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Farmer's understanding and adoption of agricultural practices in southern part of India

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Abstract
India is fulfilling the consumption requirement of its pulses and oilseeds largely through importing. Andhra Pradesh is a leading state in the country, significantly contributes to the production of these crops. Low yield of pulses and groundnuts in India should be addressed through adoption of proven technological interventions along with enhancing farmers knowledge. The present study aimed to determine the differences in knowledge of Sustainable Agricultural Practices (SAPs) and adoption of improved agricultural practices (IAPs) among farmers at the baseline and endline phase of the study. The association of possible factors such as age, gender, education, farm experience, mass media, social participation, risk orientation, innovativeness with knowledge and adoption of Sustainable agricultural practices was evaluated. The study also examined the result of the technological intervention on crop yield at pre and post intervention. The study included 240 farmers with poor pulse and groundnut yield from villages of Andhra Pradesh with inadequate technological developments. At biotech intervention phase, farmers received training, field demonstration etc. The results revealed that at endline, 80% of farmers had knowledge of SAPs (compared to 48% at baseline) and the adoption rate of IAPs was 50% (compared to 3% at baseline). Factors such as mass media, social participation, risk orientation showed significant reduced risk on farmers with high knowledge of SAPs and with complete adoption of IAPs. The average yield per hectare of pulses during baseline was found to be 403.5 kg/ha ± 128.4 while during endline it was 601.25 kg/ha ± 206.8 (p-value = 0.001). The average yield per hectare of groundnut during baseline was found to be 983.75 kg/ha ± 444.9 and during endline it was 1216.78 kg/ha ± 473.9 (p-value = 0.000). Innovative technological interventions and capacity building of farmers increased yield of crops in Andhra Pradesh.

Keywords Sustainable agriculture practices · Knowledge and Adoption · Farmers · India

1 Introduction

Indian agriculture contributes approximately 15–18% of the country's gross domestic product (GDP), which is the highest share of national income among the major agricultural sectors [19, 24]. It contributes to livelihoods (for more than 60% of the population), ensures the fulfilment of food demand [19], and provides 21% of total exports and raw materials to a variety of industries (including manufacturing) [39] India has surpassed all other countries as

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the world's leading producer of agricultural commodities, including pulses [39] India is the world's largest producer of pulses (producing 25% of global production), consumer (27% of global consumption), but yet India imports majority of its pulses needs across the globe (14% of world imports). It is estimated that India produces 67% of the world's chickpeas, with the rest coming from countries such as Australia, Pakistan, Myanmar, Turkey, Ethiopia, and Iran, accounting from 2.5 to 6% of global production [33] Madhya Pradesh, Maharashtra, Rajasthan, Uttar Pradesh, Andhra Pradesh, and Karnataka are the states that produce the most pulses and groundnuts in India.

Not only in India, but also around the world, there has been growing concern about the declining production and cultivation of agricultural crops in recent decades, particularly in the arid lands. The world population is expected to reach 9.5 billion by 2050 [19] which will be accompanied by increased demand for meat and dairy products, as well as increased use of biofuels. Agricultural growth, in addition to ensuring food security, plays a critical role in the development of rural areas [11, 28]. In order to meet this rising demand, global agriculture must produce an adequate amount of food. The most important component of food security is availability of food (production, distribution, and exchange) [35]. Previous studies indicated that India's agricultural growth had slowed from approximately 3.6% during period 1985–1995 to less than 2% during the period 1995–2005 [35] prompting a slow progression towards the agriculture growth rate. According to the eleventh five year plan by Planning commission, Government of India, the annual agricultural growth rate reached upto 3.7% during period 2007–2012 and reached upto 4.0% during period 2012–2017 (Twelfth five year plan). This has an impact on the overall agricultural decline because India is pulse and oilseed deficit nation (but not a cereal deficit). As per the third advance estimates for year 2022–23 provided by Ministry of agriculture and farmers welfare, Government of India, the estimates of production of foodgrains during year 2017–18 was 2850.14 lakh tonnes and during year 2018–19 was 2852.15 lakh tonnes and during 2019–2020 was 2975.04 lakh tonnes,. The quantity of food required by year 2031–32 is 1016 million tonnes [9] clearly indicates growth rate of agriculture must increase to meet the National food demand by 2030. Among the states that produce pulses and oilseeds, Andhra Pradesh is the sixth-largest producer. Agricultural crops such as pulses and groundnuts are grown in Andhra Pradesh's climatic zones of the north coast, the southern zone, and the scarce rain fall region. Pulses such as pigeonpea, chickpea, blackgram, and greengram are the most commonly grown in the state of Andhra Pradesh. In India, the kharif seasons are used to grow pigeonpea, blackgram and greengram while rabi seasons are used to grow chickpea. The area under pulse crops in the state of Andhra Pradesh decreased gradually from 14.49 lakh hectares (ha) in the year 2015–16 to 14.13 lakh ha in the year 2016–17 and 14.08 lakh ha in the year 2017–18, 13.26 lakh ha in the year 2018–19, and 12.52 lakh ha in the year 2019–20 [16]. The production of pulse crops in the state also decreased from 12.29 lakh tonnes in the 2015–16 season to 9.31 lakh tonnes in the following season (yr 2016–17). The groundnut crop experienced the same situation in Andhra Pradesh. Even though Andhra Pradesh was ranked fourth in groundnut production during the year 2018–19, the state's groundnut crop area decreased gradually from 10.13 lakh ha (year 2016–17) to 7.35 lakh ha (year 2017–18), to 7.48 lakh ha (year 2018–19), and 6.61 lakh ha (year 2019–20) [16]. Additionally, the production of groundnut crop in the state decreased from 12.29 lakh tones in the year 2017–18 to 9.31 lakh tones in the year 2018–19 to 8.50 lakh tones in the year 2019–20) [16]. Researchers observed that the reason for this decline was due to the fact that, since Independence, the emphasis has been solely on major cereal crops, such as wheat and rice. Hence, there was a need to develop strategies in Andhra Pradesh to increase crop yield, conduct research, and make new investments in underperforming regions (while maintaining the consistency of productivity in high-performing areas), which has also been advocated by a number of authors [35]. Not only technological or biophysical factors (such as a lack of land and water management, poor disease management, insignificant irrigation infrastructure, institutional constraints, low nutrient application and a dearth of fallows to restore soil fertility levels, and a lack of availability of suitable high-yielding crop varieties) but also socio-economic limitations leading to lack of farmer expertise were found to be contributing to the decline in agricultural growth [39]. Several studies [2, 35] have emphasized that knowledge and adoption of best management practices be implemented in order to overcome the agricultural crisis, rather than relying on an unscientific and haphazard farming practices approach [19, 39]. Sustainability in agricultural practices includes efficient resource management, the adoption of local and improved seed varieties, the integration of traditional and modern skill-sets, the reduction of agro-chemical use, the preservation of soil quality through the use of renewable bio-resources, and the improvement of socio-economic status [19, 30]. Because sustainable agriculture varies from agriculture to agriculture locally, nationally, and internationally [28], it is necessary to investigate regional specific development of SAPs, which is currently missing. In order to address the issues in the production of pulse and groundnut crops across India, biotech interventions were required in low-performing areas. Thus, Department of Biotechnology (DBT), Government of India, launched the Biotech- Krishi Innovation Science Application Network (KISAN) Mission to connect scientists with farmer to find out local solutions and technologies that can be applied at farm level. It was a Pan-India program with 36 Biotech-KISAN Hubs covering 112 aspirational districts covering all 15 agro-climatic zones. The Biotech-KISAN mission aimed to narrow the yield gaps for groundnut and pulse producers (pigeonpea, chickpea, rice fallow urdbean, and moongbean) through technological interventions, training and education. Pertaining to the present study, SAPs is defined as a concept for resource saving agricultural crop production through use of improved crop varieties along with eco-friendly, low-cost, abiotic & biotic stress tolerant biotechnological interventions that strives to achieve high and sustainable crop yield together with acceptable profit. The operational definition of SAPs was modified from the study by Adesida and co-authors (2021). Under Biotech KISAN program, various technological strategies were implemented such as use of high yield crop varieties, intercropping, appropriate sowing time and pattern, use of biofertilizers, integrated nutrient management (INM), integrated pest management (IPM) and few others. The influence of climate change on crop yield has been documented in previous studies. To withstand the influence of climate change, farmers are encouraged to adopt these technological innovations to adapt to climate change as well. The cultivation of pulses through intercropping system will be an effective way to maintain soil fertility. Drought mitigation measures were also initiated in the current research to withstand the effect of climate change. Adoption of these innovations by the farmers in the current research will maintain soil fertility, address the effect of climate change resulting in increased yield of selected crops.

