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Development and evaluation of fungicide-amended urea briquettes (FAUB's) to combat fruit rot disease of arecanut: A farmers-friendly approach

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ABSTRACT

Fruit rot disease (FRD) of arecanut caused by *Phytophthora meadii* (McRae) is a major limiting factor in arecanut production across the globe. Prophylactic sprayings of Bordeaux mixture (1%) and other oomycete-specific fungicides are recommended to manage this serious malady in arecanut. However, the tall nature of palms is a greater challenge for the application of plant protection measures on fruit bunches. Manual climbing of the palms during the rainy season is yet another risky task for proper spraying of chemicals up to the crown region. In this context, fungicide-loaded urea briquettes (FAUB's) were developed and assessed under field conditions against FRD in arecanut. Results proved that systemic fungicide-based urea briquettes are highly potent in protecting arecanut from FRD infection. Meanwhile, in the modern fungicidal delivery approach, the ambient fungicides such as fosetyl-Al, a combination of fosetyl-Al - propineb briquettes had achieved stronger fungicidal activity against FRD, reducing severity by 70% when applied twice with increased dry nut yield of 100% compared to control plots. Fosetyl-al briquettes found significantly higher in terms of control efficiency (Severity of 8.5 ± 0.22, 80%), yield response (19.04 ± 0.39q/ha), and economic analysis (3,08,400 Rs./ha). Further, the present study demonstrated that the soil application of FAUB's is an alternative to arduous conventional spraying. The experiment proved and demonstrated that, FAUB's could potential replacement for Bordeaux mixture and copper-oxychloride application under field conditions. Hence, we recommend to implement in integrated FRD management program.

1. Introduction

Arecanut (*Areca catechu* L.) is an important cash crop in India that sets an economic base for a substantial number of farming communities due to its valuable exporting potential (Mitra and Devi, 2018). India stands first in the world with respect to the area (7,30,823 ha) and production (12, 08, 938 tonnes) contributing 49% and 50% respectively (DASD, 2021). It also provides livelihood security to five million people in the country and contributes significantly to the national economy and foreign exchange owing to its domestic and global significance (Chowdappa et al., 2014). Diseases caused by fungi and oomycetes are considered the major threat to arecanut production which results in qualitative and quantitative losses (Coleman, 1910; Saraswathy, 1994). In particular, fruit rot disease (FRD) caused by *Phytophthora meadii* (McRae) has been reported as a fatal disease, resulting in yield loss of up to 90% (Koti Reddy and Anandaraj, 1980; Sastry and Hedge, 1985; Jose et al., 2008). The fungus can infect the immature tender nuts, growing buds, and the crown regions leading to fruit, bud, and crown rots, respectively (Saraswathy, 2004). It can cause economic loss up to 100% under congenial conditions *i.e.*, 22–25 °C temperature and 80–95% relative humidity coupled with continuous rainfall of >1000 mm (Anandaraj et al., 1992).

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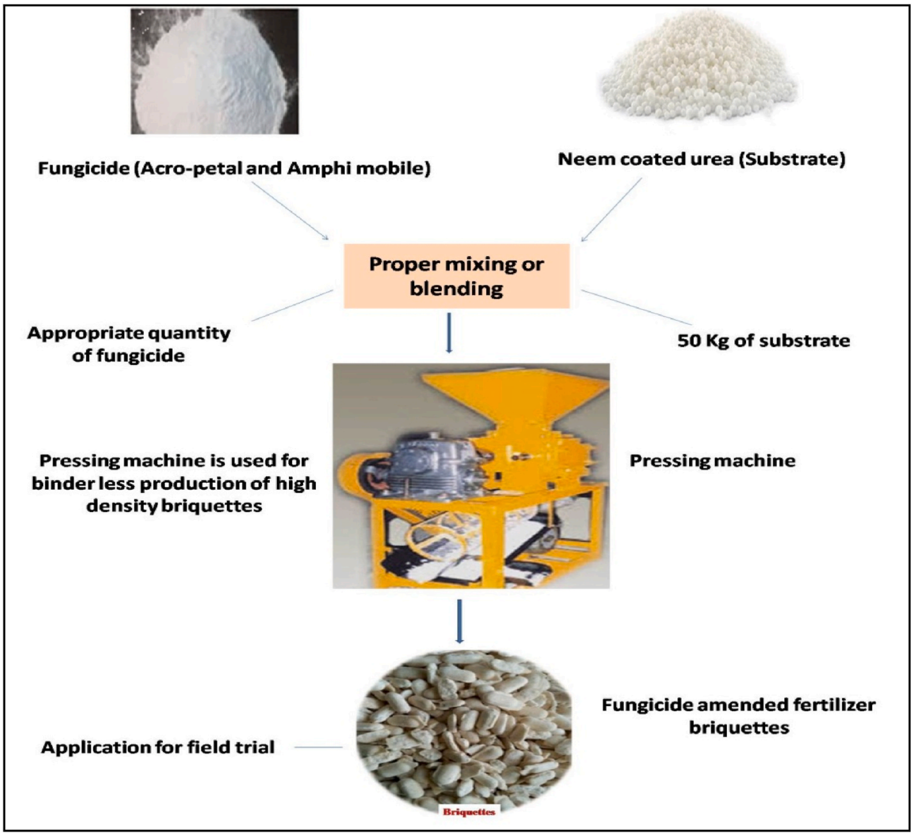

Fig. 1. Schematic representation for production of fungicide-amended urea briquettes (FAUB's) against FRD of arecanut.

Although safe and organic fungicides *viz*., Bordeaux mixture and Copper oxychloride have been promoted to combat FRD in arecanut, the role of chemical fungicides plays a vital role in the management. Single-site fungicides have proven to be very effective against many *Phytophthora* diseases, but they have also been found to stimulate the development of fungicidal resistance against pathogen populations (Brent and Hollomon, 2007). Fungicidal resistance to *Phytophthora* has been reported in many other hosts across the countries (Heungens et al., 2016; Matheron and Porchas, 2000; Perez-Sierra et al., 2011; Turner et al., 2008; Vercauteren et al., 2010; Wagner et al., 2008) and many strategies were attempted to overcome this issue by developing and testing of newer fungicides (Matheron and Porchas, 2000; Prathibha et al., 2016). Although many novel fungicidal molecules were assessed for the management of FRD in arecanut in recent years (Hegde, 2015; Lokesh et al., 2014; Pande et al., 2016; Ravikumar et al., 2019). As of now, integrated disease management (IDM) approach involving phytosanitation and prophylactic spraying of Bordeaux mixture (1%) just before the onset of monsoon and additional spray after 40–45 days has been recommended and widely adopted strategy across the country for the management of FRD (Chowdappa et al., 2000; Gangadhara Naik et al., 2019; Narayanaswamy et al., 2017). Hence, to safeguard the arecanut plantations from FRD infection, arecanut growers' resort to the periodical, indiscriminate use of the Bordeaux mixture. Over a period of time, continuous application of this copper-based fungicide leads to the deposition of copper residues in the arecanut ecosystem. Such arecanuts with high copper content used in quid or commercial products may be responsible for the increasing prevalence of oral submucous fibrosis (OSMF) (Mathew et al., 2015; Anandaraj, 1985; Rao, 1962).

