Evaluation of mancozeb-based fungicides in potato late blight control under field conditions in Ismailia Governorate

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Abstract: Present work aimed to compare the effectiveness of mancozeb-based fungicides commonly used in the control of *Phytophthora infestans* in potato fields using the recommended field application rates on Spunta cultivar during the summer cropping seasons of 2016 and 2017 at El-Kssassin Agricultural Research Station in Ismailia Governorate. In this experiment, twelve commercial fungicides (Typhoon 80% WP, Manfil 75% WG, Electis 75% WG, Rado El Nasr 72% WP, Ridomil Gold MZ 68% WG, Galben Mancozeb 58% WP, Remiltine S Pepite 50.5% WG, Goldstone 69% WP, Revus MZ 65% WG, Sereno 60% WG, Triomax 66% WP and Premitox forte 41% WP) and untreated check were used. Typhoon 80% WP and Manfil 75% WG (mancozeb only) were used as a standard treatment checks. The obtained results showed that the pressure of late blight disease can effectively be controlled by using these fungicides; potato late blight severity was significantly more in untreated check than in fungicide-sprayed treatments. All fungicides tested were significantly increased tuber yields as compared to untreated control. Although a significant reduction in the severity of late blight with subsequent improvement in quantity and quality of potato yields was obtained in all fungicide treatments, the above attributes differed with the fungicides used. Triomax 66% WP fungicide (cymoxanil + mancozeb + copper oxychloride) was the most effective against potato late blight infection and consequently produced the highest potato yields, while Manfil 75% WG fungicide produced the least potato yields compared to control. It could be observed that the late blight infection can decrease potato yields and subsequently net returns to the growers if appropriate management program is not undertaken particularly in areas where epidemics of late blight disease occur early in the season. Thus, it appears that the tested fungicide mixtures could be recommended to control the late blight disease and can serve as viable alternatives to the presently used fungicides against late blight in potato fields. To obtain the best control against late blight it must be used fungicides at spray intervals of 7-days in control programs with fungicides belong to different chemical classes. This suggestion might be valuable to implement the appropriate management programs considering fungicides selection and the optimum application in order to achieve both disease control and reduced risk of failure.

Keywords: Fungicides, Mancozeb, Mixtures, Potato late blight, Field conditions

1.Introduction

Potato (*Solanum tuberosum* L) is the world's most important food commodity non-grain as its production increases each year (**FAO, 2012**), and considered a high-potential food security crop because of its potency to give a high yield product with high-quality per unit input with the shorter crop cycle (mostly<120 days) than most cereal crops such as maize. Worldwide, potato plants are attacked by many of pathogens such as fungi which caused significant losses **(Guchi, 2015)**. Susceptibility to diseases partially is one of the potential factors limiting growing this crop commercially. Late blight disease caused by *Phytophthora infestans* (Mont.) de Bary is economically regarded the most important one (**Ghorbani *et al*., 2004**). Late blight disease can occur on several members of the Solanaceae family **(Fry, 1998)**, but potatoes and tomatoes are the species mainly affected **(Son *et al.* 2008)**. This disease attacks leaves, stems and tubers that present potential host tissues for infection **(Olson, 2000)**.

Losses by this disease can be reached 100%, if it is not controlled and the crop may be unsuitable for storage or usage even with low infection level **(Fernández-Northcote *et al*., 2000)**. Late blight disease has spread far and wide, and now occurs wherever potatoes are grown. The losses of quantity and quality of potato tuber yield due to this disease have been estimated to 12 billion Euro annually of which has been estimated around 10 billion Euro in developing countries **(Haverkort *et al*., 2009)**. Several major mechanisms of the dissemination of late blight disease and pathogen may occur simultaneously which is resulting from combinations of aerial dispersal of *P. infestans* sporangia from stems and leaves of diseased plants from field to field over large areas, alternate hosts or through human activity across continental and regional scales **(Olanya *et al*., 2015)**.

Because of the most widely grown genotypes of potato are susceptible to late blights, therefore fungicides treatment are a necessity **(Oyarzún *et al*., 2005)** and considering a vital factor in the production of potato as the resistant varieties are being not available **(Olanya *et al.*, 2001)**. Outbreaks of late blight disease are controlled by extensive and regular applications of fungicides which have reduced the potato late blight foliar infection **(Kirk *et al*., 2005)**. Fungicides research has caused a diverse range of fungicidal products during the last two decades with multiple modes of action which had a significant effect on plant diseases control **(Nabi *et al*., 2017)**. It was previously reported the fungicide combinations containing mancozeb proved highly effective in the control of late blight disease in potatoes **(Kumar *et al*., 2012)**. There are two fungicide types are routinely used: the protectant fungicides including dithiocarbamates as mancozeb and the systemic fungicides including aliphatic nitrogen compounds such as cymoxanil, phenylamides such as metalaxyl and morpholines such as dimethomorph **(Nowicki *et al*., 2012)**.

Although chemical control of the late blight pathogen by fungicide treatments of contact, penetrating or systemic products enables to destroy, weaken or suppress the pathogen **(Muchiri *et al.*, 2009)**. Unfortunately, a protectant fungicide needs to be applied more regularly in the wet weather **(Schepers, 1996)** since the late blight disease is devastating when air, temperature and humidity are favourable at 12-25ºC with relative humidity more than 85% **(Dey and Ali, 1994)**. However, randomized use of systemic fungicides produces chance to develop the resistance of fungus strains broad-spectrum **(Singh, 2000)**; pathogens can easily resistant the systemic fungicides such as metalaxyl because they have a single site mode of action **(Deahl *et al.*, 1995)**. Therefore, to reduce the risk of resistance of *P. infestans* to the systemic fungicides usually applied the mixtures of both protectant and systemic fungicides **(Samoucha and Cohen, 1989)** that consequently reduced the sprays number per season **(Staub and Sozzi, 1984)**.

