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Research Article

COTFLY: A Weather-Based Mobile Application for the Management of Whitefly in Cotton

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ABSTRACT

Cotton is a major fibre crop cultivated in the semi-arid plains of the south-western regions of Punjab. After the introduction of Bt-cotton cultivars, the menace of bollworms has been checked, but sucking pests are the major threats to cotton crops. Amongst these, whitefly (*Bemisia tabaci Gennadius*) is one of the key pests causing economic damage to the crop. Weather is one of the major drivers controlling the growth of cotton crops as well as the whitefly. When the weather parameters become favourable for the growth and multiplication of whiteflies, a proactive approach by farmers is adopted. Many times, excessive spraying of the cotton crop is done. A weather-based and object-oriented mobile application COTFLY was developed. The favourable limits for the whitefly population are maximum temperature within 32-39^{o}C, minimum temperature within 22-28^{o}C, maximum RH within 73-91% and minimum RH within 38-63%. The temperature humidity index (THI), a derived index within 0.35-0.55 helps the growth and propagation of whitefly. The rainfall in light showers helps the whitefly grow, but a heavy downpour of >35mm reduces its population. Based on these thumb rules, the expert knowledge section predicts and then enters the user interface section. This section has been designed to give the output/ advisory after getting the inputs from the farmer w.r.t. whitefly population in his field and earlier management options adopted. This application's interactive interface helps the grower get real-time information on whitefly incidence. Moreover, when the grower gives information on the actual field condition w.r.t. whitefly population and the control measures already adopted, the application accordingly advises the farmer regarding the next step control measures to be adopted. The COTFLY application provides timely information on whitefly and the advisories which prevent both the excessive application of insecticides as well as pollution of soil and air.

Key words: Cotton, Rainfall, Temperature, THI index, Whitefly, Punjab

Introduction

At the global level, the usage of pesticides in the form of insecticides is 44%, while in India it is as high as 76 % (Mathur 1999). India stands 12th in pesticide usage at global level, while it stands 3rd in Asia after China and Turkey (Nayak and Solanki, 2021). The FAOSTAT report (https://www.fao.org/3/cc0918en/cc0918en.pdf) informed that during 2020, at global level ~3.39 million tons of pesticides were used in agriculture, with India accounting for 0.061 million tons (1.8%) usage. Amongst these insecticides, nearly 36-50% are used in cotton followed by paddy and wheat (Akhtar *et al.,* 2009; Ranganathan *et al*., 2018). Cotton is an important commercial crop cultivated for its fibre in the semi-arid regions of the southwestern Punjab. It was grown over 2.47 lakh ha during the year 2022-23 (https://www.pau.edu/content/ccil/pf/pp_kharif.pdf). The

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cotton whitefly (*Bemisia tabaci Gennadius*) is a serious pest of American cotton and its outbreak was recorded in 2015 in Punjab and Haryana (Kumar *et al.,* 2020). Both nymphs and adults suck the cell sap of the plant and so early control of whitefly is needed. When it attacks the crop during early vegetative stages then the growth gets adversely affected, while the attack during later growth period (boll bursting stage) affects the yield. Hence, cotton growers tend to use excessive insecticides to manage whitefly in cotton, which pollutes the environment and increases the cost of cultivation. The indiscriminate usage of insecticides can be checked by following the "Integrated Pest Management" (IPM) approach (Deguine *et al.,* 2021). However, the main hindrance is providing information on the need-based application of these insecticides to farmers promptly.

Pest forecasting models are an essential constituent of the IPM approach. They provide a lead time for managing imminent pest attacks and thus curtail crop loss as well as optimize pest control thereby reducing the cost of cultivation (Damos and Soultani, 2010; Rossi *et al.,* 2023). A Decision Support System (DSS) has a user-friendly front end while at the back end often complex models, knowledge bases, expert systems, and database technologies provide pest control measures to the user (Marinko *et al.,* 2024). An IPM-DSS is an important tool since it addresses two major aspects of pest management, i.e., (i) proper identification of pests, and (ii) precise use of chemical insecticides. Hence it provides the growers with all the important information on pest development and population along with the necessary management options (Franck *et al.,* 2024). These systems are essential to enhance the adoption and spread of IPM in the country.

Several DSS and expert systems have been developed for cotton crop management. Baker and Lemon (1985) developed COMAX which provides integrated information on the management of cotton. The expert system (Lemmon, 1986) has an inbuilt model which predicts the growth and yield of cotton in response to weather parameters, soil variables and pest damage. IPM CALEW Cotton (Goodell *et al.,* 1990) is a user-friendly computer program that simulates the response of cotton to pests, irrigation, and weeds and predicts the effects of any one of the decisions on subsequent events. In Australia, Bange *et al.* (2004) have developed a handheld DSS with an inbuilt *EntomoLOGIC* software for pest management in cotton. Under the NAIP (National Agricultural Innovation Project) of the Indian Council of Agricultural Research (ICAR) a Crop Pest DSS was developed which has inbuilt pest forewarning models for rice and cotton (http://www.icar-crida.res.in:8080/naip/home.jsp). For cotton crop, an online application (https: //www.bighaat.com/kisan-vedika/blogs/management-of-insect-pests-in-cotton?srsltid=AfmBOopGS6G7D IS762AZGz0FWb6dfKdeXhqhSWvYhtgftIBGBkRc_hsA) have provided the biotic and abiotic factors conductive for pest incidence. They have specified that in the absence of natural enemies, hot (27 – 32°C) and humid environmental conditions are conducive for whitefly incidence in cotton.

