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ORIGINAL PAPER

Impact of climate-smart agriculture adoption on the food security of coastal farmers in Bangladesh

Md Kamrul Hasan [1,2] · Sam Desiere [3] · Marijke D'Haese [3] · Lalit Kumar [1]

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Abstract
Climate-smart agriculture (CSA) is a suggested pathway to the improvement of food security in a changing climate. The Department of Agricultural Extension under the Bangladesh Ministry of Agriculture has been promoting CSA with farmers through climate field schools since 2010. This study investigated the impact of adoption of CSA practices on the household food security of coastal farmers in southern Bangladesh. Factors determining household food security were also explored. Data were collected from 118 randomly selected farmers of Kalapara sub-district in Patuakhali, Bangladesh. We identified 17 CSA practices that were adopted by the farmers in the study area. Those practices were saline-tolerant crop varieties, flood-tolerant crop varieties, drought-resistant crop varieties, early maturing rice, vegetables in a floating bed, 'sorjan' method of farming, pond-side vegetable cultivation, the cultivation of watermelon, sunflower or plum, relay cropping, urea deep placement, organic fertilizer, mulching, use of pheromone trap, rain water harvesting and seed storage in plastic bags or glass bottles. The farmers adopted on average seven out of these CSA practices. Among the sampled households, 32% were assessed as food secure, 51% were mildly to moderately food insecure and 17% were severely food insecure. Adoption of CSA practices was positively associated with household food security in terms of per capita annual food expenditure ($\beta = 1.48$ Euro, $p = 0.015$). Households with a better educational level, farming as a major occupation, a larger pond size, greater number of cattle, higher household income, smaller family size and less difficulty with access to markets were likely to be more food secure. Increasing the adoption of CSA was important to enhance food security but not a sufficient condition since other characteristics of the farmers (personal education, pond size, cattle ownership and market difficulty) had large effects on food security. Nevertheless, increased adoption of saline-tolerant and flood-tolerant crop varieties, pond-side vegetable cultivation and rainwater harvesting for irrigation could further improve the food security of coastal farmers in southern Bangladesh.

Keywords Climate-smart agriculture · Climate field school · Adoption quotient · Food security indicators · Coastal farmers · Southern Bangladesh

1 Introduction

Our planet's climate change is a reality (Ramachandran 2013) and this will have major consequences on food production and food security (Acevedo 2011; Aleksandrova et al. 2014; Beuchelt and Badstue 2013; Burke and Lobell 2010), particularly in developing countries such as Bangladesh (Eva 2014). Increasing temperatures, melting ice-caps, rising sea level, changing rainfall patterns and changing humidity are the primary indicators of climate change (IPCC 2012). Secondary consequences of climate change, such as cyclones, tidal surges, floods, droughts and soil salinity, are directly detrimental for agriculture. A crop model for South Asia forecasts that the average yield of rice will decline by 17% due to climate change (IFPRI 2009). As rice is a staple food in many countries, climate change has obvious negative impacts on food security (Brown and Funk 2008; IPCC 2007; Schmidhuber and Tubiello 2007; Wheeler and von Braun 2013). Accordingly, food security in a changing climate has been prioritized in discussions at all levels of government

✉ Md Kamrul Hasan
kamrulext@pstu.ac.bd

[1] School of Environmental and Rural Science, University of New England, Armidale, NSW, Australia

[2] Department of Agricultural Extension and Rural Development, Patuakhali Science and Technology University, Patuakhali, Bangladesh

[3] Department of Agricultural Economics, Ghent University, Ghent, Belgium

(Abah et al. 2010). In order to feed the growing population under scenarios of declining yield of major crops, climate-smart agriculture (CSA) has been recommended by researchers and development organizations (FAO 2013).

Climate change is a global phenomenon (Molnar and England 1990) and Bangladesh is also a victim of climate change, even though her per capita CO_2 emission is only 0.5 t per year (World Bank 2016). Bangladesh has experienced an increasing trend of average temperature (Basak et al. 2013; Karmalkar et al. 2010). It is also clear that the dry season will get drier and the wet season wetter (Ahmed 2006; Basak et al. 2013; Karmalkar et al. 2010). Though the long-term prediction of cyclones is difficult due to inadequate observation capabilities (IPCC 2013), evidence indicates that tropical cyclones are likely to become more intense under a warmer climate. Besides, coastal farming is becoming more challenging due to the fluctuating monsoon, tidal cyclones and soil salinity (Haque 2006; Ramachandran 2013; World Bank 2012). Many areas in the coastal regions of Bangladesh will experience a significant increase in soil salinity during coming decades (Dasgupta et al. 2014). For these reasons, coastal farming is very vulnerable to climate change. As the coastal zone of Bangladesh constitutes 32% of the country's area and hosts 28% of the population (M. R. Islam 2004), declining food production in coastal areas will also have major implications for food security in the rest of the country. Therefore, the adaptation of agriculture to climate change by coastal farmers is vitally important to ensure food security in Bangladesh.

Conceptually "CSA is an approach for transforming and reorienting agricultural systems to support food security under the new realities of climate change" (Lipper et al. 2014: 1068). In a changing climate, CSA can sustainably increase productivity and resilience (adaptation), reduce/remove greenhouse gas emission (mitigation) and enhance the achievement of national food security (FAO 2013). For example, deep placement of urea is a CSA practice that requires placing urea briquettes (1 to 3 g/granule) 7 to 10 cm deep in the soil after paddy rice is transplanted. In Bangladesh, this practice is found to reduce nitrogen loss by 40%, increase rice grain yield by 25%, decrease urea cost by 25% and minimize greenhouse gas emission and water pollution (FAO 2014; S. M. M. Islam et al. 2018). Therefore, CSA is recommended to improve production and mitigate climate change (Pye-Smith 2011). Existing literature shows that CSA practices can increase crop productivity and thus contribute to food security (Branca et al. 2011; Brüssow et al. 2017). A quarter of the population of Bangladesh is food insecure. Bangladesh is ranked 68th out of 79 countries in the 2012 Global Hunger Index (WFP 2015). However, establishing a direct link between the adoption of CSA practices and food security has received limited attention to date.