However, Bordeaux mixture spraying becomes ineffective sometimes due to improper preparation and delay in scheduled application due to continuous rainfall in FRD endemic areas. Spraying of fungicidal solution on tall palms requires skilled labor and the height of palms coupled with heavy rain during spraying poses a serious risk to the labor. In this context, many researchers and stakeholders have attempted to find out an alternative to the Bordeaux mixture for FRD management under field conditions (Gangadhara Naik et al., 2019; Pande et al., 2016). Attempts are also being made for the utilization of unmanned aerial vehicle (UAV) and mechanized devices (air blasters) for spraying on the arecanut bunches (Desale et al., 2019; Faical et al., 2014; Panagiota et al., 2017).

Soil application and/or root feeding of systemic fungicides or inducing the systemic resistance (ISR) in the palms with rhizosphere application of microbes and/or chemicals could be one of the approaches for managing the diseases of tree crops (Andreu et al., 2006; Walters and Fountaine, 2009). Fosetyl Aluminum (Fosetyl- Al), a systemic fungicide developed way back in the 1970s which has got both upward and downward (Amphi-mobile) movement in plants was successfully used for the management of *Phytophthora* diseases in many crops (Davis, 1989; González et al., 2019; Silva et al., 2015). This fungicide works both directly on the fungus and indirectly, by stimulating the plant's natural defenses – a unique mode of action resulting in an extremely low risk of resistance. The fungicide has also been tested for the management of FRD on arecanut (Pande et al., 2016) with partial success. Root feeding of Fosetyl-Al though reported to be useful for the management of FRD, did not become popular because finding out the feeder roots of palm is cumbersome and time-consuming. Limited attempts were made earlier to apply Fosetyl-Al through fertilizer-amended urea briquettes (Pande et al., 2016). Fertilizer-amended urea briquettes (FAUB's) is found useful in the application of fertilizer in low-land rice (De Datta et al., 1989; Mohanty et al., 1999; Nayak et al., 2017), however meager literature is available on briquette technology for slow delivery of fungicides to the root zone.

In the current study, the efficacy of oomycete-specific fungicides for the management of FRD was investigated to determine the pathogen baseline sensitivity, disease control efficiency, yield response, and cost-economic analysis under field conditions through soil application of FAUB's. However, there is an urgent need for a more effective alternate fungicide application method as well as an efficient and farmer-friendly fungicide delivery approach. Hence the objective of the present study was to assess the soil application of FAUB's for the management of FRD in arecanut.

2. Materials and methods

2.1. Description of the experimental site

The fungicide-amended urea briquettes (FAUB's) were developed and evaluated in a farmer field located in the FRD endemic/hot-spot area of India (Bandigadi village, Chickmagalur, Karnataka) during the monsoon season of 2018 and 2019. The field was located at 709 m above mean sea level (MSL), with GPS coordinates 13°55′ N 75°26′ E. The weather conditions prevailed during experimentation such as weekly mean temperature (°C) and total rainfall (mm) from 1st June to 30th September during both crop seasons were documented from the meteorological station of Agricultural and Horticultural Research Station (AHRS), Thirthahalli, comes under the jurisdiction of UAHS, Shivamogga. The meteorological station was run by the State Agricultural Departmental (SAD) Service of Thirthahalli and both adhere to India Meteorological Department (IMD), Pune, India.

2.2. Development of FAUB's

Present investigations deployed a Briquette technology (FAUB's) to improve the fungicidal delivery, reduce environmental drift, and enhance the control efficiency to manage FRD in high rainfall zone and major arecanut growing regions of Karnataka. The FAUB's were prepared in a briquette forming machine (Machine code: 16726612, powder coated, portable SE brand, 250 kg briquettes/hour capacity, Pune, India) as per the process described by Pande et al. (2016) with some modifications. The complete production process of different FAUB's prepared during our study was depicted through the flow chart (Fig. 1).

FAUB's were prepared by using the neem-coated urea (Procured from a commercial dealer shop approved by the Government of India and Pesticide and Fertilizer Act) as a substrate and test fungicide/s as an active ingredient with a 25:1 ratio. These two ingredients were passed through an automated electrical pressing machine (which uses the principle of Dry Compression) to produce uniformly sized (10 mm), weighed (3g), and pillow-shaped briquettes. Likewise, the machine was calibrated to prepare 16,500 uniform-sized briquettes from 50 kg of neem-coated urea and 2 kg of test fungicides. A total of six fungicides (Fosetyl-Al 80% WP, Fosetyl-Al 80 WP + Propineb 61.25% WP, Cymoxanil 8% + Mancozeb 64% WP, Iprovalicarb 5.5% + Propineb 61.25% WP and Dimethomorph 50 WP + Mancozeb 80% WP) were amended separately with the urea to form briquettes as per the above mentioned protocol for further evaluation under field condition.

2.3. Confirmation of fruit rot pathogen

To confirm the identity of the FRD pathogen that exists in the experimental field, symptomatic nuts were subjected to cultural and molecular characterization of the associated pathogen. A total of 20 symptomatic nuts from ten different palms were collected, washed under running tap water, cut into small pieces, surface sterilized in 2% NaOCl for 60 s, rinsed in distilled water four times, and air dried. A small piece of infected tissue was placed on carrot agar (CA) plates and incubated at 24 ± 2 °C for 6–8 days (Ribeiro 1978; Pandian et al., 2021). Cultural and morphological observations of the isolated pathogen were carried out as per the description given by Balanagouda et al., 2022). Total genomic DNA was isolated from the pure culture of the pathogen following the CTAB method with minor modifications (Pandian et al., 2018). Molecular amplification of internal transcribed spacer region of ribosomal DNA using ITS1 (5′-TCC GTA GGT GAA CCT GCG G-3′) and ITS4 (5′-TCC TCC GCT TAT TGA TAT GC-3′) primers was carried out to confirm the identity of the pathogen (White et al., 1990). The amplified product was evaluated with electrophoresis (Major Science, USA) using a 1.2% agarose gel (Sambrook and Russell, 2001). The PCR amplified products were purified using a PCR purification kit (Geneaid, Taiwan) and purified products were sent for Sanger sequencing (Agrigenome Labs Pvt. Ltd., Cochin, India). Obtained sequences were aligned using BioEdit (Biological sequence alignment editor – Tom Hall, http://www.mbio.ncsu. edu/BioEdit/bioedit.html) and compared with the available sequences in NCBI (http://www.ncbi. nlm.nih.gov/BLAST) and BOLD database (http://www.boldsystems.org/). The multiple sequence alignment was performed by using the Clustal-W program with the pathogen sequence along with available sequences (Thompson et al., 1994). End trimmed pathogen sequence was deposited in the NCBI database.

