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Coffee leaf rust or Orange rust caused by the fungus *Hemileia vastatrix* Berk. & Br. is the major disease of coffee in all the coffee growing countries. In the present investigation, evaluation of a new combi-product fungicide molecule against coffee leaf rust disease was carried out under *in vitro* conditions and also in field conditions during 2015-16 and 2016-17 season. The results revealed that under *in vitro* conditions, complete inhibition of uredospore germination in fluxapyroxad 167 g/l + pyraclostrobin 333 g/l in three concentrations 0.4 ml/l, 0.5 ml/l & 0.6 ml/l and pyraclostrobin 20% WG (0.5 ml/l), hexaconazole 5% EC (2.0 ml/l) whereas least (20.42%) uredospore germination in fluxapyroxad 333 g/l @ 0.3 ml/l treatment. Highest (92.65%) spore germination was recorded in untreated control. Under field conditions, during 2015-16 least mean rust incidence (8.71%) was recorded in fluxapyroxad 167 g/l + pyraclostrobin 333 g/l @ 0.5 ml/l, where as highest (18.47%) in untreated control. During the season 2016-17 least mean rust incidence (2.36%) was recorded in fluxapyroxad 167 g/l + pyraclostrobin 333 g/l @ 0.6 ml/l, where as highest (17.67%) in untreated control. Use of combi-product fungicides avoids the development of resistance of fungi to systemic fungicides and manages the disease for longer duration.

Key words: Coffee, field evaluation, fluxapyroxad + pyraclostrobin, *Hemileia vastatrix,* leaf rust, uredospores

INTRODUCTION

Coffee leaf rust or Orange rust caused by the fungus *Hemileia vastatrix* Berk. & Br. is the earliest classic plant disease among the major tropical plant diseases. It is thought to have developed on wild arabica coffee in its centre of diversity in Ethiopia . When the coffee leaf rust first appeared on coffee estates in Sri Lanka and South India, it caused enormous damage to productivity and resulted in the collapse or conversion of many estates as reduced yields made coffee growing uneconomic and replanted with tea which change the social habit of the people from coffee drinking to tea (Waller *et al.* 2007). Besides India, coffee leaf rust has been reported from over 80 coffee growing countries throughout the world . The economic impact of coffee leaf rust occurs not only through reduction of both quality and quantity but also through the expensive control measures on susceptible cultivars. Coffee leaf rust affects the berry yield in many ways *viz.,* reducing photosynthetic efficiency by inducing chlorosis of leaf, inducing defoliation and reducing vigour of plants due to altered physiology. Depending on its severity, not only fewer flowers are formed but also the flower and fruit fall prematurely, the remaining berries in the process of development to mature become floats (Sudhakar *et al.* 2014 ; Daivasikamani *et al.* 2016). In severely affected areas, the leaf rust disease may cause foliage loss up to 50% and berries up to 70% . Further, the pathogen is capable of evolving new races and makes the existing tolerant / resistant cultivar into susceptible. Currently, leaf rust is managed in Indian coffee plantations by growing rust tolerant varieties, proper shade maintenance and spraying prophylactic Bordeaux mixture 0.5% and systemic fungicide hexaconazole (Santoshreddy *et al.* 2016). In the present paper the efficacy of a new combi-product fungicide fluxapyroxad 167 g/l + pyraclostrobin 333 g/l 500 SC is described.

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MATERIALS AND METHODS

Efficacy of fluxapyroxad 167 g/l + pyraclostrobin 333 g/l 500 SC against Hemileia vastatrix Berk. & Br. under in vitro conditions

The matured golden yellow orange colour uredospores of *Hemileia vastatrix* were collected from infected leaves of susceptible *Coffea arabica* variety S.795 in gelatin capsules at Central Coffee Research Institute (CCRI) farm, Coffee Research Station, Chikkamagaluru District, Karnataka, India. The fungicide solutions were prepared with required concentrations in two per cent water agar medium and poured 15 ml solution to 90 mm Petri dishes under controlled conditions. After solidification the collected uredospores were transferred with sterile water on these different fungicide solution incorporated Petri plates and spread uniformly with the help of sterilised spreader. Control is maintained with only water agar medium without fungicide solution. The Petri plates were incubated in dark room at room temperature (25±2°C) and observed for germination of uredospores under microscope 24 hrs after inoculation. Observations on inhibition of germination of uredospores were calculated by using the formula

Per cent inhibition I = C - T / C × 100
where, C – Uredospores germination in control
T - Uredospores germination in fungicide treatments.