The field trials emphasize the importance of effective fungicides as the preventative applications for late blight disease prevention **(Stein and Kirk, 2002)** . Pre-season and early of the season, the management target of late blight is the primary infection. As the season progressed, the target of management develops to reduce the pathogen spread rate. If the pathogen spreads widely during the period of rapid plant growth the infection may no longer be controllable. Late of the season, the target of management develops to not allowing the disease to reach maximum limit **(Johnson, 2007)**. Intervals of sprays are usually between 7 to 14 days, sometimes reduced to 5 days depending on the risk of blight and growth stage of crop. In the high-risk conditions, it is essential to maintain short spray intervals between fungicide applications which are often important as the product choice **(Bradshaw *et al.*, 2000)**. Treatment of potato foliage must be frequent, often at intervals of 7 days, because of leaf surface losses through weather case and the need of new foliage protection **(Hollomon, 2015)**. In addition, fungicides choice and timing are provided successfully key factors to late blight control (**Kalkdijk *et al.*, 2007)**.

Mancozeb was used for the control of many fungal pathogens on plant and developed in over seventy crops **(Gullino *et al.*, 2010)**. Contact fungicidal products belonging to dithiocarbamates and copper formulations classes are widely used, whether in specific formulations in or isolated applications. Among the active ingredients registered most significant products are based on cymoxanil, metalaxyl-M, mandipropamid and dimethomorph **(Töfoli *et al.*, 2013)**. However, protectant fungicides principally inhibit the germination and penetration of spores but once the pathogen enters the plant leaves, these preventive fungicides become ineffective. Generally, a fungicidal product having some systemic and curative activity is desirable under such conditions **(Schwinn and Margot, 1991)**. The systemic fungicides possess long persistence on the plant surface and are being used as mixtures with contact fungicides against potato late blight to avoid development of resistance of pathogen **(Davidse *et al.*, 1989)**.

Accordingly, the use of systemic and protectant fungicides for controlling this disease has perhaps been the most important aspect of the late blight's control. Because of mancozeb (the protectant fungicide) gave good control of potato late blight in the field experiments **(Olanya *et al.*, 2001)**, trials are conducted to compose the strategies that improve the control of late blight (**Kalkdijk *et al.*, 2007)**. Unfortunately, the important studies showed that yield losses from 25.5 to 57.25% occurred due to late blight incidence depending on the age of plant infection, time of appearance and degree of susceptibility of the cultivar **(Dey and Ali, 1994)**, however, fungicides application for late blight management increased tuber yield by as much as 60% **(Fontem and Aighew, 1993)**.

Consequently, according to the abovementioned introduction, assessment of fungicide efficacy and optimization of fungicide application which shows the importance of choosing the suitable fungicides mixtures in the management programme which may improve the control of late blight, minimize build-up of resistance of fungicide and reduce costs of potato production. Therefore, the objectives of the present study were (I) to evaluate the efficacy of ten mancozeb mixtures (Electis 75% WG, Rado El Nasr 72% WP, Ridomil Gold MZ 68% WG, Galben Mancozeb 58% WP, Remiltine S Pepite 50.5% WG, Goldstone 69% WP, Revus MZ 65% WG, Sereno 60% WG, Triomax 66% WP and Premitox forte 41% WP) commonly used to the management of late blight on potato foliar in comparison to mancozeb alone (Typhoon 80% WP and Manfil 75% WG) at their recommended application rates on Spunta cultivar in the field and untreated control, and (II) to evaluate the relationship between fungicide treatments and potato tuber yields and yield over control (YOC).

2.Materials and Methods

The present investigation was performed to evaluate the effectiveness of commercial mancozeb products at their recommended rates, often mixtures, against late blight disease on potato Spunta cultivar in the field.

2.1.Field experiment:

A field trails were conducted on the farm of the Agricultural Research Center, Ministry of Agriculture and Land Reclamation at El-Kssassin Agricultural Research Station in Ismailia Governorate, Egypt during the summer growing seasons of 2016 and 2017 with the variety named Spunta which obtained from Agricultural Research Center, Ministry of Agriculture and Land Reclamation, Egypt. The field trials were designed as a completely randomized blocks with four replicates for each treatment with a replicate size of 42 m^2. Apparently healthy seed tubers were planted into the experimental field and the distance between plants and rows were maintained as 20 cm and 60 cm, respectively. Experimental field was irrigated and fertilized by the customary aspersion system which is done for commercial potato production in Egypt and stopped 15 days before harvesting.

In this experiment, twelve commercial fungicides (Typhoon 80% WP, Manfil 75% WG, Electis 75% WG, Rado El Nasr 72% WP, Ridomil Gold MZ 68% WG, Galben Mancozeb 58% WP, Remiltine S Pepite 50.5% WG, Goldstone 69% WP, Revus MZ 65% WG, Sereno 60% WG, Triomax 66% WP and Premitox forte 41% WP) were used comparing to untreated check. Typhoon 80% WP and Manfil 75% WG (mancozeb only) were used as a standard treatment checks. Likewise, other fungicide treatments were mixtures, represent different chemical groups, based on mancozeb (mancozeb plus) which used for control of late blight disease in Egypt. Recommended rates of all experimental fungicides were applied and untreated plots served as check. Disease onset was observed at 45 days after planting and the first spray of fungicides used was begun soon after appearance of the initial disease symptoms by using knap-sack sprayer and continued every 7 to 10 days of intervals till the destruction of most of the untreated check replicates. The interesting information belongs to the experimental fungicides of the present study are summarized in Table (1).

Natural infection was relied upon in all replicates and the late blight incidence and severity were determined. Subsequently, five plants were randomly selected from each replicate per each treatment, and then five leaves from each plant were used for the disease severity determination. The data of late blight disease severity were visually recorded by estimating leaves with lesions one day before spray and at intervals after spraying using a recommended CRS/NAPIAP scale from 1 to 6 disease rating scale as shown in Table (2) according to **Dillard *et al.* (1997)**.

The disease severity is calculated by the equation of **Townsed and Huberger (1943)** as follows:

$$\textbf{Disease Severity \%} = \sum \frac{(n \cdot v)}{6N} \times 100$$

Where: n = number of leaves within infection category.
v = numerical value of each leave.
N = total number of leaves.
6 = the highest severity rating.

NAPIAP: National Agricultural Pesticide Impact Assessment Program.

CRS: Congressional Research Service.

