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The Efficiency of some Essential Oils for Controlling Powdery Mildew on Flax Plants

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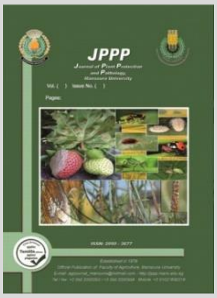

ABSTRACT

Twenty-two essential oils were tested over three years to examine how effective they were in controlling powdery mildew of flax when they were used as foliar sprays in an outdoor pot experiment. Certain oils exhibited an inconsistency trend across years with some were effective in controlling the disease and others were not. None of the tested oils failed in controlling the disease in all tested years. The cluster analysis grouping of the oils was unrelated to the taxonomic position of their plant sources. Onion, caraway, celery, and black cumin oils were promising for commercialization due to two reasons; firstly, they significantly reduced incidence and severity of disease each year, and secondly, they had no negative effects on seed and straw production.

Keywords: Essential oils, powdery mildew, and flax

INTRODUCTION

In Egypt, flax (*Linum usitatissimum* L.) is a key oilseed and fibre crops (Aly *et al*., 2021). Flax belongs to the genus *Linum*, which is a part of the family Linaceae. This family includes 14 genera and approximately 200 species. Only, *L. usitatissimum* has both agronomic and economic qualities, and it is used for both industrial and human consumption. Generally, every portion of the flax plant is used economically, either directly or after processing (Singh *et al*., 2016).

Powdery mildew (PM) is currently the most visible, widespread, and easily identified foliar disease on flax plants in Egypt. Flax is grown throughout the Nile Delta, particularly in the northern governorates, for both seeds and fibers. During the late period of the flax growing season, this area is characterized by the prevalence of warm, damp weather. When virulent races of the causative agent occur, such meteorological conditions favor epiphytotic disease spread (Mansour, 1998). Yield losses and disease intensity, on the other hand, vary from season to season (Mansour, 1998).

Because the causal fungus of flax PM perfect state has not been characterized in Egypt, the causal fungus has been identified as *Oidium lini* Skoric based on its conidial stage (Aly *et al*., 1994).

Oidium lini is a flax bio-trophic parasite that obtains nutrition via haustoria. When disease resistant cultivars are spread across greater regions, *O. lini* is able to generate physiological races under severe selection pressure (Sran *et al*., 2021).

A sexual conidia formed on diseased plant parts transmit the disease. The disease appears as little greyish white powdery spots on young plant leaves, which might be round or irregular in shape. They quickly cover all of the foliage decreasing photosynthetic area and activity (Sran *et al*., 2021). Flax PM can affect seed and fiber raw material output and quality, with the majority of losses resulting from premature ripening and seed loss during harvest, while early infection can lower seed number per plant (Stafecka *et al*., 2019). Yield losses in India ranged from 12-38 %, 18 % in the United Kingdom, and 10-20 % in Canada (Rashid and Duguid, 2005). Yield losses from flax PM have not been assessed in Egypt; however, strong negative relationships between disease severity and yield has been identified (Aly *et al*., 2012).

Resistance to PM is currently unavailable in commercially cultivated flax cultivars in Egypt (Aly *et al*., 2002). As a result, in years when environmental conditions favour disease spread, foliar spraying of synthetic fungicides has become the only commercially accessible disease management strategy. While effective fungicides are available (Aly *et al*., 2021), it is becoming clear that their intensive usage is connected with various issues, including the potential harm to non-target organisms, the emergence of resistant races of the pathogen, and possibly carcinogenicity. Other issues include the gradual removal and phase-out of certain chemicals (Aly *et al*., 2013). In general, better fungal disease management based on alternatives to synthetic fungicides is highly required. Plant-derived essential oils therefore are one among the many available choices.

Production of essential oils by plants is believed to be predominantly a defense mechanism against pathogens and pests (Oxenham, 2003). Essential oils are made up of many different volatile compounds and the make-up of oil quite often varies between species. It seems that the antifungal effects of essential oils are the results of many compounds acting synergistically. This means that

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individual compounds by themselves are not as effective (Jobling, 2000).