The present study was conducted in four districts of Andhra Pradesh, which is a Biotech KISAN Hub. Andhra Pradesh was selected for the present study as there was declining land area and production of pulses and groundnuts in the State. The state has a strong labor force participation rate which is above the national average indicating towards the high dependency on agricultural sector in the state as compared to other pulse/groundnut producing states. Andhra Pradesh has the second highest number of farmer families after Uttar Pradesh [15]. There is 37% agricultural share to Andhra Pradesh's gross value added, almost double of national level (19%). Also in the year 2019–20, the growth rate of agricultural and allied sector was 16% against 6.5% the previous fiscal year [46]. The present study's main goal was to determine whether there were any differences in knowledge of Sustainable Agricultural Practices (SAPs) and adoption of Improved Agricultural Practices (IAPs) between farmers who had received biotech intervention training at the start and end of the study and whether there were any possible factors associated with knowledge of SAPs and adoption of IAPs at the start and end of the study among pulse and groundnut producers who had not received biotech intervention training. The study will help to understand possible factors associated with knowledge of SAPs and adoption of IAPs which will enhance the productivity and meet the agricultural demands at national and global markets.

2 Literature review

There was plethora of literature available on the knowledge and adoption of SAPs across the globe. In a study, Nigerian farmers were schooled about the different policy programmes on the adoption of SAPs showing better adoption rates [1]. Another study conducted among Mongolian wheat farmers revealed that information and training were positively associated with the adoption of SAPs [31]. The authors further mentioned that adoption intensity varied from one crop region to another crop region, suggesting that training of SAPs should be region specific for effective adoption [31]. Another study from Vietnam studied factors such as extension agents and learning from peers, which influenced adoption of SAPs [26]. Another study from Malaysia, studied multidimensional factors (socio-economic, agro-ecological, institutional, informational, psychological, perceived attributes and others) to understand SAPs and mentioned that geographical location was the dominant factor in the adoption of SAPs [45] In India, a baseline survey was conducted in South India to evaluate socio-economic impact on sugarcane farmers who received support and training from period 2016–2018 to adopt sustainable practices [27] A study conducted in Uttar Pradesh; North India revealed that use of adequate dosage of fertilizer enhanced the agricultural growth [20]. Another study conducted in Punjab state of India reported farmer's intension to adopt SAPs where economic factor i.e., perceived usefulness, self-efficacy and extension services were associated with adoption [42]. A study conducted in Kerela, South India, reported that perception of profitability of inter-cropping, type of intercrops, availability of family labor influenced the decision of adoption [32]. Social networking/learning influence sustainable agricultural developments through adoption of new technology as reported in a review with examples from India [11]. Another review with examples from India revealed that rate of adoption of SAPs depends on various factors such as socio-economic, biophysical, institutional, financial, technical, psychological [29]. Another study from eastern India reported that socio-economic and infrastructural constraints were the main factors for non-adoption of modern technology [34] Another impact study was conducted in the north-western

Himalayas in India where farmers were trained on the integrated nutrient management (INM) technology for developing sustainable crop production systems under cash crops and vegetables [12]. The study found that after farmers training, knowledge about the agricultural practices such as soil testing, dose, time of application of organics, chemical fertilizers, integrated use increased from 41 to 88% and INM technology adoption rate increased from 66 to 70% [12]. On the other hand, it was also reported that new agricultural technologies were not adopted by farmers from different Africa regions [43]. Poor access to information through extension services, poor seed supply and lack of credit effected adoption of new improved technologies in African regions [43]. Another study from Nigeria reported that small holder farmers were not adopting SAPs actively due to poor resources and poor engagement in technology over the traditional methods [47]. Studies also reported the importance to build knowledge and adoption of farm management practices which will help in sustainable agricultural practices increasing crop yield suitable for local conditions [6, 7]. A study from Maharashtra, India reported that implementation of biofertilizer such as *Rhizobium* with Phosphate Solubilizing Bacteria (PSB) along with Trichoderma soil application was found to be effective integrated pest management in pigeonpea and chickpea increasing its yield [36]. Another study from Jammu, North India reported that use of pheromone traps and intercropping of chickpea with other crops increased chickpea yield and this was an effective integrated pest management practice [40]. Another study from Uttar Pradesh, North India reported that implementation of nuclear polyhedrosis virus (NPV) and *Bacillus thuringiensis* (Bt) solutions along with neem-based application was found to be effective integrated pest management strategy in chickpea yield [3]. Implementation of *Rhizobium* along with use of yellow traps increased yield in green gram in lower Gangetic plains of West Bengal [21], and use of delta trap increased yield in cotton [37].

3 Objectives of the study

1. To evaluate the differences in knowledge of SAPs and adoption of IAPs at the baseline and endline of a biotechnology intervention programme among farmers.
2. To ascertain the relationship between various factors such as socio-demographic characteristics, mass media usage, risk aversion and innovativeness with knowledge of SAPs and adoption of IAPs.
3. To evaluate the difference in yield of pulses and groundnut from baseline to endline phase.

4 Methodology

4.1 Study design and area

The current study was a cross-sectional study that was conducted in the state of Andhra Pradesh (South India), which is one of the DBT Biotech-KISAN Hub. In Andhra Pradesh, Acharya N. G. Ranga Agricultural University was approached to collect the data of the present study. The aim was to bridge the yield gaps for groundnut and pulse producers (Pigeonpea, Chickpea, Rice fallow Urdbean and Moongbean), reduce the cost of cultivation, and create job opportunities, development of entrepreneurs for better livelihood to small and marginal farmers through biotechnological interventions. In this study, baseline and endline survey were conducted. During baseline study, rapport was developed with the farmers producing pulses and groundnuts, village heads and other local heads. The present study was explained in details to all of them in local language. Farmers actively participated in group discussions on various issues they were facing in farming and also participated in possible solutions that included local requirements and preferences to increase the crop production. Informed written consent was take n from all the participants prior to recruitment process. After the baseline survey, intervention was done which included farming activities to generate awareness, field classes and demonstrations to enhance knowledge, adoption rate of farmers, and yield of selected crops. For sustainability of agricultural practices; availability of resources (improved varieties of seed, herbicides, bio-fertilizers, chemicals for insect /pest control) and active engagement in technology (sowing method, proper sowing time, seed rate, integrated nutrition management practices, integrated pest management practices) were maintained by the trainers/demonstrators in the field during the endline phase.