Efficacy of treatments on disease severity % (as % reduction in the severity of disease) was calculated by the following equation:

$$\text{Efficacy\%} = \frac{\text{\% of disease severity in control - \% of disease severity in treatment}}{\text{\% of disease severity in control}} \times 100$$

Total tuber yield (TTY) of each treatment as well as check plants was determined by harvesting the two inner rows of all replicates of each treatment at exactly 120 days after planting of the summer cropping seasons of 2016 and 2017. Tubers were sorted as marketable and unmarketable (deformed, blighted and rotten) from the total tuber yields. Total tuber yields were given in Ton/Fed., which was derived by extrapolation from the yield per replicate. Increase % (yield over control) in tuber yield was calculated as follow:

$$\text{Increase\%} = \frac{\text{Tuber yield in treatment - tuber yield in control}}{\text{Tuber yield in treatment}} \times 100$$

2.2.Data Analysis:

The data collected on late blight severity and yield were subjected for significance by a two-way analysis of variance (ANOVA) using multiple range comparisons (CoStat) software. Means of treatments were separated by using Least Significant Difference (LSD) at ($P \leq 0.05$ whenever ANOVA showed significant treatment effects. Multiple range test means was analyzed by using the method of **Duncan (1955).**

3.Results and Discussion

Studies on tuber foliar late blight management have been reviewed by various researchers; **Hooker (1980)** stated that symptoms of late blight disease are described partially from the total foliage necrosis. **Shattock (2002)** reported that the manifestations of tuber and foliage blights are very different, with necrosis of tuber tissues being a much slower compared with a rapid foliage necrosis. **Johnson (2007)** demonstrated that late blight infection starts off producing an extreme lesion on foliage and the low lesion on tubers. This risk goes to high, to medium and to low foliage risk at the end of season vice versa the late blight lesion on tubers goes to low, to medium and to high, during the same period.

3.1.Evaluation of fungicides on potato late blight in the field:

Following tested fungicides application in the field as may be supposed, not all the fungicides applied to the potato foliage will be equally effective in controlling tuber blights but the most common method of preventing tuber blights is spraying the foliage. Foliar application can reduce disease in tubers due to reducing sporulation and the viability of sporangia on leaves, and fungicide residues falling from sprayed leaves may inhibit motility of zoospores in the soil **(CIP, 2010)**. Accordinglly, fungicides producing companies' recommended that control of late blight has to be begun at the row closing and has to continue with repeated intervals from 7 to 10 days reaching the end of season **(Koppel and Runno-Paurson, 2007)**. So, the repeated application at proper intervals is mandatory **(Namanda *et al*., 2004)**.

The present field experiment aimed to compare the effectiveness of mancozeb-based fungicides used to control foliar late blight on potato in the field. The effect of recommended field application rates of mancozeb mixtures on the severity of *P. infestans* in potatoes of cv Spunta during the summer cropping seasons of 2016 and 2017 is presented in Table (3); it was found that the fungicides used were highly effective since they reduced significantly the potato late blight foliar infection. After crop emergence, the first attack of late blight was seen in the untreated control. However, at 25 days after cropping emergence (after planting at 45 days), symptoms of late blight were observed in the leaves of the canopy lower parts. Results in Table (3) showed that, however, mancozeb mixtures gradually produced significant protection against late blight disease on the potato foliage of Spunta cultivar in the field during the experimental cropping seasons. Mancozeb alone and in mixtures examined produced reduction in potato late blight infection ranged from 78.69-79.20% for Manfil 75% WG and 89.35-87.73% for Triomax 66% WP at the first and second cropping seasons, respectively, compared to untreated checks as long as the fungicides were applied before the onset with late blight incidence. This trend of the results was found similarly during both two trials seasons.

In general, there were significant differences between all the treatments during experimental cropping seasons in respect to late blight disease control; fungicides application significantly reduced ($P \leq 0.05$) the progress of late blight disease. Additionally, late blight incidences varied in their effect depended on the disease pressure and fungicides used meaning that the disease incidence decreased by using fungicides recommended rates. There is no doubt when mancozeb fungicide mixtures used at their recommended rates seemed to be effective for management of late blight in Spunta cultivar in the field.

In the present study, there were significant variabilities between formulations of mancozeb in potato late blight management. These results are validating the previous studies, in which successful management of late

Table (1): The interesting information belongs to the experimental fungicides

*Trade names	*Common names	**Chemical names according to IUPAC	*Rate of application / 100L water	*Manufacturer
Typhoon 80% WP	**Mancozeb**	Manganese ethylene bis (dithiocarbamate) (polymeric) complex with zinc salt	250g	AAKO BV, Lebanon
Manfil 75% WG	**Mancozeb**	Manganese ethylene bis (dithiocarbamate) (polymeric) complex with zinc salt	200g	Indofil Industries Limited, India
Electis 75% WG	**Mancozeb + Zoxamide**	Manganese ethylene bis (dithiocarbamate) (polymeric) complex with zinc salt + (RS)-3,5-dichloro-N-(3-chloro-1-ethyl-1 -methyl-2-oxopropyl)-*p*-toluamide	200g	Gowan Crop Protection Limited, UK
Rado El Nasr 72% WP	**Mancozeb + Metalaxyl**	Manganese ethylene bis (dithiocarbamate) (polymeric) complex with zinc salt + Methyl N- (methoxyacetyl) -N- (2,6-xylyl) -DL-alaninate**;** methyl 2-{[(2,6-dimethylphenyl) methoxyacetyl] amino} propionate	300g	UPL Ltd, India
Ridomil Gold MZ 68% WG	**Mancozeb + Metalaxyl-M**	Manganese ethylene bis (dithiocarbamate) (polymeric) complex with zinc salt + methyl *N*-(methoxyacetyl)-*N*-(2,6-xylyl) -D-alaninate; methyl (*R*)-2-{[(2,6-dimethylphenyl) methoxyacetyl]amino}propionate	200g	Syngenta Crop Protection AG, Switzerland
Galben Mancozeb 58% WP	**Mancozeb + Benalaxyl**	Manganese ethylene bis (dithiocarbamate) (polymeric) complex with zinc salt + methyl *N*-phenylacetyl-*N*-2,6-xylyl-DL-alaninate	250g	Isagro S.P.A, Italy
Remiltine S Pepite 50.5% WG	**Mancozeb + Cymoxanil**	Manganese ethylene bis (dithiocarbamate) (polymeric) complex with zinc salt + 1-(2-cyano-2-methoxyiminoacetyl)-3-ethylurea	250g	Syngenta Crop Protection AG, Switzerland
Goldstone 69% WP	**Mancozeb + Dimethomorph**	Manganese ethylene bis (dithiocarbamate) (polymeric) complex with zinc salt + (E,Z)-4-[3-(4-chlorophenyl)-3-(3,4-dimethoxyphenyl)acryloyl]morpholine	250g	Shandong Cynda Chemical Co., Ltd, China
Revus MZ 65% WG	**Mancozeb + Mandipropamid**	Manganese ethylene bis (dithiocarbamate) (polymeric) complex with zinc salt + (RS)-2-(4-chlorophenyl)-N-[3-methoxy-4-(prop-2-ynyloxy)phenethyl]-2-(prop-2-ynyloxy) acetamide	1kg / Feddan	Syngenta Crop Protection AG, Switzerland
Sereno 60% WG	**Mancozeb + Fenamidone**	Manganese ethylene bis (dithiocarbamate) (polymeric) complex with zinc salt + (*S*)-1-anilino-4-methyl-2-methylthio-4-phenylimidazolin-5-one	150g	Bayer AG, France
Triomax 66% WP	**Mancozeb + Cymoxanil + Copper oxychloride**	Manganese ethylene bis (dithiocarbamate) (polymeric) complex with zinc salt + 1-(2-cyano-2-methoxyiminoacetyl)-3-ethylurea + Dicopper chloride trihydroxide (approximate composition) ; copper oxychloride	250g	Agria S.A, Bulgaria
Premitox forte %41WP	**Mancozeb + Copper Sulfate + Copper carbonate + Copper oxy chloride**	Manganese ethylene bis (dithiocarbamate) (polymeric) complex with zinc salt + Copper Sulfate + Copper carbonate + Dicopper chloride trihydroxide (approximate composition) ; copper oxychloride	250g	Premier Shukuroglou Ltd, Cyprus

