Novel management strategy to minimize the growing threat of fruit rot and powdery mildew diseases of chilli (*Capsicum annuum*) in India

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**Abstract**

Chilli (*Capsicum annuum* L.), is severely infected by anthracnose (*Colletotrichum capsici*) and powdery mildew (*Leveillula taurica*), which significantly reduces the quality and yield of chilli in India, especially in the recent years. The concern of modern plant breeding for improvement of new varieties with escape behavior to diseases or genetic resistance, but currently, the use of chemicals offers a practical and rapid solution to combat the disease outbreaks. Compounds having a novel mode of action are of special interest, since they play a key role in resistance management strategies with enhanced characteristics such as systemicity and longer protection period in plant disease management. In the present study, an experiment was conducted for the management of fruit rot and powdery mildew in chilli at Horticulture Research and Extension Center, Devihsour, Bagalkot, Karnataka, India. Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l + 500 SC @ 0.05% recorded significantly least per cent disease index and significantly highest dry yield of chilli compared to all other treatments. It has also recorded significant improvement in quality parameters such as increase in capsanthin and capsaicin content along with improved plant health characters such as prolonged greening and greater dry matter production. The untreated check recorded significantly highest per cent disease index and least dry yield of chilli. The technical feature of this fungicide will provide useful information for stakeholder for target specific action against anthracnose and powdery mildew diseases along with improved plant health, quality and increase in yield.

**Keywords:** Chemical, chilli, fruit rot, management, powdery mildew

1. **Introduction**

Chilli, botanical called *Capsicum annuum* (2n=24) belongs to *Solanaceae* family. It is an indispensable spice and used as basic ingredient in a great variety of cuisines. Chillies are rich in vitamins and are also packed with potassium, magnesium and iron. They have long been used as pain relief as the extracts of chilli peppers are used for alleviating the pain of arthritis, headaches, burns and neuralgia. It also has the property to boost immune system. India, China, Ethiopia, Mexico, Vietnam, Pakistan and Bangladesh accounted for more than 85% of the world production. India is the largest producer and exporter of chilli, grown over an area of 0.794 million hectares with an annual production of 0.13 million tonnes with the productivity of 1.5 tonnes/ha (Anonymous, 2014) [1]. The important states growing chilli are Andhra Pradesh, Karnataka, Maharashtra, West Bengal, Rajasthan and Tamil Nadu. Karnataka ranks second in area and production of dry chilli ([100.73 ('000 ha) and 107.00 ('000 MT)] after Andhra Pradesh (Anonymous, 2014) [3]. In Northern Karnataka, chilli production is highly concentrated in the districts like Dharmawad, Gadag, Haveri, Koppal, Ballari and Raichur. Byadgi chilli varieties grown in Karnataka are well known for quality throughout the world. They possess a unique characteristic flavor and aroma, high colour (175-180 ASTA units) and oleoresin with very less pungency, which makes it the best variety for oleoresin extraction and chilli powder industries. Quality wise it is comparable only to Paprika varieties grown in European countries. There is lot of demand for these chillies both in domestic and international market. Nearly 75 per cent of Byadgi chillies sold in the market are exported in either direct or indirect forms. In 2018-19, around 4 - 5 lakh tonnes of chilli was exported to countries like China, Sri Lanka, Bangladesh, U.A.E, Malaysia, Vietnam and Thailand. For 2019-20, the chilli exports are halted due to COVID 19.
Unfortunately, chilli suffers from many diseases caused by fungi, bacteria, viruses and nematodes. Among the fungal diseases anthracnose or fruit rot caused by *Colletotrichum capsici* and powdery mildew caused by *Leveillula taurica* are most prevalent. These diseases have attained the economic status in the Karnataka state by considering the disease severity, economic damage and exorbitant losses caused by them. The *Colletotrichum capsici* cause severe damage to ripened fruits and reduce the quality and quantity of immature and mature fruits. The economic losses are high due to pre and post harvest involvement of the pathogen causing 10-80 per cent of the marketable yield loss of chilli fruits (Than et al., 2008) [38]. Anthracnose disease is the most damaging disease of chilli reducing marketable yield up to 80 per cent (Poonpolgul and Kumphai, 2007) [28]. Due to anthracnose, more than 50 per cent crop loss has been reported from different parts of India (Ramachandran et al., 2008) [29]. The disease has been reported to cause 19-59 per cent yield loss in Karnataka, 20-60 per cent in Punjab and Haryana and 30-76 per cent in Tamil Nadu (Shilpa and Mesta, 2017) [33].