Andhra Pradesh has an 8.46 million population, with 5.6 million people living in rural areas [8]. The state has 23 districts where the male literacy rate (75.56%) is higher than the female literacy rate (59.74%). During the 2010–11 crop year, the total geographical area covered in Andhra Pradesh was 2.75 lakh ha, with the total food crop area covering 1.45 lakh ha. The total area under total pulses in the state was 21.30 lakh ha, with the highest concentration in Kurnool district (3.18

lakh ha) (Fig. 1a) among the state's 23 administrative districts. Anantapur, Srikakulam, and Visakhapatnam were among the districts with the highest total pulse area, with 1.64 lakh ha, 0.81 lakh ha, and 0.23 lakh ha, respectively. Among all 23 districts, Anantapur district had the highest amount of groundnut planted (8.34 lakh ha), followed by Kurnool district (1.78 lakh ha) (Fig. 1b). The total groundnut area in the Srikakulam and Visakhapatnam districts was 0.26 lakh ha and 0.04 lakh ha, respectively, in the two districts [8]. Additionally, according to the Census 2001 data, the total number of cultivators in Andhra Pradesh was 7.85 lakhs, with agricultural labourers numbering 138 lakhs [8]. There were 5.29 lakhs cultivators in Anantapur, with Visakhapatnam (4.33 lakh), Kurnool (3.86 lakhs), and Srikakulam (3.86 lakhs) having the second and third highest numbers of cultivators, respectively (2.66 lakhs). Kurnool had the highest number of agricultural labourers (8.02 lakhs), followed by Anantapur (6.70 lakhs), Srikakulam (5.57 lakhs), and Visakhapatnam (4.21 lakhs) in terms of agricultural labourers [8]. North coastal zone, Godavari Zone, Krishna Zone, Southern zone, Scarce rainfall zone, and high-altitude zone are some of the agro-climatic zones in Andhra Pradesh, which are broadly divided into six categories. Districts with large pulse and groundnut cultivation area facing extreme climatic conditions (i.e., recurrent

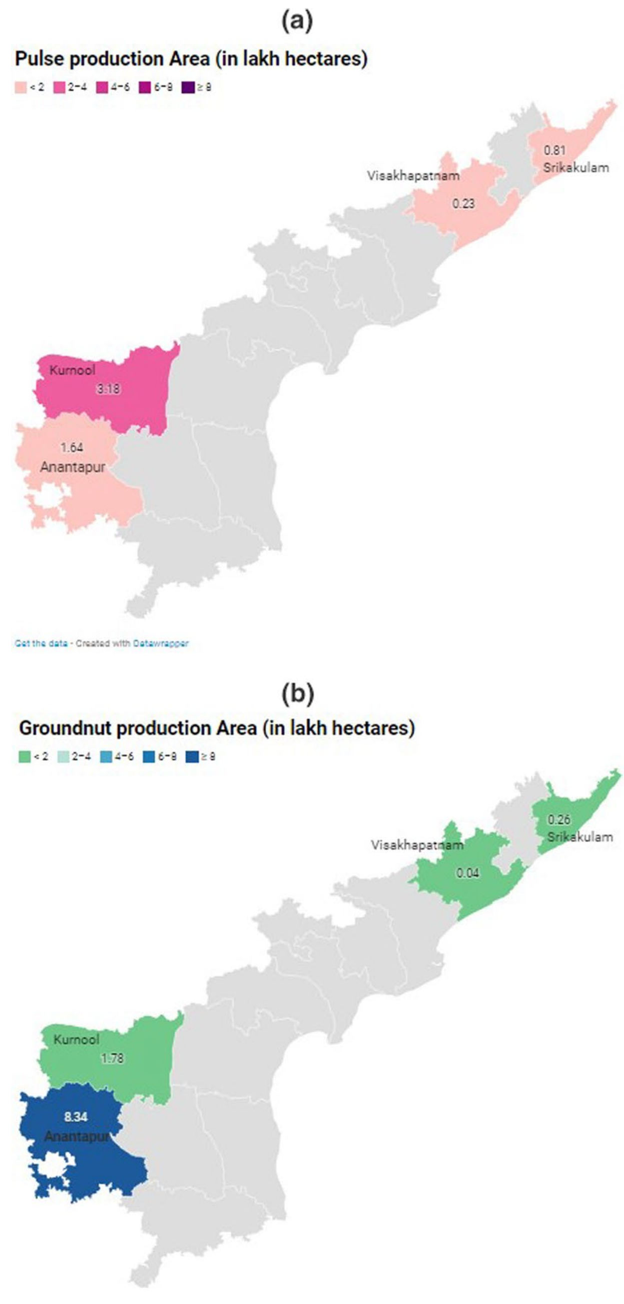


Fig. 1 **a** Studied districts of Andhra Pradesh showing average pulse production area (in lakh ha) (Census 2011). **b**: Studied districts of Andhra Pradesh showing average groundnut production area (in lakh ha) (Census 2011)

drought and recurrent cyclones) were selected. Kurnool, Anantapur districts fall under scarce rainfall zone. These are vulnerable districts where farming is not viable due to less than 550 mm rainfall (range 500–670 mm), recurrent drought leading to crop damage. On the other hand, Srikakulam district falls under North coastal zone (1000–1100 mm rainfall) and Visakhapatnam falls under North coastal zone (1000–1100 mm rainfall) as well as high altitude zone (1400 mm & above rainfall). Farming is not viable in these vulnerable districts due to increased number of cyclones, high rainfall, and northern montane leading to coastal erosion, crop damage, and infrastructural damage. So, keeping in view of the area under cultivation, low yield of crops (pulses and groundnut) and climatic extremities, we have selected the districts for the study.

4.2 Details of technological innovations applied in pulses and groundnuts during baseline phase in selected districts of Andhra Pradesh

Groundnut		
Particulars	Constraints identified	Potential biotech solutions followed
Varieties	Old varieties like TAG24, Kadiri 6	Improved varieties like Kadiri 9, Dharani, Dheeraj, Kadiri Amaravathi
Seed treatment	No seed treatment	Seed treatment with Imidacloprid 600FS-2 ml and Tebuconazole-51 per kg seed
Fertilizers	Di Ammonium Phosphate (DAP)-2bags	Soil test-based fertilizer application Urea-26 kg; Single Super Phosphate (SSP)-116 kg, Muriate of Potash (MOP)-54 kg-Kharif Urea-27 kg; SSP-116 kg, MOP-54 kg-Rabi
Biofertilizers/Gypsum	Not followed	Application of biofertilizers *Rhizobium*, Phosphate Solubilizing Bacteria (PSB) and Potassium Solubilizing Bacteria (KSB) and gypsum @200 kg/ac
Drought mitigation measures and micro nutrient application	Not followed	Foliar spraying of urea 2 g/lit of water and multi max (Formula-4)- 1 kg per acre foliar spraying
Pests and disease management	Blanket sprays of chemicals	Integrated Pests and disease management (*Trichoderma* soil application, Delta sticky traps, yellow and blue sticky traps etc.) and need based application of chemicals
Pigeonpea		
Particulars	Constraints identified	Potential biotech solutions followed
Varieties	Use of old varieties like LRG 40, Lakshmi	Improved variety seed LRG52
Seed treatment	Not followed	Seed treatment with *Trichoderma viride*-10 g/kg seed
Fertilizers	Improper fertilizer application	Integrated nutrient management with application of Farmyard manure (FYM), recommended dose of fertilizers @18 kg urea and 125 kg SSP per acre
Biofertilizers	Not followed	Usage of *Rhizobium* and PSB 200 g/10 kg seed
Drought mitigation measures and micro nutrient application	Not followed	Foliar application of 13:0:45 @1 kg/acre
Pests and disease management	Blanket sprays of chemicals	Integrated pest management with Pheromone traps, nuclear polyhedrosis virus (NPV) and Bacillus thuringiensis (Bt) solutions and neem oil and need based application of chemicals
Chickpea		
Particulars	Constraints identified	Potential biotech solutions followed
Varieties	Use of old varieties JG11	Improved variety NBeG 49
Seed treatment	Not followed	Seed treatment with *Rhizobium* 100 g per acre + Tebuconazole-50 g per kg seed, soil application of *T. viride* 200 kg/acre