*According to **(APC-Egypt, 2018),** ** According to **(Anonymous, 2003)**

blight using fungicides, amongst the many experiments conducted so far in field trials. It was found that the mancozeb using recommended application rate reduced spore germination and was highly effective in late blight management **(Stevenson, 1993; Rehman *et al.* 2008 and Muhinyuza *et al.* (2008)** particularly when applied before infection **(Stevenson, 1993)** reducing the late blight impact **(Namanda *et al.*, 2004)**. **Dowley and Sullivan (1994)** revealed that mixtures of phenylamides plus mancozeb significantly delayed onset of late blight disease on potatoes in six of the seven years, while the leaf blight level was significantly lower at the end of the season in 5 years of the experiments. There is evidence from field experiments of **(Staub, 1994)** that mancozeb mixtures with phenylamides continued to be better than mancozeb alone **(Dowley, 1994)** even in re-entry positions where a phenylamides alone were usually used and then withdrawn. **Kirk *et al.* (2001)** observed that the protective fungicides significantly reduced late blight on foliage to acceptable levels and gave better foliage over untreated as well as tuber yields. **Sengupta *et al.* (2008); Amin *et al.* (2013)** and **Anwar *et al.* (2015)** observed that the combination of mancozeb + metalaxyl significantly reduced the late blight severity on potato and gave best management against *P. infestans*. **Shailabala and Pundhir (2008)** demonstrated that the mancozeb and mancozeb + metalaxyl reduced the recovery of potato phylloplane fungi. **Muhinyuza *et al.* (2008)** and **Muchiri *et al.* (2009)** illustrated that mixtures of mancozeb + metalaxyl and mancozeb + fenamidone, respectively, were effective in con-

Table (2):Rating scale for the late blight severity assessment on potato leaves according to Dillard *et al*. (1997)

Severity		Infection Level Description
Disease rating scale	**Disease incidence percentage**	
1	**0%**	No disease was observed with late blight symptoms
2	**1-10%**	Small lesion area between 1-10% infection of leaf area with late blight symptoms
3	**11-30%**	Lesion area between 11-30% infection of leaf area with late blight symptoms
4	**31-70%**	Lesion area between 31-70% infection of leaf area with late blight symptoms
5	**71-90%**	Lesion area between 71-90% infection of leaf area with late blight symptoms
6	**91-100%**	Lesion area between 91-100% leaf infection of leaf area with late blight symptoms or the entire plant defoliation

trolling late blight compared to mancozeb alone or the untreated controls.

Mancozeb is classified as mode of action group M (Multi Site Action) by the Fungicide Resistance Action Committee, FRAC. Mancozeb is not fungicidal and can effective as a profungicide which degrades to release ethylene bisisothiocyanate sulfide, EBIS, which is given ethylene bisisothiocyanate, EBI. Both EBIS and EBI are considered to be the active toxicants and are thought to conjugate with the enzymes that containing sulfhydryl groups. These core enzymatic processes are fatal disruption to inhibit or interfere with at least six different biochemical processes into the cell cytoplasm and mitochondria of fungus. Mancozeb displays the aspects of a typical multi-site protectant fungicide following application onto the target plants; the fungicide does not penetrate through the leaf cuticle and remains on the surface of leaves to where systemic rearrangement can occur **(Kaars Sijpesteijn, 1984)**. This is clearly important because penetration of a general toxophore such as mancozeb into plant cells would likely cause phytotoxicity **(Gullino *et al*., 2010)**. Specifically mancozeb combinations (and any other phenylamide fungicide in combination with any contact fungicide) introduced strong synergistic interactions **(Gisi and Cohen, 1996)**.

The present results may be agreed with the suggestion previously that the risk of developing field resistance is likely to be much lower for zoxamide than for metalaxyl. Therefore, it is important to apply an appropriate management programme for zoxamide to save its effectiveness and detect any change in the sensitivity of pathogen over time. Thus, an important tool of this programme will be the use of zoxamide with mancozeb in combination **(Young *et al*., 2001)**. While phenylamides may still be applied as components in blight programmes and available as co-formulations with other fungicides that have multi modes of action (e.g. mancozeb), a wide range of

Table (3): Evaluation of the tested fungicides on late blight disease (*Phytophthora infestans*) in potato fields during the 2016 and 2017 cropping seasons at El-Kssassin district, Ismailia Governorate