2. Materials and methods

2.1 Study area and location

The experiment was laid down in randomized block design with three replications at Horticulture Extension and Research Center, Devihsour, Haveri, Karnataka, India (14°47’ North Latitude and 75°21’ East Longitude). This research center is exclusively working on dry chilli especially on byadgi cultivar, as it is one of the most important variety preferred by the consumers both in domestic and international market. The area of individual plot was 17.28 m². Field trial was set up under naturally occurring inoculum of anthracnose (*Colletotrichum capsici*) and powdery mildew (*Leveillula taurica*) as it is one of the important hot spot for both the diseases.

2.2 Plant material and application of fungicides

Seedlings of chilli cv. Byadgi Dabbi were planted in the experimental plot (4.8 m x 3.6 m) with a spacing of 0.6 m x 0.6 m. First spray was given immediately after the initial symptoms of disease were observed and remaining two sprays were given at 15 days interval. Control was maintained with no fungicidal spray. The percent disease was measured using 0-9 disease rating scale as per phytopathometry (Mayee and Datar, 1986) [25]. Per cent disease index was calculated to as per the formula given by Wheeler (1969) [38].

3. Results

3.1 Bio-efficacy

The effect of Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC on fruit rot and powdery mildew diseases of chilli during the year 2016 and 2017 are presented below in the respective tables.

3.1.1 Bio-efficacy of Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC on fruit rot and powdery mildew diseases of chilli during the year 2016

The incidence of fruit rot differed significantly with respect to all the treatments at all stages of observation. Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC @ 300 ml/ha recorded significantly least per cent disease index of 6.6% and it was on par with Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC @ 250 ml/ha (9.62% PDI). The untreated check recorded significantly highest per cent disease index of 24.42% (Table 1 and Figure 1).

Similarly, the severity of powdery mildew differed significantly with respect to all the treatments at all stages of observation. Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC @ 300 ml/ha recorded significantly least per cent disease index of 7.40% and it was on par with Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC @ 250 ml/ha (9.62% PDI). The untreated check recorded significantly highest per cent disease index of 21.46% (Table 2 and Figure 1).

3.1.2 Bio-efficacy of Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC on fruit rot and powdery mildew diseases of chilli during the year 2017

The incidence of fruit rot differed significantly with respect to all the treatments at all stages of observation. Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC @ 300 ml/ha recorded significantly least per cent disease index of 8.14% and it was on par with Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC @ 250 ml/ha (10.36% PDI). The untreated check recorded significantly highest per cent disease index of 25.90% (Table 1).

Similarly, the severity of powdery mildew differed significantly with respect to all the treatments at all stages of observation. Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC @ 300 ml/ha recorded significantly least per cent disease index of 9.62% and it was on par with Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC @ 250 ml/ha (12.58% PDI). The untreated check recorded significantly highest per cent disease index of 34.78% (Table 2).

3.2 Dry yield of chilli

3.2.1 Effect of Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC on dry yield of chilli during 2016

The treatments differed significantly with respect to yield of dry chilli. Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC @ 300 ml/ha recorded significantly highest dry yield of chilli (7.17 q/ha) than all the treatments and it was on par with Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC @ 250 ml/ha (7.04 q/ha). The untreated check (3.41 q/ha) recorded significantly least dry yield of chilli (Table 3).

3.2.2 Effect of Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC on dry yield of chilli during 2017

The treatments differed significantly with respect to yield of dry chilli. Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC @ 300 ml/ha recorded significantly highest dry yield of chilli (9.65 q/ha) than all the treatments and it was on par with Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC @ 250 ml/ha (9.07 q/ha). The untreated check (3.41 q/ha) recorded significantly least dry yield of chilli (Table 3).

3.3 Plant health and quality parameters

The laboratory analysis on quality parameters such as colour and pungency content in chilli fruits revealed that there was significant increase in both colour and pungency content when treated with the test chemical. The treatments differed with respect to colour and pungency content in chilli fruits. Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC @ 250 ml/ha recorded highest colour and pungency content (231 ASTA and 6369 SHU respectively) than compared to carbenzim 50% WP (201 ASTA and 4128 SHU respectively). Further, it was observed that there was significant improvement in plant health characters such as prolonged greening, flowering and fruiting (Table 5 and Figure 1).
3.4 Phytotoxicity
No phytotoxicity symptoms were observed at all stage of crop growth by application of the test chemical Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC of any concentration at 1, 3, 5, 7 and 10 days after the application (Table 4).

4. Discussion
In the present study, Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC @ 250 ml/ha was found effective in controlling fruit rot and powdery mildew without any symptoms of phytotoxicity with significant increase in dry yield of chilli. It has also shown significant improvement in plant health such as prolonged greening and greater dry matter production and quality parameters such as increase in capsanthin and capsaicin content resulting in better market price and higher profit margin.

