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Amelioration of Biotic Stress Induced by *Onion Yellow Dwarf Potyvirus* on Onion Seed Crop Using Nutrition

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study was conducted in the field to evaluate the effect of onion yellow dwarf virus (OYDV) on growth and yield of onion seed crop of two local onion genotypes (var. "Saggai" and Shendi"). It evaluated the possibility of alleviating the disease expression through the use of phosphorus and foliar spray (ADB) fertilizers. OYDV caused pronounced stunting of plants and reduction of leaf length, leaf width, and height and diameter of floral stalk. The virus infection was also associated with significant reduction in yields as demonstrated by umbel size and number of fertile florets carried by the small heads. Nutrition (phosphorus and ADB) was found to have a profound enhancement on growth and seed yield and seed quality of onion plants infected with OYDV. This was demonstrated by a substantial increase in the size of var. "Saggai" leaves (31.0% in length, 17.2% in width) and in the size of "Shendi" floral stalks (28.6% in height, 33.3% in diameter) in response to phosphorus plus foliar spray or phosphorus alone. Significant improvement in yield

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components, particularly in umbel size and number of fertile florets was obtained from both onion genotypes. The umbel diameter and number of fertile florets decreased in infected plants of cv. "Saggai" by 42.2% and 47.0% and in "Shendi" by 19.1% and 30.6%, respectively. Consequently, the loss in the final seed yield was substantial with reductions of 47.1% and 32.5% in "Saggai" and "Shendi", respectively. Although "Shendi" was comparably affected in its growth parameters to cv."Saggai", but it was affected considerably less in the yield components indicating that "Shendi" is perhaps tolerant to OYDV infection as far as the seed yield is concerned. However, the response to nutrition under test was noticeable for both onion genotypes in all growth and yield components including the final seed yield.

Keywords: Foliar fertilizers; nutrition; management; onion yellow dwarf potyvirus; OYDV; onion; phosphorus; Sudan.

1. INTRODUCTION

Onion (*Allium cepa*) is one of the most important vegetable crops worldwide [1,2]. In Sudan, it is considered as the most popular and widely grown vegetable crop planted annually, primarily as a winter crop [3,4]. However, the area under cultivation is steadily increasing due to the growing local market and potential foreign markets [4]. The main production areas of onion in Sudan include Kassala, Gezira, Khartoum, White Nile, Western Darfur, River Nile and Northern State [3,4]. The season of production in the Sudan extends from August to May and the crop may be grown twice a year; an autumn crop from August to December, and a winter crop from December to May. Three kinds of onion crops are common in the Sudan; a green salad crop, a dry bulb crop grown from tree seeds, and a seed crop raised from bulbs [5,3].

Onions are subject to a variety of fungal, bacterial and viral diseases throughout the world [6] and some of these diseases cause great losses in onions grown in different parts of Sudan. Such diseases include pink root rot (*Pyrenochaeta terresteris*), downy mildew (*Peronospora destructor*), Fusarium basal rot (*Fusarium oxysporum*), purple blotch (*Alternaria porri*), soft rot (*Erwinia carotovora*) and onion yellow dwarf caused by onion yellow dwarf potyvirus (OYDV) [7,8,9]. OYDV which belongs to genus *potyvirus* [10] was first described by Bos [11] and Ploaie [12]. It is transmitted by more than 50 different species of aphids in a non-persistent manner [7]. Among these are *Aphis gossypii*, *A. helianthi*, *A. laburni*, *Macrosiphum pisi* and *Myzus persicae* [13,14,11,15,5]. The host range of OYDV is limited mainly to some species of genera *Allium* and *Narcissus*. Species of the genus *Allium* that were found susceptible to OYDV include: onion (*Allium cepa*), garlic (*A. sativum*) and shallot (*A. asculentum*) [16,17].

The characteristic symptoms of OYDV are mainly yellowing of the infected foliage and the stunted growth of the whole plant [11,9]. Stunting of the infected plants takes place in the first year of growth with irregular yellow streaks on leaves that develop to complete yellowing. The infected leaves lose their shape and become flattened; crinclined and curling occur downloads with flaccidity. The leaves also lose their turgidity and bend down with their tips touching the ground [11,15,3].

The disease has been reported to cause an injurious and massive effect on growth of onion plants and consequently on bulb or seed production [18,19,20,21,9].