The Bangladesh government, NGOs and researchers are attempting to mitigate the adverse effects of climate change through promotion and dissemination of CSA practices (Ahmad and Rahman 2011; FAO 2014). Important thematic areas of the Bangladesh Climate Change Strategy Action Plan (Mallik et al. 2012) are food security and comprehensive disaster management (The Asia Foundation 2012). In this respect, the Comprehensive Disaster Management Programme (CDMP) is a collaborative project of the Bangladesh government and some donor organizations, including the Department for International Development (DFID), the United Nations Development Programme (UNDP) and the European Union (UNDP 2013). CDMP's main focus is disaster risk reduction and climate change adaptation (FAO 2013). The Department of Agricultural Extension (DAE) is the largest government extension organization in Bangladesh and has a nationwide network to disseminate agricultural technologies to farmers. In the second phase of CDMP (2010–2015), the DAE has established Climate Field Schools (CFS) to disseminate CSA practices (Ajij et al. 2014) through result demonstrations, farmer rallies, field days and motivational tours (Mainuddin et al. 2011).

Although it is widely acknowledged that CSA farming is an important element in the adaptation of agriculture to climate change (Campbell et al. 2014), studies of the impacts of CSA adoption on food security for smallholder farmers are lacking, particularly in Bangladesh, where national development programs promoting CSA adoption are currently being implemented (Ajij et al. 2014; CIAT and World Bank 2017). This paper addresses this issue by evaluating the adoption of CSA and food security for climatically vulnerable coastal farmers in Bangladesh. The main focus of the study was to gain a better understanding of how CSA is linked to household food security. We selected CSA practices that could be adopted by smallholder coastal farmers. Adoption of these techniques is not capital or knowledge-intensive, and therefore within the reach of smallholder farmers. If these techniques could be shown to improve food security, it would be easier to plan food security programs with CSA. Considering the aforementioned perspectives, this study investigated the relationships of CSA adoption with household food security taking into account the socio-economic characteristics of the farmers.

2 Materials and methods

The study area was selected based on the representativeness of coastal farmers who have experienced coastal events including flood, tidal surges and cyclones (M. B. Islam et al. 2011). Kalapara upazila (sub-district) is the coastal part of Patuakhali district of Bangladesh. This is one of the areas most vulnerable to climate change in Bangladesh. It is close to the Bay of

Bengal (Fig. 1). Kalapara sub-district, with an area of 492 sq. km, has 247 villages under 12 unions (Bangladesh National Portal 2017). The DAE has established 156 CFSs in 52 sub-districts of 26 districts out of 64 districts in Bangladesh (Ajij et al. 2014). Three CFSs were located in three villages (Pachjunia, Majidpur and Islampur) of two unions (Dhankhali and Nilganj) in Kalapara sub-district. Those three villages were purposively selected since 75 households within the villages were involved in CFS, and they had previously received training, information and consultancy support from extension agents on CSA practices.

The population of this study comprised a total of 902 households in the selected villages (Table 1). These households were dependent on a mixed type of farming activity with crop, livestock and fisheries farms. Firstly, all of the 75 CFS households were contacted, but only 59 farmers (each from one household) were willing to provide information. Secondly, 59 non-CFS households were randomly selected from the three villages to better understand the link between CSA adoption and household food security irrespective of their learning sources of CSA. As such, 13% of the households from the three villages constituted the sample for this study. Respondents were the household heads or active family members who took the major responsibility of agricultural activities or were able to give information on other household members and on agricultural production (USAID 2013). A pre-tested structured interview schedule was used to collect data through face-to-face personal interviews during April and May 2016. Focus group discussions and key informant interviews were also performed to collect qualitative information.

This research focused on the link between adoption of CSA and household food security whereby the adoption of CSA was considered as a means of adaptation to climate change. Additionally, independent variables in addition to the adoption of CSA, namely farmers' CFS membership, personal education, occupation, family size, cultivated farm size, pond size, cattle ownership, annual household income, market difficulty, access to farm information and perception of climate change, were selected, considering their linkage with household food security in Bangladesh (see Bashir and Schilizzi 2013; Coates et al. 2006; De Cock et al. 2013; Mason et al. 2015).

CFS membership was measured as a dummy variable and scored as 1 for CFS and 0 for non-CFS farmers. Personal education reflected the total years of schooling by the interviewed farmers. Occupation indicated whether a household's major occupation (main income source) was farming or not. Family size was measured in terms of the number of household members living and sharing meals together. Cultivated farm size was calculated based on total cultivated areas during the last twelve months in three cropping seasons (USAID 2013). The farmers had ponds artificially formed by excavating the soil to store water and raise fish close to their homesteads. Pond size of the farmer was measured in terms of total area of pond in m^2. Cattle ownership was expressed as the total number of oxen, cows and buffalo owned by the farmer. Annual household income was estimated based on total annual earnings in the Bangladeshi currency *Taka* (BDT) from farm and non-farm sources by all the earning members of the household. This was converted to Euro (exchange rate 1 Euro = 87.85 BDT on 2 June 2016) for broader comprehension. The measurement of household income is challenging in case of subsistence types of farming. Besides, the intermittent selling of agricultural products from smallholder households makes calculation of income

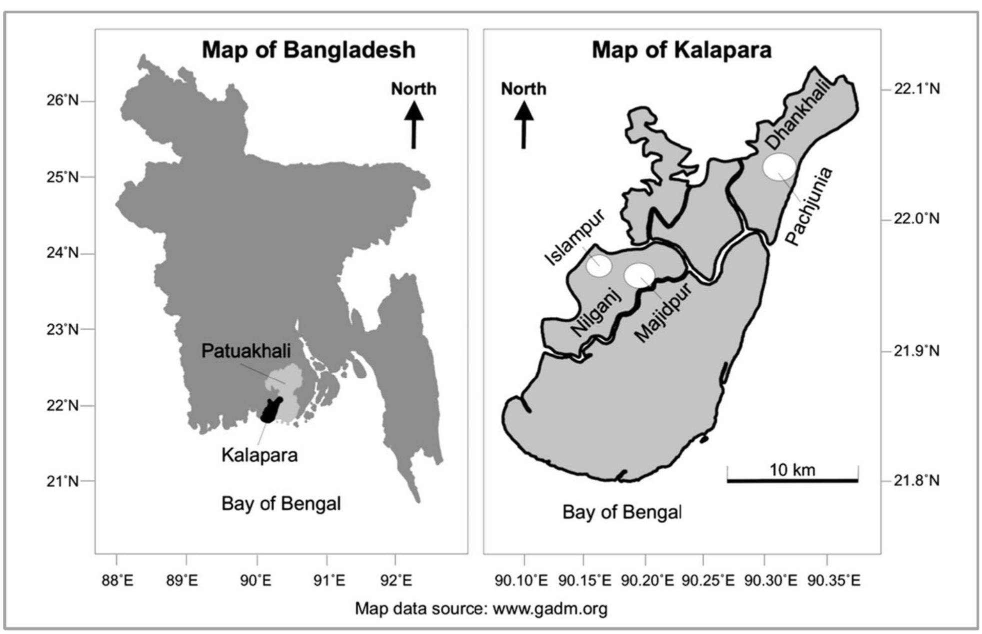

Fig. 1 Maps showing three selected villages in Kalapara, Patuakhali, Bangladesh

Table 1 Population and sample for the study of climate-smart agricultural practices in coastal Bangladesh

Union	Village	Total households	Total CFS households	Sampled CFS households	Sampled non-CFS households	Total sample	Percentage of households in the sample
Nilganj	Majidpur	102	25	16	12	28	27.5
Nilganj	Islampur	80	25	19	23	42	52.5
Dhankhali	Pachjunia	720	25	24	24	48	6.67
Total		902	75	59	59	118	13.1

CFS = Climate field school

more obscure. As incomes are difficult to capture by interview, there might be an underestimation of annual household income in our study (Pettersson 2005).