Similar results were found in the literature, Santoshreddy et al., 2014 [31] reported that among the three systemic fungicides evaluated at 0.2% concentration, pyraclostrobin 20% WG shown least infection (11.63%) of fruit rot and highest vigour index (861.17) in chilli. Abdul Kareem et al., 2016 [1] reported that pyraclostrobin 20% WG @ 375 g/ha recorded significantly least per cent disease index of fruit rot and significantly highest dry yield of chilli (7.05 q/ha). Difenconazole 25% EC @ 0.05% (28.62 PDI) recorded significantly least per cent disease index of fruit rot and powdery mildew (Abdul Kareem et al., 2017) [2]. Pyraclostrobin produced more fruits with higher productivity.

Increases in productivity by the application of strobilurins have also been reported in tomatoes (Cantore et al., 2016) [9], grapes (Berkelmann-Loehnertz et al., 2001; Diaz-Espejo et al., 2012) [6, 12], wheat (Ishikawa et al., 2012; Jorgensen and Olesen, 2002; Kildea et al., 2010; Ruske et al., 2003) [17, 19, 20, 30], corn (Barbosa et al., 2011; Blandino et al., 2012) [4], beans (Jadoski et al., 2015; Kozlowski et al., 2009) [18, 22] and soybeans (Fagan et al., 2010) [13] and beans (Jadoski et al., 2015) [18], the application of different strobilurins also increased carbon dioxide assimilation rates.

The reduction of chlorophyll degradation, combined with better nitrogen utilization, slows plant senescence and contributes to the increase in the net assimilation rate of carbon dioxide, since chlorophyll is an essential component for photosynthesis (Hortensteiner and Krautler, 2011) [16]. Increased photosynthetic activity in the leaves was the main factor for the increase in productivity of the plants treated with strobilurins, since the delay in senescence, even for a few days, tends to increase production (Bertelsen et al., 2001).

The application of azoxystrobin also decreased the rate of net carbon dioxide assimilation, transpiration rate and stomatal conductance in wheat (Nason et al., 2007), barley (Nason et al., 2007), soybean (Nason et al., 2007) and rice (Debona et al., 2016). Similarly, in soybean (Soares et al., 2011) [34] and corn (Barbosa et al., 2011) [4], increase in nitrate reductase enzyme activity occurred.

Table 1: Bio-efficacy of Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC on fruit rot disease of chilli

| Sl. No. | Treatments | Dosage (per ha) | Fruit rot (PDI) |
|---------|------------|----------------|-----------------|
|         | a. i. (g) | Formulation (g) | 2016 | 2017 | Pooled |
| 1. | Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC | 75 | 150 | 15.54 (23.22) | 16.28 (23.80) | 15.91 (23.50) |
| 2. | Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC | 100 | 200 | 13.32 (21.41) | 13.32 (21.41) | 13.32 (21.41) |
| 3. | Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC | 125 | 250 | 9.62 (18.07) | 10.36 (18.78) | 9.99 (18.42) |
| 4. | Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC | 150 | 300 | 6.66 (14.96) | 8.14 (16.58) | 7.40 (15.78) |
| 5. | Pyraclostrobin 20% WG | 100 | 500 | 10.36 (18.78) | 14.06 (22.02) | 12.21 (20.45) |
| 6. | Fluxapyroxad 300 g/l SC | 62.5 | 209 | 11.10 (19.46) | 15.54 (23.22) | 13.32 (21.41) |
| 7. | Hexaconazole 5% EC | 25 | 500 | 10.36 (18.78) | 14.80 (22.63) | 12.58 (20.77) |
| 8. | Carbendazim 50% WP | 250 | 500 | 11.84 (20.13) | 18.50 (25.47) | 15.17 (22.92) |
| 9. | Control | - | - | 24.42 (29.61) | 25.90 (30.59) | 25.16 (30.10) |

Figures in parenthesis are arsine transformed values
Table 2: Bio-efficacy of Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC on powdery mildew of chilli

| Sl. No. | Treatments | Dosage (per ha) | 2016 | 2017 | Pooled |
|---------|------------|----------------|------|------|--------|
|         |            | a. i. (g)      | Formulation (g) |      |        |        |
| 1       | Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC | 75 | 150 | 14.80 (22.63) | 19.98 (26.55) | 17.39 (24.64) |
| 2       | Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC | 100 | 200 | 11.84 (20.13) | 15.54 (23.22) | 13.69 (21.71) |
| 3       | Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC | 125 | 250 | 9.62 (18.07) | 12.58 (20.77) | 11.10 (19.46) |
| 4       | Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC | 150 | 300 | 7.40 (15.79) | 9.62 (18.07) | 8.51 (16.90) |
| 5       | Pyraclostrobin 20% WG | 100 | 500 | 11.84 (20.13) | 17.02 (24.37) | 14.43 (22.32) |
| 6       | Fluxapyroxad 300 g/l SC | 62.5 | 209 | 12.58 (20.77) | 18.50 (25.47) | 15.54 (23.21) |
| 7       | Hexaconazole 5% EC | 25 | 500 | 10.36 (18.78) | 14.80 (22.68) | 12.58 (20.77) |
| 8       | Carbendazim 50% WP | 250 | 500 | 13.32 (21.41) | 22.94 (28.62) | 18.13 (25.20) |
| 9       | Control | - | - | 21.46 (27.60) | 34.78 (36.14) | 28.12 (32.02) |