Fungicide treatments	Infection % ± SD		Efficiency %	
	2016	**2017**	**2016**	**2017**
Manfil 75% WG	9.0±0.816b	9.75±1.707b	78.69	79.20
Typhoon 80% WP	8.5±0.577bc	9.0±0.816bc	79.88	80.80
Rado El Nasr 72% WP	7.75±0.500cd	8.75±0.957bc	81.65	81.33
Ridomil Gold MZ 68% WG	7.5±0.577cde	8.5±0.577bc	82.25	81.87
Galben Mancozeb 58% WP	7.0±0.00def	8.25±0.500bc	83.43	82.40
Electis 75% WG	6.75±0.500defg	8.0±0.00c	84.02	82.93
Goldstone 69% WP	6.25±0.500efgh	7.75±0.957cd	85.21	83.47
Remiltine S Pepite 50.5% WG	6.5±0.577defg	6.5±1.290de	84.61	86.13
Revus MZ 65% WG	5.75±0.500fghi	6.5±1.290de	86.39	86.13
Sereno 60% WG	5.5±0.577ghi	6.25±0.957e	86.98	86.67
Premitox forte 41% WP	5.0±0.816hi	6.0±0.816e	88.16	87.20
Triomax 66% WP	4.5±0.557i	5.75±0.500e	89.35	87.73
Control	42.25±2.217a	46.875±0.853a		

*Means of the same column with the same letters are not significantly different according to Duncan's multiple range test (p = 0.05).

many fungicides available for late blight control with different modes of action are increasingly used **(FRAG -UK, 2016)**.

Among the tested fungicides, Triomax 66% WP (cymoxanil + mancozeb + copper oxychloride) found to be achieved the highest reduction in late blight disease in the field followed by Premitox forte 41% WP. Triomax 66% WP has both systemic and two protectant fungicides differed in their modes of action, gave the best control compared to other treatments. When compared to the control, however, the remained fungicides significantly ($P<0.05$) controlled late blight. The above result may be attributed to the modes of action combined of these mixtures; therefore, the diversity in fungicides modes of action is an important component of anti-resistance tactics **(Phillips McDoughall, 2012 and Leadbeater, 2015)** or to delay buildup of resistance **(Josepovits and Dobrevalszky, 1985)**. Cymoxanil fungicide is reported as several biochemical disruptions including the biosynthesis of amino acids (i.e. cysteine, glycine and serine) and nucleic acid **(Despreaux *et al*., 1981)**, therefore, it metabolized quickly in plant tissues **(Belasco *et al*., 1981)** resulting in the greater protection may be achieved by using combinations than by alternations **(Samoucha and Gisi, 1987)**.

In accordance with the copper in their co-formulations, copper fungicides are widely used for several decades; their main properties being to act on various cell targets. They are generally considered preventive fungicides because they are non-systemic and do not penetrate the plant such as thiocarbamates **(Gisi, 2002)**. Moreover, copper fungicides can be highly effective preventively with complete coverage of foliar surfaces, including the leaves undersides that hindering the development of fungus on the leaf surface by their contact action **(Hermeziu and Hermeziu, 2014)** to maintain a good layer where the treatment will take place **(Fernández-Northcote *et al.,* 1999)**. Subsequently, the above fact could be responsible to denaturation of the enzymes of the respiratory chain by affecting the zoospores structure of *P. infestans* by acting on the different stages of germination and penetration **(Schwinn and Margot, 1991)**.

Consequently, the obtained results also indicated that mancozeb mixtures tested with each of the systemic fungicides produced better protection of newly developed leaves when compared with untreated check due to good redistribution and the short time interval between disease incidence discovery and fungicide spraying resulted in best disease management on new leaves causing better protection. Overall, the fungicides tested can be used to give effective control of potato late blight.

The above statements are agreed with many other researchers; **Muchiri *et al*. (2009)**; **(Kankwasta *et al*., 2003)** and **Samoucha and Cohen (1989)** published that the relatively enhanced disease control obtained with fungicide mixtures from moderate to severe late blight conditions suggested that these mixtures could be a promising approach for late blight control in established epidemics compared with using a protectant or systemic fungicide alone such as mancozeb or cymoxanil **(Samoucha and Cohen, 1988)** and the use of rate alone is not sufficient to control of late blight **(Stein and Kirk, 2002)** because of the potentiation between mancozeb and cymoxanil has been occurred **(Evenhuis *et al*., 1996)**. Additionally, the mixing objectives may be due to apply the protectant fungicide until the disease symptoms appearance, and then apply the systemic fungicide to produce a curative treatment. Mixtures of systemic and protectant fungicides were equally effective for the late blight control in various treatments **(Samoucha and Gisi, 1987)**. **Platt (1985)** suggested that using fungicide combinations such as mancozeb + metalaxyl combination could enable growers to control of established infections with the systemic compound and hopefully with the inclusion of the protectant compound to retard the pathogen resistance development.

Similar to the present findings, however, when only three applications of mancozeb plus metalaxyl were included in mancozeb spray program at a 7 -day significantly excellent control during early season about 20% defoliation was obtained, rapidly developing epidemic conditions **(Platt, 1985)**. Mancozeb and its combinations can be applied as a protectant fungicide at a 7-10 days schedule producing better control. This may be attributed to the resistance risks are very low against mancozeb but certain strains of *P. infestans* may also have different sensitivities **(Brent and Hollomon, 2007a)**. **Subhani *et al.* (2015)** illustrated that the disease severity was reduced as the number of sprays were raised under field conditions and the most fungicides are more effective when applied before infection than after the symptoms have appeared, or after the infection has occurred.

Indeed, as contact fungicides produce a protective film over the treated surfaces, however, they are more susceptible to the adverse environmental effects of humidity, dew, and rain; mancozeb showed lower efficacy and tenacity in a wet environments **(Suheri and Latin, 1991)**. In addition to introducing systemic or local protection for the plant, the fungicide efficacy is clearly related to the potency of its active ingredient for combating chemical, physical or biological degradation caused by environmental factors such as wind erosion, heat, solar radiation, and rain wash-off or irrigation water since systemic fungicides are absorbed and redistributed by the plant **(Schilder, 2010)**. So, the systemic fungicides have good persistence on the plant surface and are being used as mixtures with contact fungicides against late blight to avoid resistance development in *P. infestans* pathogen **(Davidse *et al*., 1989)**. This will be useful to minimize the yield losses due to late blight and assist in reducing development of pathogen resistance against fungicides (**Mehi *et al*., 2015)**.