Market difficulty was measured as the farmers' perceived difficulty to access one input market (for a combination of seeds, fertilizers and pesticides) and six output markets (crops, vegetables, milk/egg/meat, chicken/duck, cattle/goat/sheep, fish) in terms of distance, transport cost, middle-men interference and illegal tax/donation for buying and selling the farm commodities. Based on our interviews, the seven markets were separately scored as 0, 1, 2 and 3 for no, low, medium and high difficulty, respectively. Total scores ranged from 0 to 21 and indicated the market difficulty score for an individual household. Similarly, access to farm information was measured on a three-point rating scale (not at all, sometimes and frequently) based on how frequently a farmer accessed the selected 14 sources of farm information. These sources were neighbors, friends, relatives, input dealers, bulk buyers, extension service providers, NGO personnel, group meeting, demonstration plot, poster/leaflet/bulletin, newspaper, radio, television and mobile phone. Perception of climate change, as a psychological variable, was defined in terms of how the farmers understood climate change. A Likert type scale is widely used to measure perception (Gbetibouo 2009; Leiserowitz 2006). In this study, the questions concerning the perception of climate change focused on the farmers' belief and mental images of climate change indicators (Bonatti et al. 2011). Based on the extent to which they identified the probabilities, causes, consequences of (and adaptation to) climate change, the responses were coded against a 6-point Likert type scale (do not know, very low, low, medium, high and very high).

The CSA practices were identified based on the agricultural practices disseminated by DAE through CFS (Ajij et al. 2014). Additionally, three key informant interviews with agricultural extension officers and two focus group discussions with the CFS farmers were performed. Based on their opinions, 17 agricultural practices were identified to be climate-smart (Table 2). These practices conform to the principles and examples of CSA provided by FAO (FAO 2010, 2013, 2014) and Sain et al. (2017). According to the definition of CSA (FAO 2013; Thierfelder et al. 2017), CSA should deliver benefits from adaptation, resilience and mitigation. The selected practices in this study were considered climate-smart because they help adapt to climate change, mitigate climate change effects or build resilience to climate change. These practices were considered to build resilience as their adoption could reduce the exposure to climate change, increase the ability to withstand a climatic shock or increase the adaptive capacity of the farmers. We did not include many other potential CSA practices such as crop diversification, crop rotation, shifting planting dates and altered cropping patterns (FAO 2010) because the farmers did not adopt these practices to a considerable extent. To keep this research manageable, climate-smart livestock, fisheries and agroforestry practices were also not included.

Finally, the adoption of CSA practices was measured in terms of an adoption quotient (Pareek and Chattopadhyay 1966), as follows:

$$AQ = \frac{\sum_{j=1}^{N}\left(\frac{\left(e_j/p_j\right)\times\left(t_p - t_2 - g\right)}{t_p - t_1}\times W_j\right)}{\sum_{j=1}^{N} W_j}\times 100$$

Where,

AQ	Adoption Quotient
N	Number of practices which the individual has the potential to adopt[1]
$\Sigma_{j=1}^{N}$	Summation over each of the N practices, of which j=1 to N
W	Weight to be given to a j^{th} practice based on its difficulty of adoption
e_j	Extent of adoption of j^{th} practice; actual number or weight of or area under j^{th} practice
p_j	Potential of adoption of j^{th} practice; highest possible number or weight of or area under j^{th} practice
t_p	Time of investigation (year), in this study, tp = 2016
t_1	Time of first introduction of j^{th} practice in a community (year)[2]
t_2	Time of first adoption of j^{th} practice by the farmer (year)
g	gap or discontinuance in the adoption period for j^{th} practice (duration in year)

Table 2 Selected climate-smart agricultural practices for southern Bangladesh

Serial no.	CSA practices	Why are these practices climate-smart? (as explained by the extension officers and farmers)
1	Saline tolerant crop varieties	Can withstand soil salinity to some extent.
2	Flood tolerant crop varieties	Can withstand waterlogging.
3	Drought resistant crop varieties	These varieties can withstand water scarce conditions, and hence, less irrigation is needed.
4	Early variety of rice	This variety is of short duration (110–120 days). So, it can be harvested before cyclones that are likely to hit in November. After harvesting, the field can also be used for other crops.
5	Vegetables in floating bed	Vegetables can be grown successfully in floating beds under waterlogged condition caused by flood.
6	Sorjan method	This is suitable for vegetable cultivation in saline soils. In this method, alternate ridges and furrows are made. Salts from the ridge can leach down to the furrows. Vegetables are grown on the ridges and furrows can be used for fish culture.
7	Pond side vegetable cultivation	Sides of the ponds or embankments are a little raised, and hence, remain above water during less severe floods. Salinity is also lower than the crop fields. So, vegetables can be grown by the sides of the ponds.
8	Watermelon cultivation	Can tolerate soil salinity to some extent.
9	Sunflower cultivation	Can tolerate soil salinity to some extent.
10	Plum cultivation	Can tolerate soil salinity to some extent. Additional irrigation water is not needed.
11	Relay cropping	Felon (cowpea) seeds are sown before harvesting aman rice (after monsoon). It does not need any tillage operations that can cause water loss from the soil. Relay crop can also ensure greater use of a single piece of land. Less nitrogenous fertilizer is needed for the next crop as cowpea adds some nitrogen to the soil.
12	Urea deep placement	Deep placement of urea super granules decreases volatilization loss of nitrogen, and hence, it reduces the total amount of nitrogenous fertilizers needed to be applied. So there is less emission of nitrous oxide to the atmosphere.
13	Organic fertilizer	Application of organic fertilizers (e.g. vermi-compost) reduces the emission of CO_2 and NO_2 from production and application of chemical fertilizers.
14	Mulching	Mulching preserves soil moisture, and thus, crops need less irrigation water.
15	Use of pheromone trap	This trap is used to control insect pests of crops and vegetables. Therefore, less chemical pesticide is required.
16	Rain water harvesting	Rain water harvesting in canals and ponds reduces the pressure on groundwater for irrigation. River water is saline in coastal areas but rain water is fresh. So, harvested rain water is a good source of water for irrigation during dry periods.
17	Seed storage	Seeds stored in plastic bags/glass bottles remain protected against disease, insect pests and damp weather conditions.