Essential oils do not have the same broad spectrum of action as synthetic fungicides and are frequently fungistatic rather than fungicidal. This means that they inhibit fungal development while they are exposed to the oil, but once the oil is withdrawn, the fungi can again resume growth (Jobling, 2000).

The benefits of employing essential oils for phytopathogenic fungal management are they low cost, ease of preparation, effectiveness at low concentrations, and safety for the environment and human health. Furthermore, they can be applied on a wide scale in organic farming (Hafez, 2008).

Essential oils have long been used to combat phytopathogenic fungus. Thyme oils, for example, have been shown to have antifungal activity against fungi such as *Botrytis cinerea*, *Rhizopus stolonifer* (Ehrenberg), *Aspergillus* spp. (Micheli), *Rhizoctonia solani* (Kühn), *Pythium ultimum* (Trow), *Fusarium solani* (Mart.) , and *Colletotrichum lindemuthianum* (Sacc. & Magnus), with thymol appearing to be one of the primary active components (Pradhanang *et al*., 2003). Both cassia and thyme oils inhibited *Alternaria alternata* growth. At 300-500 ppm, cassia oil stopped the growth of *A. alternata* completely. At 500 ppm, thyme oils inhibited 62.0 % of the growth. The inclusion of 500 ppm cassia oil decreased pathogen spore germination and germ tube elongation in potato dextrose broth. The severity of powdery mildew on cucumber was decreased from 52 % (control) to 7.7 % when cucumber leaves were treated with 0.5 % black cumin oil (BCO). Similarly, the severity of powdery mildew on barley was decreased from 63.4 to 9.4 % (control). BCO anti-powdery mildew activity was mostly due to inhibition of conidial germination and suppression of mycelia proliferation (Hafez, 2008). Garlic oil prevented the growth and production of sclerotium in *Rhizoctonia solani* (Kühn) (Singh and Singh, 1980). Antimicrobial efficacy of lemongrass oil has been demonstrated against *R. solani*, *Sclerotium rolfsii*, and *Sclerotinia sclerotiurum* (Chaijuckam and Davis, 2010). Jojoba and coriander oils were particularly efficient in suppressing flax powdery mildew, with 66.24 and 68.64 % reductions in disease severity, respectively (Aly *et al*., 2013).

As far as we know, relatively few essential oils have been studied for their ability to control PM on flax (Aly *et al*., 2013).

The target of this study was conducted to examine how foliar application of specific plant essential oils affect the incidence and severity of flax PM in an outdoor pot experiment. The impact of essential oils on seed and straw yields are also investigated.

MATERIALS AND METHODS

Foliar application of essential oils:

Seeds of flax cultivar Sakha 2 were planted on 27th December 2019, on 25th December 2020, and on 22nd December 2021 in autoclaved clay soil to eliminate the pathogenic soil-borne fungi, which may attack the plants, and the soil was dispensed in 25-cm-diameter clay pots (20 seeds/pot). PM was allowed to develop naturally, and the initial application of treatments to plants coincided with the first signs of the disease. Plants were treated with a suspension of 700 µl of essential oils dissolved in 6.3 ml of 70 % ethanol and detergent (Super-Film 70) at 0.1 % in 56 ml of water to prepare a stable essential oil suspension (Pradhanang *et al*., 2003). Essential oils were obtained from Cap Pharm for Extracting Natural oils, Herbs, and Cosmetics, Cairo, Egypt, while Super-Film 70 was obtained from Arab Company for Chemical Industeries, Cairo, Egypt. The experiment included two control treatments. In the control 1, the plants were treated with the delivery system (same amount of ethanol, detergent, and water as mentioned earlier). In the control 2, the plants were left without any treatment. Two foliar sprays with the essential oils were applied to run-off each season on 19th March and on 4th April 2020; on 12th March and on 27th March 2021; and on 24th March and on 8th April 2022. Each year, disease incidence and disease severity were measured 10 days after the second spray. Disease incidence was measured as percentage of infected plants/pot. Disease severity was measured as percentage of infected leaves/plant in a random sample of 10 plants/ pot (Nutter *et al*., 1991). At harvest, straw and seed weights were recorded for each plant to evaluate the effects of treatments on plant growth.