In Sudan, the causal virus was isolated for the first time in 1982 [22]. OYD disease is usually very serious and often reaches an epiphytotic level that leads to considerable yield losses [15, 3,4]. Yield losses due to OYDV differ according to the crop. They were found to be very heavy on the bulb crop, but more serious on the seed crop. In Sudan, both high and low levels of infection have been reported. Morgan [15] working in the Khartoum area reported a strikingly high incidence of infection (96%-99%) in onion plants grown from bulbs (seed crops) saved by farmers from the previous season's crop. On the other hand, she reported low levels of infection (0-29%). Salih [5] recorded a high incidence (55%-95%) of OYD disease in onion fields grown from dry bulbs compared to fields grown from true seeds (8%-38%). Certain management practices such as cultural, chemical and biological practices play a crucial role in the disease management [5,23,24,25,4,8]. Application of high doses of superphosphate at time of planting

along the side of the ridges was found to improve both the plant growth and crop yield as well as reduce the harmful effect of the virus [23].

The present study is intended to study the effect of OYDV infection on growth and yield of onion seed crop and the amelioration of the virus infection on these components as influenced by nutrition using phosphorus and foliar spray fertilizers.

2. MATERIALS AND METHODS

2.1 Site of the Experiment

A field experiment was conducted at the Top Farm, University of Khartoum (Latitude 15°: 40' N, Longitude 32°: 32'). This locality lies in the semiarid region with tropical climate and has considerable seasonal variations in both rainfall and temperature [4]. The farm is irrigated from the adjacent main River Nile.

2.2 Planting Materials

Onion bulbs of two local varieties: "Saggai" and "Shendi" were used. The bulbs of var. "Saggai" were harvested from commercial onion field at Garri, Wad Ramly and Wawisi (out-skirts of Khartoum North) while bulbs of var. "Shendi" were obtained from Shendi. Both cultivars are of the red Type.

2.3 Fertilizers

Three different types of fertilizers were used in the experiment. These were super phosphate (granular single superphosphate), Ammonium sulphate $(NH_4)_2SO_4$ and Foliar spray (ADB special liquid fertilizer that contains trace elements: Mg (0.01%), Boron (0.01%), Fe (0.02%), Cu (0.01%), Mn (0.01%), Zinc (0.005%) and Molybdenum (0.005%).

2.4 Pre-planting Sprouting of Onion Bulbs

The bulbs of the two varieties were stored in a refrigerator (5×5 m^2) at a temperature of 10°C. Bulbs tips were first cut so as to stimulate sprouting. After 20 days storage, the sprouted leaf length ranged between 0.5-5 cm. The sprouted bulbs were then exposed to sunlight under the trees shade in the nursery for 7 days. After the exposure to sun light, symptoms of onion yellow dwarf virus (OYDV) started to appear on the emerging sprouts of the infected bulbs that harvested from the previous season. Medium-sized infected bulbs and non-infected ones were selected from the two varieties using a magnifier lens (X10).

2.5 Planting and Cultural Practices

The infected and healthy bulbs were planted on the second week of November at spacing of 30 cm along the ridges (10 bulbs per ridge). Superphosphate as a source of phosphorus was applied at the time of planting along the side of the ridges at 3 levels (P1=178.57 kg/ha, P2=357.14 kg/ha and P3= 0.00 kg/ha).

The use of liquid fertilizer as a foliar spray was started after three weeks from planting and followed weekly for eight times (5 ml/l water) using sprayer. Ammonium sulphate $[(NH_4)_2SO_4]$ was applied at a rate of 238 kg/ha in two equal split doses as a source nitrogen and sulphur to help lower the alkaline PH in order to make super sulphate available. The first dose was applied along the ridges after a month from planting and the second dose after a month from the first one.

2.6 Experimental Design

The experiment was arranged in a split plot-design with 3 replicates in each of the two onion varieties (Saggai and Shendi). Two fertilizers were used: super phosphate at 3-levels (P_0, P_1 and P_2) and foliar fertilizer at 2-levels (F_0, F_1) as shown in Table 1.

2.7 Data Collection

Data was collected four weeks after planting. 3-9 plants were selected randomly from each plot.

2.7.1 The effect of nutrition on growth components of OYDV-infected seed crop

The following parameters were taken to assess the effect of nutrition on growth components of OYDV-infected seed crop: The main number of leaves/plant, leaf length (cm), leaf width (cm), number of floral stalks/plant (=number of umbels /plant), length of the main floral stalks (cm), diameter of the main flower stalk (cm) using a vernier caliper.