2.4. Evaluation of manufactured FAUB's

The field evaluation of six different FAUB's was carried out along with bunch spraying of 1% Bordeaux mixture and root feeding of amphimobile fungicide *i.e.*, Fosetyl-Al 80 WP (0.3%) for two consecutive years *i.e.*, 2018–2019. The experiment was laid out under randomized block design (RBD) in a 10-year-old arecanut plantation (Thirthahalli local variety) and details of the treatments utilized in the study were shown in Table 1. FAUB's were manually placed at 5–6 cm soil depth at the rate of 33 (100g) briquettes/palm near the feeding root zone (1m away from the base of the palm) as per the International Fertilizer Development Center (IFDC) guidelines. Each treatment consists of 60 palms with three replications (20 palms/replication). As the first shower of monsoon favors the occurrence and spread of FRD in arecanut, initial treatments were imposed prior to the onset of monsoon *i.e.*, the second fortnight of May 2018. The treatments were re-imposed after the 45th day of the first application. The observations on fallen/dropped nuts with FRD symptoms were recorded on the 45th and 90th days of treatment application respectively. Percent disease severity (PDS) was computed by recording a 1–6 rating scale and formula given by Sastry and Hedge (1987).

$$Percent\ Disease\ Severity\ (PDS) = \frac{Sum\ of\ numerical\ ratings}{total\ number\ of\ plants\ observed \times Maximum\ grade}$$

The entire experiment was repeated during the year 2019.

2.5. Yield response and economic analysis

2.5.1. Yield parameters

The effect of various treatments on fresh and dry yield of arecanut was estimated by recording the yield (kg) of freshly harvested nuts and 40 days after drying of fresh nuts respectively. Upon maturity of the nuts, yield in different treated plots was estimated separately by harvesting fruits from respective plots and untreated control.

2.5.2. Incremental cost-benefit ratio (ICBR)

Cost of FAUB's (Rs/ha): The cost of FAUB's was estimated by adding up the cost of individual fungicide and substrate required to produce the

Table 1
Details of treatments used for evaluation of fungicide-amended urea briquettes (FAUB's) against fruit rot disease (FRD) of arecanut.

Treatments	Description of the treatments
	Duration of experiment: 2 years (2018 and 2019); Statistical design: RBD; First application: Second fortnight of May; Second application: 45 days interval
T_1	Spraying of Bordeaux mixture @ 1% (BM)
T_2	Soil application of Fosetyl-Al 80 WP + Propineb 61.25% WP (0.5%) through urea briquettes (FSTL_PROP + Urea)
T_3	Soil application of Fosetyl-Al 80 WP (0.5%) through urea briquettes (FSTL + Urea)
T_4	Soil application of Cymoxanil 8% + Mancozeb 64% WP (0.5%) through urea briquettes (CYM_MZB + Urea)
T_5	Soil application of Iprovalicarb 5.5% +Propineb 61.25% WP (0.5%) through urea briquettes (IPR_PROP + Urea)
T_6	Root feeding of palms with Fosetyl-Al 80 WP (0.3%) (50 ml/root, 2 roots/palm)
T_7	Soil application of Dimethomorph 50 WP + Mancozeb 80 WP (0.5%) through urea briquettes (DIM_MZB + Urea)
T_8	Control (Water)

quantity of briquettes sufficient for 1 ha plantation (33 briquettes/palm).

Laborer Wages (Rs/ha): A four number of labours were calibrated and found sufficient to apply FAUB's on 1 ha arecanut plantation. A prevailing labour hiring rate of Rs.500/labour was considered for calculating the labour wages for 1 ha plantation.

Cost of Treatment (Rs/ha): The cost of FAUB's (Rs/ha) for individual fungicides and laborer wages (Rs/ha) were summed up to work out the cost of respective treatments.

Additional Yield (q/ha): An additional yield increment of each treatment over control was estimated by subtracting the values of control yield from the total nut yield of respective treatments.

Additional Income (Rs./ha): An additional income from each treatment was calculated by multiplying the additional yield of the respective treatment over the untreated control with the prevailing minimum price (@Rs.30,000/q.

Net Return (Rs/ha): Computed separately by subtracting the cost of treatment from the additional income of the respective treatment.

Incremental Cost-Benefit Ratio (ICBR): ICBC was calculated separately for each treatment as per the following formula;

Incremental Cost-Benefit Ratio: Net return/Cost of treatment.

2.6. Statistical analysis

To compare the statistical significant difference between fungicides and briquettes treatments with the untreated control, disease severity values were subjected to a two-way analysis of variance (ANOVA) with Duncan's Multiple Range Test (DMRT) at $P < 0.05$ using SPSS V.20 software developed by IBM York, USA.

3. Results

3.1. Meteorological data

The weekly average of weather data during the experimental period was recorded and presented in Fig. 2. During the 2018 crop season, the total rainfall received at the experimental site was 2010 mm (maximum was 847 mm/week), and the average temperature was 24.09 °C, respectively. During the 2019 crop season, the total rainfall was 2134 mm (maximum was 1059 mm/week), and the average temperature was 24.38 °C (Fig. 2).

3.2. Morphological and moleculecular characterization of pathogen

The pathogen associated with FRD in experimental field was identified as Phytophthora meadii. The PCR amplification of the ITS gene sequence resulted in amplification of 641 bp nucleotide which was 100% nucleotide similarity with P. meadii with GenBank accession No. LC076469 and the amplified gene sequence were submitted to GenBank

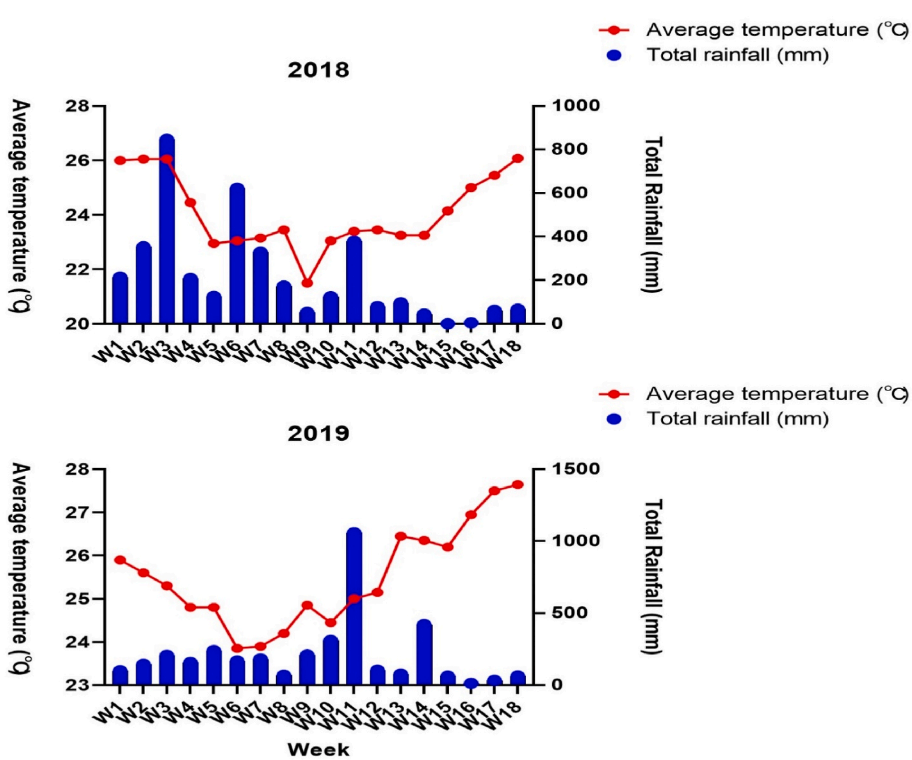

Fig. 2. Mean weekly temperature (°C) and rainfall (mm) during both crop seasons 2018–2019 prevailed in field trials measured at meteorological stations AHRS, Thirthahalli.