Statistical analysis:

The experimental design of the present study was a randomized complete block with three replications (blocks). Percentage data were transformed into arc sine angles before carrying out the analysis of variance (ANOVA) to produce an approximately constant variance. Treatment means were compared using Duncan's multiple range test. ANOVA was performed with MSTAT-C Statistical Package (Michigan State Univ., M1, USA). Correlation and cluster analysis were performed with a computerized program (SPSS Inc. version 13.0, Chicago, IL, USA).

RESULTS AND DISCUSSION

Results

When sprayed as foliar sprays in an outdoor pot experiment, twenty-two essential oils were investigated for their effectiveness in suppressing flax PM. Table 1 shows the sources of these essential oils as well as their key components (Anonymous, 2012). Six sources (27.27 %) belonged to the family apiaceae, whereas five sources (22.73 %) belonged to the family lamiaceae. The remaining families were represented by one (4.55 %) or two (9.09 %) sources (Table 1).

The use of a delivery system lowered disease incidence and severity in 2022 and 2021, respectively (Tables 2 and 3). In 2022, the delivery technique considerably enhanced seed and straw yields (Tables 4 and 5).

Table 1. List of essential oils used in the present study.

Common name (English name)	Scientific name	Family name	Major components
1-Onion	*Allium cepa*	*Amaryllidaceae*	Propyl disulphide, propyl trisulphide, methylpropyl disulphide, and methylpropyltrisulphide.
2-Flax	*Linumusitatissimum L.*	Linaceae	Amino acids, steroidal compounds, omega 3, and omega 6 fatty acids
3-Caraway	*Carum carvi*	Apiaceae	(+) Carvone, limonene, dihydrocarvne and carveol
4-Turnip	*Brassiarapa*	Brassiaceae	35% polyunsaturad fatty acids, Myristic acid (0.5%), palmitic acid (13.7%), palmitoleic acid (0.1%), stearic acid (2.6 %), oleic acid (23%) linoleic acid (omega-6), linolenic acid (omega 3) (0.2%), Arachidic (1.3)
5-Spearmint	*Menthe spicata*	Lamiaceae	a-pinene-b-pinene, carvone, 1.8-cineole, linalool, limonene, myrcene, caryophyllene, menthol (0.5%)
6-Celery	*Apium graveolens*	Apiaceae	d-limonene, selinene, sesquiterpene alcohols, sedanolide and sedanonic anhydride
7-Basil	*Ocimumbasilicum*	Lamiaceae	Linalool, eugenol
8-Pepermint	*Menthe piperita*	Lamiaceae	Menthol (29-48%), menthone (20-31%) and omega-3, omega-6
9-Cumin	*Cuminum cyminum*	Apiaceae	Cuminaldhyde, dihyrocuminaldehyde
10-Rocket	*Eruca sativa*	Brassiaceae	Plamitic 5.1%, streaic 1.3%, oleic 15.1% linolenic 14.7%, linoleic 8.3%, eicosenoic 7.4%, erucic 44.7
11-Garlic	*Allium sativum*	*Amaryllidaceae*	Propyldisulphide, alliin, and allicin
12-Rosemary	*Rosmarinus officinals*	Lamiaceae	Carnosic acid, rosmarinic acid, caffeic acid, ursolic acid, betulinic acid, pinene, cineal, camphor, camphene, bornyeal, verbenon
13-Fenugreek	*Trigonella foenumgraecum*	Fabaceae	Phtoestorogen (0.38%) trigonelline and 3mg% nicotinic acid
14-Dill	*Peucedanum graveolens*	Apiaceae	d-crvone, dillapiol, dhceugenol, limonene, terpinene, and myristiein
15-Fennel	*Foeniculum vulgare*	Apiaceae	Anethole, myrcene, cineole, eugenol, methyl chavicol, thymol, limonene, phellandrene, alphaterpene, pinene, fenchone
16-Pumpkin	*Cucurbita pepo L*	*Cucurbitaceae*	Amino acid, steroidal compounds, and omega 3, omega 6 fatty acids
17-Jojoba	*Simmondsia chinensis*	*Simmondsiaceae*	14% Erucic acid
18-Thyme	*Thymus vulgaris*	Lamiaceae	Thymol, terpinen 4-0, 1, carvcol, p-cymene, pinene, camphene, myrcene, 1.8-cineole, terpinene, d-linalool
19-Bitter almond	*Amygdalus communis*	Rosaceae	Crystalline, glucoside, amygdalin
20-Coriander	*Coriandrum sativum*	Apiaceae	Borneol, linalool, cineole, cymene, trepinol, dipentene, phellandrene, pinene, terpinolene
21-Sweet almond	*Amygdalus dulcis mill*	Rosaceae	Small proportion acid of glyceride, of lionlic, and other glycerides
22-Black cumin	*Nigella sativa*	*Ranunculaceae*	Myristic acid (0.5%) palmitic acid (13.7%), palmitoleic acid (0.1%), stearic acid (2.6%), olic acid (23.7%), linoleic acid (omega 6), linolenic acid (omega 3)(0.2%) arachidic acid (1.3%)