Table 1. The different treatments and rates of application of fertilizers

Treatments	Rate of application per hectare
SHF_0P_0	Zero level foliar + zero level phosphorus
SHF_0P_1	Zero level foliar + phosphorus 357.14 kg/ha
SHF_1P_0	Foliar 5 ml/l of water + zero level phosphorus
SHF_1P_1	Foliar 5 ml/l of water + phosphorus 178.57 kg/ha
SHF_0P_2	Zero level foliar + phosphorus 375.14 kg/ha
SHF_1P_2	Foliar 5 ml/l of water + phosphorus 375.14 kg/ha
SIn_0P_0	Zero level foliar + zero level phosphorus
SIn_0P_1	Zero level foliar + phosphorus 178.57 kg/ha
SIn_1P_0	Foliar 5 ml/l of water + zero level phosphorus
SIn_1P_1	Foliar 5 ml/l of water + 178.57 kg/ha
SIn_0P_2	Zero level foliar + phosphorus 357.14 kg/ha
$ShHF_0P_0$	Foliar 5 ml/l of water + phosphorus 357.14 kg/ha
$ShHF_0P_1$	Zero level foliar + zero level phosphorus
$ShHF_1P_0$	Zero level foliar + phosphorus 178.57 kg/ha
$ShHF_1P_1$	Foliar 5 ml/l of water + zero level phosphorus
$ShHF_0P_2$	Zero level foliar + phosphorus 357.14 kg/ha
$ShHF_1P_2$	Foliar 5 ml/l of water + phosphorus 357.14 kg/ha
$ShInF_0P_0$	Zero level foliar + zero level phosphorus
$ShInF_0P_1$	Zero level of foliar + phosphorus 178.57 kg/ha
$ShInF_1P_0$	Foliar 5 ml/l of water + zero level of phosphorus
$ShInF_1P_1$	Foliar 5 ml/l of water + phosphorus 178.57 kg/ha
$ShInF_0P_2$	Zero level of foliar + phosphorus 357.14 kg/ha
$ShInF_1P_2$	Foliar 5 ml/l of water + phosphorus 357.14 kg/ha

S: Saggai variety Sh: Shendi variety H: Healthy plants In: Infected plants

2.7.2 The effect of nutrition on yield of OYDV infected seed crop

A month later data was collected for the following parameters to assess the effect of nutrition on yield of OYDV infected seed crop: diameter of the main umbel (cm) using a vernier caliper, number of florets/umbel (5 umbels were taken from each treatment), number of fertile florets/umbel and percentage of abortive floret using the formula [3]:

% abortive florets =

{(Number of abortive florets)/(Total number of florets/umbel) x 100}

After harvest, a sample of five umbels from each treatment was harvested, collected, separated and left to dry for three weeks before threshing and cleaning by hand. The following parameters were taken:

- The average number of seeds per floret: 50 florets from each umbel were randomly selected and threshed. Their total numbers of seeds were calculated and the average number of seeds per floret was determined.
- Number of seeds /umbel.
- Weight of a thousand seeds (g) using Mettler balance
- Fertilization efficiency using the formula:

%Fertilization efficiency=

{(Number of fertile florets/umbel)/ Total number of florets/umbel× 100}

2.7.3 The effect of nutrition on onion yellow dwarf virus on seed germination

The following tests were carried out:

(i) Seed germination in Petri-dishes (%): 25 seeds from infected and healthy plants respectively, were taken randomly from each variety and placed in 9-cm diameter Petri-dishes fitted with a filter paper saturated with distilled water. Each treatment was replicated in 4 Petri-dishes, and then kept in an incubator at a constant temperature of 25°C in the dark for 7 days. The percentage of germination was counted.

(ii) Percentage emergence under plastic house conditions: The percentage

emergence conducted under plastic house condition in black plastic bags (15 x 20) cm at temperature between 25-31°C. Two replications for each treatment were made. Percentage of emergence was recorded after 15 days after sowing. The length of seedling was measured three weeks after emergence from 10 randomly selected seedlings from each treatment.

2.7.4 Data analyses

Data was analyzed statistically using SAS computer software (version 9.2). ANOVA tables were computed and means were separated by Duncan's Multiple Range Test (DMRT) for comparisons.