The adoption quotient is a multiplication of three indices, namely extent (e_j/p_j), time ($t_p - t_2 - g/t_p - t_1$) and difficulty $\left(W_j/\sum_{j=1}^{N} W_j\right)$. The geometric mean of these three indices was computed to obtain the aggregate adoption status (UNDP 2016). Hence, the larger extent to which the technology was adopted, the earlier the technology was adopted, and the more difficult the adopted technology, the higher would be the adoption coefficient. The difficulty of adoption was defined as the average score of difficulty of adoption mentioned by the adopters. A given technology is not adopted by all the farmers, so only adopter farmers were asked about how difficult the technology was to practice. Based on their opinion (0 = easy, 1 = slightly difficult, 2 = very difficult), an average score was computed for each of the 17 selected CSA practices.

Thus, the overall adoption quotient was the weighted average of 17 CSA practices with respect to the difficulty of adoption. However, difficulty weight was not used to compute the adoption quotient of individual CSA practices. Therefore, this multidimensional approach to measure adoption provides more detailed information than other simple measurement techniques of adoption, such as adoption vs. non-adoption, number of adopted practices, or other one-dimensional measurements.

Three important indicators were used to measure household food security status: the Household Food Insecurity Access Score (HFIAS) (Coates et al. 2007; Deitchler et al. 2010), the Household Dietary Diversity Score (HDDS) (Adesina and Baidu-Forson 1995); and per capita annual food expenditure (Frankenberger 1992; Rose and Charlton 2002);. The HFIAS consists of nine occurrence questions with four levels of severity based on a recall period of the previous four weeks (30 days). The four severity options represent a range of frequencies (0 = not at all, 1 = rarely, 2 = sometimes, 3 = often). The maximum score for a household is 27, indicating severe food insecurity; the minimum score is 0, which signals that the household is food secure (Coates et al. 2007). The HDDS was measured by the number of food groups (out of 12 groups) consumed by the household one day before the interview (Swindale and Bilinsky 2006). Finally, per capita annual food expenditure was measured by annualizing the weekly expenditures on rice, potato, vegetables, fish, meat, fruits, beverages and grocery items such as spices, onion, garlic, sugar and salt. Farmers consume many of these foods produced on their own farms. Therefore, total consumed food products from their own production, food received as a wage and that purchased from markets were converted to monetary values considering the existing market price.

In order to determine the association of the farmers' CSA adoption and characteristics with their household food security, the three food security indicators were considered as three outcome variables. The following regression was estimated separately for each of the food security indicators:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_k X_{ki} + u_i$$

Where, Y_i represent the food security status of household i and X_{ki} is a vector of farm and household characteristics. The independent variables used in the regression models had VIF less than 2. The model was found to have a problem with heteroscedasticity or non-constant variance in the predicted values of dependent variables. To obtain more efficient estimates, White's heteroscedasticity consistent robust standard errors were computed. The coefficient of determination (R^2) and F statistics were used to validate the models (Faraway 2002; Gujarati and Porter 2009). Data analysis and mapping were performed using statistical and graphical software RStudio (Version 1.0.153) along with the additional 'car' and 'ggplot2' packages (Fox and Weisberg 2011; R Core Team 2016; Wickham 2009).

3 Results

3.1 Adoption of CSA practices

The sampled farmers knew on average 14 practices and adopted an average of seven out of the 17 CSA practices. The number of CSA practices adopted by the farmers varied from one to 16. Farmers had an average adoption quotient of 48.4% ($SD = 13.8$), while the total adoption quotient ranged from 11 to 75%. Among the CSA practices, urea deep placement followed by sorjan method, pheromone trap and seed storage techniques had the highest adoption quotients (Table 3). CSA practices with the lowest adoption quotients were plum cultivation followed by sunflower cultivation, vegetable cultivation on a floating bed, water melon cultivation, mulching and pond-side vegetable cultivation. The total number of adopters among the 118 households after the establishment of CFS in 2013 increased for all the CSA practices. The difficulty weight of the CSA practices did not show a significant correlation with average adoption quotients ($r = -0.11$, $p = 0.67$). However, when we dropped two CSA practices (urea deep placement and sorjan method of vegetable cultivation), the correlation coefficient became significant ($r = -0.59$, $p = 0.02$). Therefore, all other CSA practices except these two followed Rogers' (2003) theory which states that the more complex an innovation is to practice the less will be its adoption.

3.2 Household food security status

Household food security was measured using three different indicators: HFIAS, HDDS and per capita annual food expenditure. The observed HFIAS ranged from 0 to 24 against a possible range of 0 to 27. The selected households had overall low food insecurity scores ($M = 5.48$, $SD = 5.42$). Based on the guidelines of the Food and Nutrition Technical Assistance (FANTA) project of the United States Agency for International Development (USAID) (Coates et al. 2007), the respondents were categorized into four groups of household food insecurity access prevalence (HFIAP) according to the occurrence of different food insecurity conditions. Among the sampled households, 32% were assessed as food secure, 16% mildly insecure, 35% moderately insecure and 17% were severely food insecure. Average scores for occurrence

Table 3 Adoption of individual climate-smart agricultural (CSA) practices in southern Bangladesh

Climate-smart agricultural practices	Total number of adopters in 2016	Number of adopters before 2013	Difficulty weight out of 2	Average adoption (%)	Observed range of adoption	Maximum years of adoption
Seed storage	113	108	0.12	21.7	0–92	30
Urea deep placement	81	49	1.05	42.2	0–100	4
Sorjan method	62	49	0.89	25.8	0–100	9
Relay cropping	62	55	0.40	15.7	0–100	30
Pond side vegetable cultivation	55	38	0.35	9.50	0–67	30
Organic fertilizer	55	44	0.62	13.8	0–100	25
Drought resistant crop varieties	52	40	0.52	12.5	0–100	30
Saline tolerant crop varieties	46	30	0.85	17.9	0–100	7
Use of pheromone trap	45	37	0.40	23.1	0–100	7
Mulching	44	32	0.55	7.39	0–60	25
Rain water harvesting	39	35	0.59	10.4	0–100	30
Flood tolerant crop varieties	39	24	0.64	18.6	0–100	6
Early variety of rice	31	18	0.84	11.9	0–100	7
Water melon cultivation	22	17	1.05	6.54	0–100	20
Vegetables on floating bed	20	10	1.25	4.57	0–71	9
Plum cultivation	11	5	0.55	1.70	0–40	25
Sunflower cultivation	8	5	1.38	2.52	0–100	10

questions revealed that farmers mostly worried about food availability, quantity, quality and preference. Severe conditions, such as skipping meals, going to bed hungry or without food were less common (Fig. 2).