Generally, the DSS/Expert systems developed for cotton are not providing real time information by integrating the actual field observations on incidence and management of pest for cotton growers. So, the *COTFLY* application was developed with a *"Weather rule-based predictor section"* which simulates the information on the incidence and multiplication of whitefly attacks in cotton. The mobile application can cater to the needs of farmers in the cotton-growing regions of Punjab, India.

Material and Methods

The expert systems which have interactive interfaces are built by interlinking three sections, i.e. i) Expert knowledge section, ii) Predictor section, and iii) Interactive predictor section which are described as under:

Expert Knowledge Section

A fundamental part of building an *"Expert system"* is to collect and organize the knowledge needed to attain a required level of operation. This section is similar to the brain in the human body. In the COTFLY system, the knowledge for running the application has been collected through three primary knowledge sources: (i) human experts, (ii) published literature, and (iii) field observations.

(i) **Human experts:** The Punjab Agricultural University publishes "*Package of Practices*" for crops and this document is updated with the latest research findings. Detailed information on the management of whitefly in cotton crops is available in the package prepared for *kharif* crops. The details of the insecticides and their respective dosage recommended for whitefly management in cotton (Table 1) were incorporated in the expert knowledge section of the COTFLY application.

(ii) **Published literature:** The COFLY application has an inbuilt rule-based predictor section in which the limits for meteorological parameters are specified. An earlier study by Prabhjyot-Kaur *et al.* (2009) reported that hot (maximum temperature >32°C and minimum temperature >25°C) and dry weather with clear sky (sunshine hours >9 hr) conditions are favourable for the build-up of cotton whitefly. In 2021, another study by Prabhjyot-Kaur *et al.* analyzed the whitefly population data to derive the specific ranges of weather parameters conducive to their growth and development. They concluded that the whitefly population flourishes with a maximum temperature of 32-37°C, minimum temperature of 21-29°C, maximum relative humidity of 73-90%, and minimum relative humidity of 38-74%. Light rainfall showers are conducive for whitefly, but rainfall >35mm reduces their population build-up.

(iii) **Field observations:** The COTFLY application is weather rule-based and to derive these thumb rules, whitefly population data collected from farmers' fields from two major cotton growing districts (Bathinda and Faridkot) of Punjab from 2004 to 2015 were analyzed. The weekly pest population data w.r.t. weather data was analyzed and the limits of temperature, relative humidity and rainfall were derived. The comfort index (Temperature humidity index: THI) for whitefly was evaluated using the data on temperature and humidity. The favourable limits of weather for the whitefly population are:

Maximum Temperature >32°C and < 39°C

Minimum Temperature >22°C and < 28°C

Maximum Relative humidity > 73% to <91%

Minimum Relative humidity > 38% to <63%

THI (Temperature Humidity Index) >0.35 and <0.55

The rainfall in light showers helps the whitefly growth but a heavy downpour of >35mm reduces its population. This information was used to build the expert knowledge section of the expert system.

Table 1. Recommended insecticides for management of whitefly in cotton

Brand (Insecticides)	Dose / acre
Clasto 20WG (pyrefluquinazon*)	200 g
Sefina 50 DC (afidopyropen)	400 ml
Osheen 20 SG (dinotefuran)	60 g
Polo/Craze/Ruby/Ludo/Shou 50 WP (diafenthiuron)	200 g
#Lano/Daita 10EC (pyriproxfen)	500 ml
#Oberon/ Voltage 22.9 SC (spiromesifen)	200 ml
Ulala 50 WG (flonicamid)	80 g
Dantotsu 50 WG (clothiandin)	20 g
Fosimite/ E-mite/ Volthion/ Gold Mit 50 EC (ethion)	800 ml
Nimbecidine or Achoo (neem based biopesticide)	1.0 litre
*PAU Homemade Neem extract	1200 ml

(https://www.pau.edu/content/ccil/pf/pp_kharif.pdf)
Safer green chemistry insecticides
More effective against whitefly nymphs

Predictor Section

The COTFLY application was designed to simulate actual conditions of a cotton field using real-time weather data and input from the farmer w.r.t. whitefly population in his field and earlier management options adopted. The basic layout plan of the application is given in Fig. 1.

The predictor section uses an Android app written in HTML and Java for the user interface, and PHP with JavaScript as the backend to calculate and provide the output to the user. It is based on a rule-based simulator which starts each day by reading the temperature (maximum and minimum) and relative humidity (maximum and minimum) data. The flow of information in the predictor is given in Fig. 2. The inbuilt calculator program computes the