3. RESULTS

3.1 Effect of OYDV on Onion Seed Crop

Infection by OYDV caused pronounced stunting of onion plants and reduction of leaf length, leaf width, and height and diameter of floral stalk. Compared to growth parameters of healthy plants, the leaf size was reduced in var. "Saggai" and var. "Shendi", by 24.0% and 27.0% in the leaf length and by 18.7% and 13.6% in the leaf width, respectively (Table 2 and Fig. 1). Similarly, the floral stalks of the two genotypes decreased by 18.1% and 23.5% with respect to their heights and 27.0% and 13.6% in the diameter, respectively (Table 3 and Fig. 1). The results also demonstrated a significant (P= 0.05) damage caused by the virus infection on yield as indicated by the significant effect on umbel size and number of fertile florets carried by the small heads. The umbel diameter and number of fertile florets decreased in infected plants of var. "Saggai" by 42.2% and 47.0% and in var. "Shendi" by 19.1% and 30.6%, respectively (Table 4 and Fig. 1). Consequently, the loss in the final seed yield was substantial with reductions of 47.1% and 32.5% in var. "Saggai" and var. "Shendi", respectively. Although, var. "Shendi" was comparably affected in its growth parameters to var. "Saggai", but it was affected considerably less in the yield components (Table 5). On the other hand, the rest umbel parameters were significantly affected by the nutrition under study (Table 4, Fig. 1).

3.2 Effect of Nutrition on Leaf and Floral Stalk Parameters of OYDV-infected Seed Crop

Tables 2 and 3 show the effect of nutrition on the two onion varieties ("Saggai" and "Shendi") which were treated by three levels of superphosphate (P0, P1, P2) and two levels of foliar fertilizer (F0, F1). The results showed that nutrition has profound enhancement on growth and seed yield and quality of onion plants infected by OYDV. This was demonstrated by a substantial increase in the size of var. "Saggai" leaves (31.0% in length, 17.2% in width) and in the size of var. "Shendi" floral stalk (28.6% in height, 33.3% in diameter) in response to phosphorus plus foliar spray or phosphorus alone (Tables 2 and 3, Fig. 2).

3.3 Effect of Nutrition on Umbel Parameters of OYDV-infected Seed Crop

The nutritional treatments had significant effect (P=.0.05) on the rest of umbel parameters and most treatments produced a bigger umbel size compared to their respective controls (Table 4 and Fig. 2 and 3). The overall mean of the umbel size of infected plants was increased in both varieties in response to nutrition, particularly in var. "Saggai".

The overall mean number of florets per umbel of the infected plants was increased in both varieties in response to nutrition; particularly var. "Saggai" which was increased from 56.5% to 74.9% in comparison to their healthy controls.

All treatments produced greater values of seeds per floret compared to their respective controls (Table 4). The results indicated that the overall mean number of seeds per floret of the infected plants was increased in both varieties in response to nutrition in the range of 19.7%-15.8%, while the overall mean of the number of seeds per umbel of the infected plants was also increased in both varieties in response to nutrition in the range of 67.5% in "Shendi" to 69.6% in var. "Saggai" (Table 4). Significant improvement in yield components, particularly in umbel size and number of fertile florets was obtained from both onion genotypes (Table 4).

Table 2. Effect of nutrition on Leaf parameters of onion yellow dwarf virus-infected seed crop

Treatments	No. of leaves/plant		Leaf length (cm)		Leaf width (cm)	
	H	I	H	I	H	I
$SF_0 P_0$	6.01 bc	6.48 Abc	36.39 Efghij	27.67(78.04)j	1.07defg	0.87(81.31)g
$SF_0 P_1$	6.40 abc	6.14 Bc	41.83 bcdefgh	31.22(74.64)hij	1.13cdefg	0.9(79.65)fg
$SF_0 P_2$	7.51abc	5.92 Bc	37.86 defghij	28.50(75.28)ij	1.12cdefg	0.88(78.57)g
$SF_1 P_0$	6.53abc	7.11 Abc	42.06 bcdefgh	31.33(74.46)hij	1.12cdefg	0.88(78.57)g
$SF_1 P_1$	7.3abc	6.54 Abc	41.33 Cdefgh	36.25(78.71)fghij	1.26abcd	0.94(74.6)efg
$SF_1 P_2$	6.51abc	6.83 abc	45.69 abcdefg	33.58(73.5)abcd	1.25abcde	1.02(81.6)defg
Mean	6.71	6.50	40.86	31.43(76.94)	1.16	0.92(79.31)
Sh $F_0 P_0$	7.69abc	7.34 abc	47.00 abcdef	34.33(73.04)hij	1.25abcde	1.08(86.4)defg
Sh $F_0 P_1$	7.29abc	6.83 abc	50.5 Abc	40.33(79.86)cdefgh	1.27abcd	1.23(96.95)abcdf
Sh $F_0 P_2$	7.00abc	5.47 c	52.67 Ab	39.75(75.84)cdefgh	1.32abcd	1.2(90.91)ab
Sh $F_1 P_0$	8.78a	6.72 abc	47.61 Abcde	37.58(78.93)defghij	1.5a	1.22(74.78)abcdef
Sh $F_1 P_1$	6.69abc	7.88 ab	48.33 Abcd	35.67(73.81)ghij	1.4abc	1.15(82.14)abcdefg
Sh $F_1 P_2$	7.94ab	6.83 abc	55.33 A	38.00(68.68)deffghij	1.45ab	1.12(77.24)cdefgh
Mean	7.56	6.85	50.24	37.61(74.86)	1.37	1.17(85.4)