The observed HDDS of the sampled farmers indicates that the households consumed three to 12 different food groups daily ($M = 7.88$, $SD = 1.85$). Table 4 shows that all the households consumed rice daily since this is the staple food in Bangladesh. More than 100 households also consumed potatoes and vegetables. However, meat consumption was low. All other food groups were consumed by more than half of the sampled households.

The other indicator of food security used in this paper was per capita annual food expenditure of the households. It included monetary value in Euro incurred per person per year for his/her food consumption from own farms and from other sources such as purchase from markets and food for work. The annual expenditure on food per person ranged from 50 to 472 Euro with an average of 198.2 Euro ($SD = 98.8$). Among the households, 16% had up to 100 Euro, 39% had more than 100 to 200, 29% had more than 200 to 300 and 16% had more than 300 Euro of per capita annual food expenditure. The median value of per capita annual food expenditure was 180 Euro, which was less than the mean value. Thus, over half of the households occupied the lower side of the positively skewed distribution, which implies that a smaller fraction of them (46%) could spend on food items more than the

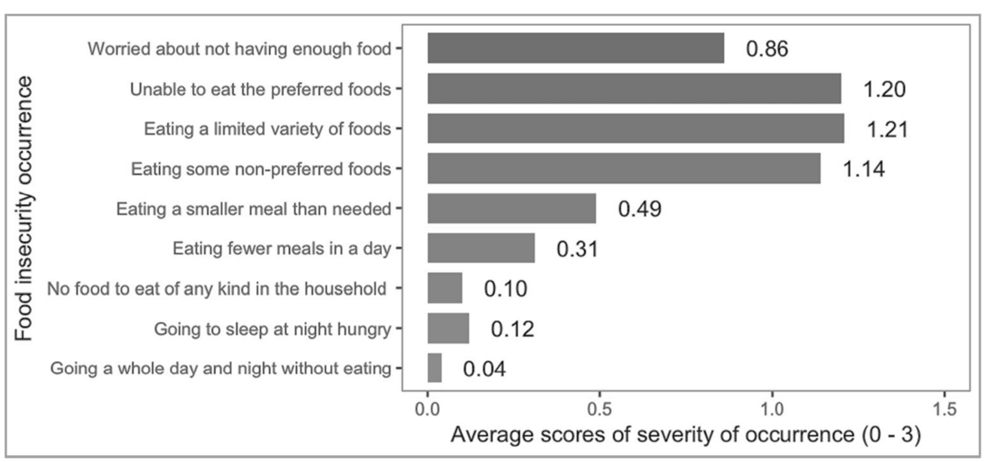

Fig. 2 The average scores on the items of household food insecurity access scale for coastal Bangladesh

Table 4 Number of households having food items one day before the interview

Food groups	Number of households	Percentage of households
1. Rice/grain	118	100
2. Potatoes/roots/tubers	102	86.4
3. Vegetables	104	88.1
4. Fruits	68	57.6
5. Meat	19	16.1
6. Eggs	62	52.5
7. Fish	87	73.7
8. Beans/peas/lentils/nuts	73	61.9
9. Milk/milk products	77	65.3
10. Oil/fat/butter	67	56.8
11. Sugar/honey	79	67.0
12. Tea/coffee	74	62.7

average value of per capita annual food expenditure. In comparison to non-food expenditure, the interviewed farmers spent 51% of their total expenditure on food items (Table 5). The most important food items in food expenditure were whole rice (unhusked), potato, vegetables and grocery items such as oil, salt, sugar, spices, onion, garlic, meat, fish, milk and eggs. They spent little on fruits, biscuits, beverages and eating outside their homes. After meeting food expenses, households had limited scope to spend on other items. About half of the non-food expenditure of the households went to farm operations, the repayment of loans and medical costs.

3.3 Description of the predictor variables

The explanatory variables in Table 6 were selected for multiple regression considering their importance to explain the dependent variables. The relative importance of the predictor variables was determined by correlation test and stepwise regressions. Among the sampled farmers, 52% were middle-aged (36 to 55 years old), 25% were young (< 36 years) and 23% were old (> 55 years). Young people were less involved in farming activities as they preferred other non-farm diversified activities for their income generation. On the other hand, old people were not likely to perform farm activities as they preferred to transfer farm responsibilities to their middle-aged sons. Therefore, middle-aged farmers were the majority of the respondent farmers. Three-quarters of the farmers had small to medium family size (< 5 members) while only 25% of them had large families. The average family size of the sampled households (5.37) was larger than the national average household size of 4.53, which was 5.19 in 2000 (BBS 2010). Traditionally, rural areas of Bangladesh have joint and large families, though the number of large families has decreased due to economic diversification.

The average personal education level of farmers was 5.47 years of schooling, with a high level of variation (coefficient of variation 79%). The literacy rate of the farmers was 83% but they had mostly (49% of the farmers) primary level education. The majority of the respondent farmers (64%) had only farming activities as their occupation, and the remaining 36% had farming along with other income generating activities such as job/service, wage labor, a business, self-employed small enterprise, being a driver and retired service holders. Farming was the major earning activity of the sampled households. Among the total 216 employed household members, 56% were only farmers, 31% were retired, drivers and mixed occupation holders, and the remaining 13% were job/service holders, wage laborers, businessmen and self-employed persons in shoe shops, other shops, library booksellers, tailors and middlemen in cattle, rice and vegetable markets. The average cultivated land area was 1.15 ha, which included the total area cultivated in three crop growing seasons in a year. Farmers had high variation in the ownership of pond and cattle as indicated by a standard deviation above average values.