Field evaluation of fluxapyroxad 167 g/l + pyraclostrobin 333 g/l 500 SC against coffee leaf rust

Efficacy of fluxapyroxad 167 g/l + pyraclostrobin 333 g/l 500 SC against coffee leaf rust was evaluated at CCRI farm on fifteen years old arabica variety S.795 with eight treatments and three replications using complete randomized block design. The experiment was conducted for two consecutive years i.e., 2015-16 and 2016-17 season. The details are presented in Table 1. The Treatments were imposed by chemical sprays two times during pre and post monsoon and observations on the incidence of coffee leaf rust (CLR) were recorded at regular monthly intervals. The per cent disease incidence was calculated by using the formula;

$$\text{Per cent disease incidence} = \frac{\text{Total number of diseased leaves}}{\text{Total number of leaves examined}} \times 100$$

Actual leaf rust incidence data in per cent were converted to angular transformed values and further subjected to statistical analysis as per the procedures given by Panse and Sukhatme (1985) and Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Use of chemicals are the most common and practical method of managing rust in agricultural crops including coffee leaf rust. However, fungicide tolerance often arises quickly, if a single compound is relied upon too heavily. The CLR disease can be managed under normal weather conditions with a reasonable spray program. The evaluation of new combi-product fungicide molecule fluxapyroxad 167 g/l + pyraclostrobin 333 g/l 500 SC against coffee leaf rust was carried out during 2015-16 and 2016-17 at CCRI, Chikkamagaluru District, Karnataka. The results of the study were presented and discussed in this article.

Efficacy of fluxapyroxad 167 g/l + pyraclostrobin 333 g/l 500 SC against Hemileia vastatrix Berk. & Br. under in vitro conditions

Efficacy of fluxapyroxad 167 g/l + pyraclostrobin 333 g/l 500 SC against *Hemileia vastatrix* was observed under *in vitro* conditions. The results are presented in Table 2.

The results indicated uredospore germination was nil in fluxapyroxad 167 g/l + pyraclostrobin 333 g/l at all the three concentrations tested *viz.,* 0.4 ml/l, 0.5 ml/l and 0.6 ml/l. Pyraclostrobin 20% WG 0.5 ml/l and hexaconazole 5% EC 2.0 ml/l also recorded complete inhibition of ureedospore germination, whereas least (20.42%) uredospore germination was recorded in fluxapyroxad 333 g/l @ 0.3 ml/l treatment. Highest (92.65%) spore germination was recorded in untreated control.

Field evaluation of fluxapyroxad 167 g/l + pyraclostrobin 333 g/l 500 SC against coffee leaf rust

Effect of fungicide fluxapyroxad 167 g/l + pyraclostrobin 333 g/l 500 SC against coffee leaf

Table 1: Treatment details and dosage of chemicals used

	Treatment	Dosage (per ha)		
		a.i. (g)	Formulation	Formulation/lit. water
T_1	Fluxapyroxad 167 g/l + Pyraclostrobin 333 g/l 500 SC	200	400 ml	0.4 ml/l
T_2	Fluxapyroxad 167 g/l + Pyraclostrobin 333 g/l 500 SC	250	500 ml	0.5 ml/l
T_3	Fluxapyroxad 167 g/l + Pyraclostrobin 333 g/l 500 SC	300	600 ml	0.6 ml/l
T_4	Fluxapyroxad 333 g/l	100	300 ml	0.3 ml/l
T_5	Pyraclostrobin 20% WG	100	500 g	0.5 g/l
T_6	Hexaconazole 5% EC	100	2000 ml	2.0 ml/l
T_7	Copper oxy chloride 50% WP	1875	3750 g	3.75 g/l
T_8	Control			-

Table 2: *In vitro* evaluation of fluxapyroxad 167 g/l + pyraclostrobin 333 g/l 500 SC against *Hemileia vastatrix*

	Treatment	Concentration	Germination of uredospores (%)
T_1	Fluxapyroxad 167 g/l + Pyraclostrobin 333 g/l	0.4 ml/l	0.00 (0.00)*
T_2	Fluxapyroxad 167 g/l + Pyraclostrobin 333 g/l	0.5 ml/l	0.00 (0.00)
T_3	Fluxapyroxad 167 g/l + Pyraclostrobin 333 g/l	0.6 ml/l	0.00 (0.00)
T_4	Fluxapyroxad 333 g/l	0.3 ml/l	20.42 (26.87)
T_5	Pyraclostrobin 20% WG	0.5 g/l	0.00 (0.00)
T_6	Hexaconazole 5% EC	2.0 ml/l	0.00 (0.00)
T_7	Copper oxy chloride 50% WG	3.75 g/l	36.04 (36.84)
T_8	Control		92.65 (74.34)
	S.Em. ±	-	1.03
	CD @ 1%	-	4.26

*Figures in parentheses are arc sine values

Table 3: Field efficacy of fluxapyroxad 167 g/l + pyraclostrobin 333 g/l 500 SC against coffee leaf rust during the year 2015-16 at CCRI