Table 2. Effect of essential oils on incidence (%) of powdery mildew on flax cultivar Sakha 2 in an outdoor pot experiment.

Essential oil		Incidence (%)[a] of powdery mildew in		
No.	Botanic source	2020	2021	2022
1	Onion	26.67 I*	10.00 K*	13.33 G*
2	Flax	43.33 G-I*	20.00 H-J*	16.67 G*
3	Caraway	56.67 D-H*	36.67 D-F*	16.67 G*
4	Turnip	50.00 F-I*	46.67 D-F*	23.33 G*
5	Spearmint	63.33 C-G*	26.67 F-I*	73.33 A-C
6	Celery	63.33 C-G*	16.67 I-K*	40.00 F*
7	Basil	66.67 C-G*	30.00 E-H*	70.00 B-D
8	Pepermint	63.33 C-G*	36.67 D-F*	70.00 B-D
9	Cumin	66.67 C-G*	33.33 E-G*	76.67 A-C
10	Rocket	76.67 B-E	23.33 G-I*	43.33 F*
11	Garlic	73.33 C-F*	43.33 DE*	76.67 A-C
12	Rosemary	53.33 E-H*	43.33 DE*	80.00 AB
13	Fenugreek	73.33 C-F*	60.00 BC	50.00 EF*
14	Dill	43.33 G-I*	50.00 CD*	43.33 F*
15	Fennel	66.67 C-G*	40.00 D-F*	56.67 D-F
16	Pumpkin	76.67 B-E	73.33AB	76.67 A-C
17	Jojoba	90.00 A-C	43.33 DE*	76.67 A-C
18	Thyme	80.00 A-D	16.67 I-K*	76.67 A-C
19	Bitter almond	80.00 A-D	10.00 JK*	63.33 C-E
20	Coriander	66.67 C-G*	16.67 I-K*	73.33 A-C
21	Sweet almond	50.00 F-I*	10.00 JK*	46.67 F*
22	Black cumin	33.33 HI*	10.00 JK*	20.00 G*
23	Bunch[b]	6.67 J[x]	3.33 L[x]	0.00 H[x]
24	Control 1[c]	90.00 AB	70.00 AB	66.67 B-D
25	Control 2[d]	93.33 A	76.67 A	86.67 A

[a] **percentage data were transformed into arcsine angles before carrying out the analysis of variance to produce approximately constant variance. Means followed by the same letter(s) are not significantly different (p≤0.05) according to Duncan`s multiple range test.**

[b] **The fungicide Bunch was sprayed at a rate of 3 ml/100 l water.**

[c] **plants were sprayed with ethanol + detergent + water.**

[d] **plants were left without any treatment.**

* **Significant difference from control 1.**

[x] **Significant difference from control 2.**

Table 3. Effect of essential oils on severity (%) of powdery mildew on flax cultivar Sakha 2 in an outdoor pot experiment.