Groundnut		
Particulars	Constraints identified	Potential biotech solutions followed
Fertilizers	Improper fertilizer application	Integrated nutrient management with application of farm yard manure and recommended dose of fertilizer application @18 kg urea, 125 kg SSP and 20 kg Zinc sulphate and 10 kg water soluble Sulphur
Biofertilizers	Not followed	One sprinkler irrigation wherever possible
Pests and disease management	Blanket sprays of chemicals	Integrated pest and disease management with Pheromone traps, NPV and Neem kernel suspension and need based application of plant protection chemicals
Rice fallow Urdbean		
Particulars	Constraints identified	Potential biotech solutions followed
Varieties	Use of old varieties *(Buttaminumu* and other local varieties)	Introduction of new high yielding suitable varieties viz LGG460, IPM2-14 (tolerant to yellow mosaic)
Sowing time	During November end or December 1st fortnight	Before November 15th
Seed treatment	Not followed	Seed treatment with Imidacloprid 600 @5 ml + mancozeb @3 g per kg seed
Fertilizers	Improper fertilizer application	Application of only biofertilizers- *Rhizobium* and PSB
Weed management	Not followed	Weed management- Sodium acifluorfen + Clodinafo ppropargyl (Iris)-400 ml per acre
Drought mitigation measures	Not followed	Foliar application of 19:19:19, 13:0:45@1 kg/acre with a gap of 15 days
Pests and disease management	Improper management	Integrated pest and disease management (Yellow and Blue sticky traps, spraying of neem kernel suspension 5% and need based spraying of chemicals for the management of *Maruca* pod borer
Rice fallow Moongbean		
Particulars	Constraints identified	Potential biotech solutions followed
Varieties	Use of old varieties *(Buttaminumu* and other local varieties)	Introduction of new high yielding suitable varieties viz PU31, TBG104, GBG1 (Yellow mosaic tolerant/ resistant varieties)
Sowing time	During November end or December 1st fortnight	Before November 15th
Seed treatment	Not followed	Seed treatment with Imidacloprid 600 @5 ml + mancozeb @3 g per kg seed
Fertilizers	Improper fertilizer application	Application of only biofertilizers- *Rhizobium* and PSB
Weed management	Not followed	Weed management- Sodium acifluorfen + Clodinafo ppropargyl (Iris)-400 ml per acre
Drought mitigation measures	Not followed	Foliar application of 19:19:19, 13:0:45@1 kg/acre with a gap of 15 days
Pests and disease management	Improper management	Integrated pest and disease management (Yellow and Blue sticky traps, spraying of neem kernel suspension 5% and need based spraying of chemicals for the management of *Maruca* pod borer

4.3 Inclusion and exclusion criteria

Baseline inclusion criteria were those farmers with age 25 years and above, those with pulse and groundnut farm occupation, both males and females. The exclusion criteria were those below 25 years, with no pulse and groundnut farm occupation. Only those farmers who participated in the baseline survey and were trained in the intervention program were recruited in the endline survey. Informed consent was obtained from all the participants prior to their recruitment in baseline and endline survey.

4.4 Study duration and sampling method

We followed the STROBE cross-sectional guidelines during the present research study. Baseline survey was done during June to July 2018 and endline survey was done during April to May, 2020. Selection of the villages was based on low pulse/groundnut yields and poor technological implementation. Recruitment of participants was through random sampling method.

4.5 Sample size calculations

Epi-info software was used to calculate the sample size. Population size considered, i.e., number of cultivators and agriculture workers in Andhra Pradesh state was 146,00, 000. In the software, considering 95% confidence interval, 5% sampling error, estimated true proportion 0.3, and 10% drop out, the sample size calculated was 291. Hence, total 291 farmers should be recruited, i.e., approximately 73 farmers from each district. Based on low pulse/groundnut yields and poor technological implementation, villages from four districts of Andhra Pradesh were selected.

4.6 Sampling design

Several factors were considered in the selection of the State and districts and ultimately zeroed in on the number of farmers selected for the study. One of the major reasons for the selection of Andhra Pradesh is the early onboarding by the State to Biotech Kisan Mission initiatives and demonstrative capabilities/capacities of the Agriculture University to the farmers and the presence of a vibrant ecosystem to adopt new and innovative biotechnology solutions by the farmers.

The selection of districts is based on the premise that the total area under total pulses in the state was 21.30 lakh ha, with the highest concentration in Kurnool district (3.18 lakh ha) among the state's 23 administrative districts. Anantapur, Srikakulam, and Visakhapatnam were among the districts with the highest total pulse area, with 1.64 lakh ha, 0.81 lakh ha, and 0.23 lakh ha, respectively. The selection of the villages was based on low pulse/groundnut yields and poor technological implementation. Based on the literature review, the number of farmers who expressed their willingness to participate, the availability of funds and plausible outreach activities in the Biotech Kisan initiatives are factored in to consider the estimated true proportion as 0.3 to arrive at the sample size. The recruitment of participants was done through a random sampling method. The number of farmers was selected considering a 95% confidence interval, 5% sampling error, with an estimated true proportion of 0.3, and 10% dropout, the sample size calculated was 291.

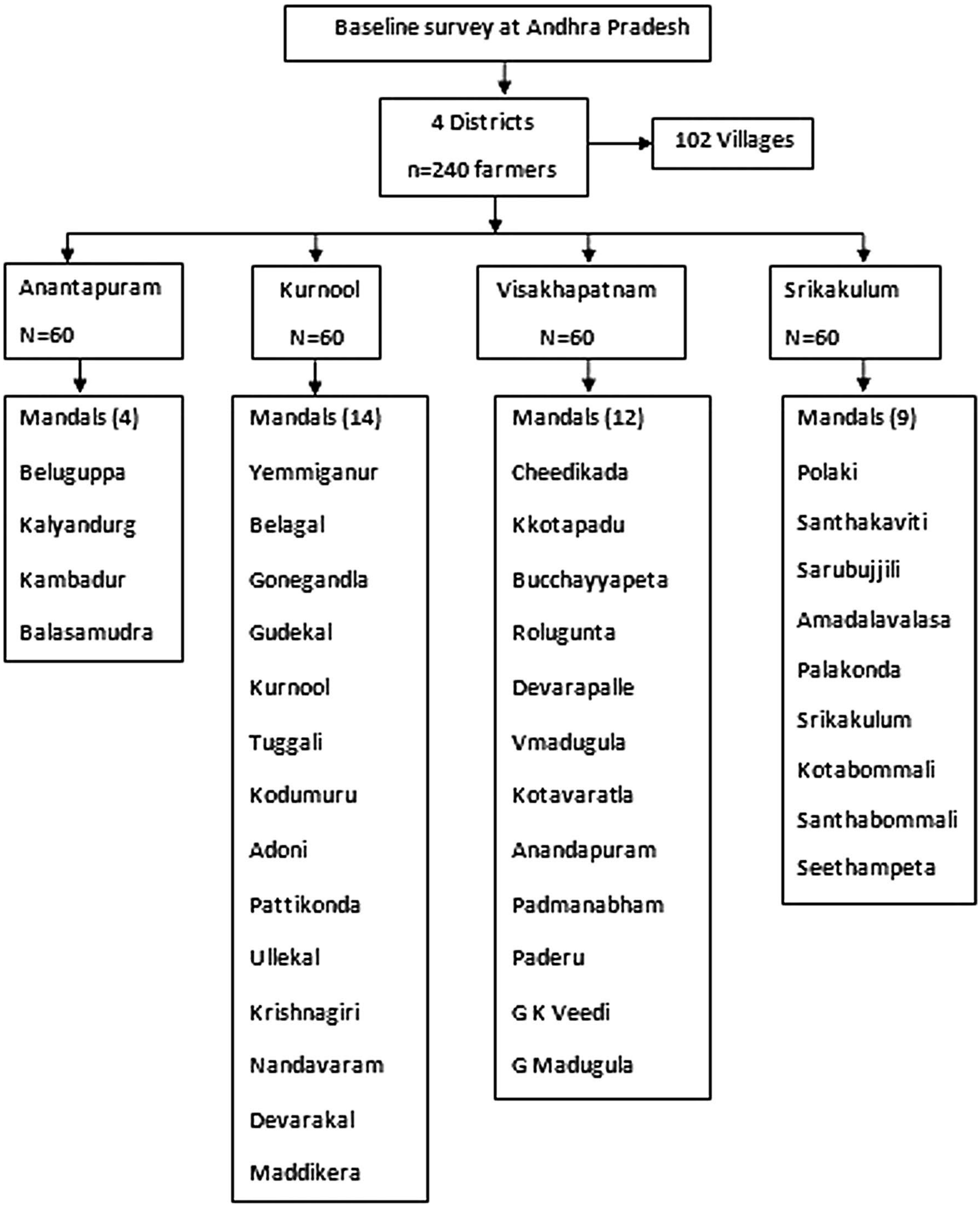
4.7 Data collection

The participants were administered with a pre-tested and modified interview schedule. The current study collected data on demographic and social characteristics such as age, gender, education, farming experience, membership in any organization, and so on. Data on communication behavior such as use of mass media (Radio, Television, News Paper, Farm Magazine, Cyber Media), knowledge of SAPs and adoption of IAPs, risk orientation, and innovativeness were also collected. SAPs included recommended improved varieties, seed treatment, spacing, suitable soils, recommended fertilizer dose sowing times, sowing methods, seed rate, recommended chemicals for disease management, recommended herbicides, intercropping, recommended chemicals for insect/pest control, INM practices, and IPM practices. The detailed questionnaire on the data collected and the scoring method used is mentioned in supplementary information (SI) Table.