Values followed by the same letter (s) within a column do not differ significantly according to Duncan's Multiple Range Test at 5% level.
Figures between parentheses represent percentages relative to the healthy parameters.

Table 3. Effect of nutrition on floral stalk parameters of onion yellow dwarf virus-infected seed crop

Treatments	No. of floral stalks / plant		Height of floral stalks (cm)		Diameter of floral stalks (cm)	
	H	I	H	I	H	I
$SF_0 P_0$	5.83ab	5.58b	61.82 Abcde	50.67 (81.96)bcde	1.11abcd	1.03 (73.05)b
$SF_0 P_1$	9.55ab	8.06abc	69.20Ab	53.02 (76.62)bcde	1.423cdefgh	1.15 (80.99)effgh
$SF_0 P_2$	7.67ab	8.05ab	67.58Abed	51.53 (76.25)bcde	1.77abcde	1.24defgh
$SF_1 P_0$	7.9ab	8.11ab	68.02Abc	56.92 (83.68)abcde	1.7abcde	1.12 (65.88)efgh
$SF_1 P_1$	9.52ab	9.81a	69.29Ab	59.60 (89.92)bcde	1.61cdefgh	1.22 (75.78)defgh
$SF_1 P_2$	8.73ab	8.56ab	66.28Abcd	33.58 (73.5)abcde	1.23abcde	.02 (81.6)gh
Mean	8.20	8.02	67.03	54.33 (81.05)	1.59	1.14 (71.7)
Sh $F_0 P_0$	7.17ab	5.89ab	47.00Cde	34.33 (73.04)hij	1.25abcde	1.08 (86.4)defg
Sh $F_0 P_1$	6.83ab	8.5ab	74.00Ac	56.94 (76.95)abcde	1.94abc	1.44 (68.6)bcdefgh
Sh $F_0 P_2$	6.59ab	8.76ab	63.00Abcde	48.17 (76.46)c	1.25cdefg	1.08 (86.4)fgh
Sh $F_1 P_0$	9.61ab	9.11ab	64.00Abcde	51.00 (79.69)cde	1.52bcdefgh	1.13 (74.34)efgh
Sh $F_1 P_1$	8.64ab	7.44ab	74.89A	49.5 (66.1)de	1.65abcdef	1.13 (68.48)efgh
Sh $F_1 P_2$	9.02ab	8.17ab	68.5Abc	59.44 (86.77)abcde	2.00ab	1.31 (68.5)defgh
Mean	7.98	7.98	67.91	54.50 (80.25)	1.74	1.2 (68.97)

Values followed by the same letter (s) within a column do not differ significantly according to Duncan's Multiple Range Test at 5% level
Figures between parentheses represent percentages relative to the healthy parameters

Table 4. Effect of nutrition on yield components of onion yellow dwarf virus-infected seed crop