Essential oil		severity (%)[a] of powdery mildew in		
No.	Botanic source	2020	2021	2022
1	Onion	8.19 F*	3.63 M*	3.07 HI*
2	Flax	18.49 CD*	7.27 LM*	3.47 H*
3	Caraway	18.89 CD*	15.47 I-L*	4.03 H*
4	Turnip	19.30 CD*	23.50 G-J*	5.30 H*
5	Spearmint	24.84 B-D*	16.13 I-L*	33.93 FG*
6	Celery	21.38 B-D*	11.77 KL*	30.13 G*
7	Basil	27.11 B-D*	20.40 H-K*	43.27 D-G*
8	Pepermint	19.15 CD*	24.73 F-I*	53.23 C-F*
9	Cumin	26.87 B-D*	12.77 J-L*	55.87 C-E*
10	Rocket	23.60 B-D*	13.20 J-L*	34.13 FG*
11	Garlic	20.22 B-D*	28.67 E-H*	63.40 B-D
12	Rosemary	18.53 CD*	34.03 D-G*	63.30 B-D
13	Fenugreek	29.16 BC*	47.17 CD	49.93 C-G*
14	Dill	16.40 DE*	34.37 D-F*	32.27 G*
15	Fennel	20.76 B-D*	32.90 E-G*	37.23 E-G*
16	Pumpkin	25.82 B-D*	64.43 AB	50.27 C-G*
17	Jojoba	32.46 B*	38.17 DE*	61.53 B-D
18	Thyme	28.58 BC*	13.37 I-L*	68.37 BC
19	Bitter almond	24.58 B-D*	4.03 M*	57.27 CD*
20	Coriander	30.13 BC*	16.07 I-L*	60.23 B-D
21	Sweet almond	33.20 B*	12.63 J-L*	46.60 D-G*
22	Black cumin	9.10 EF*	11.57 KL*	43.17 D-G*
23	Bunch[b]	1.27 G[x]	1.07 N[x]	0.00 I[x]
24	Control 1[c]	63.27 A	54.00 BC	77.83 AB
25	Control 2[d]	66.71 A	74.90 A	85.73 A

[a] **percentage data were transformed into arcsine angles before carrying out the analysis of variance to produce approximately constant variance. Means followed by the same letter(s) are not significantly different (p≤0.05) according to Duncan`s multiple range test.**

[b] **The fungicide Bunch was sprayed at a rate of 3 ml/100 l water.**

[c] **plants were sprayed with ethanol + detergent + water.**

[d] **plants were left without any treatment.**

* **Significant difference from control 1.**

[x] **Significant difference from control 2.**

Table 4. Effect of essential oils on seed yield (g/plant) of flax plants cultivar Sakha 2 infected with powdery mildew in an outdoor pot experiment.

Essential oil		Seed yield (g/plant)[a] in		
No.	Botanic source	2020	2021	2022
1	Onion	0.317 AB	0.353 A-D	0.207 A-D
2	Flax	0.263 A-C	0.263 B-E*	0.220 A-D
3	Caraway	0.223 A-C	0.320 A-E	0.213 A-D
4	Turnip	0.210 A-C	0.307 A-E	0.147 CD*
5	Spearmint	0.230 A-C	0.367 A-C	0.210 A-D
6	Celery	0.213 A-C	0.310 A-E	0.267 A
7	Basil	0.180 BC*	0.320 A-E	0.153 B-D
8	Pepermint	0.180 BC*	0.267 B-E*	0.147 CD*
9	Cumin	0.210 A-C	0.193 E*	0.117 D*
10	Rocket	0.140 C*	0.230 C-E*	0.170 A-D
11	Garlic	0.223 A-C	0.240 C-E*	0.163 A-D
12	Rosemary	0.267 A-C	0.293 A-E	0.160 A-D
13	Fenugreek	0.197 A-C	0.230 C-E*	0.170 A-D
14	Dill	0.147 C*	0.277 B-E*	0.220 A-D
15	Fennel	0.220 A-C	0.253 C-E*	0.187 A-D
16	Pumpkin	0.170 C*	0.280 B-E*	0.130 CD*
17	Jojoba	0.173 C*	0.277 B-E*	0.160 A-D
18	Thyme	0.220 A-C	0.313 A-E	0.210 A-D
19	Bitter almond	0.157 C*	0.210 DE*	0.153 B-D
20	Coriander	0.130 C*	0.243 C-E*	0.157 B-D
21	Sweet almond	0.170 C*	0.243 C-E*	0.180 A-D
22	Black cumin	0.183 A-C	0.410 AB	0.200 A-D
23	Bunch[b]	0.243 A-C	0.283 B-E	0.233 A-C
24	Control 1[c]	0.323 A	0.443 A	0.260 AB
25	Control 2[d]	0.187 A-C	0.307 A-E	0.140 CD