Moreover, regarding to the benefits of contact and systemic fungicides mixtures, contact fungicides prevents *P. infestans* infection during handling from tuber to tuber but does not prevent infections in young plants in the field. Therefore, mixture of dimethomorph (DMM) + mancozeb can contain both above aspects due to the systemic and contact actions, respectively, in Spunta cultivar, considerable foliage protection was observed up to 35 days after emergence in the field **(Caldiz *et al*., 2007)**. Consequently, lesion expansion was suppressed and sporulation was reduced when established lesions on potato stems caused by *P. infestans* were treated with fungicide mixtures of dimethomorph plus mancozeb and cymoxanil plus mancozeb reduced sporulation more consistently **(Schwinn and Margot, 1991; Cohen *et al*., 1995 and Johnson**

***et al*., 2000a)**. Although most fungicides had protective modes of action and were not effective after *P. infestans* entered plant tissues **(Johnson, *et al.,* 2000b)**, some fungicides combinations have post-infection activity that inhibited sporulation and/or restricted lesion expansion **(Johnson *et al.,* 1997)** such as cymoxanil plus mancozeb and dimethomorph plus mancozeb that were partially systemic and given current capabilities effective in plant uptake **(Kirk and Stein, 2000)**.

Because of the fungicides were classified according to their biochemical modes of action in fungal organisms **(FRAC, 2012)**, fungicides tested are highly specific in their modes of action. It was interesting to demonstrate that the ratio of dose and frequency and the fungicide mode of action could have a significant effect on fungicide performance **(Hall *et al.*, 2007)**. In addition, the availability of a range of alternative fungicides can also protect the new growths in a rapidly developing canopy and have led growers to exclude single resistance fungicides from the control programmes. This large number of fungicides used represents a broad portfolio with different modes of action by meaning fungicides with various attack mechanisms which ensures that most acquired resistance in *P. infestans* strains can be managed. So, using single fungicide products may be enhanced by incorporating fungicide coformulations which provide further modes of actions with curative and anti-sporulant effects **(Cooke *et al*., 2011)**.

Considering that many fungicides including mancozeb are used broadly as seed treatments and foliar sprays. Because of their multi-site modes of action and considering their extensive use, resistance has not contained these widely protectant fungicides. Systemic fungicides have a close association inevitably with the physiology and biochemistry of their hosts, their modes of action are specific and seek out the lethal biochemical target-site in pathogen but not in the host. Clearly, at least 45 modes of action are identified for fungicides; control tactics depending on the use of fungicide mixtures that have multi-site inhibitors with at-risk fungicides; a key challenge is finding and exploiting new modes of action **(Hollomon, 2015)**. Therefore, fungicides reduce, inhibit or restrict disease development in plants by damage of pathogen cell membranes, interfering with key life processes such as energy production, inactivating critical enzymes or proteins required for growth and reproduction, affecting metabolic pathways such as the formation of sterols and chitin, or by triggering immunity responses in host plants **(Hirooka and Ishii, 2013)**. Consequently, fungicides target some basic cellular processes include inhibition of fungal sterols biosynthesis, tubulin or cytochrome-c reductase activity **(Casida, 2009)**.

In addition, many fungicides target single biochemical sites, but few fungicides target multiple sites. The ten general categories are: mitosis and cell division, respiration, nucleic acids synthesis, signal transduction, proteins and amino acids synthesis, melanin synthesis in cell wall, lipids and membrane synthesis, glucan synthesis, sterol biosynthesis in membranes, and host plant defense induction. The 11th mode is multi-site contact activity and the 12th classification is for those compounds with fungicidal activity and an unknown mode of action **(Brent and Hollomon, 2007b)**. Although the major mechanism of action reported for phenylamide fungicides is the inhibition of ribosomal RNA synthesis (reduced sensitivity of RNA polymerase), some studies suggested the reduction in the fungicides uptake as additional resistance mechanism **(Clerjeau *et al*., 1985)** and specifically have selective activity exclusively against Peronosporales. Endogenous nuclear RNA polymerase activity of resistant strains is affected less than that of wild-type strains. In addition, some phenylamides such as benalaxyl may also affect uridine uptake into fungal cells **(Davidse, 1995)** .Additionally, fungicide activity on both direct and indirect germination of sporangia provides strong and reliable action against the disease, regardless of temperature. The power to control mycelial growth also blocks the pathogen's sexual reproduction route by preventing the mycelia of different mating types from meeting **(Bayer CropScience, 2015)**.

3.2.Relationship between tuber yield and potato late blight management:

Late blight disease plays an important role for low potato tuber yield all over the world including Egypt. The effect of late blight disease and its management on potato tuber yield have been broadly investigated over the years. All areas of potato production are at infection risk by late blight regarding for yield and quality (**Van Damme and Ridao, 1994)**. The qualitative and quantitative reductions in potato tuber yield due to late blight can be considered **(Haverkort *et al.,* 2009)**. The relationship between potato foliage late blight and tuber yield has been studied widely in the field focusing on varieties and fungicides **(Rakotonindraina *et al*., 2012)** and it is essential to use fungicides in conventional potato production **(Runno-Paurson *et al*., 2013)** because the synthetic fungicides had an important role for increasing of crop yields **(Hirooka and Ishii, 2013)**. Nevertheless, yield loss caused by late blight is determined to be approximately 16 % of potato production in the world, in spite of these efforts **(Haverkort *et al.,* 2009)**.

The effect of mancozeb fungicide mixtures at their recommended application rates for late blight control in potato Spunta cultivar in the field during the summer of 2016 and 2017 cropping seasons on the average and percentage increase of potato tuber yield is presented in Table (4). The obtained results showed that there were differences in potato tuber yields between fungicide treatments and untreated control since the total yields significantly increased ($p<0.05$) in treated potatoes as compared with untreated control during the 2016 and 2017 successive seasons. Potato yield increment of 22.777 and 26.645% for Triomax 66% WP (mancozeb + cymoxanil + copper oxychloride) and 21.291 and 26.327% Premitox forte 41% WP (mancozeb + copper complex) corresponding to the least increment of 13.985 and 14.680% for Manfil 75% WG (mancozeb alone) were obtained at the end of the growing period with average total tuber yields of 22.50, 23.175 and 22.075, 23.075 (Ton/Feddan), respectively, compared to 20.20, 19.925 (Ton/Feddan) for Manfil 75% WG treatment.

Generally, as shown in Table (4) the two growing seasons comparing to the untreated control, the potato tuber yields were higher in all treatments in 2017 cropping season than the yields realized in cropping season of 2016. Total yields in untreated check were significantly reduced as compared to all fungicide treatments.