Treatments	Mean diameter Of umbel (cm)		Total No. of florets/umbel		Mean No of fertile florets/umbel		%aborted florets/ umbel		Mean No. of Seeds/florets		Mean No. of Seeds/umbel		Fertilization efficiency (%)	
	H	I	H	I	H	I	H	I	H	I	H	I	H	I
$SF_0 P_0$	5.83ebcdef	3.38 (57.98)H	708.4 abcde	400 (56.47)h	517.34 efgh	274.12 (52.99)K	26.95 A	31.02a	3.60f	3.56 (98.89)f	1862.69ghij	985.76 (52.92l	60.00a	59.33 (98.89)g
$SF_0 P_1$	6.20abcde	5.01 (80.65)Cdefg	644cde	603.4 (93.7)defg	515.14efgh	453.03 (87.94)Ghi	20.17A	25.06a	4.2abcdef	4.2(-)abcdef	2200.85efg	1907.53(86.67)ghi	70.00abcdefg	70.00(+)abcdefg
$SF_0 P_2$	5.87abcdef	4.15 (70.7)Eh	735.6abed	717.6(97.55)abcde	570.02bcde	529.10 (92.82)Defg	21.00A	26.31a	4.84a	4.82 (99.59)a	2759.59bed	2573.25(93.25)bcdef	80.66a	80.33 (99.59)a
$SF_1 P_0$	7.06a	5.94 (84.14)Abcdef	744.2abc	423.6 (56.92)k	519.15bcdef	292.17 (59.2)K	27.37A	30.95a	3.94bcdef	3.62 (91.88)f	2185.60efg	1069.24(48.92)kl	65.66bcdefg	60.33 (91.88)g
$SF_1 P_1$	6.5abcd	5.14 (80.94)Bcdsfg	717.0abcde	505.4 (70.78)fgh	454.42ghi	38.15 (84.54)H	23.05A	22.23a	4.46bcdef	3.90 (87.44)	2418.48cdefg	1511.59(62.5)ijkl	74.33abcdef	65.00 (87.45)defg
$SF_1 P_2$	6.00abcdef	5.12 (85.33)Bcdefg	824.6a	622.2 (75.45)cdef	687.8a	471.07(68.49)Fghi	16.19A	24.07a	4.94a	4.76 (96.36)a	3384.67a	2262.47(66.84)defg	82.33a	79.33 (96.36)a
Mean	**6.22**	**4.79 (27.04)**	**728.5**	**545.4 (74.87)**	**548.97**	**400.6 (72.97)**	**21.96A**	**26.61**	**4.33**	**4.14 (95.61)**	**2.468.65**	**1.718.31(69.61)**	**72.16**	**69.05(95.09)**
Sh $F_0 P_0$	5.66abcdef	4.58 (80.92)Fab	646cde	477.4 (73.9)gh	474.36fghi	329.13(69.38)Jk	24.36A	30.39a	3.46f	3.44 (99.42)f	1356.24ijkl	1332.31(89.24)kl	57.67g	57.33 (99.41)g
Sh $F_0 P_1$	6.40abc	4.8 (75)Cfg	725abcde	587.4 (81.03)efg	628.28abc	430.33(68.49)Hi	12.56A	24.59a	4.56abcd	3.76 (82.46)ef	2878.30abc	1614.99 (56.11)hijk	76.00abcde	63.67 (8246)fg
Sh $F_0 P_2$	6.38abcd	5.87 (78.06)Cdefg	791.25ab	659.8 (83.39)bcde	615.04abcd	473.62(77.07)Fghi	22.13A	26.79a	4.66abc	4.52 (97)abcde	2860.15abc	2147.68 (75.09)efgh	77.67abcd	75.33 (96.99)abcdef
Sh $F_1 P_0$	6.59ab	4.58 (69.5)Gh	761.3abe	589.13 (73.38)cfg	639.04ab	473.01(74.02)Fghi	15.57A	18.89a	4.7ab	3.92 (83.4)bcdef	2997.89ab	1854.89 (61.87)ghij	78.33ab	65.33 (83.4)cdefg
Sh $F_1 P_1$	5.23bcdefg	4.98 (95.22)Cdefg	678bcde	420 (61.95)h	540.98cdefg	336.99(71.53)Ij	18.79	22.76a	3.82def	35 (91.52)f	2076.11fgh	1370.68 (66.02)ijkl	63.66efg	58.33 (91.63)g
Sh $F_1 P_2$	5.88abcdef	4.88(82.99)Cdefg	742.7abcd	589.83(79.45)efg	570.16bcde	448.8(78.71)Ghi	23.00A	22.89a	4.68abc	4.22(90.17)abcdef	2666.95bcde	1897.05(71.13)hi	78.00abc	70.33(99.17)abcdefg
Mean	**6.02**	**4.95(82.23)**	**724**	**555.93(76.51)**	**577.98**	**423.6(73.29)**	**19.49**	**24.39**	**4.31**	**3.89(90.26)**	**2.522.61**	**1.702.93(67.51)**	**71.89**	**64.89(90.26)**

Values followed by the same letter (s) within a column do not differ significantly according to Duncan's Multiple Range Test at 5% level
Figures between parentheses represent percentages relative to the healthy parameters

Table 5. Effect of nutrition on quality of progeny seed parameters of OYDV – infected seed