The households had a low level of annual income; 64% with less than 2000 Euro, and only 13% with more than 3000 Euro. Fruits and forestry were found to add negligible income to the total amount, but these items could contribute more if the farmers could properly translate their consumed portion into monetary value. The average extent of market difficulty was apparently low against a possible range of 0 to 24. Among the farmers, 33% did not have difficulty to access markets while the others (67%) mentioned different levels of difficulty to access markets in terms of long distance, lower price, high rate of tax for a stall in the market and inappropriate weight

Table 5 Share of total expenditures on food and non-food items

Food items	Percentage	Non-food items	Percentage
Rice, wheat	14.7	Clothing, footwear	8.50
Potato, vegetables	5.87	Electric appliances, furniture, kitchen-wear	6.84
Grocery items	9.18	Cleaning, cosmetics	2.65
Fish, meat	9.03	Electricity, telephone	2.40
Milk, eggs	5.19	Schooling, books	4.66
Fruits, sweets, bakery	2.76	Farm operation	11.9
Beverage, others	4.30	Loan repay, medical, others	12.0
Total share on food items (%)	51.0	Total share on non-food items	49.0

measurement. The farmers said that middlemen generally bought 46 *ser* (42.9 kg) of rice but paid for 40 *ser* (37.3 kg). Thus, they lost the revenue for 5.6 kg of rice per *maund* (a local unit that is equal to 37.3 kg) of rice selling. Among the farmers, 77% could reach a market within half an hour by walking. In some cases, middlemen went to the farmers for their farm produce, such as vegetables, cattle, chicken and fish as they had prior communication with each other. The scores for farmers' access to farm information on crop, vegetable, fisheries and livestock production could vary from 0 to 30. Farmers had relatively low access to farm information. They considered input dealers to be a less credible source of farm information because they have a tendency to advise the purchase of products that are more profitable for their business. Agricultural extension agents were considered by the farmers to be the most reliable sources of farm information because of their expertise, professionalism and trustworthy information.

Perception of climate change scores could vary from 0 to 130, whereas the observed scores ranged from 27 to 118. The majority (61%) of the farmers had a medium (score 46 to 90) perception of climate change. Farmers understood climate change by a single indicator, or a combination of different indicators such as increased warming, more tidal cyclones, change in rainfall, increase in soil salinity and increased occurrences of flood. Deforestation was the topmost perceived cause of climate change while the top scored consequence of climate change was warmer summers. Farmers perceived that climate change would mainly result in the loss of food production and could be tackled by awareness building and tree planting. These perceptions concur with scientific findings about climate change. Farmers obtained information on climate change from the CFS, informed family members, friends and mass media. The main cause of climate change is the anthropogenic emission of CO_2 from fossil fuel combustion in mills, industries and oil-operated engines (IPCC 2014) that was also well reflected in their responses.

Table 6 Description of the variables for multiple regression

Variables (unit/score)	Obs. range	Mean	SD
Adoption of CSA (%)	11–75	48.4	13.8
CFS membership (yes/no)	0–1	0.50	0.50
Personal education (years of schooling)	0–20	5.47	4.31
Occupation (farming/other)	0–1	0.64	0.48
Family size (number)	2–9	5.37	1.43
Cultivated farm size (ha)	0–5.87	1.15	1.07
Pond size (100 m^2)	0–67.2	7.03	10.5
Cattle ownership (number)	0–15	3.22	3.25
Annual household income (thousand Euro)	0.19–6.78	1.94	1.26
Market difficulty (score)	0–21	5.08	6.29
Access to farm information (score)	1–24	8.19	5.74
Perception of climate change (score)	27–118	80.2	18.8

3.4 Association of adoption of CSA and farmers' attributes with food security

To assess the association of adoption of CSA practices by the farmers with their household food security status, multiple linear regression analysis was undertaken (see Table 7). We found that food security was determined by the adoption of CSA practices, along with other characteristics of the farmers such as CFS membership status, personal education, occupation, family size, pond size, cattle ownership, income, market difficulty and access to information. Our main focus, the adoption of CSA practices, was expected to positively contribute to household food security. Adoption of CSA practices had a significant positive correlation only with the per capita annual food expenditure. It did not have a significant correlation with the HFIAS and the HDDS. Overall, the household food security status of resource-poor coastal farmers was positively influenced by the adoption of CSA practices along with their personal education, farming as a major occupation, number of cattle owned and annual household income, and was negatively influenced by the family size and difficulty with market access. These findings are generally consistent with other studies and reviews (see Bashir and Schilizzi 2013; De Cock et al. 2013; Kassie et al. 2012; Mason et al. 2015; Misselhorn 2005; Sekhampu 2013).

Table 7 Multiple linear regression of food security indicators

Predictors	HFIAS[a]***		HDDS[b]***		Per capita food expenditure[c]***	
	Coeff.	Robust SE	Coeff.	Robust SE	Coeff.	Robust SE
Adoption of CSA	0.05	0.03	0.01	0.01	1.48**	0.58
CFS membership	−1.93***	0.65	−0.73*	0.33	9.51	15.6
Personal education	−0.05	0.09	0.08**	0.03	5.52***	1.91
Occupation	0.84	0.70	1.15***	0.32	15.1	15.0
Family size	0.32	0.21	0.03	0.12	−20.4***	5.13
Cultivated farm size	–	–	−0.12	0.13	−0.52	6.95
Pond size	−0.05	0.03	0.03**	0.01	1.35*	0.64
Cattle ownership	−0.22*	0.11	0.09*	0.04	8.82***	2.24
Annual household income	−0.07	0.39	0.23*	0.11	–	–
Market difficulty	0.29***	0.06	−0.08***	0.02	−0.34	1.56
Access to farm information	0.48***	0.09	–	–	1.91	1.90
Perception of climate change	0.01	0.02	0.01	0.01	−0.45	0.43
(Intercept)	−2.54	2.47	5.43***	0.96	177***	48.1

*, ** and *** denote significant at 5%, 1%, and 0.1% level of probability

[a] Household Food Insecurity Access Score (HFIAS): $R^2 = 0.62$, F (11, 106) = 15.4, p = 0.00

[b] Household Dietary Diversity Score (HDDS). $R^2 = 0.32$. F (11, 106) = 4.47, $p = 0.00$

[c] Per capita annual food expenditure: $R^2 = 0.41$, F (11, 106) = 6.81, p = 0.00

3.5 Linkage between individual CSA practices and food security

Table 7 indicates that the adoption of CSA and household food security in terms of per capita annual food expenditure were positively correlated. To identify the most important CSA practices, Pearson simple correlation coefficients (r) were computed between CSA practices and per capita food expenditure (Table 8). Adoption of salinity resistant crop varieties, flood tolerant crop varieties, pond side vegetable cultivation and water harvesting practices had significant positive relationships with the per capita food expenditure.