Table 2
Effect of FAUB's on arecanut fruit rot disease severity during 2018 and 2019. Mean ± standard deviations followed by the same letter in the same column do not significantly differ at $P < 0.05$ when analyzed using the DMRT of the two-way ANOVA test.

Treatment	No. of briquettes/Application	Disease severity (%)					
		2018		2019		Pooled	
		45 DAA	90 DAA	45 DAA	90 DAA	45 DAA	90 DAA
T_1	35 (100 g)	17.58 ± 1.38^{b}	15.25 ± 1.15^{b}	19.33 ± 0.76^{c}	13.33 ± 0.76^{d}	19.37 ± 1.19^{b}	15.96 ± 0.19^{b}
T_2	35 (100 g)	12 ± 0.66^{ef}	11 ± 1.09^{d}	14.42 ± 0.8^{d}	10.83 ± 1.26^{de}	14.25 ± 0.45^{cd}	12.09 ± 1.39^{c}
T_3	35 (100 g)	10.5 ± 0.89^{f}[a]	7.17 ± 0.35^{e}	11.83 ± 0.29^{d}	9.47 ± 0.55^{e}	11.96 ± 1.11^{d}	8.5 ± 0.22^{d}
T_4	35 (100 g)	16.08 ± 1.66^{bc}	13.67 ± 1.26^{bc}	21.08 ± 2.1^{bc}	16.42 ± 1.91^{c}	18.96 ± 1.65^{b}	15.87 ± 1.82^{b}
T_5	35 (100 g)	13.5 ± 1.5^{de}	10.5 ± 1.32^{d}	23.75 ± 1.15^{b}	19.17 ± 1.61^{bc}	19 ± 0.43^{b}	15.58 ± 0.95^{b}
T_6	35 (100 g)	14.25 ± 0.75^{cd}	11.92 ± 1.01^{cd}	22.42 ± 2.77^{b}	19.8 ± 2.52^{b}	19.7 ± 0.78^{b}	16.54 ± 1.48^{b}
T_7	35 (100 g)	12.67 ± 0.38^{de}	11 ± 0.25^{d}	22.33 ± 1.15^{bc}	20.17 ± 0.76^{b}	18.33 ± 0.19^{bc}	15.58 ± 0.31^{b}
T_8	–	23.33 ± 1.63^{a}	20.43 ± 1.78^{a}	34.52 ± 2.56^{a}	24.52 ± 2.56^{a}	26.51 ± 6.62^{a}	23.47 ± 2.17^{a}
S.Em±[b]		**0.69**	**0.73**	**1.10**	**0.88**	**0.79**	**1.32**
CD (p = 0.05)[c]		**2.19**	**2.24**	**3.36**	**2.68**	**2.43**	**3.69**

DAA = Days After Application.
T1- Spraying of Bordeaux mixture @ 1%.
T2- Soil application of Fosetyl-Al 80 WP + Propineb 61.25% WP (0.5%) briquettes.
T3- Soil application of Fosetyl-Al 80 WP (0.5%) through urea briquettes.
T4- Soil application of Cymoxanil 8% + Mancozeb 64% WP (0.5%) briquettes.
T5- Soil application of Iprovalicarb 5.5% +Propineb 61.25% WP (0.5%) briquettes.
T6- Root feeding of palms with Fosetyl-Al 80 WP (0.3%) (50 ml/root, 2 roots/palm).
T7- Soil application of Dimethomorph 50 WP + Mancozeb 80 WP (0.5%) briquettes.
T8- Control (Water).
[a] Least values in the parenthesis indicated the best treatment.
[b] Standard error of the means.
[c] Critical difference.

(ON999172).

3.3. Disease control efficiency of FAUB's

The disease control efficiency of all the treatments evaluated against fruit rot disease (FRD) of arecanut for two consecutive years (2018 and 2019) varied significantly at P = 0.05 (Table 2). In both years, fosetyl aluminum (0.3%) amended briquettes recorded the lowest disease severity (8.5%) which was significantly lower than all other treatments (Fig. 3). All the FAUB's treatments were found effective in both years and recorded significantly lower disease severity as compared to untreated control (23.43%; 23.47% respectively). Among the various treatments, the reduction in disease severity was ranged from 32% in Bordeaux mixture (T1) to 66% in fosetyl aluminum (T3) over untreated control. However treatments T1 (Bordeaux mixture 1%), T4 (Cymoxanil 8% + Mancozeb 64% WP), T5 (Iprovalicarb 5.5% +Propineb 61.25% WP), T6 (root feeding of Fosetyl-Al 80 WP) and T7 (Dimethomorph 50 WP + Mancozeb 80 WP) are statistically on par ($P < 0.05$) with each other. The highest disease occurrence was recorded in untreated control with 23.47% disease severity.

In 2019 occurrence of FRD was significantly higher than in 2018 with disease severity ranging from 11.83% to 34.52% and 9.47–24.52% at 45 and 90 days after application respectively. Due to prolonged wet conditions and relatively lower temperatures during the study period, the FRD infection rate was higher during 2019 than in 2018. However, the results of the fungicidal effects of briquettes on FRD infection are paralleled in 2018 and 2019 (Fig. 3). Overall, two-time soil applications of briquettes realized better disease control than a single-time application with reduced disease severity.

3.4. Yield response to FAUB's

Unlike in the control and standard check (Spraying of Bordeaux mixture), significantly lower FRD incidence was witnessed in FAUBs in both years (Table 3).

A significant improvement in terms of fresh and dry yield of arecanut was recorded in all the palms treated with FAUB's. Among all treatments the soil application of fosetyl aluminum 80 WP and fosetyl-Al 80 WP + propineb 61.25% WP was found to be most effective with dry nut yield of 20.60 and 19.04 q/ha respectively than control 9.82 q/ha. Likewise, all other treatments were statistically on par with each other (Table 3). A maximum percent increase in yields was noticed in fosetyl aluminum and a combination of fosetyl aluminium + propineb treated plots (109.77 and 93.89%, respectively).

3.5. Economic analysis of FAUB's

Economic analysis of various treatments in terms of yield, net income, and incremental cost-benefit ratio (ICBR) differed significantly for both years. The soil application of fosetyl aluminum 80 WP was found to be most economical than other treatments with a maximum net income of Rs. 308,400 R/ha corresponding to the lower disease pressure and enhanced yield with ICBR of 1:20.56 (Table 4). Although, the net returns from remaining treatments were lower than fosetyl aluminum 80 WP but found to be significantly higher than untreated and standard checks. The significant variation in ICBR was recorded in the range of 1:8.48 in untreated control to 1:20.56 in fosetyl aluminum 80 WP.

4. Discussion

India topped in the world concerning the arecanut growing scenarios by accounting for the area and production of 49% and 50%, respectively (Patil et al., 2022). Karnataka ranks first among the various arecanut-producing states of India. However, FRD is reported as one of the key constraints in global arecanut production. The weather conditions of Karnataka are often favorable for the FRD epidemics thereby resulting in significant reductions in arecanut yield. The recorded weather parameters in the experimental site were favouring the FRD throughout the season in both years. Morphological, and molecular characterization performed under the present investigations and previous reports confirmed the predominance of a virulent strain of *P. meadii* in the present experimental site (Patil et al., 2022).

