96***	3.95	0.2	4.03	0.57	3.94	0.21	0.09
Main produce income ($/ha)	686.81	65.12	617.15	35.86	69.66	489.63	39.95	633.85	77.89	407.22	41.29	226.63***	816	42.87	822.99	114.46	814.54	46.42	8.46
By produce production (tons/ha)	4.00	0.38	3.68	0.2	−0.32	2.9	0.23	3.64	0.44	2.48	0.24	1.16***	4.86	0.24	4.96	0.7	4.84	0.25	0.11
By produce income ($/ha)	143.1	13.56	131.77	7.24	11.33	103.22	8.09	129.9	15.77	87.98	8.49	41.92***	173.66	8.6	177.05	25.14	172.95	9.07	4.1
Gross income ($/ha)	829.91	78.41	748.92	42.86	80.99	592.86	47.84	763.75	93.28	495.2	49.55	268.55***	989.66	51.07	1,000.05	139.4	987.49	54.96	12.56
Net income ($/ha)	195.95	69.89	139.24	38.59	56.71	34.26	42.82	148.46	83.11	−30.99	46.23	179.45***	302.55	49.8	318.08	127.89	299.31	54.4	18.77
Cost of production ($/ton)	195.06	–	203.9	–	−8.84	239.6	–	209.17	–	265.39	–	−56.23	173.81	–	169.2	–	174.8	–	−5.59
B:C ratio	1.31	–	1.22	–	0.09	1.06	–	1.24	–	0.94	–	0.3	1.44	–	1.47	–	1.43	–	0.04

Exchange rate: 1US $ = 70 INR.

***, **indicates statistically significant at 1 and 5% respectively. SE, standard error; Diff#, difference.

Cost-A1: (include cost of) Hired labor + Bullock labor + FYM + Seed cost + Fertilize used + Plant protection + Machinery cost + Depreciation on implements & machinery + Irrigation cost (almost zero as rain-fed cropping system) + Land revenue + Interest on working capital @ 7%.

Cost-A2: (include cost of) Cost-A1 + Rent paid for leased-in land.

Cost-B: Cost-A2 + Rental value of own land + Interest on fixed capital excluding land.

Cost-C: Cost-B + imputed value of family labor.

TABLE 3 Multi-location trial (MLT) of MRM4070 with other hybrids (checks) in Khaif 2017 (Yield: t/ha).

	Optimal						Rainfed		
Hybrid	Shamirpet	Bengaluru	Aurangabad location I	Aurangabad location II	Ranebennur	Ludhiana	Godhra	Chittorgarh	Begusarai
CAH153 (MRM 4070)	9.202	16.779	7.944	8.424	8.691	8.555	1.666	6.366	3.373
CAH1511	7.838	13.639	8.363	6.919	NA	8.485	0.769	5.969	2.976
900MG	9.202	14.403	6.912	7.915	7.461	7.815	1.244	5.636	2.381
P3502	8.052	13.159	4.803	6.820	8.072	7.470	0.766	4.978	2.302
HYTECH-5106	8.882	NA	5.200	NA	5.634	NA	1.439	5.864	3.175

MLTs conducted by CIMMYT under the project Heat-Tolerant Maize for Asia (HTMA). Note: t-tons.

TABLE 4 Factors affecting on the adoption of SR maize hybrids in rain-fed environment (probit).

Variables	Marginal effects	SE
Location (1 = Gadag district, 0 = otherwise)	0.174**	0.082
Age of household head (years)	0.002	0.002
Caste (1 = OBC, 0 = otherwise)	0.137**	0.060
Education of household heads (years)	−0.004	0.006
Leased-in land (1 = yes, 0 = otherwise)	0.016	0.072
Proportionate of maize area (%)	−0.001	0.001
Seed cost ($/ha)	0.003	0.002
Insecticide used (1 = yes, 0 = otherwise)	0.023	0.075
Weedicide used (1 = yes, 0 = otherwise)	0.006	0.077
Irrigation (1 = yes, 0 = otherwise)	0.026	0.080
Access to credit (1 = yes, 0 = otherwise)	0.289***	0.084
Distance to seed input shop (km)	0.000	0.006
Extension visits (Number/year)	−0.053***	0.019
Field day participation (1 = yes, 0 = otherwise)	0.321***	0.067
Drought encounter frequency (in last 10 years)	0.016	0.028
Cost-C ($/ha)	0.000	0.000
Model correctly predicted (%)	79.44	–
N	180	–

***, **indicates statistically significant at 1 and 5% respectively. SE, standard errors.

different results in this study. Farmers belonging to the OBC category have a 0.137 higher probability of adopting stress-resilient trait innovation. This is because of more accessibility of general category farmers to non-farm/service/business income and difference in subsidy amount.

