joints in the rock. This was also the main cause of slope failure in the Raunthi catchment.

The disasters have increased in the area as a result of increasing anthropogenic activities. This trend is likely to continue in future as development activities are a threat to the environment. The natural flow paths of rivers have been obstructed due to the construction of man-made structures, resulting in the deviation of natural flow. Apprehending the tendency of increasing urbanization due to increase in developmental activities in the area, selection of safe land-use locations would be a formidable task to accomplish. However, the Government has to consider these issues in future while rebuilding the devastated area.

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Economic analysis of pesticide expenditure for managing the invasive fall armyworm, *Spodoptera frugiperda* (J.E. Smith) by maize farmers in Karnataka, India

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The fall armyworm (FAW) *Spodoptera frugiperda* (J.E. Smith) invaded India for the first time in May 2018 in Karnataka and since then has threatened maize production in the country. In this study conducted during 2017–2020, a total of 150 smallholder maize farms were randomly selected and surveyed from three major maize-growing districts in Karnataka for the pesticide usage patterns, pesticide cost and yield. During 2020, FAW infestation level was recorded at 2.15 larvae per 100 plants with an overall Davis damage score of 3.80. Maize farmers used on an average 2.12 pesticide sprays per season for FAW management in the surveyed districts in 2020. Maize yield was 4.46, 3.76, 4.06 and 4.18 tonnes per hectare in 2017, 2018, 2019 and 2020 respectively, and the average cost on

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pesticides spent by farmers per 100 kg maize grain during the same years was US$ 0.124, US$ 2.04, US$ 1.68 and US$ 1.39 respectively. The study highlights the effect of FAW invasion on pest management regime in the maize crops of Karnataka. Integrated pest management is the need of the hour to reduce the environmental impact of synthetic pesticides use and to protect the incomes and livelihood of the smallholders.

Keywords: Economic analysis, fall armyworm, maize farmers, pesticide expenditure, yield.

In India, maize is the third most important cereal crop grown after rice and wheat. In 2019, the crop was grown on an area of 9.20 million hectare with a production of 27.82 million metric tonnes (MMT)[1]. The area under maize in Karnataka was 1.34 million hectare with a production of 3.73 MMT and average yield of 2.77 metric tonnes per hectare (t/ha)[2]. Davanagere, Shivamogga and Chitradurga are the major maize-growing districts in Karnataka covering an area of 0.30 million hectare (ref. 3).Various factors affect maize production and productivity in the tropical maize-growing areas in India, insect pests being one among them.

The fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) is a pest native to the Americas[4,5]. It is highly migratory in nature, has high fecundity and a voracious feeding behaviour without diapause. These characteristics make it one of the most destructive insect-pests of crops. Outside the Americas, FAW was first reported in West Africa in January 2016 (ref. 6) and has spread to more than 40 countries across Africa[7,8].

During May 2018, FAW was noticed for the first time in India on maize crops in Karnataka[9], and subsequently reported in various states in the country as well as other countries across the Asia-Pacific[10,11]. The FAW life cycle ranges from 32 to 46 days[12]. The pest was even reported to have displaced the native stem borers in some areas[13]. FAW feeds extensively on maize foliage; however, most of the economic damage is caused by the late instar larvae that bore into the maize ears[8]. Since its invasion in 2018, FAW has rapidly spread across India[14–16]. The damage to maize crops during July 2018 to February 2019 varied between 20% and 80% (ref. 17). This was estimated to have resulted in a reduction in total maize output by 37,000–75,000 tonnes[18].

In Africa, farmers in several countries responded to FAW invasion by resorting to excessive application of chemical insecticides[8]. This has resulted in an increase in the usage of highly dangerous or restricted-use pesticides by smallholder farmers in the region, many of whom are completely unaware of proper pesticide handling procedures[19]. According to integrated pest management (IPM) guidelines, synthetic pesticides can only be used as a last resort, that too after proper field-level monitoring of the pests using appropriate pheromone traps. In Karnataka, IPM-based practices for FAW control were widely disseminated to the farmers since the invasion of the pest in mid-2018. However, no studies were conducted on the economic analysis of pesticide expenditure for managing FAW. In this study, we analysed the effect of FAW invasion on the pest management practices (e.g. pesticide usage, number of applications) by the maize farmers in Davanagere, Shivamogga and Chitradurga districts of Karnataka, a major maize-growing state in India and pesticide expenditure to maize farmers for controlling FAW.