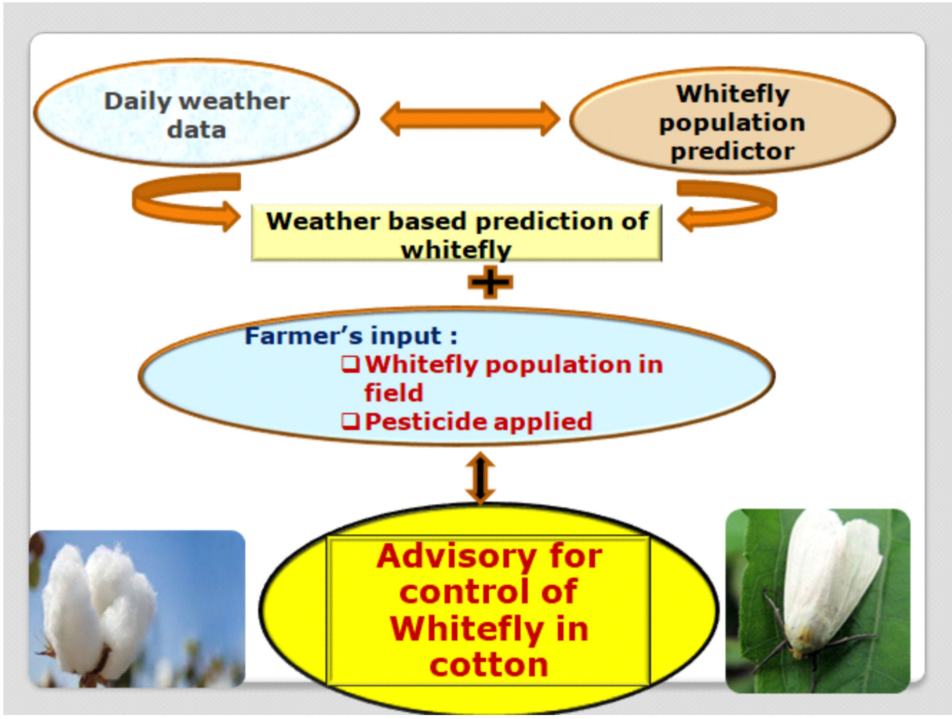

Fig. 1. Basic layout plan of the COTFLY application

THI index. The predicator simulates based on FOUR rules (Table 4), thereafter it enters the user interactive section of the application.

Interactive Predictor Section

This section of the COTFLY application has been designed to give the output/advisory after getting the inputs from the farmer w.r.t. whitefly population in his field and earlier management options adopted. This section works as follows:

1. In the beginning, the user is asked to enter the "DATE" for which the prediction is required. Thereafter, the predictor of the application gives the weather conditions w.r.t. whitefly (Fig. 2) by following the set of RULES defined in Table 2.
2. Then the user is asked to select the level of whitefly population in the field, i.e. 0-4, 4-6 and >6 adult whitefly per leaf in the upper canopy of the plant (Table 3).
3. Then the user is asked to select from the list of spray options, the management already adopted (Table 3).
4. Then the predicator simulates the advisory by

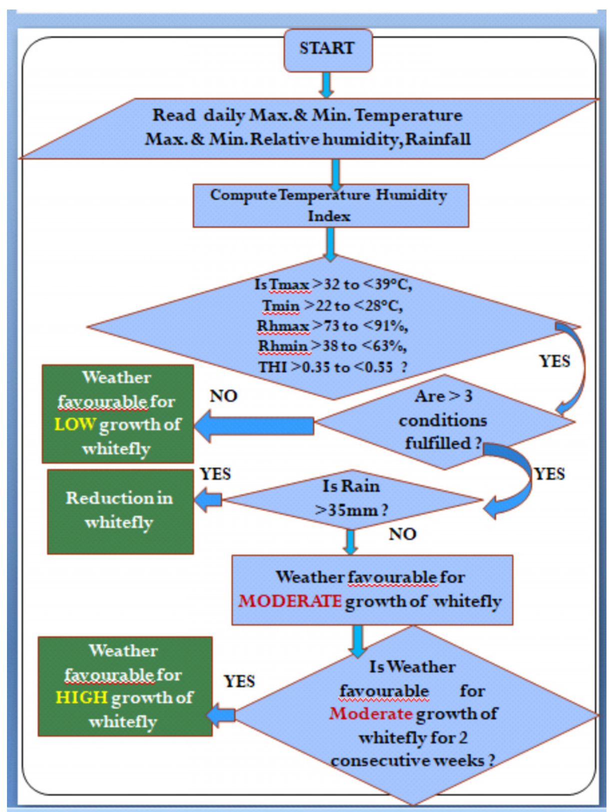

Fig. 2. Flow of information in Predictor Section of COTFLY application

Table 2. Summary of RULES used in the Predictor section of the COTFLY application

RULES	Conditions tested	Output to be given
RULE 1	Read daily Tmax, Tmin, RHmax, RHmin, Rainfall data. Compute THI = $\frac{(Tmax + Tmin\ ) / 2}{(RMmax=RHmin)/2}$	Give weekly average Tmax, Tmin, RHmax, RHmin, THI. Give cumulative rainfall for past week.
RULE 2	Are three conditions satisfied? i) Out of five conditions, < three are satisfied ii) Out of five conditions, > three are satisfied	i) Weather favourable for LOW growth and development of whitefly ii) Weather favourable for MODERATE growth and development of whitefly
RULE 3	Is RAIN >35 mm	iii) Reduction in whitefly population iv) CAUTION : Regular monitoring require
RULE 4	Is weather favourable for MODERATE growth of whitefly for 2 consecutive weeks ?	v) Weather favourable for HIGH growth and development of whitefly

Table 3. Summary of ADVISORY given in the Interactive Predictor section of the COTFLY application

If ETL : <4.0 adults per leaf in the upper canopy of plant	If ETL : 4.0 to 6.0 adults per leaf in the upper canopy of plant	If ETL : >6.0 adults per leaf in the upper canopy of plant				
		Insecticides	Brand	Dose/acre	Life stage affected	Effect become visible
Regular monitoring of whitefly be done	First two sprays should be done at 5 days interval with Nimbecidine /Achook @ 1.0 litre/acre in 100-150 liters of water to manage whitefly and to conserve the natural enemies	Pyriproxyfen 10 EC	Lano	500 ml	Nymphs	5-7 days after spray
		Spiromesifen 240 SC	Oberon	200 ml	Nymphs	5-7 days after spray
		Pyriflucinazon 20WG	Clasto	200 g	Adults and numphs	3 days after spray
		Flonicamid 50 WG	Ulala	80 g	Adults and nymphs	3 days after spray
		Diafenthiuron 50 WP	Polo/Craze	200 g	Adults and nymphs	3 days after spray
		Ethion 50 EC	Fosmite/ E-mite/ Volthion	800 ml	Adults	2-3 days after spray
		Triazophos 40 EC	Sutathion/ Marktriazo	600 ml	Adults	2-3 days after spray

following an interactive flow of information on the basis of conditions as given in Table 4a, 4b and 4c.