[a] Means followed by the same letter(s) are not significantly different (p≤0.05) according to Duncan's multiple range test.
[b] The fungicide Bunch was sprayed at a rate of 3 ml/100 l water.
[c]plants were sprayed with ethanol + detergent + water.
[d]plants were left without any treatment.
***Significant difference from control 1.**
[x]Significant difference from control 2.

Certain oils were beneficial in controlling PM in some years (Tables 2 and 3); however, there was a lack of consistency across years, with some oils unsuccessful in controlling PM in other years. None of the oils failed in controlling the disease in all years. In 2020, 2021, and 2022, seventeen oils (77.27 %), twenty oils (90.91 %), and ten oils (45.45 %) were effective in reducing disease incidence, respectively. (Table 2). In 2020, 2021, and 2022, all of the tested oils (100%), twenty oils (90.91%), and seventeen oils (27.27%), respectively, significantly reduced disease severity (Table 3). These findings revealed that the tested oils ability to suppress the disease was year-specific. The effects of the oils on seed output were likewise year-specific, whereas the effects of the oils on straw production were not, with the exception of turnip oil (Tables 4 and 5).

Table 5. Effect of essential oils on straw yield (g/plant) of flax plants cultivar Sakha 2 infected with powdery mildew in an outdoor pot experiment.

Essential oil		Straw yield (g/plant)[a] in		
No.	Botanic source	2020	2021	2022
1	Onion	0.990 A	0.737 AB	0.587 A-D
2	Flax	0.903 A	0.503 B	0.682 A-C
3	Caraway	0.857 A	0.643 AB	0.573 A-D
4	Turnip	0.930 A	0.643 AB	0.452 CD*
5	Spearmint	0.787 A	0.677 AB	0.662 A-D
6	Celery	0.857 A	0.693 AB	0.788 A
7	Basil	0.803 A	0.750 AB	0.593 A-D
8	Pepermint	0.707 A	0..640 AB	0.524 B-D
9	Cumin	0.890 A	0.430 B	0.513 B-D
10	Rocket	0.737 A	0.610 AB	0.521 B-D
11	Garlic	0.863 A	0.587 AB	0.610 A-D
12	Rosemary	0.867 A	0.623 AB	0.545 A-D
13	Fenugreek	0.960 A	0.573 AB	0.555 A-D
14	Dill	0.873 A	0.573 AB	0.633 A-D
15	Fennel	0.763 A	0.773 AB	0.617 A-D
16	Pumpkin	0.650 A	0.697 AB	0.543 A-D
17	Jojoba	0.810 A	0.937 A	0.602 A-D
18	Thyme	0.870 A	0.753 AB	0.594 A-D
19	Bitter almond	0.803 A	0.750 AB	0.524 B-D
20	Coriander	0.883 A	0.587 AB	0.654 A-D
21	Sweet almond	0.763 A	0.597 AB	0.611 A-D
22	Black cumin	0.850 A	0.750 AB	0.616 A-D
23	Bunch[b]	0.783 A	0.613 AB	0.691 A-C[x]
24	Control 1[c]	0.910 A	0.737 AB	0.728 AB
25	Control 2[d]	0.680 A	0.593 AB	0.428 D

[a] Means followed by the same letter(s) are not significantly different (p≤0.05) according to Duncan's multiple range test.
[b] The fungicide Bunch was sprayed at a rate of 3 ml/100 l water.
[c]plants were sprayed with ethanol + detergent + water.
[d]plants were left without any treatment.
***Significant difference from control 1.**
[x]Significant difference from control 2.

Disease incidence and disease severity were positively correlated (P≤0.01) each year (Table 6). Disease incidence was negatively correlated (p≤0.01) with seed weight only in 2022.

Table 6. Correlation[a] among variables used for evaluating efficiency of essential oils in controlling flax powdery mildew.