It was appeared that difficult to investigate a correlation between the loss resulting in foliage late blight in potato and loss of yield due to the potential yields varying in different locations **(Rotem and Bashi, 1983)**. Under favourable weather conditions, the pathogen can destroy potato foliage in 10 to 15 days and potential yield can be reduced by 50 to 70% **(Tymčenko and Jefronová, 1987)**. **Fry (2007)** suggested that the losses due to pota-

Table (4): Average and yield over control in potato tuber yield resulted in late blight (*Phytophthora infestans*) disease control with the tested fungicides in the field during the 2016 and 2017 cropping seasons

Treatments	Tuber yield (Ton/Fed.) ± SD		Yield over control	
	2016	2017	2016	2017
Manfil 75% WG	20.20±0.216g	19.925±0.298h	13.985	14.680
Typhoon 80% WP	20.25±0.173g	20.30±0.081g	14.197	16.256
Rado El-Nasr 72% WP	20.275±0.125g	20.675±0.150f	14.303	17.775
Ridomil Gold MZ 68% WG	20.90±0.081e	21.00±0.081e	16.866	19.047
Galben Mancozeb 58% WP	20.775±0.050ef	21.125±0.125e	16.365	19.526
Electis 75% WG	21.675±0.170c	21.525±0.095d	19.838	21.022
Goldstone 69% WP	20.625±0.095f	21.775±0.050c	15.757	21.928
Remiltine S Pepite 50.5% WG	21.95±0.129b	21.95±0.129c	20.842	22.551
Revus MZ 65% WG	21.60±0.163c	22.525±0.095b	19.560	24.528
Sereno 60% WG	21.175±0.095d	22.975±0.170a	17.945	26.006
Premitox forte 41% WP	22.075±0.170b	23.075±0.330a	21.291	26.327
Triomax 66% WP	22.50±0.081a	23.175±0.095a	22.777	26.645
Control	17.375±0.206h	17.00±0.216i	---	---

*Means in the same column having the same letters are not significantly different according to Duncan's multiple range test (p = 0.05).

to late blight disease consist of yield reduction attributed to premature foliage death and tuber rots in the field and storage and excessive financial losses associated with fungicide use for disease control. **Bouws and Finckh (2008)** postulated that the quality and yield of table potato tubers may be reduced by a bad forecrop, nutrient deficiency, and infections caused by pathogens that attack both the aboveground parts of potato plants and tubers. Therefore, **Mantecón (2009)** assumed that potato late blight causes a higher damage to marketable tubers and reducing tuber size than on the total number of tubers. **Muhinyuza *et al.* (2008)** cleared that the increases in yields were correlated with decreasing foliar late blight severity. **Bayer CropScience (2015)** demonstrated that the key to optimal yield and tuber quality is successful protection of leaves and stems. To keep building yield to full potential the canopy has to be kept healthy and completely.

The results of potato tuber yield shown in Table (4) are consistent with the findings of many previous studies. However, there were significant increase in potato yield resulted in metalaxyl/mancozeb treatment of late blight as compared to untreated check **(Platt *et al.*, 1998)**. **Kankwatsa *et al.* (2003)** proved that the mixture of metalaxyl and mancozeb increased the yield. These findings were coincided with **Speiser *et al.* (2006)** who studied the effect of fungicides containing copper on *Phytophthora infestans* for two years. The copper fungicide reduced foliar blight severity in both years by 27% and increased yield by 20% on average. **Mantecón (2009)** reported that contact or systemic fungicide sprays significantly increase the marketable tubers at 41.8% and total potato yields at 35.6%; however, fungicide treatment appears to be essential to obtain high quality yields. **(Kumar *et al.*, 2012)** observed that field efficacy of seven fungicides containing mancozeb against late blight of potato resulted in corresponding increase in potato tuber yield at 99.0 to 173.2% in fungicide treatments over untreated control. **Sharma and Saikia (2013)** found that the maximum yields of 73.20 q/ha or 62.60 q/ha were recorded in the prophylactic spray treatment with mixture of cymoxanil + mancozeb or metalaxyl + mancozeb, respectively, followed by two additional sprays with the same fungicide at 10 days interval in the field.

Moreover, **Chakraborty and Banerjee (2016)** found that prophylactic spray with mancozeb followed by fenamidone + mancozeb at the onset of the late blight disease on potato followed by mancozeb at seven days followed by one more spray with fenamidone + mancozeb at intervals of seven days exhibited the highest total tuber yield of 25.84 and 26.78 t/ha during two successive seasons, respectively, in comparison to control. **Khadka *et al.* (2016)** stated that dimethomorph and fenamidone with mancozeb produced highest yield/ha under field conditions. **Prasad *et al.*, (2018)** indicated that when manage late blight of potato, the mixtures of famoxadone + cymoxanil, ametoctradin + dimethomorph and fenamidone + mancozeb resulted in highest marketable tuber yield of 17.77, 14.27 and 13.78 t/ha with lowest blighted tubers of 0.42 t/ha, 0.57 t/ha and 0.65 t/ha corresponding to lowest marketable tuber yield of 6.79 t/ha and highest blighted tubers of 1.22 t/ha in control were recorded.

Generally, it was suggested that different fungicides having modes of action are usually used to meet the need for eradicative or preventive action during the cropping season to completely control of late blight and then infected tubers **(Cooke *et al.*, 2011)**. Fungicides having a new mode of action (preferably with low resistance risk) are special interest, since they play an important key role in control of disease in modern, adapted population of plant pathogens, and in strategies of resistance management, but new fungicides are equally important with enhanced characteristics such as well-established mode of action, systemicity, curativity, and longevity in disease control **(Chao *et al*., 2011; Nabi *et al*., 2017)**. Thus fungicides with single-site modes of action are at relatively high risk for resistance development compared to those with multi-site modes of action **(Mueller and Bradley, 2008)**.