4.8 Recruitment of participants

Farmers who could not be present on the baseline survey due to unavoidable circumstances, or the farmers data which was insufficient or of poor quality in the baseline phase were not included. A total of 240 farmers instead of 291 were finally recruited in the study.

4.9 Flowchart showing studied area in the district of Andhra Pradesh



4.10 Scoring of data

4.10.1 Knowledge about sustainable agricultural practices (SAPs)

Data on Knowledge of SAPs were collected through various SAPs such as names of improved varieties recommended, Sowing time (s), Suitable soils, Seed treatment, Sowing methods, Spacing, seed rate, Recommended fertilizer and their dosage, Recommended herbicides and their dosage, Inter-cultivation, Intercrops, Recommended chemicals for insect /pest control, Recommended chemicals for disease management, integrated nutrition management (INM) practices, integrated pest management (IPM) practices. Total 15 questions were recorded. Responses were recorded as Yes or No for various questions. If the response to question was 'Yes' then the value was taken as 1, but when the response was 'No' then value was taken as zero. Based on the responses, scoring was done and categories were made. Participants who scored less than five were grouped as 'Low Knowledge', scoring between 5 and 10 were grouped as 'Moderate Knowledge' and scoring greater than 10 were grouped as 'High Knowledge'.

4.10.2 Adoption of improved agricultural practices (IAPs)

Adoption refers to the current status of using the list of recommended practices by the pulses and groundnut farmers, i.e., use of improved varieties recommended, following sowing time (s), use of suitable soils, following seed treatment, following sowing methods, following spacing, following seed rate, following recommended fertilizer and their dosage, following recommended herbicides and their dosage, following inter-cultivation, following intercrops, following recommended chemicals for insect/pest control, following recommended chemicals for disease management, following INM practices following IPM practices. The scoring was done as complete adoption (score greater than 10), partial adoption (score 5–10) and no adoption (score < 5).

4.10.3 Mass media

Data on use of various modes of mass media was collected through usage of Radio, TV, news-paper, farm magazine, and cyber media. Responses were recorded as Yes (value given as 1) or No (value given zero) for various modes of mass media. Scoring was done based on the responses. Scoring of two or less than two mode of mass media was categorized as low. Scoring of three to four was categorized as moderate, and where there is usage of all five mode of mass media scoring was categorized as high.

4.10.4 Participation in social work

Data related to participation in social organization and social work were collected based on four questions, i.e., Financial contribution to common fund for common work, Office bearer in any farmer's organization, membership in any farmer's organization and farmer's association/involvement in community work. Responses were recorded in Yes (value given as 1) or No (value given zero). Scoring of one or less than one was categorized as inactive whereas those scoring greater than one were categorized as socially active.

4.10.5 Risk orientation

Data related to Risk orientation were collected based on six questions and responses were recorded as Yes (value given as 1) or No (value given zero). Scoring was done based on the responses. Score of three or less than three was categorized as low, score of four to five was categorized as moderate and a score of six was categorized as high.

4.10.6 Innovativeness

Data on innovativeness was collected using seven questions and responses were recorded as Yes (value given as 1) or No (value given zero). Those scoring less than or equal to two was categorized as low, between three to four as moderate and greater than four as high.

4.11 Ethical approval

This study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. The ethics committee of Acharya N.G.Nanga Agricultural University, Andhra Pradesh (South India) provided ethical approval for the study.

4.12 Statistical analysis

Statistical analysis for data was performed using SPSS 20.0 version. Chi square test was done for frequency distribution for categorical variables. Multivariate logistic regression analysis was used to analyze risk of various independent variables such as age, gender, education, farm experience, use of mass media, social participation, risk orientation and innovativeness on dependent variables i.e., knowledge of SAPs and adoption status of IAPs, both at baseline and endline. A significance level of 5% was used for all the statistical tests.

4.13 Model specification

Based on review of literature, knowledge and adoption levels of any new technology by farmers can be treated as a function of education level, age, gender, experience of the farmer, hence the variables were captured in the present study. Additionally, several studies across the globe depicted use of mass media, risk orientation, social participation and innovativeness were associated with adoption level of farmers, hence these variables were captured in the present study. Accordingly, empirical model has been derived. Logistic regression model characterizing knowledge of various technology by the sample farmer also mentioned by Ashrit and Thakur (2021) is as follows:

$$\ln[Pi1 - Pi] = \beta 0 + \beta ijxij + uij; i = 1, \ldots, 240\ j = 1, \ldots, 8(\text{no. of independent variables})$$

where ln = natural logarithm, Pi = probability of knowledge/adoption of the technology by the ith farmer, β0 = intercept term, xij = a vector of independent variables which impact the probability of knowledge/adoption of the ith farmer (age, gender, farming experience, education, social media awareness, risk orientation, social participation and innovativeness), βij = coefficient associated with ith farmer and jth independent variable, uij = the error term which follows standard normal distribution.

4.14 Evaluation plan

The study emphasizes on the impact/result of the intervention through improvement in yield of pulses and groundnuts in the selected studied area.

5 Results

A total of 240 farmers participated in the baseline study, as opposed to the calculated sample size of 291. The endline survey included all 240 participants who had taken part in the baseline survey. In each of the four selected Andhra Pradesh districts, namely Srikakulam, Visakhapatnam, Kurnool, and Anantapur, a total of 60 participants were interviewed during both phases of the study. In the course of the baseline survey, only one set of socio-economic and demographic characteristics of the farmers was collected. The distribution of socio-economic and demographic characteristics of the participants, which were collected at the outset, revealed that their overall mean age was 44 years. There was no significant difference in the mean age of participants between the four districts (Table 1). Overall, males outnumbered females by an 80–20 ratio, with no statistically significant differences in gender distribution patterns among participants across the four districts (Table 1). 30% of those recruited were illiterate, while 70% were literate (primary level (21.3%) and secondary and higher education (48.8%). In terms of educational attainment, there was a significant disparity between farmers from the various districts studied. Not literate people were found in the highest in Anantapur district (43.3%), followed by Srikakulam (31.7%), Kurnool (23.3%), and Vishakhapatnam (21.7%). It was Anantapur district that had the highest proportion of participants with secondary (or higher) education (56.7%), followed by Kurnool (53.3%), Vishakhapatnam (46.7%), and Srikakulam (38.3%). Farming experience

Table 1 General characteristics of the farmers at Biotech Kisan Mission program at Andhra Pradesh

Endline-Demographic variables	Sub-categories	Total N (%)	Srikakulam N (%)	Vishakhapatnam N (%)	Anantapur N (%)	Kurnool N (%)	Chi-square test p-value
Total participants	–	240	60	60	60	60	–
Gender	Males	192 (80)	44 (73.3)	47 (78.3)	53 (88.3)	48 (80)	0.223
	Females	48 (20)	16 (26.7)	13 (21.7)	7 (11.7)	12 (20)	
Age (yrs) (Mean ± S.D)	–	44.44 ± 8.91	44.55 ± 8.46	45.01 ± 9.21	44.58 ± 8.17	43.63 ± 9.89	0.781 (t-test)
Education	Not-Literate	72 (30)	19 (31.7)	13 (21.7)	26 (43.3)	14 (23.3)	0.000
	Primary	51 (21.3)	18 (30)	19 (31.7)	–	14 (23.3)	
	Secondary and above	117 (48.8)	23 (38.3)	28 (46.7)	34 (56.7)	32(53.3)	
Experience of farming (yrs)	< 10 yrs	13 (5.41)	3 (5.0)	6 (10)	0 (0)	4 (6.6)	0.000
	10–20 yrs	200 (83.33)	43 (71.6)	53 (88.3)	58 (96.6)	46 (76.6)	
	> 20 yrs	27 (11.25)	14 (23.3)	1 (1.6)	2 (3.4)	10 (16.6)	
Use of Mass Media	Radio	41 (5.52)	12 (7.40)	11 (6.96)	9 (4.10)	9 (4.43)	0.008
	TV	192 (25.87)	47 (29.01)	46 (29.11)	56 (25.57)	43 (21.18)	
	News Paper	221 (29.78)	52 (32.09)	55 (34.81)	60 (27.39)	54 (26.60)	
	Farm Magazine	149 (20.08)	28 (17.28)	24 (15.19)	56 (25.57)	41 (20.19)	
	Cyber Media	139 (18.73)	23 (14.19)	22 (13.92)	38 (17.35)	56 (27.58)	

Significant at p-value ≤ 0.05

was the most prevalent among farmers in Srikakulam district (23.3%), followed by Kurnool (16.6%) Anantapur (3.3%) and Vishakhapatnam (1.6%) in terms of number of farmers with more than 20 years of farming experience (Table 1).