Results and Discussion

Verification of the results of the Expert knowledge section

The weather-based thumb rules on the basis of which the system is predicting the whitefly population count were verified with actual field results on the weekly build-up of whitefly population during 2016 and 2017 (Tables 5 and 6). The verification was done for three major cotton growing districts, i.e. Abohar, Bathinda and Faridkot from Standard Meteorological Week (SMW) 24 (June 11-17) to 42 (October 16-23). When the whitefly count, i.e., <4.0 (Low), 4.0 – 6.0 (Moderate) and >6.0 (High) adults per leaf in the upper canopy of plant predicted by the predictor matched with actual field observations, then it was given a score of 1 and when it did not match then it was given a score of 0. At

Table 4a. Summary of ADVISORY given in the Interactive Predictor section of the COTFLY application
Whitefly count ETL : <4.0 adults per leaf in the upper canopy of plant

User input		Model calculated ouptut	Advisory
0-4	No spray One spray of Nimbecidine /Achook Two spray of Nimbecidine /Achook Flonicamid 50 WG Diafenthiuron 50 WP Pyriproxyfen 10 EC Spiromesifen 240 SC Ethion 50 EC Triazophos 40 EC	"Weather favourable for low growth and development of whitefly"	Do regular monitoring of whitefly
		"Weather favourable for moderate growth and development of whitefly"	Do regular monitoring of whitefly
		"Weather favourable for high growth and development of whitefly"	Do regular monitoring of whitefly
		Reduction in the whitefly population	Do regular monitoring of whitefly

Table 4b. Summary of ADVISORY given in the Interactive Predictor section of the COTFLY application
Whitefly count ETL: 4.0 – 6.0 adults per leaf in the upper canopy of the plant

User input		Model calculated output	Advisory
4-6	No spray One spray of Nimbecidine/ Achook Two sprays of Nimbecidine/ Achook Flonicamid 50 WG Diafenthiuron 50 WP Pyriproxyfen 10 EC Spiromesifen 240 SC Ethion 50 EC Triazophos 40 EC	"Weather favourable for low growth and development of whitefly"	Nimbecidine /Achook @ 1.0 litre/acre in 100-150 litres The second spray of Nimbecidine /Achook be done 5 days after the first spray Do regular monitoring of whitefly
		"Weather favourable for moderate growth and development of whitefly"	Nimbecidine /Achook @ 1.0 litre/acre in 100-150 litres 1. When the adult population is high, spray 200 g Clasto 20WG (pyriflucinazon) or 80 g of Ulala 50WP (flonicamid) or 200 g Polo/ Craze/Ruby/ Ludo/Shoku 50WP (diafenthiuron) or 800 ml E mite/ Fosmite/ Goldmit 50 EC (ethion) or sutathion/ Marktriazo 40EC (triazophos). 2. When nymphal population on the under surface of leaves is high or when honey dew symptoms appear on the plants, spray 500 ml Lano 10EC (pyriproxyfen) or 200 ml Oberon /Voltage 22.9SC (spiromesifen) per acre
		"Weather favourable for high growth and development of whitefly"	Nimbecidine /Achook @ 1.0 litre/acre in 100-150 liters 1. When adult population is high, spray 200 g Clasto 20WG (pyriflucinazon) or 80 g of Ulala 50WP (flonicamid) or 200 g Polo/Craze/Ruby/ Ludo/Shoku 50WP (diafenthiuron) or 800 ml E mite/Fosmite /Goldmit 50 EC (ethion) or sutathion/ Marktriazo 40EC (triazophos). 2. When nymphal population on the under surface of leaves is high or when honey dew symptoms appear on the plants, spray 500 ml Lano 10EC(pyriproxyfen) or 200 ml Oberon/ Voltage 22.9SC (spiromesifen) per acre
		Reduction in whitefly population	Do regular monitoring of whitefly

Table 4c. Summary of ADVISORY given in the Interactive Predictor section of the COTFLY application
Whitefly count ETL >6.0 adults per leaf in the upper canopy of the plant