Year and variable	Variable										
	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11
2019-2020											
Disease incidence(X1)											
Disease severity (X2)	0.763**										
Seed weight (X3)	-0.254	0.001									
Straw weight (X4)	-0.279	-0.203	0.478*								
2020-2021											
Disease incidence (X5)	0.560**	0.607**	0.037	-0.183							
Disease severity (X6)	0.581**	0.677**	-0.045	-0.323	0.945**						
Seed weight (X7)	-0.130	0.164	0.522**	0.170	0.096	0.126					
Straw weight (X8)	0.233	0.045	0.043	-0.128	-0.040	0.077	0.433*				
2021-2022											
Disease incidence (X9)	0.790**	0.590**	-0.253	-0.353	0.467*	0.532**	-0.185	0.103			
Disease severity (X10)	0.753**	0.692**	-0.147	-0.304	0.482*	0.596**	-0.011	0.168	0.845**		
Seed weight (X11)	-0.341	-0.119	0.490*	0.334	0.280	-0.275	0.548**	0.158	-0.511**	-0.335	
Straw weight (X12)	-0.257	-0.152	0.311	0.248	-0.346	-0.300	0.335	0.150	-0.254	-0.234	0.814**

[a]N=25 Pearson's correlation coefficient is significant at 0.01 (**) or 0.05 (*).

Cluster analysis detected the presence of seven groups of similar oils (oils 8, 11, 9, 12, 15, 17; oils 5, 7, 20; oils 6, 10; oils 18, 19, 21;oils 14, 16, 13; oils 1, 2; and oils 3, 4) (Fig. 1). The effect pattern of oil 22 was quite different from the others. Grouping the oils was not related to the taxonomic position of their plant sources- for example, plant sources of oils 3, 6, 9, 14, 15, and20 belonged to family apiaceae; however, they were placed in remotely related sub-clusters. Another example was plant sources of oils 5, 7, 8, 12, and 18, which were placed in remotely related sub-clusters although they belonged to family lamiaceae.

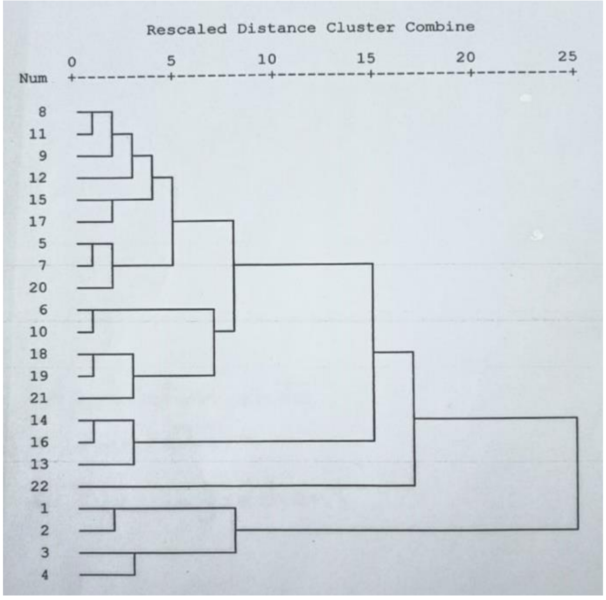

Fig 1. Phenogram based on average linkage cluster analysis of sources of essential oils used in the present study. The sources of essential oils were Onion (1), Flax (2), Caraway (3), Turnip (4), Spearmint (5), Celery (6), Basil (7), Pepermint (8), Cumin (9), Rocket (10), Garlic (11), Rosemary (12), Fenugreek (13), Dill (14), Fennel (15), Pumpkin (16), Jojoba (17), Thyme (18), Bitter almond (19), Coriander (20), Sweet almond (21), and Black cumin (22).

Discussion

Based on the findings of this study, it appears reasonable to conclude that onion, caraway, celery, and black cumin oils are commercially suitable for two reasons: firstly, they significantly reduced disease incidence and severity each year, and secondly, they had no negative impact on seed or straw production. As a result, organic flax growers may be able to utilize these oils instead of synthetic fungicides. The high price of essential oils in the Egyptian market now prevents them from being used on a big scale in the field. However, if essential oils are applied in a limited area, rapid transmission of PM from a single point of infection from field to field can be effectively stopped in a short period of time, protecting the majority of the crop from infection (Paret *et al*., 2010).