Both baseline and endline data on knowledge of SAPs and adoption of IAPs and associated factors such as social participation, mass media use, risk orientation, and innovativeness were collected. There was decrease in percentage of farmers with moderate knowledge and low knowledge of SAPs in the endline. Further, the comparison of farmers' knowledge levels on SAPs at baseline and endline revealed a significant increase in farmers with high knowledge (80.4%) at endline compared to baseline (48%). Similarly, high adoption increased significantly (50.8%) at the endline compared to the baseline (3 percent) (Table 2, Fig. 2). Percentage change in adoption of IAPs from baseline to endline is provided in supplementary information (SI) Table.

Further, it was found that there was significant increase in social participation of farmers during endline (68.8%) as compared to baseline (46%) (Table 3). The comparison between farmer's usage of mass media at baseline and endline showed that 30% of the farmers had low level of mass media usage at endline as compared to 50% at the baseline survey. Moderate and high usage of mass media increased significantly at the endline (60 and 10% respectively) as compared to baseline (48 and 2.5% respectively) (p-value < 0.001) (Table 4). Endline survey results showed that farmers with high (32.5%) and moderate (55.4%) level risk orientation were significantly higher as compared to baseline (22.1 and 47.5% respectively). In terms of Innovativeness, farmers with high level of innovativeness were significantly higher (94.2%) at endline as compared to baseline (66%) (Table 4).

The results of a logistic regression analysis were used to examine the relationship between knowledge of SAPs and adoption of IAPs and factors such as socio-demographic characteristics, mass media usage, social participation, risk orientation, and innovativeness, both at the baseline and endline survey levels (Table 5) (Fig. 3a, b). The findings revealed that, at baseline, older age was associated with greater SAPs knowledge, but this was not the case at the end of the study. At both the baseline and endline surveys, there was no correlation between age and the level of IAPs adoption (Table 5). Similarly, there was no association of gender and knowledge of SAPs or with adoption of IAPs at either the baseline or endpoint. Farmers with more than 20 years of farming experience pursued high knowledge on SAPs with reduced risk (OR- 1.21, 95% CI (0.46–3.22), P-value- 0.691) at the end of the study as compared to farmers (OR-2.27, 95% CI (1.05–4.92), P-value- 0.03) at the beginning of the study. The findings were found to be statistically significant. Farmers with education up to secondary school and higher had better knowledge of SAPs and were at lower risk during the endline study (OR-4.240, 95% confidence interval (1.90–9.41), P-value-0.000) when compared to farmers at baseline (OR-7.85, 95% confidence interval (3.187–19.47), P-value-0.000). Additionally, adoption of IAPs was found to be associated with farmers' educational levels, both at the outset and at the end of the study.

Education level was identified as the most significant confounder, and the associations between various factors such as mass media usage, social participation, risk orientation, and innovativeness with knowledge of SAPS and adoption of IAPs were examined after controlling for confounder (i.e., education). The findings revealed that, at the end of the study, trained farmers who had a high level of awareness and usage of various mass media had increased knowledge of SAPs and adoption of IAPs when compared to farmers who had a low level of awareness and usage of mass media at the beginning (Table 5). According to the findings of the study, farmers who were active in social participation increased their knowledge of SAPs and adoption of IAPs with a significantly lower risk as compared to farmers who were inactive in social participation at the start of the study and showed a fivefold and threefold increased risk for low knowledge of SAPs and adoption of IAPs, respectively. The findings were found to be statistically significant (Fig. 3a, b).

The results for risk orientation and innovativeness factors were found to be comparable. At the endline survey, it was observed that farmers with a more risk management approach had a higher level of knowledge of SAPs and adoption of IAPs than farmers at the baseline. At the outset, farmers with a low risk tolerance exhibited a low level of knowledge of SAPs and adoption of IAPs. Similarly, farmers with a high level of innovativeness had significantly increased knowledge of SAPs and adoption of IAPs at endline, compared to farmers at baseline. At the outset, farmers with a low capacity for innovation pursued a low level of knowledge of SAPs and adoption of IAPs (Table 5).

5.1 Yield of pulses and groundnut pre and post intervention

The study also demonstrated the effect of the biotech intervention on improved yield of pulses and groundnut through the adoption of IAPs. The average yield per hectare of pulses during baseline was found to be 403.5 kg/ha ± 128.4. While during endline it was 601.25 kg/ha ± 206.8. Statistically significant difference between baseline and endline was found on the average yield of pulses (p-value = 0.001). The average yield per hectare of groundnut

Table 2 Baseline and endline differences on Knowledge of SAPs and Adoption of IAPs

Level (score)	Knowledge level on SAPs			Level (score)	Adoption level of IAPs		
	Baseline Total N (%)	Endline Total N (%)	(Chi- square) P-value		Baseline Total N (%)	Endline Total N (%)	(Chi- square) P-value
Low (0–5)	41 (17.1)	2 (0.8)	(66.91) < 0.001	No Adoption (0–5)	114 (47.5)	46 (19.2)	(142.98) < 0.001
Moderate (5–10)	84 (35)	45 (18.8)		Partial Adoption (5–10)	119 (49.58)	72 (30)	
High (> 10)	115 (48)	193 (80.4)		Complete Adoption (> 10)	7 (3)	122 (50.8)	

Significant at p-value ≤ 0.05

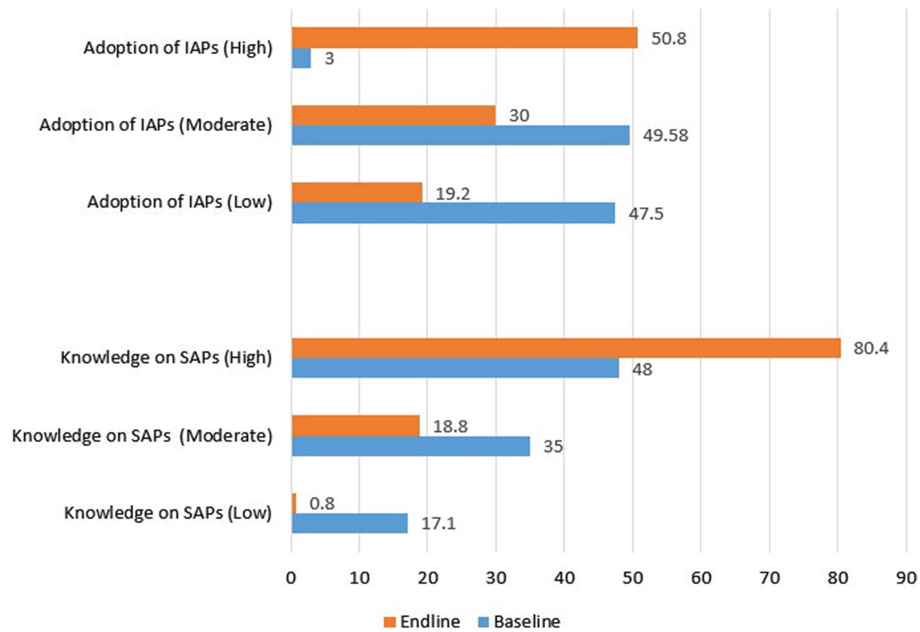


Fig. 2 Knowledge of SAPs and Adoption level of IAPs in Andhra Pradesh. The figure explains change from baseline to endline. After the intervention, farmer's knowledge level of SAPs increased tremendously (99%) at endline phase. Similarly, farmer's adoption level of IAPs also increased at endline (80%)