User input		Model calculated output	Advisory
>6.0	No spray One spray of Nimbecidine/ Achook Two sprays of Nimbecidine/ Achook Flonicamid 50 WG Diafenthiuron 50 WP Pyriproxyfen 10 EC Spiromesifen 240 SC Ethion 50 EC Triazophos 40 EC	"Weather favourable for low growth and development of whitefly"	Nimbecidine /Achook @ 1.0 litre/acre in 100-150 litres 1. when the adult population is high, spray 200 g Clasto 20WG (pyriflucinazon) or 80 g of Ulala 50WP (flonicamid) or 200 g Polo/ Craze/Ruby/Ludo/Shoku 50WP (diafenthiuron) or 800 ml E mite/ Fosmite/ Goldmit 50 EC (ethion) or sutathion/ Marktriazo 40EC (triazophos). 2. When the nymphal population on the undersurface of leaves is high or when honeydew symptoms appear on the plants, spray 500 ml Lano 10EC (pyriproxyfen) or 200 ml Oberon/Voltage 22.9SC (spiromesifen) per acre
		"Weather favourable for moderate growth and development of whitefly"	1. When adult population is high, spray 200 g Clasto 20WG (pyriflucinazon) or 80 g of Ulala 50WP (flonicamid) or 200 g Polo/ Craze/Ruby/ Ludo/Shoku 50WP (diafenthiuron) or 800 ml E mite/Fosmite /Goldmit 50 EC (ethion) or sutathion/ Marktriazo 40EC (triazophos). 2. When nymphal population on the under surface of leaves is high or when honeydew symptoms appear on the plants, spray 500 ml Lano 10EC (pyriproxyfen) or 200 ml Oberon/ Voltage 22.9SC (spiromesifen) per acre
		"Weather favourable for high growth and development of whitefly"	1. When adult population is high, spray 200 g Clasto 20WG (pyriflucinazon) or 80 g of Ulala 50WP (flonicamid) or 200 g Polo/Craze/Ruby/ Ludo/Shoku 50WP (diafenthiuron) or 800 ml E mite/Fosmite/ Goldmit 50 EC (ethion) or sutathion/ Marktriazo 40EC (triazophos). 2. When nymphal population on the under surface of leaves is high or when honeydew symptoms appear on the plants, spray 500 ml Lano 10EC (pyriproxyfen) or 200 ml Oberon/ Voltage 22.9SC (spiromesifen) per acre
		Reduction in the whitefly population	Do regular monitoring of whitefly

Abohar, Bathinda and Faridkot stations, the validation score during 2016 was 79, 95 and 84 per cent, respectively (Table 5); and during 2017 it was 74, 95 and 84%, respectively (Table 6). So, the overall predictive score of 86 and 82% during crop year 2016 and 2017, respectively depicted that the predictor section was simulating the incidence and propagation of whitefly based on FIVE conditions

Table 5. Validation of prediction of whitefly count by the Expert knowledge section predictor with actual farmer's field results for three cotton growing stations during 2016 in Punjab

SMW	Dates	Abohar			Bathinda			Faridkot		
		Whitefly count	Predictor output	Score	Whitefly count	Predictor output	Score	Whitefly count	Predictor output	Score
24	11/6-17/6	18.90	Low	0	8.40	Moderate	1	0.60	Moderate	0
25	18/6-24/6	16.89	Low	0	9.67	Moderate	1	11.47	Moderate	1
26	25/6-1/7	14.10	Reduction	1	14.33	High	1	15.27	High	1
27	2/7-8/7	19.65	Moderate	1	16.67	High	1	10.27	High	1
28	9/7-15/7	12.15	Moderate	1	9.33	Reduction	1	9.27	High	1
29	16/7-22/7	11.70	High	1	17.33	Moderate	1	29.00	Reduction	0
30	23/7-29/7	10.35	High	1	19.78	Moderate	1	17.70	Moderate	1
31	30/7-5/8	9.00	High	1	20.33	Moderate	1	8.00	Moderate	1
32	6/8-12/8	7.05	High	1	17.67	Reduction	1	8.50	Reduction	0
33	13/8-19/8	8.01	High	1	7.78	Reduction	1	12.10	Moderate	1
34	20/8-26/8	7.83	High	1	7.00	Reduction	1	10.70	Reduction	1
35	27/8-2/9	6.60	Reduction	1	15.11	Low	0	7.50	Low	0
36	3/9-9/9	7.20	Moderate	1	18.33	Moderate	1	12.50	Moderate	1
37	10/9-16/9	9.60	Moderate	1	38.42	Moderate	1	16.00	Moderate	1
38	17/9-23/9	12.90	High	1	14.70	Moderate	1	14.80	High	1
39	24/9-30/9	11.16	High	1	11.60	Moderate	1	16.15	High	1
40	1/10-7/10	10.62	High	1	9.30	Moderate	1	9.90	High	1
41	8/10-15/10	7.05	Low	0	8.40	Moderate	1	9.00	High	1
42	16/10-23/10	4.38	Low	0	5.40	Moderate	1	5.91	High	1
Validation score				78.94%			94.73%			84.21%
Overall Validation Score : 85.96%										

Table 6. Validation of prediction of whitefly count by the Expert knowledge section predictor with actual farmer's field results for three cotton growing stations during 2017 in Punjab

SMW	Dates	Abohar			Bathinda			Faridkot		
		Whitefly count	Predictor output	Score	Whitefly count	Predictor output	Score	Whitefly count	Predictor output	Score
24	11/6-17/6	1.29	Moderate	0	6.60	Moderate	1	5.20	Low	0
25	18/6-24/6	1.50	Moderate	0	7.80	Reduction	0	12.40	Reduction	0
26	25/6-1/7	3.18	Reduction	0	3.90	Reduction	1	6.30	Reduction	1
27	2/7-8/7	4.50	Moderate	1	2.10	Moderate	0	23.60	Moderate	1
28	9/7-15/7	3.39	Reduction	1	12.60	Moderate	1	13.30	Moderate	1
29	16/7-22/7	7.89	Moderate	1	18.20	Reduction	0	14.50	High	1
30	23/7-29/7	14.01	Moderate	1	27.99	Moderate	1	47.80	High	1
31	30/7-5/8	16.08	Reduction	1	27.30	Reduction	1	11.40	High	1
32	6/8-12/8	20.88	Moderate	1	29.01	Moderate	1	15.10	High	1
33	13/8-19/8	12.93	Moderate	1	29.10	Moderate	1	8.91	High	1
34	20/8-26/8	11.49	High	1	21.30	High	1	6.69	High	1
35	27/8-2/9	9.30	High	1	12.60	High	1	4.20	Reduction	1
36	3/9-9/9	15.09	High	1	15.90	High	1	9.60	Moderate	1
37	10/9-16/9	16.80	High	1	10.50	High	1	15.60	Moderate	1
38	17/9-23/9	12.60	High	1	14.40	High	1	11.10	High	1
39	24/9-30/9	10.80	High	1	13.50	High	1	17.10	High	1
40	1/10-7/10	10.80	High	1	9.90	High	1	14.70	High	1
41	8/10-15/10	9.60	Low	0	8.70	High	1	9.90	High	1
42	16/10-23/10	6.30	Low	0	6.60	High	1	6.60	High	1
Validation score				73.68%			84.21%			89.47%
Overall Validation Score : 82.45%										