Field visits and farmer surveys were conducted during June–July 2020 in Davanagere, Shivamogga and Chitradurga districts of Karnataka. In these three districts, majority of the farmers cultivate maize during the *kharif* (monsoon) season. Farmers also grow maize in the *rabi* (winter) and summer seasons, depending upon the irrigation available. In the three districts, the surveyed maize fields ranged from 0.5 to 8 hectare in size (average size of around 1.2 hectare). In June 2018, FAW occurred for the first time in these three districts at high population densities.

Field surveys were carried out to assess the relative abundance of FAW larvae in the maize fields during 15 June to 30 July 2020 in the three districts. Data were recorded from a total of 150 individual farms through household (face-to-face) surveys/interviews. In most of the fields, farmers planted commercial maize hybrids (CP 818, NK6240, S6668 plus, P3550 and TATA Dhanya). The growth stages of the crop varied from V2 to V8 (i.e. 2–8 leaves with visible leaf collars). The seed rate used by the surveyed farmers was 18 kg per ha. In each field, observations were recorded by walking in a 'W'-shape with recording done in five spots (20 plants per spot). A total of 100 plants were screened per field to record observations on the number of FAW larvae, per cent damaged plants and the level of leaf damage caused by FAW on the Davis 0–9 scale[20].

In addition to the above-mentioned surveys in farmer-managed fields, in 2020, two experimental plots (1000 m^2 each) were established in Agricultural and Horticultural Research Station, Kattalagere, Davanagere district, and Zonal Agricultural and Horticultural Research Station, Shivamogga, to assess pest infestation levels in the absence of pesticide use. A commercial maize hybrid CP 818 (CP Seeds Pvt India Limited, Mumbai) was planted in the second week of June 2020 with a spacing of 60 cm row-to-row and 20 cm plant-to-plant. Observations were recorded at 30 days after planting on the mean number of FAW larvae, per cent damaged plants and the level of leaf damage (based on Davis scale). For the surveyed fields in 2020, the farmers in each of the surveyed fields were interviewed about their pest management practices, using a questionnaire with open-ended choice questions. Each farmer was asked to freely list the type of pesticide that was used during the cropping season and the number of applications. In case of products about which the farmers knew only the trade name, pesticide packages were photographed and the local pesticide dealers were contacted to get information on the active ingredients.

Pesticide application data were gathered for the maize crop seasons (*kharif*) of 2017, 2018, 2019 and 2020. A total of 150 farmers were interviewed in December 2018, 2019 and 2020. In 2018, the data for 2017 were also collected from the surveyed farmers on the pesticides used and the number of applications. In addition, interviews were conducted with 10 agro-dealers to confirm the details regarding local pesticide application regimes during 2017–20. Each questionnaire covered the type of pesticides that were used for FAW management, their respective costs, application frequency and any other IPM practices that were implemented by the farmers. Further, yearly pricing information for the main pesticides from 2018 to 2020 was obtained from 15 local pesticide dealers, whereas the pricing data of harvested maize were provided by the Davanagere maize merchants. Other data, as obtained through household surveys and farmer recalls, could be subject to error and interviewer bias; this was taken into account when interpreting or extrapolating the findings from this study.

The pesticide application frequency and cost of pesticides were compared between the study years (i.e. 2017–2020). Households applying the pesticide were determined and the data, expressed in percentage, were compared over the years. Data on the number of pesticide sprays per crop, pesticide expenditure, maize grain yield and pesticide expenditure (US$/100 kg of maize grain production) were subjected to analysis of variance (ANOVA) and mean values were compared by Tukey's HSD test.

During 2020, FAW was the dominant herbivore in the farmers' maize fields in the surveyed districts, with infestation levels occurring at 2.15 ± 0.16 (mean ± SE) larvae per 100 plants (range 0–71 larvae per 100 plants). Across the surveyed fields, 23.71 ± 0.70% plants exhibited leaf or whorl damage, and the overall Davis damage score was low (i.e. 3.80 ± 0.12 on a 0–9 numerical scale). In the experimental plots without pesticide use, FAW infestation was significantly higher with 156 ± 10.25 larvae per 100 plants, 80.00 ± 0.04% damage incidence and a Davis damage score of 5.73 ± 0.19 (30 days after planting). Within a given field, an average of 1.2 ± 0.80 active ingredients were used to control FAW. Emamectin benzoate was applied in 93% fields, whereas other synthetic pesticides were less common; no farmer had reported to have used biopesticides.