The best striking feature and the most important recommendation are the commercialization of contact fungicides in pre-pack mixtures with systemic fungicides **(Fernández-Northcote *et al*., 2000)**. Since protectant fungicides kill the pathogen on the plant surface before infection occurs, however, systemic fungicides could penetrate potato plant tissues and kill the late blight pathogen in the tissue. These curative fungicides could be applied after the spores arrived on the potato plant and were widely used **(Tsakiris *et al.* 2002)**. The significant advantages of systemic fungicides compared with contact fungicides, mainly in the areas that are very favored to late blight pathogen. Contact fungicides affect the pathogen structures in the surface area of plants by acting during the penetration and germination phases. When using contact fungicides, it is very important to remain suitable layer of fungicide on the foliage, both on the lower and the upper surface of leaves; it must be covered the external part of the plant. The fungicidal potency will be effective only as long as the fungicide maintains on the plant leaves and is not washed off by rainfall. Systemic fungicides move translaminarly from the upper surface to the abaxial side of the leaf, and then to the upper part of the plant. After application the systemic fungicides penetrate into the plant and migrate acropetally even into the non-sprayed plant parts **(Fernández-Northcote *et al*., 2000)**. Systemic fungicides were penetrated the leaflets and mobilized into potato. Consequently, it banned the synthesis of some or more specific stages of metabolism (nucleic acids, lipids and amino acids) of zoospores **(Pérez and Forbes, 2008)**. Thus, this fungicide which is double-acting is able to create a physical barrier preventing the germination and penetration of the inoculums.

Finally, according to **(Wiik, 2014)**, the results suggested that 7-days treatments with recommended rates of the most effective fungicides are required to obtain the best control. The average blight-free tuber yield increase corresponded well with the different actions applied during the cropping period, resulting in an increase of yield due to fungicidal treatments. Thus, it is likely continuing pursuit of reduced and optimized use of fungicides. In this regard, fair comparisons are taken between different formulations and/or products and that the right fungicide, the right application time and the right dose are identified. All possible care should be performed to optimize the fungicide use according to the profits benefit of growers, the sustainability of fungicides and the environment.

Conclusion

It could be concluded that all fungicides tested significantly reduced late blight disease progress on potatoes when compared to untreated. Different fungicides mixture types containing mancozeb could be introduced to control the rapid growth of late blight disease under common conditions in the field. Different fungicides having different modes of action were generally used to prevent late blight infection during the potato cropping season to completely control and reduce late blight and consequently tuber blight. Quantifying late blight disease symptoms within and among potato fields can enhance the ability to manage this disease. The reason for the improved result of Triomax 66% WP may be due to the combination of mancozeb + cymoxanil + copper oxychloride that had multiple modes of action which are important in potato late blight control. In order to fulfill the study objectives, given the wide diversity of fungicide mixture products, it remains an interesting avenue to explore into the battle against the virulent late blight-causing pathogen on potato (or alternate hosts such as tomato and solanaceous weeds). Moreover, new fungicidal experiments will be performed to understand if the early treatment of fungicides could really produce an enhanced management to late blight and will no doubt improve potato production in Egypt. Such recommendations must be influence the timing of the first application of fungicide and following fungicide treatments, and consider the climatic condition variations.

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تقييم مبيدات الفطريات المحتوية على المانكوزيب في إدارة الندوة المتأخرة على البطاطس تحت الظروف الحقلية في محافظة الإسماعيلية

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الملخص العربي

يهدف العمل الحالي إلى مقارنة فاعلية مبيد الفطريات مانكوزيب ومخاليطه الأكثر استخداماً في مكافحة مرض الندوة المتأخرة على البطاطس *Phytophthora infestans* باستخدام معدلات التطبيق الموصى بها في الحقل على صنف "سبونتا" خلال العروة الصيفية لعامي 2016 و 2017م في محطة البحوث الزراعية بالقصاصين في محافظة الإسماعيلية. وفي هذه التجربة، تم استخدام اثني عشر مبيداً للفطريات بصورته التجارية وهذه المبيدات هي (تيفون 80% WP ومانفيل 75% WG وإليكتس 75% WG ورادو النصر 72% WP وريدوميل جولد 68% WG وجالبن مانكوزيب 58% WP وريميلتين إس بيبيت 50,5% WG وجولدستون 69% WP وريفوس إم زد 65% WG وسيرينو 60% WG وتريوماكس 66% WP وبريميتوكس فورت 41% WP) بالإضافة إلى المقارنة غير المعاملة. واستخدم مبيدي تيفون 80% WP ومانفيل 75% WG المجهزان كمانكوزيب فقط كمقارنة قياسية.

وأظهرت النتائج المتحصل عليها خلال الموسمين 2016 و 2017م أن مبيدات الفطريات المستخدمة قد كافحت بشكل ملحوظ مرض الندوة المتأخرة على البطاطس مع زيادة كبيرة في المحصول مقارنةً بغير المعامل. وعلى الرغم من الانخفاض المعنوي في شدة مرض الندوة المتأخرة وبالتالي التحسن في كمية ونوعية محصول البطاطس، فقد تباينت مبيدات الفطريات المستخدمة في تأثيرها. وكان المبيد الفطري تريوماكس 66% WP (سيموكسانيل + مانكوزيب + أوكسي كلوريد النحاس) هو الأكثر فاعلية في مكافحة مرض الندوة المتأخرة على البطاطس وكذلك الأعلى في إنتاجية محصول البطاطس، بينما المبيد الفطري مانفيل 75% WG كان الأقل مقارنة مع غير المعامل.

ويمكن ملاحظة أن الإصابة بمرض الندوة المتأخرة قللت محصول البطاطس بشكل ملحوظ وبالتالي يقل العائد للمزارعين إذا كان البرنامج المتبع لإدارة المرض غير مناسب لا سيما في المناطق الموبوءة بالمرض وخاصةً في بداية الموسم. ولذلك فإن المخاليط المختبرة لمبيد الفطريات مانكوزيب يمكن أن يوصي بها لمكافحة مرض الندوة المتأخرة على البطاطس، ويمكن أن تكون بدائل ناجحة لمبيدات الفطريات المستخدمة حالياً. وللحصول على أفضل حماية ضد مرض الندوة المتأخرة فإنه يجب ألاّ تزيد المدة بين فترات الرش لمبيدات الفطريات عن 7 أيام في برامج المكافحة مع استخدام مبيدات فطريات من مجموعات كيميائية مختلفة، وهذا قد يكون مفيداً لتنفيذ برنامج إدارة ناجح مع اختيار مبيد الفطريات المناسب وكذلك التطبيق الأمثل بغرض تحقيق السيطرة على المرض وتقليل الخطر من فشل المكافحة.