Table 8 Correlation between CSA adoption and per capita annual food expenditure

CSA practices	Correlation (r) coefficients	*P* values with 116 d.f.
Saline tolerant crop varieties	0.20*	0.027
Flood tolerant crop varieties	0.44***	0.000
Drought resistant crop varieties	0.11	0.218
Early variety of rice	0.06	0.507
Vegetables on floating bed	0.16	0.092
Sorjan method	0.03	0.768
Pond side vegetable cultivation	0.27**	0.003
Watermelon cultivation	0.17	0.059
Sunflower cultivation	−0.01	0.912
Plum cultivation	−0.03	0.777
Relay cropping	0.09	0.353
Urea deep placement	0.09	0.352
Organic fertilizer	0.10	0.263
Mulching	0.17	0.071
Use of pheromone trap	0.17	0.070
Rain water harvesting	0.18*	0.049
Seed storage	−0.07	0.427

*, ** and *** denote significant at 5%, 1%, and 0.1% level of probability

4 Discussion and conclusion

With the aim of exploring the linkage between CSA adoption and household food security in coastal areas of Bangladesh, this study identified 17 CSA practices that may be adopted by the interviewed households. There is no suitable Bengali term for the phrase 'climate-smart agriculture (CSA)'. Although none of the respondent farmers were aware of the term CSA, they were performing practices considered to be CSA just by knowing that these practices were appropriate under adverse climatic conditions, and that they were benefiting from these practices. Farmers had been using some of these practices for a long time, well before extension agents formally introduced them. As an example, saline-tolerant and flood tolerant high yielding varieties of rice, developed by Bangladesh Rice Research Institute, were introduced in the study area in 2009 and 2010 by the extension agency, but the CFSs were only established in 2013. The most recent CSA practice, the urea deep placement technique for rice, developed and validated by the International Fertilizer Development Center (see IFDC 2017), was disseminated among farmers in the study area during 2012. Therefore, all of these practices were older than the CFS. Accordingly, the CFS itself did not add new practices but it did help to increase and intensify the awareness and adoption of those existing practices among the farmers.

The farmers had variation in the extent of adoption of the different CSA practices, which were influenced by their perceived difficulty to practice them. Yet, although urea deep placement and the sorjan method of vegetable cultivation are relatively more difficult to do, their adoption was higher than that of other practices. Farmers adopted these practices more extensively because of their need, suitability and enabling conditions to support their use. The IFDC had created enabling conditions for urea deep placement in Bangladesh through training and extension programs supported by USAID funding (Nash et al. 2016). Urea deep placement was perceived by the farmers to be helpful for the production of their staple food (rice) and the sorjan method allowed them to utilize their saline soils for the production of vegetables and fish. However, adoption of agricultural technologies does not depend only on their ease or difficulty of use; rather it depends on multiple socio-demographic and economic characteristics of farmers (Pannell et al. 2006; Knowler and Bradshaw 2007; Rogers 2003).

Food security encompasses four dimensions: availability, access, utilization and stability (FAO 1996, 2002; Schmidhuber and Tubiello 2007; USAID 1992). We only investigated the availability of appropriate foods and their consumption without addressing the stability dimension of food security. The sampled households worried about the availability of enough food and they had to often eat some non-preferred and limited varieties of foods due to a lack of resources. They had at least something to eat. Therefore, it was rare to find households in the study area having no food, going to sleep hungry or going a whole day without eating. The average per capita food expenditure (0.54 Euro per day) in a household was not sufficient to provide foods for a day. Three common homemade meals (consisting of rice, vegetables and a little fish) for a person per day in rural areas required this amount of money to pay for them. This estimation of per day food expenditure was not adjusted for children. Fifty-four percent of the households had a food expenditure that was lower than this requirement. Besides, the HDDS of the farmers indicated that they mainly consumed carbohydrate-rich food items. The share of food expenditure on total household expenditure was large (51%), though it was slightly less than that reported in the national data (54%) (BBS 2010). These food expenditures covered all food items consumed either from own production or other places in monetary values. Therefore, considering the HFIAS, HDDS and per capita annual food expenditure, there was a prevailing medium level of food security in the study area. To measure food security, we used a four week recall period for the HFIAS and a one day recall period for the HDDS. It could be that farmers may feel more food secure just after harvesting their crops but at other times of year they might feel less food secure. Therefore, the measurement of household food security might have been sensitive to the timing of the data collection. Besides, variability of rainfall, cyclones and tidal surges that also affect crop production in the coastal regions (Kabir and Golder 2017) could result in yearly variation in household food security.

The adoption of CSA practices might improve food security through improving food production, enhancing income and increasing per capita annual food expenditure. A linkage between the adoption of CSA practices and household food security in the study area was found in terms of per capita annual expenditure on foods. The number of adopted CSA practices was positively correlated with annual household income ($r = 0.28$, $p = 0.00$). Therefore, the farmers with higher extent of CSA adoption were likely to be more food secure in terms of higher per capita annual food expenditure implying a greater amount of food consumption. Brüssow et al. (2017) also found that adopters of CSA practices tended to be more food secure than non-adopters. Comparison of the standardized regression coefficients of adoption on per capita annual food expenditure ($\beta = 0.21$) with that of other significant variables, namely family size (β = −0.30), cattle ownership (β = 0.29), personal education (β = 0.24) and pond size (β = 0.14), suggested that adoption of CSA had a stronger association with food expenditure than having a larger pond, but less than other regressors. We calculated that a 1 % increase in adoption of CSA practices raises the per capita annual food expenditure by only 1.48 Euro (cf. Table 7), which is a small amount compared to other factors including family size, personal education and cattle ownership. As mentioned above, the increased total monetary value of consumed food items in terms of per capita food expenditure can be considered as a proxy indicator of the improvement of food security (Frankenberger 1992; Rose and Charlton 2002).