Treatments	Leaf rust incidence (%)								
	Jun.15	Jul.15	Aug.15	Sep.15	Oct.15	Nov.15	Dec.15	Jan.16	Mean
T_1	0.76 (20.26)	4.11 (10.70)	7.93 (15.78)*	18.30 (25.30)	17.85 (24.84)	16.77 (24.12)	19.21 (25.92)	8.38 (16.81)	11.66
T_2	1.13 (17.26)	2.41 (8.01)	4.10 (11.51)	12.78 (20.69)	14.40 (21.86)	15.22 (21.87)	15.43 (22.69)	4.24 (11.84)	8.71
T_3	1.31 (22.27)	4.03 (10.87)	4.15 (11.26)	15.53 (22.49)	16.03 (21.91)	16.63 (23.91)	16.17 (23.38)	7.05 (15.00)	10.11
T_4	1.34 (18.04)	4.26 (11.08)	7.18 (15.53)	16.99 (22.93)	20.50 (26.76)	17.76 (23.98)	22.44 (28.24)	8.57 (16.65)	12.38
T_5	1.48 (21.61)	4.96 (11.37)	4.73 (11.48)	16.08 (23.53)	22.28 (27.93)	20.28 (26.03)	23.87 (28.82)	9.50 (17.75)	12.90
T_6	1.50 (23.05)	4.03 (10.87)	4.96 (11.37)	15.31 (22.81)	16.60 (23.83)	17.85 (24.84)	20.76 (27.05)	10.07 (18.40)	11.39
T_7	1.55 (17.34)	6.52 (14.73)	8.42 (16.42)	22.25 (27.25)	25.75 (30.48)	22.92 (28.40)	25.35 (30.04)	16.60 (23.83)	16.17
T_8	4.19 (21.05)	7.65 (15.31)	8.58 (15.95)	23.30 (28.43)	27.14 (30.98)	28.30 (32.14)	29.38 (32.74)	19.18 (25.77)	18.47
S.Em. ±	3.29	3.30	2.82	3.94	3.36	3.49	3.06	2.16	-
CD @ 5%	10.00	10.00	8.56	11.95	10.20	10.60	9.27	6.54	-

*Figures in parentheses are arc sine values

Table 4 : Field efficacy of fluxapyroxad 167 g/l + pyraclostrobin 333 g/l 500 SC against coffee leaf rust during the year 2016-17 at CCRI

	Leaf rust incidence (%)								
Treatments	Jun.16	Jul.16	Aug.16	Sept.16	Oct.16	Nov.16	Dec.16	Jan.17	Mean
T_1	0.45 (3.86)	0.19 (2.48)	0.08 (0.92)	1.03 (3.38)	1.53 (5.77)	3.49 (8.01)	7.32 (12.93)	8.86 (16.18)	2.87
T_2	0.37 (3.46)	0.13 (1.70)	0.00 (0.00)	0.79 (4.04)	1.71 (6.13)	3.11 (9.76)	6.43 (12.53)	8.81 (15.25)	2.67
T_3	0.43 (3.67)	0.21 (2.11)	0.27 (2.34)	0.67 (3.84)	0.99 (4.45)	1.83 (6.36)	6.04 (9.68)	8.43 (15.57)	2.36
T_4	0.46 (3.73)	0.53 (4.15)	1.57 (6.52)	3.03 (9.52)	4.13 (11.64)	9.10 (17.02)	11.84 (19.76)	12.75 (20.05)	5.43
T_5	0.45 (3.13)	0.27 (2.35)	0.50 (2.35)	1.07 (5.89)	1.73 (6.65)	9.83 (16.76)	14.08 (20.34)	10.54 (18.76)	4.81
T_6	0.56 (6.09)	0.79 (4.14)	1.30 (5.78)	1.40 (4.92)	4.03 (10.76)	5.45 (12.93)	8.27 (16.19)	9.13 (16.94)	3.87
T_7	0.84 (4.24)	0.87 (4.61)	1.43 (6.62)	4.86 (11.06)	6.17 (13.50)	11.04 (17.17)	12.31 (20.24)	19.63 (25.42)	7.14
T_8	1.75 (2.08)	4.94 (10.10)	6.11 (12.83)	13.50 (21.19)	20.07 (25.83)	35.41 (35.95)	35.13 (36.02)	24.45 (29.63)	17.67
S.Em. ±	1.40	1.42	2.30	2.74	2.30	4.72	4.85	4.36	-
CD @ 5%	4.27	4.31	6.97	8.33	6.97	14.10	14.50	13.24	-