Table 3 Baseline and endline differences on social participation

Level (score)	Social participation		
	Baseline total N (%)	Endline total N (%)	(Chi- square), P-value
Active (2–4)	110 (46)	165 (68.8)	(25.75) < 0.001
Less Active (0–1)	130 (54.2)	75 (31.3)	

Significant at p-value ≤ 0.05

Table 4 Baseline and endline differences on use of mass media, Risk Orientation, and Innovativeness

Level (score)	Various factors for knowledge of SAPs and adoption of IAPs		
1	Use of mass media		
	Baseline total N (%)	Endline total N (%)	(Chi- square) P-value
Low (0–2)	119 (49.6)	72(30)	(25.61) < 0.001
Moderate (3–4)	115 (48)	144 (60)	
High (5)	6 (2.5)	24 (10)	
2	Risk Orientation		(25.21) < 0.001
Low (1–3)	73 (30.4)	29 (12.1)	
Moderate (4–5)	114 (47.5)	133 (55.4)	
High (6)	53 (22.1)	78 (32.5)	
3	Innovativeness		(60.22) < 0.001
Low (0–2)	16 (7)	3 (1.3)	
Moderate (3–4)	66 (27.5)	11 (4.6)	
High (5–7)	158 (66)	226 (94.2)	

Significant at p-value ≤ 0.05

during baseline was found to be 983.75 kg/ha ± 444.9 and during endline was 1216.78 kg/ha ± 473.9. The difference from baseline to endline on average yield of groundnut was found to be statistically significant (p-value = 0.000).

Table 5 Logistic regression results of various determinants on knowledge of SAPs and adoption of IAPs at baseline and endline phase at Andhra Pradesh

Sl. No	Variables	Categories	Baseline analysis Odds ratio (CI), p-value		Endline Analysis Odds ratio (CI), p-value	
			Knowledge of SAPs	Adoption of IAPs	Knowledge of SAPs	Adoption of IAPs
1	Age	–	1.04 (1–1.08), 0.03	1.03 (0.99–1.08), 0.054	1.009 (0.974–1.046), 0.621	1.028 (0.998–1.058), 0.064
2	Gender	–	0.29 (0.14–0.61), 0.001	0.37 (0.19–0.75), 0.04	0.338 (0.166–0.686), 0.003	0.283 (0.141–0.568), 0.000
3	Farming experience	10–20 yrs vs > 20 yrs (ref)	2.27 (1.05–4.92), 0.03	1.30 (0.67–2.52), 0.42	1.218 (0.460–3.22), 0.691	0.800 (0.357–1.795), 0.588
		< 10 yrs vs 10–20 yrs (ref)	0.62 (0.17–2.2), 0.46	0.87 (0.39–1.91), 0.73	0.782 (0.205–2.979), 0.718	1.167 (0.379–3.594), 0.788
4	Education	Not- Literate vs Primary	2.05 (0.87–4.78), 0.09	0.98 (0.47–2.03), 0.95	1.163 (0.526–2.571), 0.709	0.530 (0.245–1.148), 0.107
		Not- Literate vs Secondary and above (ref)	7.85 (3.187–19.47), 0.000	2.19 (1.14–4.20), 0.015	4.240 (1.90–9.41), 0.000	2.800 (1.527–5.133), 0.001
5	Mass media usage	High vs Low	5.42 (2.38–12.3), 0.000	2.59 (1.53–4.38), 0.000	0.068 (0.009–0.535), 0.011	0.132 (0.048–0.367), 0.000
6	Social participation	Active vs inactive	5.21 (2.2–12.3), 0.000	3.37 (1.9–5.7), 0.000	0.962 (0.485–1.909), 0.913	0.529 (0.304–0.921), 0.024
7	Risk orientation	High vs Moderate (ref)	2.96 (1.49–5.9), 0.000	2.77 (1.55–4.93), 0.000	1.130 (0.527–2.421), 0.753	0.465 (0.207–1.048), 0.065
8	Innovativeness	Low vs High (ref)	12.8 (4.2–38.5), 0.000	18.13 (2.34–140.3), 0.006	0.104 (0.009–1.179), 0.068	0.000 (0.00–0.00), 0.999
		Moderate vs High (ref)	3.84 (1.48–9.98), 0.006	1.16 (0.47–2.62), 0.802	0.174 (0.050–0.598), 0.006	0.337 (0.087–1.304), 0.115

Significant at P value ≤ 0.05

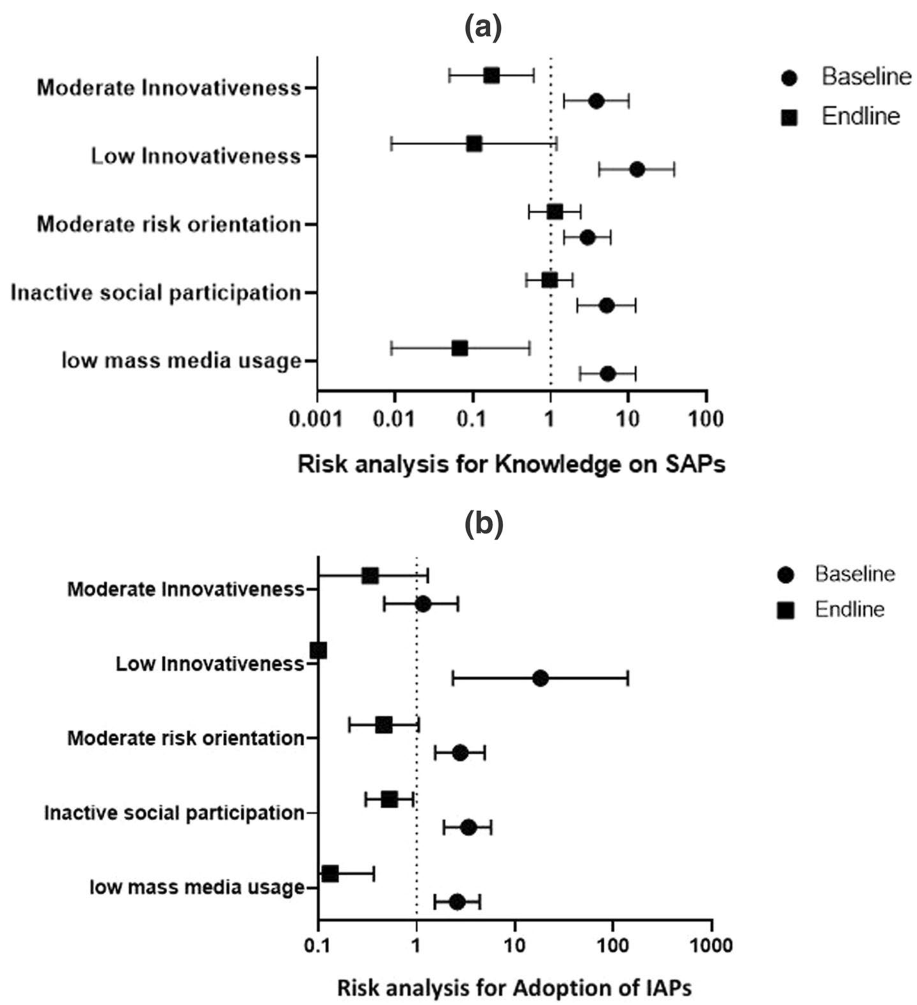


Fig. 3 **a** Graphical representation of risk analysis of various factors with Knowledge on SAPs at baseline and endline level. **a**: Graph shows difference in association of various factors such as low mass media usage, inactive social participation, moderate risk orientation, low innovativeness, moderate innovativeness with Knowledge on SAPs at baseline and endline level. Farmers with high knowledge on SAPs pursued high mass media usage, high innovativeness with reduced risk at endline as compared to increased risk at baseline. Further, farmers with high knowledge on SAPs pursued active social participation and high risk orientation with no risk at endline as compared to increased risk at baseline. **b** Graphical representation of risk analysis of various factors with Adoption of IAPs at baseline and endline level. **b**: Graph shows difference in association of various factors such as low mass media usage, inactive social participation, moderate risk orientation, low innovativeness, moderate innovativeness with Adoption of IAPs at baseline and endline level. Farmers with high adoption of IAPs pursued high mass media usage, high innovativeness with reduced risk at endline as compared to increased risk at baseline. Further, farmers with high adoption of IAPs pursued active social participation and high risk orientation with no risk at endline as compared to increased risk at baseline