Households with CFS membership tended to be more food secure, as indicated by the significant regression coefficient with the HFIAS. The farmers involved in CFS had 9% higher adoption of CSA than non-CFS farmers ($t(116) = 3.77$, $p = 0.00$). Although a positive correlation between CFS membership and food security was observed, we could not establish a causal effect because CFS and non-CFS farmers could differ in their (un)observed household and farm characteristics. For instance, the CFS farmers had a farm that was on average 0.41 ha larger than non-CFS farmers (*Welch's* $t(107) = 3.21$, $p = 0.00$) and they might also differ from non-CFS farmers in other aspects, such as 'farming ability' that we did not try to assess. We can therefore not rule out that the more food secure farmers self-selected into the CFS. Perhaps CFS farmers had less cropping diversity or were accustomed to rely more on their self-produced food items rather than purchasing various foods and fruits from markets. CFS membership might increase production but our results suggest that it did not increase crop diversity that is needed to ensure dietary diversity. Indeed, the farmers involved in CFS had a lower diversity in food items than non-CFS farmers. Personal education of the farmers was positively correlated with the HDDS and per capita annual food expenditures. This could be because better-educated farmers may have a higher income and might be more aware of nutritional requirements for a healthy lifestyle. Other studies have also found that the HDDS varied with variation in education level (De Cock et al. 2013). Households with farming as a major occupation were likely to have a higher HDDS. Our findings were as expected because the farmers mostly had a mixed type of farming, including crops, livestock and fisheries, which facilitate their access to diversified food items. Family size was negatively associated with per capita annual food expenditure because of farmers' difficulty in affording higher food expenditures for the larger family, which is consistent with findings of other studies (e.g., Mequanent and Esubalew 2015).

The HFIAS decreased with the increase in number of cattle owned by the farmers because cattle ownership could increase the consumption of milk and meat in the households. However, pond size and cattle ownership had significant positive correlations with the HDDS and per capita annual food expenditure. This makes sense because the farmers with larger ponds and more domestic animals had better opportunities to increase income and consume diversified foods, such as fish and meat. To have a pond and a few cattle (ox, cow and buffalo) works as a form of savings for resource-poor households. Those farmers can easily consume meat to improve their food security and dietary diversity. They also have the opportunity to sell their cattle to increase their investment in other productive sectors that can indirectly enhance their food security status. Annual household income is another important indicator of HDDS. With an increased income, farmers could have more choices in their selection of foods and, consequently, their HDDS tended to increase.

Market difficulty had a significant positive correlation with the HFIAS and a negative correlation with the HDDS. Farmers who faced difficulties to access markets could not purchase enough agricultural inputs and food items. In the same way, they could not sell their commodities at profitable prices to increase their income. Therefore, it was difficult for them to maintain dietary diversity. Consequently, the difficulty with market access negatively influenced their household food security. A similar association of distance to main markets with household food security was found in other research in Africa (Kassie et al. 2012). Access to farm information had a positive association with the HFIAS. This was surprising because the results suggest that farmers with better access to information had lower food security. This might be due to unobserved variables, such as the quality of information and effective use of the information. In our study, access to farm information was measured by the frequency of contact with different information sources, but we could not assess whether the information was useful and whether the farmers really used the information to enhance their farm production and food security.

The factors affecting HFIAS, HDDS and per capita annual food expenditure are not necessarily the same. Hence, recommendations useful for one of these indicators of food security may not be suitable for others. To improve household food security, promoting the adoption of CSA practices is important but not a sufficient condition because other characteristics of the farmers also appeared to be very important contributors to food security. According to the relationship of each of the CSA practices with per capita food expenditure, the most important CSA practices were saline- and flood-tolerant crop varieties, pond-side vegetable cultivation and water harvesting practices that could improve the household food security of coastal farmers. These findings appear consistent considering the geographical location of the study area. Salinity is a problem in coastal areas of Bangladesh (Shelley et al. 2016). Crop fields remain submerged for prolonged periods (Awal 2014) and the sides of ponds are raised in order to facilitate vegetable cultivation, particularly during the rainy season. During dry months (November–February), farmers can irrigate their vegetables and crop fields by using water they stored in canals or ponds during the rainy season from July to September. Therefore, salinity- and flood-tolerant crop varieties, pond side vegetable cultivation and water harvesting practices were positively correlated with per capita food expenditure.

From this study we conclude that a weak linkage between CSA adoption and household food security in terms of per capita annual food expenditure existed in this area of coastal Bangladesh. No significant linkage was found for the other two food security indicators, namely HFIAS and HDDS. This overall weak association could be due to the limitation of measuring the adoption quotient of CSA. In our study the adoption quotient was measured by assigning weights to the land area under CSA practices, the number of CSA practices used, and the duration and difficulty of use of the practices. However, the formula for the adoption quotient that we used did not consider the relative profitability of different CSA practices. These practices were of variable importance for their beneficial effects on enhancing food production and household income. For example, early maturing varieties of rice would yield more only when there was a drought experienced by regular varieties. Mulching or use of organic manure have different beneficial effects on crop production than seed storage practices. Accounting for the relative importance of these CSA practices on yield and income could generate more accurate linkages between CSA adoption and the food security of farmer households. In addition, the contribution of adoption on the HFIAS and HDDS could be too indirect to be captured. Research with a larger sample size involving structural equation modeling and eliminating measurement limitations might allow a more robust assessment of the contribution of the adoption of CSA to food security. Additionally, it is clear that food security does not depend only on the adoption of CSA practices, but on many other characteristics as well. Personal education, pond size, cattle ownership and market difficulty all showed linkages with at least two of the three food security indicators, and it appears that overall these were better contributors to food security than CSA adoption in the study area.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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Md Kamrul Hasan is a PhD Fellow in the School of Environmental and Rural Science, the University of New England, Australia. He is also an Associate Professor in the Department of Agricultural Extension and Rural Development, Patuakhali Science and Technology University, Bangladesh. Kamrul has been researching the impacts of climate change on farming systems, agricultural adaptation to climate change and food security issues. He is a graduate of Bangladesh Agricultural University and obtained an IMRD degree from Ghent University, Belgium.

Sam Desiere is currently a senior researcher at HIVA (https://hiva.kuleuven.be/en/labour-market-research-group/00112469), the research institute for work and society of the University of Leuven in Belgium. In 2015 he obtained a PhD in agricultural economics from Ghent University which focused on data quality of household surveys in developing countries. Sam has published several academic articles assessing the accuracy of instruments to measure food security.

Marijke D'Haese is a Professor in the Department of Agricultural Economics at Ghent University, Belgium, and holds a PhD in Applied Biological Sciences from that University. She has been involved in studies on rural development since 1997 with a research focus on agricultural development, food security and rural poverty.

Lalit Kumar is a Professor of Spatial Analysis and Climate Change Modelling, School of Environment and Rural Science in the University of New England, Armidale, Australia. His research experience involves environmental modelling that covers: Climate change impacts on small island states in the Pacific and the Himalayan region; Species Distribution Modelling in investigating the impacts of climate change and weeds on endemic biodiversity; Climate change impacts on agricultural productivity and land suitability; Remote Sensing of invasive weed species Ecological Remote Sensing, with emphasis on vegetation pattern analysis and monitoring, agricultural land use mapping as well as wildlife habitat evaluation. Spectral discrimination of vegetation species and biodiversity assessment using hyperspectral remote sensing.