*Figures in parentheses are arc sine values

Table 5 : Pooled analysis of field efficacy of fluxapyroxad 167 g/l + pyraclostrobin 333 g/l 500 SC against coffee leaf rust at CCRI

	Leaf rust incidence (%)								
Treatments	June	July	August	September	October	November	December	January	Mean
T_1	0.61 (4.46)	2.15 (8.44)	4.01 (11.55)	9.67 (18.12)	9.69 (18.14)	10.13 (18.57)	13.27 (21.37)	8.62 (17.08)	7.27
T_2	0.75 (4.97)	1.27 (6.47)	2.05 (8.24)	7.60 (16.00)	8.47 (16.92)	9.27 (17.73)	9.61 (18.06)	6.55 (14.83)	5.70
T_3	0.87 (5.35)	2.12 (8.38)	2.21 (8.55)	8.10 (16.54)	8.51 (16.97)	9.23 (17.69)	11.11 (19.47)	7.74 (16.16)	6.24
T_4	0. 90 (5.45)	2.40 (8.91)	4.38 (12.08)	10.01 (18.45)	12.32 (20.55)	13.43 (21.51)	17. 14 (24.47)	10.66 (19.06)	8.87
T_5	0. 97 (5.64)	2.62 (9.31)	2.62 (9.31)	8. 58 (17.03)	12.01 (20.28)	15.06 (22.84)	18.98 (25.83)	10.02 (18.46)	10.22
T_6	1.03 (5.83)	2.41 (8.93)	3.13 (10.19)	8.36 (16.81)	10.32 (18.74)	11.65 (19.97)	14.52 (22.40)	9. 60 (18.06)	7.35
T_7	1.20 (6.28)	3.70 (11.09)	4.93 (12.83)	13.56 (21.61)	15.96 (23.56)	16.98 (24.35)	18.83 (25.73)	18.12 (25.20)	11.66
T_8	2.97 (9.93)	6.30 (14.54)	7.35 (15.73)	18.40 (25.41)	23.61 (29.08)	31.86 (34.38)	32.26 (34.62)	21.82 (27.86)	18.07
S.Em. ±	2.32	2.35	2.56	3.34	2.83	4.17	3.95	3.26	-
CD @ 5%	7.14	7.16	7.77	10.14	8.59	12.65	11.99	9.89	-

*Figures in parentheses are arc sine values

rust was observed during 2015-16 season under field conditions which indicated that least mean rust incidence (8.71%) in fluxapyroxad 167 g/l + pyraclostrobin 333 g/l @ 0.5 ml/l which was on par with fluxapyroxad 167 g/l + pyraclostrobin 333 g/l @ 0.6 ml/l, whereas highest (18.47%) in untreated control. During 2016-17 rust incidence was negligible in June month. During peak period the least mean rust incidence (2.36%) in fluxapyroxad 167 g/l + pyraclostrobin 333 g/l @ 0.6 ml/l, where as highest (17.67%) in untreated control. Pooled analysis of both 2015-16 and 2016-17 season indicated that least mean rust incidence (5.70%) in fluxapyroxad 167 g/l +

pyraclostrobin 333 g/l @ 0.5 ml/l which was on par with fluxapyroxad 167 g/l + pyraclostrobin 333 g/l @ 0.6 ml/l. However, highest (18.07%) rust incidence was recorded in untreated control (Table 3, 4 and 5).

Fluxapyroxad is a new broad spectrum fungicide which inhibits respiration of fungi by blocking production of succinate dehydrogenase and it has both excellent preventive and curative activity through inhibition of fungi at several stages of its life cycle including spore germination, germ tube growth, appresorium formation and mycelia growth (Strathmann *et al.* 2011). The strobulirin group of fungicides act through inhibition of respiration by binding to the Qo center of the cytochrome b. These strobulirins have very broad and balanced spectrum of activity on the foliage and have very favorable toxicological profile rapidly dissipating from soil and surface water which are unlikely to cause hazard to non target organisms and they have both protective and curative effect.

Use of combi-product fungicides avoids the development of resistance of fungi compared to systemic fungicides because these systemic fungicides interfere with only one or sometimes two functions in the physiology of fungus which it easily overcomes by either a single mutation or by selection of resistant individuals in a population. Wherein, non-systemic protectant fungicides affect too many functions in fungus physiology to develop resistance. The fungus will have to make too many gene changes.

So, it may be concluded that spraying of new combi-product fungicide molecule fluxapyroxad 167 g/l + pyraclostrobin 333 g/l 500 SC @ 0.5 ml/l which is a combination of both systemic and non-systemic fungicide provides better management of coffee leaf rust and also help in avoiding the fungicide resistance development by pathogen. Hence, combi-product fungicides are better options in the present climate change scenario for management of epidemic plant diseases like coffee leaf rust.

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