Before the invasion of FAW in India, three pesticide-active ingredients (lambda-cyhalothrin, carbofuron and phorate) were used by farmers in Karnataka for the management of stem borers in the maize fields. Since 2018, when FAW invasion occurred, the pattern of pesticides usage appears to have changed; the most common active ingredients used was emamectin benzoate (76.67%) (Figure 1). In 2019 and 2020, nearly 84% and 91.67% households applied emamectin benzoate against FAW respectively (Figure 1). In 2020, majority of the farmers sprayed emamectin benzoate twice during the maize crop season compared to other insecticides because of its lower price in comparison with other pesticides. Farmers used only sole application of the pesticides like novaluron plus emamectin benzoate, chlorantraniliprole and spinetoram. They chose pesticides based on information obtained from pesticide dealers, State Agricultural Universities, State Department of Agriculture and neighbouring farmers.

Pesticide application frequency differed markedly between successive years ($F_{3,596} = 648.303$, $P < 0.001$). While the farmers reportedly applied pesticides at a low level (0.10 ± 0.02 per season) in 2017, the application frequencies reached 2.85, 2.25 and 2.12 sprays per season in 2018, 2019 and 2020 respectively (Figure 2). Over the course of a single cropping season, the cost of chemical pesticide used on maize crops averaged US$ 5.56 per hectare in 2017. However, in 2018, the cost of crop protection using pesticides in maize increased to US$ 71.23 per hectare ($F_{3,596} = 1.352$, $P < 0.001$) in 2018 and US$ 64.48 per hectare in 2019. In 2020, there was a decrease in the cost of plant protection (US$ 56.01 per hectare) (Figure 2). Prices of the main pesticides largely remained unchanged over 2017–2020, except for emamectin benzoate, which showed a price reduction up to 33.72% and 36.60% in 2019 and 2020 respectively. Maize yield per hectare was 4.47 ± 0.95, 3.76 ± 0.78, 4.06 ± 0.79 and 4.18 ± 0.67 tonnes/hectare ($F_{3,596} = 13.049$, $P < 0.001$) in 2017, 2018, 2019 and 2020 respectively (Figure 3), and pesticide expenditure to produce 100 kg grains increased from US$ 0.124 in 2017 to US$ 1.39 in 2020 (Figure 3). The crop protection cost to produce 100 kg of maize in fields in the assessed districts increased 11.20 times between 2017 and 2020 to manage FAW.

Among the farmers surveyed, only 6.66% used conventional insecticides (carbofuron, phorate and lambda cyhalothrin) to combat maize stem borers before FAW invasion in India. When FAW invaded Karnataka in 2018, maize farmers began using new-generation insecticides, including emamectin benzoate and novaluron-plus-emamectin benzoate in addition to chlorantraniliprole and spinetoram.

The Directorate of Plant Protection, Quarantine and Storage (DPPQS), Faridabad, Haryana, India, endorsed the use of azadirachtin-based insecticides, *Bacillus thuringiensis* (*Bt*) and other biopesticides for FAW management. However, farmers largely favoured the application of synthetic pesticides and chose emamectin benzoate and emamectin benzoate-plus-novaluron, possibly due to their relatively lower price compared to chlorantraniliprole or spinetoram, though the latter are new-generation insecticides that are highly effective against FAW.

The pesticide application frequency of farmers has increased significantly over the three-year period, with 0.10 pesticide sprays per season in 2017 to 2.10 applications

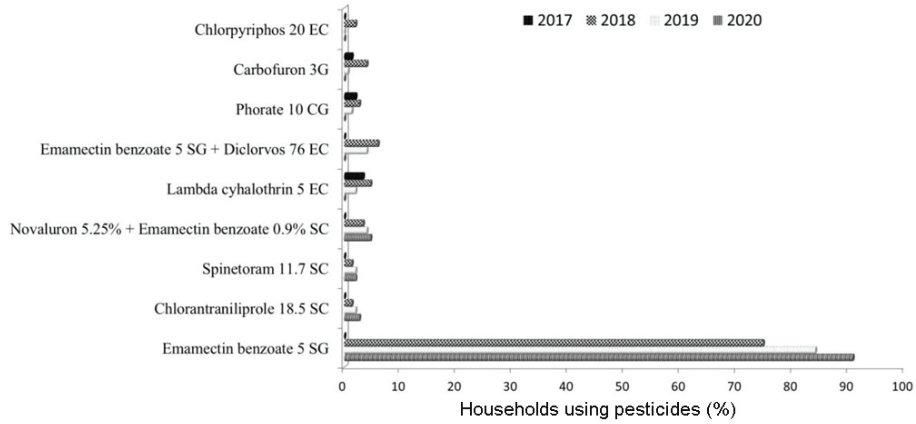

Figure 1. Synthetic pesticides used by farmers for FAW management in maize fields during 2018–2020 in Karnataka, India.