Development of resistance to many fungicidal molecules by plant pathogens has been observed under field conditions (Adams and Quesada-Ocampo, 2014; Bagi et al., 2014; Blum et al., 2011; Hausbeck and Linderman, 2014; Zhu et al., 2007). The application of fungicidal

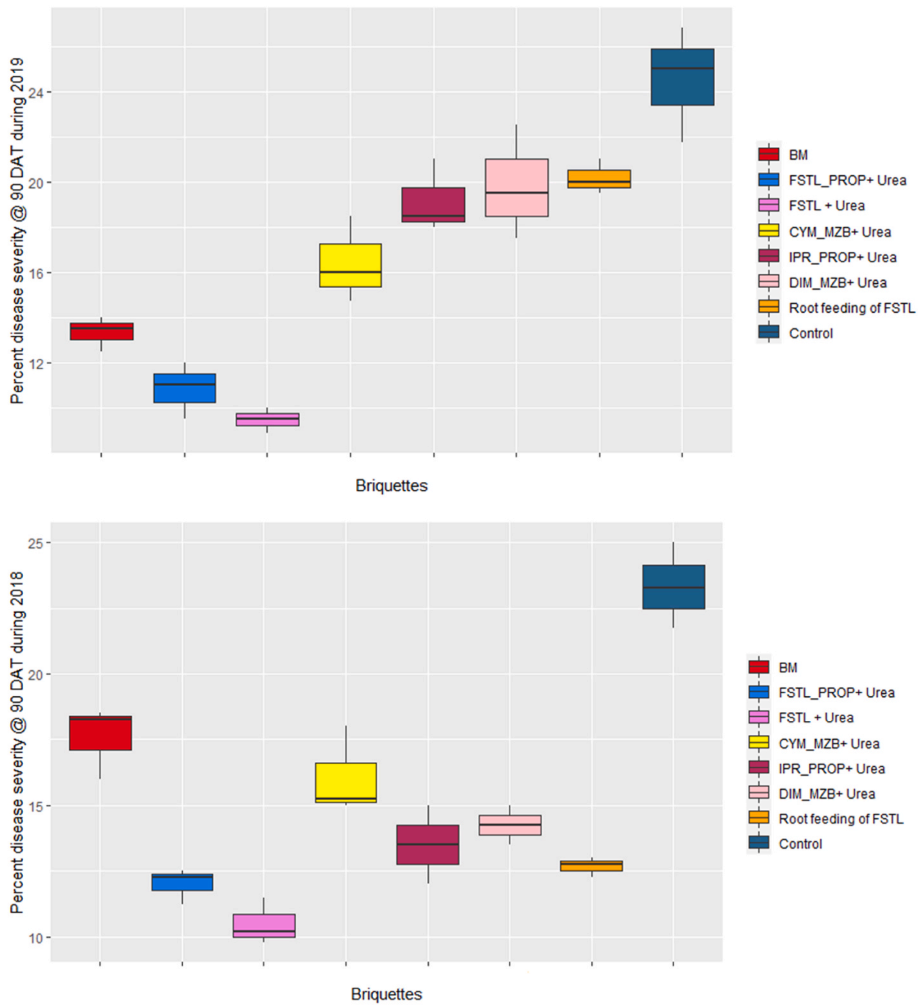

Fig. 3. Box and Whisker plots depicting control efficiency of FAUB's against arecanut fruit rot disease during 2018 and 2019. The middle bar = median, box = interquartile range (25th-75th percentile), and whiskers (error bars) above and below the box represents the 90th and 10th percentiles.

molecules through a conventional spraying system not only impose the selection pressure on pathogen but is also responsible for the contamination of natural resources through environmental drift. Thus, the deployment of novel fungicidal delivery approaches like fungicide-amended urea briquettes (FAUB's) is necessary for easy, safe, and effective delivery of fungicidal molecules to curtail the disease incidence in the agricultural and horticultural ecosystems. Hence, in the current study fungicide-loaded urea briquettes (FAUB's) were developed and assessed under the field conditions against FRD in arecanut.

During the disease period, the average minimum and maximum temperature, relative humidity, and total rainfall were recorded as 14 °C, 18 °C, 85.8%, and 2010 mm, respectively, in 2018 and 12 °C, 19 °C, 85.5%, and 2134 mm, respectively, in 2019. These prevailed weather parameters are considered as conducive factors for the development and spread of FRD (Patil et al., 2022). In the Malnad region of Karnataka, the rainfall is in the form of continuous drizzling and this condition favours the germination and spread of sporangia and subsequent heavy infections of FRD on arecanut (Balanagouda et al., 2022). The analysis of variance showed a significant effect of years on the disease severity value ($P = 0.005$), suggesting different weather conditions during both years of experimentation (Table 5).

Phosphonates, esters of phosphonic acid, generally are well known to control plant diseases caused by *Phytophthora* spp. (Vawdrey et al., 2004; Panicker and Gangadharan, 1999). One such fungicide, fosetyl-Al (also known as efosite aluminum) was registered in 1977 (Guest and Grant, 1991) and is reported to be effective against *Phytophthora* spp. when used as a soil drench (El-Hamalawi et al., 1995; Farih et al., 1981). Results of the present study revealed the potential of fosetyl aluminum to control *Phytophthora* diseases is complementary to the earlier studies (Pande et al., 2016; El-Hamalawi et al., 1995; Farih et al., 1981). Significant improvement in the dry kernel yield and net return of fosetyl aluminum treatment justifies the efficacy of this amphi-mobile fungicide against *P. meadii* infecting arecanut.

The present study proved that the soil application of FAUB's, are more effective in terms of control efficiency and profitability than the already recommended copper-based fungicide *i.e.,* the Bordeaux mixture. Our results about the high potency of fosetyl aluminum in the management of FRD are in agreement with Pande et al. (2016). This high efficiency of fosetyl aluminum may be attributed to the ability of fungicide to target oxysterol binding proteins in oomycete fungi, this novel mode of action is also credited to the minimum risk in resistance development with the advantage of being trans-located within the plant system (Cohen, 2015). The oxathiapiprolin fungicide with a similar mode of action to that of fosetyl –Al reported to inhibit all the stages of oomycete pathogens such as *Phytophthora nicotianae*, *Peronospora cubensis*, *P. belbahrii*, and *Plasmopara halstedii* (Cohen et al., 2015).

Though the conventional spraying of Bordeaux mixture on arecanut is effective against FRD, it warrants skilled/trained climbers and the height of palms coupled with heavy rain during spraying poses a serious risk to the laborers. Moreover, continuous spraying of the Bordeaux mixture resulted in heavy copper deposits in the arecanut-based

Table 3
Effect of FAUB's on yield of arecanut. Mean ± standard deviations followed by the same letter in the same column do not significantly differ at $P < 0.05$ when analyzed using the DMRT of the two-way ANOVA test.