Access to credit positively influenced farmers' probability of adopting stress-resilient hybrids, as access to credit eases the financial constraints that rural households face. Access to credit is directly associated with the adoption of any new technology (Bernard and Spielman, 2009; Hansen et al., 2015; Malek et al., 2017; Makate and Makate, 2019), a result confirmed by our study which shows that access to credit on right time increases the adoption for a stress-tolerant hybrid. Extension visit to farmers is negatively associated with the likelihood of adopting a new stress-resilient maize hybrid. Karnataka is one of the states in India where almost 100% of farmers adopted hybrid maize varieties Federation of Indian Chambers and Commerce of Industry, 2018. In such cases, extension officers/agencies promoted high-yield hybrid varieties. As this is a new hybrid, awareness about the new stress-resilient maize hybrid among farmers and extension officers should increase through different communication channels. Seeing by believing is the concept of onsite demonstration. Field day participation in onsite demonstrations positively influences the adoption of technology. If a farmer is participated in the field day demonstration, the likelihood of adopting a new hybrid increases by 0.321 compared to a non-participant.

Average treatment effects using inverse probability weighing model

IPW model estimates the result by counterfactual effect with and without treatment effect. The impact of the adoption of SR maize hybrids on three outcome variables—yield, gross income, and net income—is shown in Table 5. In full sample size models, the adoption of the SR maize hybrid had a significant and positive impact on yield (tons/ha), gross income ($/ha), and net income ($/ha). If none of the farmers had adopted the SR maize hybrid, the model estimated that the average yield would be 3.06 tons/ha. In contrast, if all farmers adopted a SR hybrid, the average yield would be 3.76 tons/ha, which shows 0.70 tons/ha more yield.

TABLE 5 Average treatment effects (ATEs) using inverse probability-weighted (IPW) model.

Outcome variables	ATE/POmean	All sample size ($n = 180$)		Gadag district ($n = 99$)		Dharwad district ($n = 81$)	
		Coefficient	Robust std. error.	Coefficient	Robust std. error.	Coefficient	Robust std. error.
Yield (ton/ha)	ATE (adopters vs. non-adopters)	0.70** (0.23)**	0.36	1.03 (0.46)	0.65	0.29 (0.07)	0.58
	Pomean (non-adopters)	3.06***	0.16	2.09***	0.23	3.98***	0.18
Gross income ($/ha)	ATE (adopters vs. non-adopters)	185.07** (0.24)*	94.62	256.22 (0.46)	175.05	52.13 (0.05)	141.03
	Pomean (non-adopters)	762.70***	41.19	532.31***	63.22	995.24***	48.75
Net income ($/ha)	ATE (adopters vs. non-adopters)	137.86* (0.89)	80.12	191.32 (14.90)	129.75	20.45 (0.06)	135.45
	Pomean (non-adopters)	154.59***	38.33	12.84	68.32	319.92***	48.70
Outcome model	Weighted mean						
Treatment model	Probit model						

Suppressed the constant term from the treatment model.
Exchange rate 1 US$ = 70 INR.
Average treatment effect as a percentage term is mentioned in parentheses.
***, **, and * indicate statistically significant at the 1, 5, and 10% significant level, respectively.

Manda et al. (2018) used the inverse probability-weighted regression adjustment (IPWRA) model and imply that improved maize varieties adoption increases the food expenditure by almost a third, and on average, the probability of being food secure is 21% higher for adopting households than non-adopting households in eastern Zambia. The treatment effect model was also deployed by Paudel et al. (2022) to estimate the impact of hybrid maize adoption on yield and found that adopters received 1586 kg/ha additional significant yield compared to non-adopters in Nepal. Amondo et al. (2019) and Simtowe et al. (2019) found that the adoption of drought-tolerant maize varieties increased yield by 15% and reduced crop failure probability by 30–36% in Uganda and Zambia. It reveals that the stress-resilient maize hybrid gives cushion to farmers under severe climatic conditions than cultivating a non–stress-resilient maize hybrid. Yield is the first and most important criterion that farmers consider while selecting maize hybrids. So, this criterion is fulfilled by a new hybrid. One of the noticeable things is that 2018 was a deficit rainfall year as compared to previous years' normal rainfall distribution. Even during such a deficit year, the SR maize hybrid performed excellently in comparison to other maize hybrids in the study location. The characteristics of the SR maize hybrid are that it performs at par with other maize hybrids under optimal weather conditions, whereas the actual value/ worth of these new stress-tolerant hybrids would be realized under stress conditions (Magorokosho et al., 2008).