6 Discussions

Currently, India is confronted with three agricultural challenges: the first is to enhance farmer's income; the second is to increase productivity; and the third is to reduce natural resource depletion and the loss of agro-biodiversity [30]. Globally, the Sustainable Development Goals (SDGs) were conceived in 2015 to dedicate two goals related to agricultural development, both of which must be achieved by the year 2030, according to the United Nations. First and foremost, to eliminate poverty, hunger, and malnutrition, and second, to increase agricultural productivity while causing the least amount of damage to soil and other natural resources [2]. Additionally, the National Mission for Sustainable Agriculture (NMSA) was established in India in 2010 to address issues related to 'sustainable agriculture' through climate change adaptation, water conservation in irrigation, natural farming, and mitigation strategies [17, 41] and emphasized the importance of promoting research and development to improve crop productivity and mechanization [17, 41]. The challenges that Indian small landholder face in sustainable agriculture include a lack of inputs, frequent pest and disease outbreaks, production and market risks, climatic changes, and limited access to markets [18]. However, small landholders are making more intensive use of their land by using higher doses of input and adopting new technology than large landholders [10]. As a result of the high number of farmer suicides occurring across the country, India's sustainable agriculture development initiatives are being held back [39]. Given the fact that India is still developing its rural sector, which includes underdeveloped rural education, agricultural information and extension services; social networking sites are beneficial for agricultural development in the country. As has been mentioned previously, studies have found that the most important determinant for technology adoption-based agricultural development is social networking, which includes social innovation. This assists in connecting people in order to ensure a smooth flow of information, goods, and services, as well as participation in participatory action to meet social, economic, and environmental needs and demands [11]. Our current findings support the notion that social participation increases technology awareness/knowledge, as well as its use and adoption. Although there has been recent interest in the potential role of farmers' social networking in agricultural development, there has been little research on the social factor in agricultural development. The availability of information through social media or through the use of various ICT tools such as mobile phones, the internet, television, and radio had a significant impact on the adoption of SAPs [38]. This is due to the fact that it not only aids in the dissemination of information and raising awareness, but it also has the potential to improve agricultural marketing [4] particularly in rural areas. Our research developed robust and systematic IAPs based on local requirements and preferences for increased pulse and groundnut production in the various districts of Andhra Pradesh, along with proper training of the farmers on IAPs. The government of Andhra Pradesh is encouraging farmers to diversify their cropping system by including pulses through SAPs technologies. This is because protein rich pulses maintain soil fertility and soil conservation. SAPs such as intercropping of legumes (pulses) along with other crops has multiple benefits. Pulses maintain the biological properties of soil (nitrogen fixation), breaks the continuous life cycle of insects and pests causing several diseases in crops, has high calorie value. In addition, pulses have the ability to adapt in wide range of environmental and climatic conditions. Previous studies have also indicated the need for systematic SAPs, as well as sophisticated training and awareness campaigns and programmes [28]. Due to the fact that in many cases, farmers used non-specific fertilizers and insecticides on specialty crops at random, there was heterogeneous crop production, improper growth, and resistance to other crops [28]. Farmers' attitudes toward SAPs have been reported in several studies from various developing countries [49, 50], and as a result, farmer's attitude influences adoption of SAPs. Farmers' decision to adopt SAPs is influenced by factors such as acceptance by the local society and perceived usefulness of SAPs [13, 25, 39, 49]. Farmers who are willing to adopt SAPs also value innovative practices [13, 42, 49]. In addition, studies have revealed that farmers' risk-taking attitudes influence their decision to use SAPs [4, 14]. As a result, our findings are in confirmation with those of other studies that have focused on the relationship between innovativeness and risk orientation and knowledge of and adoption of SAPs [2]. Several studies found that socio-demographic factors such as older age, lower qualification, and less farm experience were associated with low adoption of SAPs [2, 5, 13, 22, 23, 44, 48, 50]. The findings of our study revealed a relationship between farmer's knowledge of SAPs and adoption of IAPs and factors such as age, education, farming experience, social participation, use of communication media, risk orientation, and innovativeness. The impact of some other influential variables that may influence SAPs such as socio-economic status, value addition practices, resource management etc. were not captured due to time and fund constraints, which can be the limitations of the study.

The improvement in yield of pulses and groundnut as the impact of the biotech intervention in the selected areas were quite evident in the present study. For future research, yield through the current sustainable biotech interventions will be compared with the conventional, organic farming systems or natural farming systems. Despite the fact that previous studies have demonstrated that SAPs can be successfully implemented, resulting in increased crop yields that ultimately contribute to the achievement of the food security goal [42] and the development of the economy in many countries [20]; the implementation of systematic SAPs and the adoption rate have not met expectations [5].

It is suggested that land inequality must be reduced in favor of farmers with small land size, for better rise in agricultural productivity in India. Improvement and implementation of systematic farm technologies is required pan India, which is particularly true for rural areas.

7 Conclusions

The study attempted to evaluate the difference in knowledge of SAPs and adoption levels of improved agricultural practices (IAPs) at baseline and endline of biotechnology intervention and demonstration initiatives. It can be concluded that there was increase in knowledge through enhanced usages of mass media, social participation, risk orientation, and innovativeness among the farmers. The study also demonstrated improved adoption levels of IAPs among farmers. Further, the study also evaluated the correlates of enhanced levels of knowledge of SAPs and adoption of IAPs such as were age, experience, gender and education. Education levels of farmers played a crucial part in the increase in knowledge level but reduced influence on adoption level. The third, but an important conclusion is that there is definite increase in yield of selected crops after the proper adoption of IAPs by the farmers. Our study had few limitations. First, data that may influence adoption of IAPs such as socio-economic status, value addition practices, resource management, were not captured due to time and fund constraints. Secondly, measurements of innovativeness lack several aspects such as socio-ecological changes, peer influence, changing market demands, contribution to food security etc.

Because our study was limited to four selected districts in Andhra Pradesh, additional research on IAPs in various parts of India should be conducted to determine whether there are differences in the understanding and adoption of IAPs in the context of geographical or agroclimatic zones. Furthermore, as previously documented in the literature, there is district-level variation in agricultural practices across India, as well as differences in farmers' attitudes toward SAPs knowledge and adoption of IAPs; as a result, it is recommended that demographic, socio-economic, resource availability factors, as well as skill development, be taken into consideration when formulating policies for farmer benefit.

8 Recommendations

This study throws light on the significance of imparting knowledge to farmers on SAPs and hereby enhancing the adoption levels of improved sustainable practices. Therefore, it is recommended that large scale training and demonstrations of SAPs should be conducted for various other major crops and across various parts of the country so as to enable our farmers to fetch maximum benefits from already existing and proved biotech interventions. India, being a federal country, Agriculture and Biotechnology Departments can take up proactive initiatives to maximize the outreach activities to farmers across the country.

Author contributions Author's contribution – RRA was involved in the study design, conceptualization, interpretation and writing of the manuscript. SJ was involved in data analysis, interpretation, conceptualization and writing the manuscript. All the authors reviewed the manuscript.

Data availability Details on data analyzed in the current study can be obtained from the corresponding author on reasonable request.

Declarations

Competing interests The author has no competing interests to declare. The author certifies that the data is accurate. The author has no relevant financial or non-financial interests to disclose.

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