of weather parameters satisfactorily. The slight deviations in the predictions may be due to actual management practices followed by farmers at the field level.

COTFLY Mobile Application

The COTFLY Application (Fig. 3) was designed and developed as an Android application to provide an easier access of weather forecasts to cotton

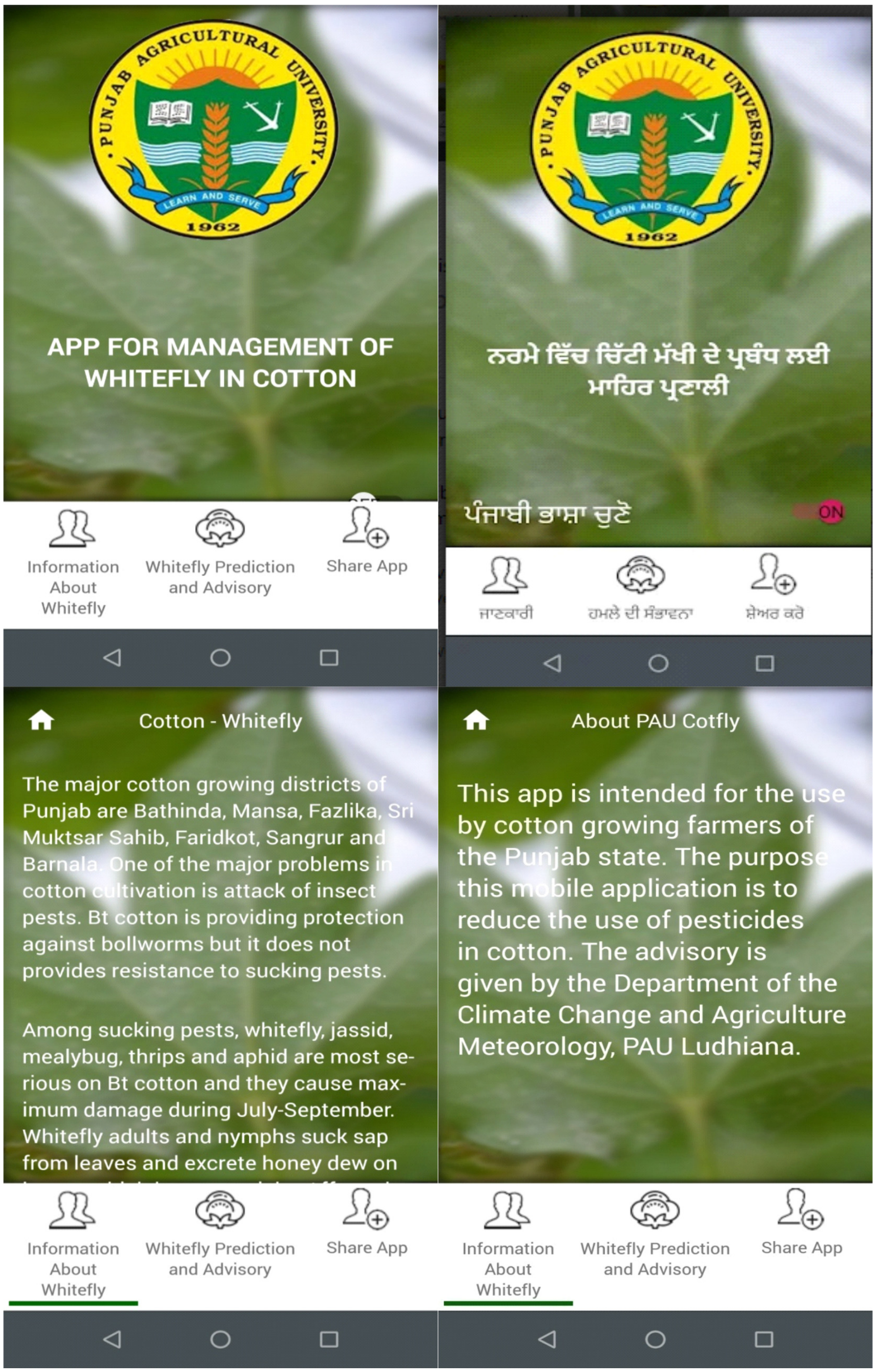

Fig. 3. Information section of the COTFLY mobile application

growing farmers in the state. The application has been developed in two languages, i.e. English and Punjabi (the vernacular language of the state). The advisory given by the application (Fig. 4a and 4b) helped the cotton grower to take precautionary actions against whitefly (insects) in the cotton field.