In full sample size models, the average gross income of farmers in case all of them was to adopt a SR hybrid would be $185.07/ha more than the average of $762.70/ha that would occur if none of the farmers had adopted SR maize hybrid. With respect to the net income parameter, the average net income of adopters SR hybrid—would be $137.86/ha more than the average of $154.59/ha that would occur if none of the farmers had adopted the SR maize hybrid. It means that the average net income if all farmers were to adopt a SR hybrid, would be $292/ha.

The district-wise analysis of the IPW model revealed that there were 1 and 0.29 tons/ha addition yields received by adopter farmers in Gadag and Dharwad districts, respectively. Gadag district adopter farmers received $191.32/ha more net income than non-adopters, whose average net income was only $12.84/ha because of drought conditions. In the Dharwad district, adopter farmers received $20.45/ha more net income than non-adopters farmers under optimal climatic conditions. It indicates that, because of the adoption of the stress-resilient maize hybrid, adopter farmers received considerable net income, even under the adverse climatic condition, whereas non-adopter farmers' net income was negligible in the Gadag district.

Average treatment effect as a percentage term mentioned in parenthesis in Table 5, with respect to full sample size, the average yield was increased by an estimated 23% when every adopter relative to the case when no farmers adopted the stress-resilient maize hybrid. We also obtain a 95% confidence interval of a −0.8% reduction to 46.70% addition. The average gross income increased by an estimated 24% for every adopter relative to the case when no farmers adopted the stress-resilient maize hybrid. The average net income increases by an estimated 89% for every adopter relative to the case when no farmers adopted the stress-resilient maize hybrid. We also obtain a 95% confidence interval of a 29.85% reduction to 214.03% addition. In a nutshell, the stress-resilient maize hybrid performed better under stress conditions and at par under optimal climatic conditions compared to the present hybrid in the market.

Conclusion and policy implications

The present study evaluated the determinants of adoption and impact of the adoption of SR maize hybrid in the rain-fed agro-environment in Karnataka state, India. As many climatic studies suggested, climatic weather parameters will not be the same in future, creating major hurdles to meeting global hunger and livelihood. It will not be easy to meet the globally increasing demand for maize with present hybrids with a facet of changing climate issues. Using a dataset from 180 maize farmer households, the study employs the inverse probability weighting estimator to estimate the impact of SR maize hybrid on yield and income in a rain-fed environment. The study revealed that location (district), caste (OBC), access to credit, extension visits, and field day participation in demonstration significantly affected the adoption of a new stress-resilient maize hybrid in the study location.

The households that grew SR maize hybrids had a significant increase in yield and net income over other commercial hybrids. The IPW model estimated that adopter farmers received 0.70 tones/ha additional yield and $137.86/ha net income over non-adopters in the rain-fed agro-environment. Farmers will be in a win–win situation in the adoption of the stress-resilient hybrid as it performs at par under optimal climatic conditions, while it gives a cushion to farmers to bear financial stress in adverse climates by giving minimum yield assurance. The stable yield will play a more important role than fluctuating yield in the rain-fed stress-prone agro-environment weather.

Farmers in the state give up water and labor-intensive crops and move to adopt maize crops. As being the C4 plant, the water use efficiency of the maize crop is more efficient than any other cereal crop. The development of SR maize hybrid and commercialization through a private company for seed production is an excellent example of a Public–Private Partnership (PPP) research, development, and deployment in the targeted areas. Technology and cultural practices followed by maize farmers vary from one place to another, and agronomic practices and cropping patterns involve synergistic effects. Hence, farmers need to acclimatize agronomic practices to local conditions recommended by research institutions. Therefore, farmers require detailed knowledge on "how to do it" and "why to do so" (Noltze et al., 2012). Understanding this empowers farmers to make important decisions on traits while buying seed, sowing methods, seed rate, and planting distance.

Training programs and onsite field demonstrations are likely to increase farmers' ability to adopt the stress-resilient maize hybrid successfully. As the SR maize hybrid is newly deployed in the market, private companies must conduct maximum demonstrations and field days to reach the maximum number of small and marginal farmers. The state agriculture extension department also needs to involve SR maize hybrid in front-line demonstrations to reach a maximum number of farmers in the rain-fed agro-environment. In line with this, the government/state agriculture department should also subsidize the SR maize hybrid through different promotion schemes to popularize the hybrid in stress-prone areas.

Study limitations

Further study needs to be conducted with a large sample size under different rain-fed agroclimatic conditions to generalize the results.

Data availability statement

The data presented in this study will be made available on request from the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by Institutional Review Board. The patients/participants provided their written informed consent to participate in this study.

Author contributions

AK and PZ: conceptualization. AK, DS, and PK: methodology and investigation. AK: software, formal analysis, data curation, writing—original draft preparation, and visualization. DR and PZ: validation. PK and DS: resources. DS, PK, and DR: writing—review and editing. PZ and PK: supervision. PZ: project administration. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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