Treatment	Yield parameters (q/ha)					
	2018		2019		Pooled	
	Green yield	Dry yield	Green yield	Dry yield	Green yield	Dry yield
T_1	145.20 ± 5.54[b][a]	16.12 ± 0.69[b]	131.4 ± 5.82[d]	15.39 ± 0.73[d]	141.89 ± 5.64[c]	15.76 ± 0.7[c]
T_2	182.16 ± 8.8[a]	20.24 ± 1.1[a]	160.56 ± 2.83[b]	17.76 ± 0.35[b]	171.34 ± 3.12[b]	19.04 ± 0.39[b]
T_3	198 ± 4.4[a]	21.92 ± 0.55[a]	172.92 ± 7.07[a]	19.21 ± 0.88[a]	185.45 ± 5.64[a]	20.60 ± 0.7[a]
T_4	151.79 ± 4.58[b]	16.88 ± 0.58[b]	151.27 ± 2.89[bc]	16.8 ± 0.36[bc]	151.54 ± 0.89[c]	16.78 ± 0.17[c]
T_5	147.83 ± 3.36[b]	16.41 ± 0.42[b]	174.04 ± 2.65[cd]	16.33 ± 0.33[cd]	147.43 ± 1.65[c]	16.36 ± 0.21[c]
T_6	150.75 ± 4.75[b]	16.75 ± 0.59[b]	143.87 ± 4.58[cd]	15.98 ± 0.57[cd]	147.31 ± 4.58[c]	16.68 ± 0.57[c]
T_7	153.12 ± 3.36[b]	17.0 ± 0.42[b]	139.22 ± 4.09[d]	15.45 ± 0.51[d]	146.12 ± 3.7[c]	16.22 ± 0.46[c]
T_8	92.39 ± 6.72[c]	10.27 ± 0.84[c]	84.41 ± 3.36[e]	9.37 ± 0.42[e]	88.43 ± 2.29[d]	9.82 ± 0.29[d]
S.Em±[b]	**3.37**	**0.65**	**2.72**	**0.41**	**2.35**	**0.32**
CD (p = 0.05)[c]	**10.22**	**1.81**	**8.57**	**1.31**	**7.15**	**1.20**

T1- Spraying of Bordeaux mixture @ 1%.
T2- Soil application of Fosetyl-Al 80 WP + Propineb 61.25% WP (0.5%) briquettes.
T3- Soil application of Fosetyl-Al 80 WP (0.5%) through urea briquettes.
T4- Soil application of Cymoxanil 8% + Mancozeb 64% WP (0.5%) briquettes.
T5- Soil application of Iprovalicarb 5.5% +Propineb 61.25% WP (0.5%) briquettes.
T6- Root feeding of palms with Fosetyl-Al 80 WP (0.3%) (50 ml/root, 2 roots/palm).
T7- Soil application of Dimethomorph 50 WP + Mancozeb 80 WP (0.5%) briquettes.
T8- Control (Water).
[a] Average yield of 20 palms/treatment are converted per hectare.
[b] Standard error of the means.
[c] Critical difference.

Table 4
Economic analysis of FAUB's on the incremental cost-benefit ratio (ICBR) as influenced by FRD of arecanut.

Treatments	Dry yield (q/ha)	Additional dry yield (q/ha)	Additional income (Rs./ha)	Cost of treatment (Rs./ha)	Net income (Rs./ha)	ICBR
T_1	15.76	5.94	178,200	13,000	165,200	1:12.70
T_2	19.04	9.22	276,600	18,000	258,600	1:14.36
T_3	20.60	10.78	323,400	15,000	308,400	1:20.56
T_4	16.78	6.96	208,800	21,375	187,425	1:8.76
T_5	16.36	6.54	196,200	19,750	176,450	1:8.93
T_6	16.68	6.86	205,800	16,250	189,550	1:11.66
T_7	16.22	6.40	192,000	20,250	171,750	1:8.48
T_8	9.82	–	–	–	–	–
S.Em ±	**0.32**	**0.26**				
CD (p = 0.05)	**1.20**	**0.73**				

Additional income = Additional yield (over control) * Market price.
Net income = Additional income – Cost of treatments.
ICBR = Net income/Cost of treatment.
T1- Spraying of Bordeaux mixture @ 1%.
T2- Soil application of Fosetyl-Al 80 WP + Propineb 61.25% WP (0.5%) briquettes.
T3- Soil application of Fosetyl-Al 80 WP (0.5%) through urea briquettes.
T4- Soil application of Cymoxanil 8% + Mancozeb 64% WP (0.5%) briquettes.
T5- Soil application of Iprovalicarb 5.5% +Propineb 61.25% WP (0.5%) briquettes.
T6- Root feeding of palms with Fosetyl-Al 80 WP (0.3%) (50 ml/root, 2 roots/palm).
T7- Soil application of Dimethomorph 50 WP + Mancozeb 80 WP (0.5%) briquettes.
T8- Control (Water).

ecosystem (Mathew et al., 2015; Anandaraj, 1985; Rao, 1962). However, Bordeaux mixture spraying becomes ineffective sometimes due to improper preparation and delay in scheduled application due to continuous rainfall in FRD endemic areas. Hence, fosetyl aluminum amended urea briquettes developed and validated under present investigations could be the viable alternative to the Bordeaux mixture for environment-responsive management of FRD in arecanut.

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Author's contributions

Conceptualization, B.P., V.H., H.N. and S.S.; Methodology, B.P., V. H., R.T.P., and S.H.T. Investigation, B.P., V.H., and H.N.; Resources, V. H., and H.N.; Writing-original draft preparation, B.P.; Writing-review and editing, V.H., S.S., R.T.P. and S.H.T. Supervision, V.H., H.N. and S.S. All authors have read and agreed the published version of manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Table 5
Analysis of Variance (ANOVA) for the effect of different treatments, years, and their interaction on FRD severity in arecanut.

Source of Variation	Degrees of Freedom (df)	Sum of Squares (SS)	Mean sum of squares (MSS)	F-Calculated	Significance
Year	1	242.328	242.328	89.477	0.00001
Treatments	7	1462.490	208.927	77.144	0.00001
Year × Treatments	7	70.564	10.081	3.722	0.00500
Error	30	81.248	2.708		
Total	47	1864.816			

Data availability

The data that has been used is confidential.