In Punjab, cotton is cultivated during the summer season, i.e. sowing starts in April and harvesting starts at the end of October (https://www.pau.edu/content/ccil/pf/pp_kharif.pdf). Since the crop passes through the hot dry summers (April-May), wet and humid monsoon (June-September) and cool humid post-

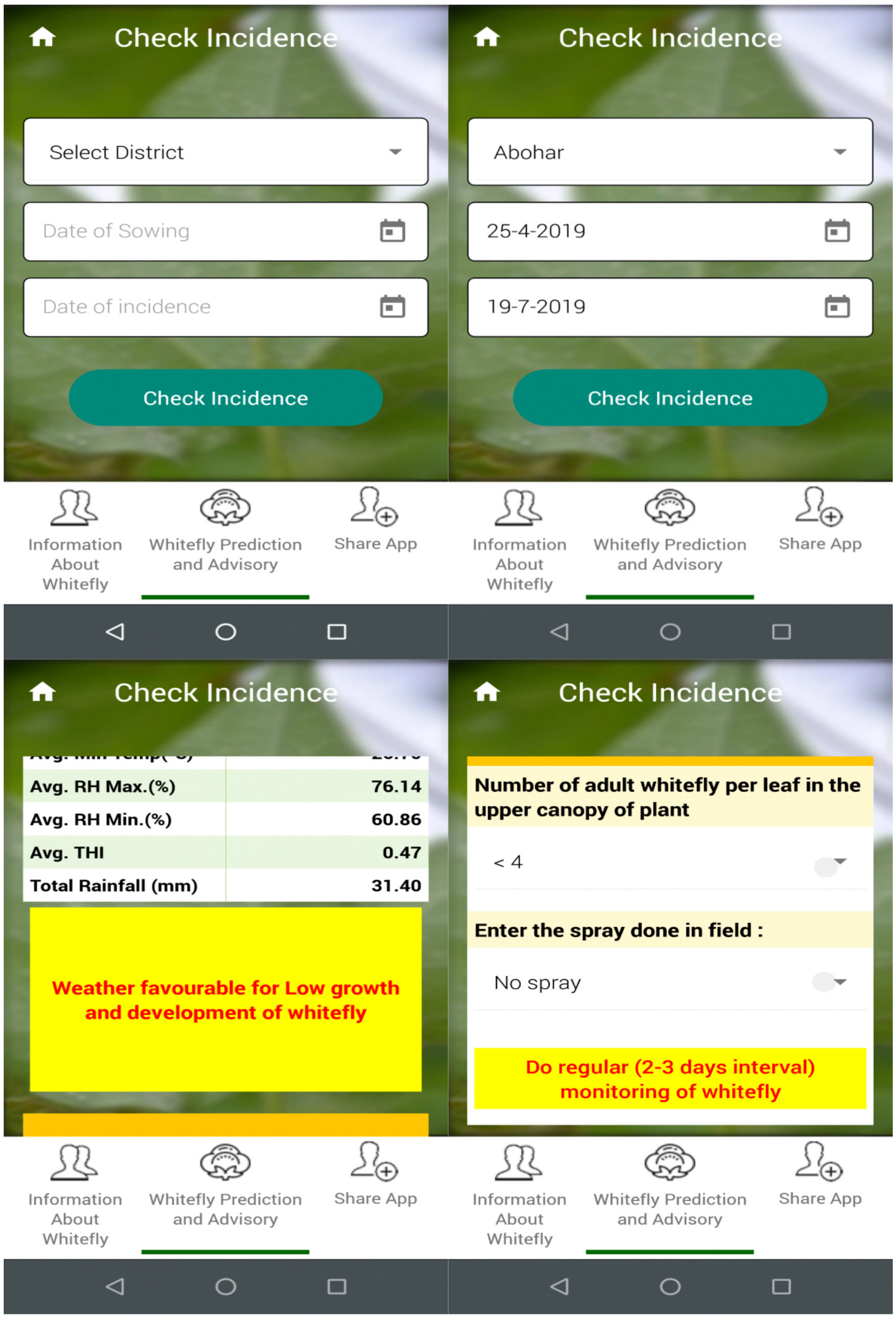

Fig. 4a. INTERACTIVE PREDICTOR section of the COTFLY mobile application

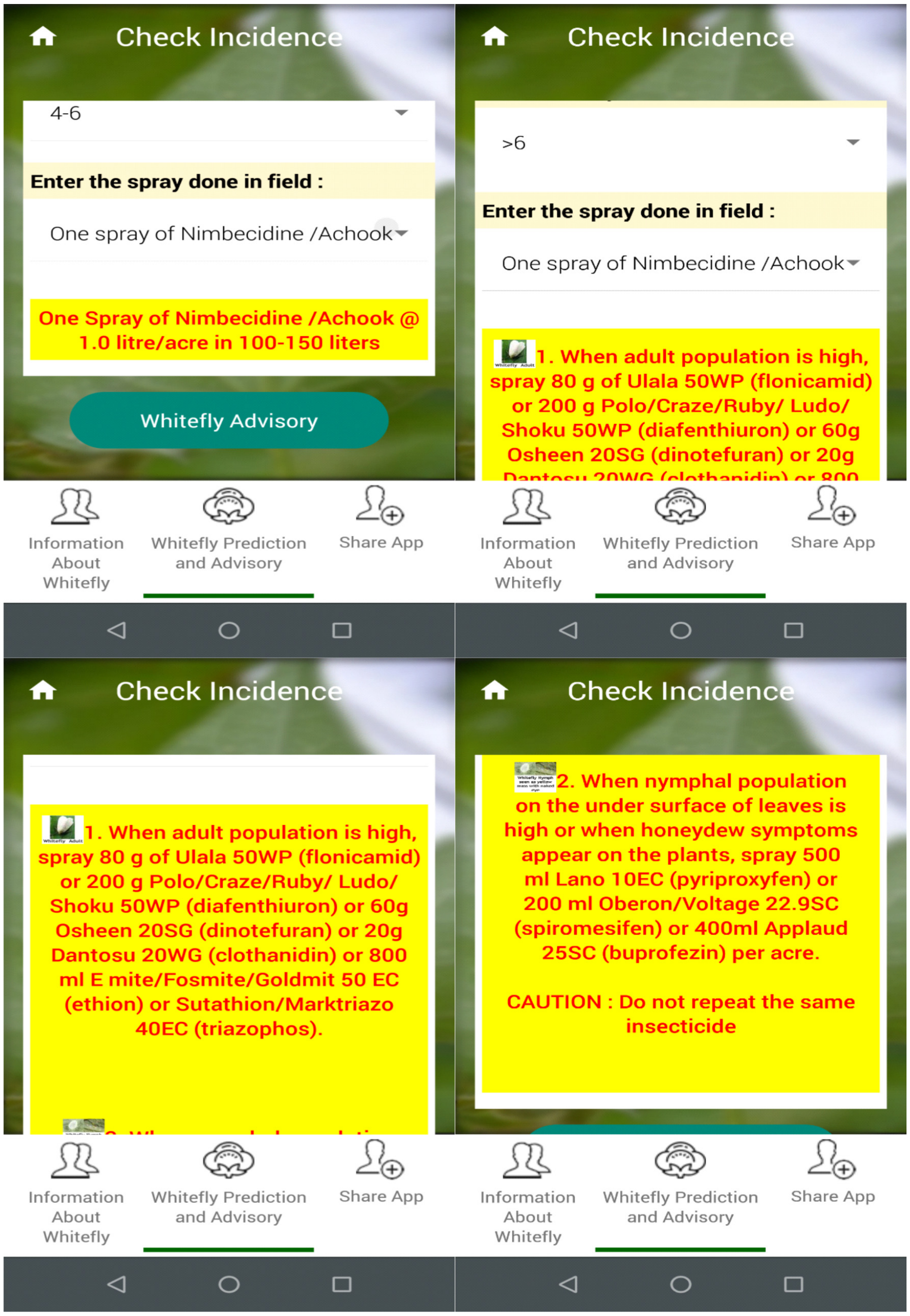

Fig. 4b. INTERACTIVE PREDICTOR section of the COTFLY mobile application

monsoon period (September-November), it is prone to attack from a wide arena of insect pests. Cotton is cultivated as a commercial cash crop, so the farmers tend to spray indiscriminately the cotton with a wide range of pesticides (Ranganathan *et al.*, 2018) which ultimately causes unnecessary environmental pollution. Here the concept of IPM can help reduce environmental pollution (Deguine *et al.,* 2021). Nowadays, interactive tools such as Expert systems (Rani *et al.*, 2011) and Decision support systems (Franck *et al.*, 2024) can be a guiding-tool for the farmers and natural control of excessive environmental degradations.

The COTFLY application is built based on weather-driven rules. Such types of applications eg TEAPEST (Ghosh and Samanta, 2003) are menudriven in which the user input can select or deselect the advisory option. So, it becomes more dynamic and being mobile based is more practically oriented. One of the online application in India have specified that high temperature (27 – 32°C) coupled with high humidity coupled with lack of natural enemies increase the chances of whitefly infestation in cotton (https://www.bighaat.com/kisan-vedika/blogs/management-of-insect-pests-in-cotton?srsltid=AfmBOopG S6G7DIS762AZGz0FWb6df Kde XhqhSWvYhtgftIBGBkRc_hsA). Recently Christakakis *et al.