Figures in parenthesis are arcsine transformed values

Table 3: Effect of Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC on dry yield of chilli

| Sl. No. | Treatments | Dosage (per ha) | Dry Yield (q/ha) | Percent increase in yield over control (%) | Benefit cost ration |
|---------|------------|----------------|-----------------|------------------------------------------|-------------------|
|         |            | a. i. (g)      | Lov     | 2016 | 2017 | Pooled |
|         |            | Formulation (g) |       |      |      |        |
| 1       | Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC | 75 | 150 | 5.45 | 7.81 | 6.63 | 84.64 | 2.52 |
| 2       | Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC | 100 | 200 | 5.98 | 8.49 | 7.23 | 101.35 | 2.67 |
| 3       | Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC | 125 | 250 | 7.04 | 9.07 | 8.05 | 124.19 | 2.88 |
| 4       | Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC | 150 | 300 | 7.17 | 9.65 | 8.41 | 134.21 | 2.93 |
| 5       | Pyraclostrobin 20% WG | 100 | 500 | 6.25 | 6.46 | 6.36 | 77.12 | 2.34 |
| 6       | Fluxapyroxad 300 g/l SC** | 62.5 | 209 | 5.73 | 6.08 | 5.90 | 64.31 | 0.00 |
| 7       | Hexaconazole 5% EC | 25 | 500 | 5.41 | 5.79 | 5.60 | 55.96 | 2.30 |
| 8       | Carbendazim 50% WP | 250 | 500 | 5.07 | 4.82 | 4.95 | 37.85 | 2.00 |
| 9       | Control | - | - | 3.41 | 3.76 | 3.59 | - | 1.50 |

Figures in parenthesis are arcsine transformed values

**Product commercially not available in the market

Table 4: Phytotoxicity of Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC on chilli

| Sl. No. | Treatments | Phytotoxicity symptoms At 1, 3, 5, 7 and 10 Days after application of test chemical |
|---------|------------|---------------------------------------------------------------|
|         |            | Yellowing | Leaf tip injury | Chlorosis | Wilting | Epinasty | Hyponasty |
|         |            | 1 3 5 7 10 | 1 3 5 7 10 | 1 3 5 7 10 | 1 3 5 7 10 | 1 3 5 7 10 |
| 1       | Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC @ 250 ml/ha | 0 0 0 0 0 | 0 0 0 0 0 | 0 0 0 0 0 | 0 0 0 0 0 | 0 0 0 0 0 |
| 2       | Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC @ 500 ml/ha | 0 0 0 0 0 | 0 0 0 0 0 | 0 0 0 0 0 | 0 0 0 0 0 | 0 0 0 0 0 |
| 3       | Control | 0 0 0 0 0 | 0 0 0 0 0 | 0 0 0 0 0 | 0 0 0 0 0 | 0 0 0 0 0 |

Table 5: Effect of Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC on quality parameters of chilli

| Sl. No. | Treatments | Colour (ASTA units) | Pungency (SHU) |
|---------|------------|---------------------|---------------|
| 1       | Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC @ 250 ml/ha | 231 | 6369 |
| 2       | Carbendazim 50% WP @ 500 g/ha | 201 | 4128 |
Fig 1: Bio-efficacy of Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC on fruit rot and powdery mildew diseases of chilli

5. Conclusion
Based on the results obtained, it was concluded that the fungicide treatments presented different responses in chilli. The new test fungicide, Fluxapyroxad 250 g/l + Pyraclostrobin 250 g/l 500 SC @ 250 ml/ha was found effective in controlling fruit rot and powdery mildew diseases of chilli without any symptoms of phytotoxicity with enhanced characteristics such as systemicity and longer protection period in plant disease management with increase in dry yield of chilli. It has also shown significant improvement in quality parameters such as increase in color content i.e., capsanthin and pungency i.e., capsaicin. The physiological benefits were more evident with test fungicide, and these benefits manifested in terms of increased fruit production and improved quality of the produce. The higher productivity probably occurred due to the better physiological performance of these plants.

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