Treatment	Mean 1000-seed weight (g)		Seed generation in Petri-dishes (%)		Rate of germination (No. of germinated seed/day) in Petri-dishes (%)		% emergence Under plastic house conditions		Rate of emergence in soil (seedlings/day)		Length of seedlings–after 3 weeks (cm)	
	H	I	H	I	H	I	H	I	H	I	H	I
SF_0P_0	2.3 fghi	2.0 i	100	99	2.24	2.66	94	82	7.63	7.57	10.99	8.88
SF_0P_1	3.3ab	3.0 bc	95	100	2.87	2.28	94	98	6.87	6.97	11.23	10.54
SF_0P_2	2.8 cde	2.8 cde	96	97	2.82	2.63	88	80	6.62	6.93	11.51	9.97
SF_1P_0	3.5 a	3.1 bc	98	97	2.67	2.72	85	81	6.86	7.52	10.27	9.48
SF_1P_1	3.0 bc	2.8 cde	99	100	2.44	2.62	89	94	7.02	6.66	13.36	10.14
SF_1P_2	2.5 efg	2.3 fghi	97	93	2.55	2.96	86	84	6.85	6.75	12.04	9.77
Mean	2.9	2.7	97.50	97.67	2.59	2.63	89	86.5	6.98	7.07	11.57	9.79
ShF_0P_0	2.2 ghi	2.0 i	93	97	2.37	2.36	86	82	7.58	7.78	9.02	9.11
ShF_0P_1	3.1 bc	3.1 bc	98	99	2.37	2.22	87	90	7.10	7.29	11.17	9.65
$SheF_0P_2$	2.4 fgh	2.3 fghi	88	100	2.87	2.31	69	90	8.72	8.82	9.87	9.28
ShF_1P_0	2.3 fghi	2.1 hi	91	97	2.87	2.80	76	84	7.67	7.24	9.30	8.45
ShF_1P_1	3.0 bc	2.9 cd	97	100	2.54	2.38	88	89	7.14	6.69	11.7	9.09
ShF_1P_2	2.6 def	2.3 fghi	98	100	2.58	2.32	91	93	7.66	6.81	10.58	9.66
Mean	2.6	2.5	94.17	98.83	2.60	2.39	85.17	88.00	7.65	7.44	10.27	9.21

Values followed by the same letter (s) within a column do not differ significantly according to Duncan's Multiple Range Test at 5% level.

Fig. 1. Effect of onion yellow dwarf virus on growth and floral stalks development in onion seed crop plants of var. "Saggai" (Top) and "Shendi" (Bottom)
Left: Plants grown from virus-infected bulbs;
Right: Plant grown from healthy bulbs

The only components which were not significantly affected by OYDV infection are; the number of leaves, number of floral stalks, percentage of aborted florets and size of progeny seed.

3.4 Effect of Nutrition on Quality of Progeny Seed Parameters of Oydv-infected Seed

The statistical analyses of variance indicated non-differences (P=0.05) in response to

nutritional treatments in all parameters of progeny seed quality, but the 1000-seed weight (Table 5). All treatments produced higher seed weight compared to their respective controls. The increase in 1000-seed weight in response to nutrition was 40% in var. "Saggai" and 27% in var. "Shendi". While the overall rate germination in Petri-dishes was 2.6 seeds/ day. A greater mean value of seeding was observed in var. "Saggai", which was 13% longer than the mean seeding length in var. "Shendi" (Table 5). It was found that all treatments produced higher values of fertilization efficiency compared to their respective controls. With comparison to infected controls, the mean of fertilization efficiency of infected plants treated with different combinations of foliar and phosphate fertilizers was increased by 19.67% in var. "Saggai" and 15.82% in var. "Shendi". The response to P2 level of phosphorus in infected plants was significant (P=0.05) in both varieties.

Fig. 2. Amelioration of OYDV effect on growth, floral stalks and umbel development of onion seed crop as influenced by nutrition

Top: Plants of var. Saggai treated with phosphorus at a rate of 178.57 kg/ha (right) compared to infected control (left)
Bottom: Plant of var. Shendi treated with phosphorus at a rate of 357.14 kg/ha (right) compared to infected control (left)

Fig. 3. Amelioration of OYDV effect on growth, floral stalks and umbel development of onion seed crop as influenced by nutrition

Top: Plants of var. Saggai treated with phosphorus at a rate of 178.57 kg/ha + foliar spray (ADB at a rate of 5ml/lwater) (right) compared to infected control (left)
Bottom: Plant of var. Shendi treated with phosphorus at a rate of 357.14 kg/ha + foliar spray (ADB at a rate of 5ml/lwater) (right) compared to infected control (left)

4. DISCUSSION

This research work confirms the previous findings concerning the drastic and crippling effect of *onion yellow dwarf potyvirus* (OYDV) on growth and yield of onion seed crop in the field. The symptoms of OYDV developed in both sprouts and plants grown from infected bulbs were typical to those described by previous workers [15,3]. These symptoms varied from mild to severe syndromes and this could be attributed to time infection of the previous crop from which the grown bulbs were obtained and to different rates

of translocation of infection to progeny bulbs.