* (2024) have developed a smartphone-based tool for plant disease and insect pest detection that can be used by the grower while standing in the field. Similarly in COTFLY, the user on his mobile phone can select the whitefly population, i.e. <4.0, 4.0-6.0 and >6.0 whitefly adults per leaf in the upper canopy of the plant before 10.00 a.m. and the spray schedule followed. Since, it is primarily driven so the application selects the advisory output by considering the three primary factors, i.e. weather, population stand in the field and spray schedule followed. Hence, this type of application can help the cotton growers decide the line of action to follow using their mobile phones.

Conclusion

Cotton growers are prone to indiscriminate spraying of pesticides during sucking pest attacks especially whitefly, as this pest is a major threat to their livelihood. Weather is a major determinant of growth of crop (Prabhjyot-Kaur *et al*., 2023) and pest. Similarly, conducive weather is a major trigger for an upsurge in whitefly growth and its population upswing, and unfavourable weather is also a major retardant for the growth of whitefly. If this knowledge is combined in the expert knowledge section of a pest expert system, then a powerful tool can be developed for management of whitefly. With this hypothesis, a mobile-based COTFLY application was developed which can help the cotton growers manage whitefly population on the basis of three tiers, i.e. weather during the preceding week, actual population stand of whitefly in the field and spray schedule already adopted. The verification of the expert section of the application was done and later it was translated into a mobile application for use by cotton growers, researchers and extension workers.

Statements and Declarations

Author Contributions

All authors contributed to the study's conception and design. Conceptualization of study [PK, SSS], data collection and analysis [VK, PK], interpretation of results [VK, PK, SSS], programming of the mobile application [RK], validation of the mobile application [PK, SSS]. The draft of the manuscript was written by [PK] and all authors added their comments on the manuscript. All authors read and approved the final manuscript.

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