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References

Adams, M.L., Quesada-Ocampo, L.M., 2014. Evaluation of fungicides for control of downy mildew on cucumber, Kinston 2013. Pl. Dis. Manag. 8, 1–2.
Anandaraj, M., 1985. Effect of adhesives on the retention of Bordeaux mixture on arecanut bunches. Ann. Trop. Res. 7, 62–65.
Anandaraj, M., Arora, P., Nagarajan, S., 1992. A linear model for predicting the prevalence level of koleroga disease of arecanut four days in advance. Indian J. Plant Protect. 20, 75–76.
Andreu, A.B., Guevara, M.G., Wolski, E.A., Daleo, G.R., Caldiz, D.O., 2006. Enhancement of natural disease resistance in potatoes by chemicals. Pest Manag. Sci. 62, 162–170.
Bagi, F.F., Budakov, D.B., Bursic, V.P., Stojsin, V.B., Lazic, S.D., Vukovic, S.M., 2014. Efficacy of azoxystrobin for the control of cucumber downy mildew (*Pseudoperonospora cubensis*) and fungicide residue analysis. J. Crop Prot. 61, 74–78.
Balanagouda, P., Hegde, V., Sridhara, S., Pandian, R.T.P., Thube, S.H., Gangaraj, K.P., Gangurde, S.S., Jha, P.K., 2022. Multigene phylogeny and haplotype analysis reveals predominance of oomycetous fungus, *Phytophthora meadii* (McRae) associated with fruit rot disease of arecanut in India. Saudi J. Biol. Sci. 29 (8) https://doi.org/10.1016/j.sjbs.2022.103341.
Blum, M., Waldner, M., Olaya, G., Cohen, Y., Gisi, U., Sierotzki, H., 2011. Resistance mechanism to carboxylic acid amide fungicides in the cucurbit downy mildew pathogen *Pseudoperonospora cubensis*. Pest Manag. Sci. 67, 1211–1214. https://doi.org/10.1002/ps.2238.
Brent, K.J., Hollomon, D.W., 2007. Fungicide Resistance: the Assessment of Risk. FRAC Monograph No. 2 second (revised).
Chowdappa, P., Saraswathy, N., Vinayagopal, K., Somala, M., 2000. Control of fruit rot of arecanut through polythene covering. Indian Phytopathol. 53, 321.
Chowdappa, P., Sharma, P., Anandaraj, M., Khetarpal, R.K., 2014. Diseases of Plantation Crops. Indian Phytopathological Society, New Delhi, India.
Cohen, Y., 2015. The novel oomycide oxathiapiprolin inhibits all stages in the asexual life cycle of *Pseudoperonospora cubensis* - causal agent of cucurbit downy mildew. PLoS One 10. https://doi.org/10.1371/journal.pone.0140015.
Cohen, Y., Van den Langenberg, K.M., Wehner, T.C., Ojiambo, P.S., Hausbeck, M.K., Quesada-Ocampo, L.M., Lebeda, A., Sierotzki, H., Gisi, U., 2015. Resurgence of *Pseudoperonospora cubensis*: the causal agent of cucurbit downy mildew. Phytopathology 105, 998–1012. https://doi.org/10.1094/PHYTO-11-14-0334-FI.
Coleman, L.C., 1910. Diseases of the areca palm. In: *Koleroga*, Mycological Series. Bulletin No. 2. Department of Agriculture, Mysore State, India, p. 92.
Davis, R.M., 1989. Effectiveness of fosetyl-Al against *Phytophthora parasitica* on tomato. Plant Dis. 73, 215–217.
De Datta, S.K., Trevitt, A.C.F., Freney, J.R., Obcemea, W.N., Real, J.G., Simpson, J.R., 1989. Measuring nitrogen losses from lowland rice using bulk aerodynamic and nitrogen-15 balance methods. Soil Sci. Soc. Am. J. 53, 1275–1281.
Desale, R., Chougule, A., Choudhari, M., Borhade, B., Teli, S.N., 2019. Unmanned aerial vehicle for pesticides spraying. Int. J. Sci. Adv. Res. Tech. 5 (4), 79–82.
Directorate of Arecanut and Spices Development, 2021. Area, Production and Productivity Statistics of Arecanut. http://www.dasd.gov.in/statistics. (Accessed 15 May 2022). accessed on.
El-Hamalawi, Z.A., Menge, J.A., Adams, C.J., 1995. Methods of fosetyl-Al application and phosphonate levels in avocado tissue needed to control stem canker caused by *Phytophthora citricola*. Plant Dis. 79, 770–778.
Faical, B.S., Costa, F.G., Pessin, G., Ueyama, J., Vieira, H.F., Colombo, A., Fini, P.H., Villas, L., Osorio, F.S., Vargas, P.A., Braun, T., 2014. The use of unmanned aerial vehicles and wireless sensor networks for spraying pesticides. J. Syst. Architect. 60 (4), 393–404.
Farih, A., Menge, J.A., Tsao, P.H., Ohr, H.D., 1981. Fungitoxic activity of efosite aluminum for control of *Phytophthora* gummosis and root rot on citrus. Plant Dis. 65, 654–657.
Gangadhara Naik, B., Maheswarappa, H.P., Nagamma, Gowdra, Latha, S., 2019. Management of fruit rot disease of arecanut (*Areca catechu* L.) caused by (*Phytophthora meadii* Mc Rae.). Inter. J. Cur. Microbiol. Appl. *Sci.* 8, 837–847.
González, M., Romero, M.S., María, S.M.E., 2019. Fosetyl-aluminium injection controls root rot disease affecting Quercus suber in southern Spain. Eur. J. Plant Pathol. 156 https://doi.org/10.1007/s10658-019-01865-1.
Guest, D.I., Grant, B., 1991. The complex action of phosphonates as antifungal agents. Biol. Rev. 66, 159–187.
Hausbeck, M.K., Linderman, S.D., 2014. Evaluation of fungicides for control of downy mildew of cucumber. Pl. Dis. Manag. 8, 1.
Hegde, G.M., 2015. Bio-efficacy of potassium phosphonate against nut rot disease of areca nut (*Areca catechu* L.) in the northern Karnataka of India. Sri Lanka J. Food Agric. 1, 9–14.
Heungens, K., De Dobbelaere, I., Maes, M., 2016. Fungicide control of *Phytophthora ramorum* on Rhododendron. In: Frankel, S.J., Shea, P.J., Haverty, M.I. (Eds.), Proceedings of the Sudden Oak Death Second Science Symposium: the State of Our Knowledge. US Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA, USA, pp. 241–257.
Jose, C.T., Balasimha, D., Kannan, C., 2008. Yield loss due to fruit rot (Mahali) disease of arecanut in Karnataka. Indian J. Arecanut, Spices and Medicinal Plants 10, 45–51.
Koti Reddy, M., Anandaraj, M., 1980. Koleroga of arecanut. In: Proc: Workshop on Phytophthora Diseases of Tropical Cultivated Plants. Central Plantation Crops Research Institute, Kasaragod, Kerala, India, pp. 71–79.
Lokesh, M.S., Patil, S.V., Palakshappa, M.G., Gurumurthy, S.B., 2014. Role of systemic fungicide metalaxyl mancozeb in management of Koleroga (*Phytophthora meadii* Mc Rae) of arecanut (*Areca catechu* L.) in Central Western Ghats of Karnataka. Asian J. Bio. Sci. 9, 131–133.
Matheron, M.E., Porchas, M., 2000. Impact of azoxystrobin, dimethomorph, fluazinam, fosetyl-Al, and metalaxyl on growth, sporulation, and zoospore cyst germination of three *Phytophthora* spp. Plant Dis. 84, 454–458.
Mathew, P., Austin, R.D., Varghese, S.S., Manojkumar, A.D., 2015. Effect of copper-based fungicide (bordeaux mixture) spray on the total copper content of areca nut: implications in increasing prevalence of oral submucous fibrosis. J. Int. Soc. Prev. Community Dent. 5, 283–289.
Mitra, S.K., Devi, H., 2018. Arecanut in India - present situation and future prospects. Acta Hortic. 1205, 789–794. https://doi.org/10.17660/ActaHortic.2018.1205.99.
Mohanty, S.K., Singh, U., Balasubramanian, V., Jha, K.P., 1999. Nitrogen deep-placement technologies for productivity, profitability, and environmental quality of rainfed lowland rice systems. Nutrient Cycl. Agroecosyst. 53, 43–57.
Narayanaswamy, H., Raju, J., Jayalakshmi, K., 2017. Management of fruit rot disease of arecanut incited by Phytophthora meadii. Inter. J. Cur. Microbiol. Appl. Sci. 6, 2824–2828.
Nayak, A.K., Mohanty, S., Chatterjee, D., Guru, P.K., Lal, B., Shahid, M., Tripathi, R., Gautam, P., Kumar, A., Bhattacharyya, P., Panda, B.B., Kumar, U., 2017. Placement of Urea Briquettes in Lowland Rice: an Environment-Friendly Technology for Enhancing Yield and Nitrogen Use Efficiency. Research Bulletin No.12. ICAR-National Rice Research Institute, Cuttack, Odisha, India, pp. 1–26.
Panagiota, P., Vasileios, S., Panagiotis, E., Ilyas, P., 2017. Use of unmanned aerial vehicles for agricultural applications with emphasis on Crop Protection: three novel case-studies. Int. J. Agric. Sci. Technol. 5 (1) https://doi.org/10.12783/ijast.2017.0501.03.
Pande, V.S., Dademal, A.A., Kasture, M.C., Bhagwat, R.G., 2016. Management of Koleroga of arecanut caused by application of fungicide amended fertilizer briquettes Phytophthora meadii. J. Indian Soc. Coastal Agric. Res. 34, 88–90.
Pandian, R.T.P., Bhat, A.I., Biju, C.N., Sasi, S., 2018. Development of diagnostic assays for rapid and sensitive detection of *Phytophthora* infecting major spices and plantation crops. J. Spices and Aromatic Crops. 27, 119–130.
Pandian, R.T.P., Thube, S.H., Merinbabu, Bhavishya, Chaitra, P., Santhoshkumar, Nirmalkumar, B., Vinayaka, Hegde, 2021. First report of Phytophthora palmivora. In: Butler, E.J. (Ed.), 1919 Causing Fruit Rot in *Areca triandra*. From India. Australasian Pl. Pathol, 50, pp. 495–499. https://doi.org/10.1007/s13313-021-00802-3. E. J. Butler.
Panicker, S., Gangadharan, K., 1999. Controlling downy mildew of maize caused by *Peronosclerospora sorghi* by foliar sprays of phosphonic acid compounds. Crop Protect. 18, 115–118.
Perez-Sierra, A., Alvarez, L.A., Vercauteren, A., Heungens, K., Abad-Campos, P., 2011. Genetic diversity, sensitivity to phenylamide fungicides, and aggressiveness of *Phytophthora ramorum* on Camellia, Rhododendron, and Viburnum plants in Spain. Plant Pathol. (Lond.) 60, 1069–1076.