The vigour of the plants was seriously affected through the harmful effect of the virus on leaf length and leaf width in addition to the pronounced reduction in floral stalks height and diameter. Several previous investigators have shown even more serious decline in the vigour of infected onion plants [26,27,15,3].

The deleterious effect of the virus on yield could clearly be inferred from the remarkably low number of fertile florets carried by the very small umbels in the infected plants.

The data regarding the loss in yield obtained in the study appear to be comparable to the results reported locally. These results may indicate that the seed of crop of var. "Shendi" is tolerant to OYDV infection, while var. "Saggai" is susceptible.

The excellent performance of the progeny seed of the infected plants in terms of germination in Petri-dishes and emergence under plastic house condition reflects the importance of improved nutritional conditions to the onion seed crop.

The only components which were not significantly (P=0.05) affected by OYDV infection are; the number of leaves, number of floral stalks, percentage of aborted florets and size of progeny seed. The plausible explanation for this could be that OYDV does not attack the buds of the bulbs giving almost similar number of leaves and floral stalks from healthy bulbs. Regarding the aborted florets, it appears that the abundant number of florets per umbel in the healthy plant poses a nutritional competition which raises the percentage of the aborted florets.

The extent of this effect on the healthy plant appears to be comparable to the effect of infection in the infected umbel where the number of florets is relatively few. This indicates that the infection acts as a nutrition sink [23]. With respect to the size of progeny seed, it is clear that development of seed in the absence of several nutritional competition will benefit the infected plants producing relative larger seed size.

However, the four growth and yield components of the infected seed crop were profoundly improved in response to nutrition added to the plots.

The epidemiological cycle of OYDV in Sudan appears to carry several vulnerable sites to which management strategies and techniques can be directed when dealing with infected table onion crop, these can be summarized in the fact that the virus is not transmitted through the true seed, is transmitted by aphids in a non-persistent manner, its host range is very restricted and there are some geographical areas in which the virus infection is not present [11,22,5].

Several plant diseases among which viruses have been managed by addition of certain elements of fertilizer compounds such as potato early blight [28,29,30] and OYDV [24]. The last author claimed that the addition of superphosphate and/or infection of VAM fungi could nullify or decrease significantly the harmful effect of OYDV artificiality inoculated to onion seedlings.

The finding of the present study clearly indicated the enhancement role of nutrition on growth of both healthy and OYDV- infected plants of the seed crop, but with varying degrees depending on the treatment. Generally, addition of phosphorus in combination with foliar spray or without it, favours the growth most, particularly the leaf length, height and diameter of floral stalks. The enhanced vigour of the infected plants in response to nutrition was also evident when compared to healthy control where measurements reaching more than 75% and in some treatments 90% were obtained.

Some treatments (F1P2, F0P2) however, gave increments of 4.8-15.2% over the healthy control in the diameter of the floral stalk.

The impact of the nutrition supplement appears to be more pronounced on the yield components of the infected plant. This could be inferred from the remarkable high increment values relatives to the infected control in most of the measurements. Addition of higher doses of phosphorous appears to be more beneficial to the yield of infected plants. However, it could be stated that the early and efficient corrections of growth aspects of the infected plants with nutrition appeared to reflect well on the yield components and the final seed yield subsequently.

5. CONCLUSION

In conclusion, few perspectives emerge from this study. Firstly, the results of the present study are

in agree with previous findings on the crippling nature of OYDV on growth and yield components of onion seed crop and it also indicates that the disease possesses a serious management challenge to onion seed crop growers [22,3,4]. Secondly, "Shendi" is more tolerant to the disease as compared to var. "Saggai" as evidenced by growth and yield data. Thirdly, foliar and superphosphate fertilizers supplement has promoted growth and yield of onion seed crop significantly compared to the non-treated infected control.

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The authors dedicate this research work to the soul of their late colleague Maha F. M. A. Gabbani, asking God forgiveness and mercy for her.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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