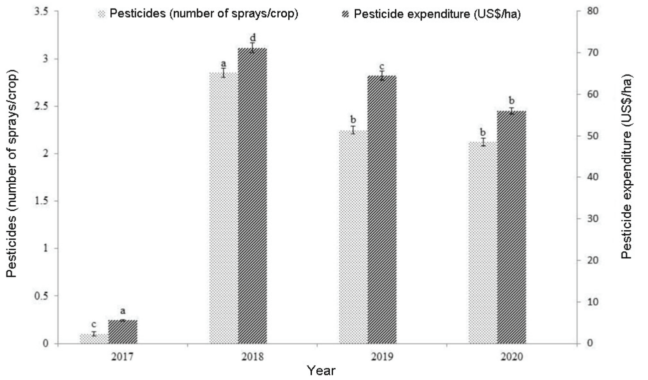

Figure 2. Number of pesticide sprays and pesticide expenditure for FAW management in maize fields from 2018 to 2020 (1 US$ = INR 75.02 on 22 April 2021).

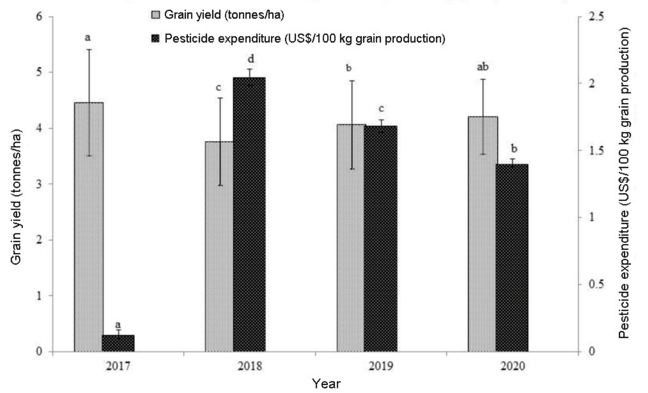

Figure 3. Maize grain yield and pesticide expenditure for FAW management in maize fields from 2018 to 2020.

in 2020. In China, however, the application of pesticides has increased from 2.1 in 2018 to 6.4 in 2020 (ref. 21). In the present study, FAW was observed mainly feeding on foliage and did not damage the maize ears, but in September 2019 and 2020 when the crop was at silk stage, greater mortality of all the larval stages was observed due to *Metarrhizium rileyi* infection. This appears to have prevented the FAW larvae from entering inside the ears and causing damage. These results conform with the findings of Mallapur *et al.*[22] and Sharanabasappa *et al.*[23], wherein higher disease incidence of *Metarrhizium* was noticed in September.

In India, there is a need for developing economic threshold for FAW management. Between 2017 (pre-invasion) and 2020 (post-invasion), Karnataka maize farmers spent an additional US$ 49.32 per hectare (average of 4 years) on pesticides for FAW control. These additional costs are considerable for resource-constrained smallholders. The maize yields during 2020 were largely at par with those in 2017, but the cost of plant protection per hectare per season increased 10 times in 2020. The increase in yield is mainly due to mass awareness programmes conducted by the State Department of Agriculture and State Agricultural Universities to take up different management strategies at the right time, including conservation biological control of FAW. Many awareness programmes were conducted by the State Agricultural Universities, national institutions (e.g. ICAR-IIMR, Ludhiana; NBAIR, Bengaluru), international organizations (CIMMYT, Nairobi, Kenya; CABI, New Delhi, India; ICRISAT, Hyderabad, India) and NGOs (SABC, New Delhi) to extension workers, scientists, pesticide dealers and farmers, soon after FAW outbreak in 2018. In 2020, during the COVID-19 pandemic, the Karnataka State Department of Agriculture and the State Agricultural Universities made intensive efforts in organizing virtual FAW management campaigns in the local language (before planting and 15 days after planting), besides print media and radio.

The use of biopesticides such as *Bt* sprays, entomopathogenic nematodes, application of *Metarhizium anisopliae* and the use of FAW pheromone lures for monitoring or mating disruption are being actively promoted by various agencies. Identification and use of native natural enemies is an important component of IPM. Several studies reported natural enemies on FAW in India[24–26]. The inundative/

augmentative release of well-validated biological enemies against FAW, especially egg parasitoids like *Trichogramma* sp. and *Telenomus* sp., should be taken up as a priority by both public and private sector institutions in India. In addition to biological control agents, biorational pesticides could also be potentially incorporated into the IPM-based strategies[24]. Udayakumar *et al.*[27] and Varshney *et al.*[28] showed that legume-based intercropping and bio-intensive management could help in reducing the incidence of FAW on maize. DPPQS made an ad-hoc recommendation of different insecticides for FAW management[29]. Chlorantraniliprole, emamectin benzoate and spinetoram were found to be suitable for managing FAW[30,31].