Flax cultivars that produce oil and flax cultivars that produce fibre are the two categories of flax cultivars (Dybing and Lay, 1981). The results of this study demonstrated that controlling PM on fiber-producing cultivars with flax, dill, and sweet almond oils is safe. Using these oils to control the disease on oil-producing cultivars, however, is not a smart idea due to their negative influence on seed yield.

Of the essential oils used in this study 27.27 % were derived from plants of the family apiaceae. The majority of the plants in this family have scented hollow stems, and many have been employed in folk medicine (Tabassum and Vidyasagar, 2013). This family includes plants like fennel. Fennel oil inhibited *Alternaria alternata*, *Fusarium oxysporum*, and *Aspergillus* spp. to a high degree. Fennel oil is primarily composed of trans-anethole. The amount of trans-anethole in the oil determines its antifungal activity (Tabassum and Vidyasagar, 2013).

Of the essential oils utilized in this investigation 22.73 % came from plants in the family Lamiaceae. The members of this family come from all over the world. Many members of this family are commercially valuable for medicinal, culinary, decorative, and commercial purposes (Tabassum and Vidyasagar, 2013). This family includes *Thymus* species. Antifungal action has been observed in the majority of Thymus species that contain substantial amounts of phenolic monoterpenes (Tabassum and Vidyasagar, 2013). The presence of phenolic chemicals such as thymol and carvacrol in *T. vulgaris*, for example, reduced fungal growth. The presence of menthol and thymol as key components of the essential oils of *Mentha piperita* and *T. vulgaris* resulted in antifungal activity (Tabassum and Vidyasagar, 2013).

The processes underlying the decrease of PM by essential oils have been the subject of debate. According to (Hafez 2008), the protective effect of essential oils against PM stems mostly from the prevention of conidial germination and suppression of mycelial growth, with a minor activation of host defense systems. Hegazi and El-Kot (2010), on the other hand, discovered that spraying zinnia plants with essential oils increased the activity of peroxidase and polyphenol oxidase enzymes compared to the controls. The highest enzyme activity was linked to a reduction in PM pathogen infection. Aly *et al*. (2013) discovered no significant relationship between the levels and activities of biochemical components of flax plants and the severity of PM after the application of essential oils, indicating that these components are not involved in the reduction of flax PM by essential oils. As a conclusion that direct toxicity of essential oils to *O. lini* is most likely the cause of flax PM suppression.

The particular processes involved in the decrease of flax PM by the use of essential oils are not investigated in this study. Thus, more research is needed to fully understand these pathways.

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فاعلية بعض الزيوت العطرية فى مقاومة البياض الدقيقى على الكتان

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الملخص

اختبر ٢٢ زيتا عطرياً لمدة ثلاث سنوات، و ذلك من حيث الفاعلية فى مقاومة البياض الدقيقى على الكتان عند رشها على المجموع الخضرى. وقد أجريت هذه الدراسة فى تجربة أصص خارج الصوبة، بالرغم من فاعلية بعض الزيوت فى مقاومة المرض فى بعض السنوات، إلا أن أداءها فى مقاومة المرض كان يفتقر إلى صفة الثبات، و ذلك لعدم فاعليتها فى سنوات أخرى. و قد أظهرت النتائج أن الزيوت المختبرة لم تفشل فى مقاومة المرض فى جميع سنوات الدراسة. و قد أمكن باستعمال التحليل العنقودى تقسيم الزيوت إلى مجموعات ، إلا أن هذه المجموعات لم ترتبط بالوضع التقسيمى للمصادر النباتية للزيوت. كما أظهرت النتائج أن الزيوت المستخلصة من البصل و الكراوية و الكرفس و الحبة السوداء كانت مبشرة من حيث إمكانية استعمالها تجارياً، حيث قللت من حدوث المرض و شدته فى جميع أعوام الدراسة، و لم يكن لها أى تأثيرات ضارة على إنتاج البذرة أو القش.

الكلمات الدلة: زيوت عطرية، بياض دقيقى، كتان.