Prathibha, V.H., Hegde, V.M., Sharadraj, K.M., Suresh, K.R., 2016. Evaluation of fungicides and biocontrol agents against *Phytophthora meadii* infecting arecanut. Bioscan 11, 1547–1550.

Rao, K.S.N., 1962. Estimation of copper on the finites sprayed with Bordeaux mixture. Agric. Res. 2, 293.

Ravikumar, M., Pradeep Kumar, B.A., Niranjana, K.S., 2019. Standardization of concentration of Bordeaux mixture for management of fruit rot disease (*P. meadii*) of arecanut. Green Farming 10, 115–117.

Ribeiro, O.K., 1978. A Source Book of the Genus *Phytophthora*, p. 40.

Sambrook, J., Russell, D.W., 2001. Molecular Cloning a Laboratory Manual. Cold Spring Harbor Laboratory, Cold Spring Harbor, New York, pp. 20–28.

Saraswathy, N., 1994. Studies on *Phytophthora* Spp. On Arecanut and Arecanut Based Cropping Systems. Ph.D. Thesis, Mangalore University, Karnataka, India.

Saraswathy, N., 2004. In: Arecanut, Rajagopal, V., Balasimha, D. (Eds.), Diseases and Disorders. Central Plantation Crops Research Institute, Kasaragod, Kerala, India, pp. 134–169.

Sastry, M.N.L., Hedge, R.K., 1985. Taxonomic identity of arecanut *Phytophthora* isolates from the gardens of Sirsi, Uttara Kannada. In: Shama Bhat, K., Radhakrishnan Nair, C.P. (Eds.), Arecanut Research and Development. Central Plantation Crops Research Institute, Kasaragod, Kerala, India, pp. 92–94.

Sastry, M.N.L., Hedge, R.K., 1987. *Phytophthora* associated with arecanut *(Areca catechu* L) in Uttara Kannada, Karnataka. Curr. Sci. 56, 367–368.

Silva, Patricia, Velez, M., Otaño, D., Nuñez, C., Greslebin, A., 2015. Action of fosetyl-al and metalaxyl against *Phytophthora austrocedri*. For. Pathol. 46 https://doi.org/10.1111/efp.12216.

Thompson, J.D., Higgins, D.G., Gibson, T.J., Clustal, W., 1994. Improving the sensitivity of progressive multiple sequence alignment through sequence weighting, position-specific gap penalties and weight matrix choice. Nucleic Acids Res. 22, 4673–4680. https://doi: 10.1093/nar/22.22.4673.

Turner, J., Jennings, P., Werres, S., Wagner, S., 2008. Report Response of Isolates of *Phytophthora ramorum* Exposed to Fungicides Commonly Used to Control *Phytophthora* Diseases in Nurseries. Deliverable Report 5. Forest Research, Central Sciences Laboratory, San Hutton, York, UK.

Vawdrey, L.L., Grice, K.E., Peterson, R.A., De Faveri, J., 2004. The use of Metalaxyl and potassium phosphonate, mounds, and organic and plastic mulches, for the management of *Phytophthora* root rot of papaya in far northern Queensland. Australas. Plant Pathol. 33, 103–107.

Vercauteren, A., De Dobbelaere, I., Grünwald, N.J., 2010. Clonal expansion of the Belgian *Phytophthora ramorum* populations based on new microsatellite markers. Mol. Ecol. 19, 92–107.

Wagner, S., Kaminski, K., Werres, S., 2008. In: Frankel, S.J., Kliejunas, J.T., Palmieri, K. M. (Eds.), Evaluation of Fungicides for Control of *Phytophthora ramorum*, Proceedings of the Sudden Oak Death Second Science Symposium: the State of Our Knowledge. US Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA, USA, pp. 481–482.

Walters, D., Fountaine, J., 2009. Practical application of induced resistance to plant diseases: an appraisal of effectiveness under field conditions. J. Agric. Sci. 147 (5), 523–535. https://doi.org/10.1017/S0021859609008806.

White, T.J., Bruns, T., Lee, S., Taylor, J.W., 1990. Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics. In: Innis, M.A., Gelf and, D.H., Sninsky, J.J., White, T.J. (Eds.), PCR Protocols: a Guide to Methods and Applications. Academic Press, New York, USA, pp. 315–332.

Zhu, S.S., Liu, X.L., Wang, Y., Wu, X.H., Liu, P.F., Li, J.Q., Yuan, S.K., Si, N.G., 2007. Resistance of *Pseudoperonospora cubensis* to flumorph on cucumber in plastic houses. Plant Pathol. (Lond.) 56, 967–975. https://doi.org/10.1111/j.1365-3059.2007.01649.x.