In the present study, we relied upon field observations in comparatively small areas and data on pest management decision-making were gathered through household surveys or farmer recalls. While the study has some limitations on sample size, the data can be effectively combined with population monitoring, participatory validation of IPM technology packages and increasing awareness among farmers for further understanding the patterns of FAW pest management regimes followed in major maize-growing areas in states like Karnataka. This will enable the design and deployment of relevant IPM-based strategies for sustainable management of FAW.

The present study demonstrates how FAW invasion on maize crops has altered the pest management regimes over the last four years in Karnataka, highlighting the heavy dependence of smallholder farmers on synthetic pesticides. In 2020, maize growers in the three surveyed districts in Karnataka applied more synthetic pesticides compared to 2017. However, farmers' dependency on high-risk pesticides appears to have decreased over the years, whereas more selective compounds such as emamectin benzoate are now more widely used. Given the adverse environmental impacts of chemical-based pest control, a transition towards more sustainable IPM is urgently needed in the smallholders' maize cropping systems in India. Intensive research is required for developing appropriate economic thresholds and to intensify FAW monitoring and surveillance. Environmentally sustainable FAW management requires effective integration of various approaches, including good agronomic practices, host plant resistance, biological control, environmentally safer pesticides and agro-ecological management.

Conflict of interest. The authors declare that they have no known competing financial or other conflicts of interest.

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Alternaria alternata causes leaf and fruit blight in makhana

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Makhana (*Euryale ferox*) is a high-value commodity of nutritional, medicinal and ritualistic significance. North Bihar has occupied a prominent position in terms of both production and productivity of makhana not only in India, but across the globe. Leaf blight disease on makhana was noticed in April 2018, with a severity of 15–20% in a survey of farmers' ponds in North Bihar. Symptoms of the disease were circular, small, light-brown, necrotic, sunken lesion that later turned into a large, dark, blighted area in the leaves. Blighting of fruits was also noticed during June and July 2018. Blighted fruits were small, distorted and twisted with less seed. *Alternaria alternata* was identified as the pathogen causing the disease based on morphological and cultural characteristics of the culture maintained on potato dextrose agar from symptomatic leaf and fruit samples. The fungus gave rise to greyish to grey–black colonies with obclavate to obpyriform, catenulate conidia in chains. Conidia consisted of 2–5 horizontal and 0–2 vertical septa and measured 15–60 × 5–9 μm in dimension. Molecular confirmation was done by sequence analysis of the internal transcribed spacer (ITS) regions of rDNA using ITS1 and ITS4 primers. Eventually, pathogenicity test inferred that leaf and fruit blight in makhana are due to *A. alternata* infection.

Keywords: *Alternaria alternata*, *Euryale ferox*, leaf and fruit blight, makhana, pathogenicity test.

MAKHANA (*Euryale ferox*), also called gorgon nut, is a floating aquatic plant with large leaves and prickly petioles. It is cultivated only in the wetland ecosystem of tropical and subtropical regions. The wild form of makhana is found in Japan, Korea, Bangladesh, China, North America, Nepal and Russia[1]. Bihar, Assam, West Bengal and Odisha are the states in India where it is grown commercially as a high-value commodity[2]. The cultivation of makhana is done in more than 20,000 ha, where Bihar occupies 80% acreage and contributes to more than 90% of the production[3]. North Bihar occupies a prominent position not only in India, but also in the world in terms of makhana production. Seeds of makhana are popped and eaten after roasting, in addition to being used in the preparation of various kinds of sweets and recipes. Makhana supports the cottage industry and is a livelihood option for thousands of fishing families, besides its high nutritional, medicinal and ritualistic significance.

Makhana plays a vital role in the Indian economy owing to its nutraceutical and cultural value. But like other crops, the production of makhana also faces threats of diseases caused by pathogens in the changing climatic scenario. Root rot, botrytis grey mould, tumour formation and many more diseases affect the production of makhana. The leaf blight disease was observed during April 2018 in North Bihar, during a survey and surveillance programme. It was widespread, involving 35–40% of leaf infection rate and 15–20% disease severity. This was based on the analysis of infected and total number of leaves of available plants (average 8) in every quadrate of 9 m^2 out of three random quadrates in each of the 120 ponds/fields representing the entire North Bihar. The occurrence of fruit blight was noticed during June–July 2018 at the

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