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Impact of intercropping soybean cultivars with maize on *Soybean Mosaic Virus* incidence and population dynamics of *Aphis gossypii* (Homoptera: Aphididae)

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ABSTRACT

Soybean is a vital crop, serving as a significant source of vegetable oil and protein. However, *soybean mosaic virus* (SMV) is a widespread pathogen that adversely affects soybean yields globally. This research provides an essential step towards understanding the effects of intercropping soybean varieties with maize and varying planting densities on SMV incidence, its relationship with aphid population, and the resulting impact on soybean crop productivity. The study was conducted over two seasons and included nine treatments, combining three soybean cultivars (Giza 21, Giza 82, and Giza 111), three planting densities (low, mid, and high), and intercropping or sole plantings. The DAS-ELISA test was employed to detect SMV, while aphid populations were monitored weekly. Jasmonic acid content was quantified, and SDS-PAGE was used to assess the synthesis of novel proteins influenced by intercropping and planting density. Agronomic traits and seed productivity were also measured, and data were analyzed using ANOVA. The results demonstrated that intercropping decreased the percentage of SMV by 48.24% and 49.12% in the first and second seasons, respectively, compared with sole ones. Moreover, high plant density reduced SMV incidence in Giza 21 and Giza 111, while the reverse was true for Giza 82. SMV incidence was highly correlated with aphid population for cultivar Giza 82 compared with the other cultivars under intercropping or sole plantings. This study recommends planting the Giza 111 soybean cultivar with high plant density, as it showed a low rate of SMV infection, tolerance to aphid infestation, and high seed productivity under intercropping.

Keywords: SMV, aphid, soybean cultivars, intercropping, plant density

INTRODUCTION

Soybean [*Glycine max* (L.) Merrill] is an important annual crop in the Fabaceae family. Globally, soybeans rank as the fourth-largest crop and serve as a major source of vegetable oil (20%) and vegetable protein (38–45%) for millions of humans and animals worldwide. Its protein is considered complete due to substantial levels of essential amino acids. Soybeans also contain significant amounts of B vitamins, dietary minerals, and phytic acid and are low in starch, making them a suitable food option for diabetics. Numerous products are derived from soybean processing, including adhesives, asphalts, resins, textile fibers, salad dressings, meat substitutes, beverage powders, nondairy creamers, infant formulas, breads, breakfast cereals, pastas, tofu, and pet foods. (Hill and Whitham, 2014; Hasan *et al*., 2023, and Shelke *et al*., 2023).

Various viruses may infect soybean plants. *Soybean mosaic virus* (SMV) (genus Potyvirus, family Potyviridae) is a common virus affecting soybean production worldwide. (Widyasari *et al*., 2020). Symptoms of SMV, including leaflet deformation, pronounced mosaic patterns, and stunted growth. Certain cultivars show a reduction of up to 57% in plant height and 68% in the pod numbers. Yield losses caused by SMV infection can range from 8 to 35%, with some cultivars experiencing up to 94% losses (Díaz-Cruz and Cassone, 2018). SMV spreads through seeds and aphids. With over 35 species of aphids transmit the virus particles in a non-persistent manner. *Aphis gossypii is* the most common aphid on soybeans in Egypt (Gawad *et al*., 2021). Controlling plant Aphid vectors with insecticides may not always prevent disease from spreading in the field. This is most likely due to the incredibly short acquisition and inoculation time periods. Additionally, ongoing infestation by winged necessitates the persistent or routine application of insecticides, which may Lead to herbivore resistance (Hooks and Fereres, 2006).

Plants employ their hormones to react to biotic and abiotic stress. Ethylene (ET), salicylic acid (SA), jasmonic acid (JA), and abscisic acid (ABA) dominate plant defense against pathogens (Alazem and Lin, 2015). JA, as one of the most critical defensive phytohormones, is often involved in a plant's defense against pathogens. Additionally, several studies have supported the concept that JA has an essential role in regulating insect infestation, plant development, and defense responses to virus diseases (Zhang *et al*., 2017; Wu & Ye, 2020). To improve crops and select the desired genotypes for breeding crop plants, attention has been paid to characterizing germplasm using proteins and molecular markers (Das and Mukarjee, 1995 and Ghafoor *et al*., 2002). Techniques like SDS-PAGE and Tricine-SDS-PAGE differentiate protein-peptide profiles of yellow and black soybeans (Stephan, 2021). The complete seed proteins of seven Egyptian soybean varieties were evaluated for variation using SDS-PAGE. The results revealed an overall total of 11 protein bands with various molecular weights (Khalifa *et al*., 2023).

Intercropping and crop density control are used as possible ways to address the problems of aphid vectors of plant viruses. Cultivating two or more crops in the same area at the same time is known as intercropping, and it is often done to increase productivity by making use of the growing resources that are already present (Blessing *et al*., 2022). Intercropping has several benefits and enormous potential. The benefits include: 1) improved soil fertility by adding legumes to the combination; 2) effective resource use; 3) soil conservation from covering a larger area of ground cover; 4) lessens the need for protective plant chemicals by reducing insect pest attacks, limiting the number of weeds, and regulating disease incidence (Maitra *et al*., 2019). The intercropping maize and soybean systems' land equivalent ratios exceeded 1.3, and their total yields outperformed those of the solo crops (Yang *et al*., 2015).

Intercropping with other suitable crops has shown promise in lowering the prevalence and severity of some viral infections. In Europe, the commercial practice of growing cereal crops in and around sugar beets is effective in preventing viral infections. Potyvirus frequency was 90% lower when Swiss chard and wheat were planted with muskmelon. Intercropping maize reduced the incidence of *Turnip mosaic virus* in radish plants by 90%. Intercropping soybeans with dwarf or tall sorghum reduced the seed mottling caused by SMV by 50%. (Damicone *et al.,* 2007; Blessing *et al.*, 2022).

The present study aims to evaluate the influence of intercropping soybean cultivars at different plant densities with maize on SMV incidence and aphid population levels and the simple correlation between them. Along with studying the effect of intercropping on the level of jasmonic acid and the formation of proteins that help soybeans resist the virus. In addition, the effect of different treatments on soybean crops' growth characteristics and productivity.

MATERIAL AND METHODS

Experimental design:

This study included nine treatments, which were the combinations of three soybean plant densities (2, 3, and 4 rows per ridge) expressed as low (50%), mid (75%), and high (100%) of the recommended plant density and three soybean cultivars (Giza 21, Giza 82, and Giza 111) either under intercropping or sole plantings. Maize hybrid TWC 321 was used in intercropping patterns. Maize was grown in one plant per hill, distanced at 25 cm between hills under intercropping plantings, while soybean was thinned to two plants per hill, distanced at 15 cm between hills under intercropping and sole plantings. Soybean plant density under intercropping and sole plantings is illustrated in **Fig. 1.** All normal agricultural practices were performed, and no insecticide treatments were applied. The two-year study (2022 and 2023) was carried out at the Giza Agricultural Experiments and Research Station, ARC, Giza, Egypt, during two successive summer seasons to evaluate the response productivity of some intercropped soybean cultivars with maize, aphid population, and SMV incidence under different plant densities. Three repetitions of a split plot distribution in a randomized full block design were employed. Soybean cultivars were distributed among sub-plots, and soybean plant density was assigned at random to the main plots. Plot area was 16.8 m^2. Each plot consisted of six ridges, 4 m long and 0.7 m wide.

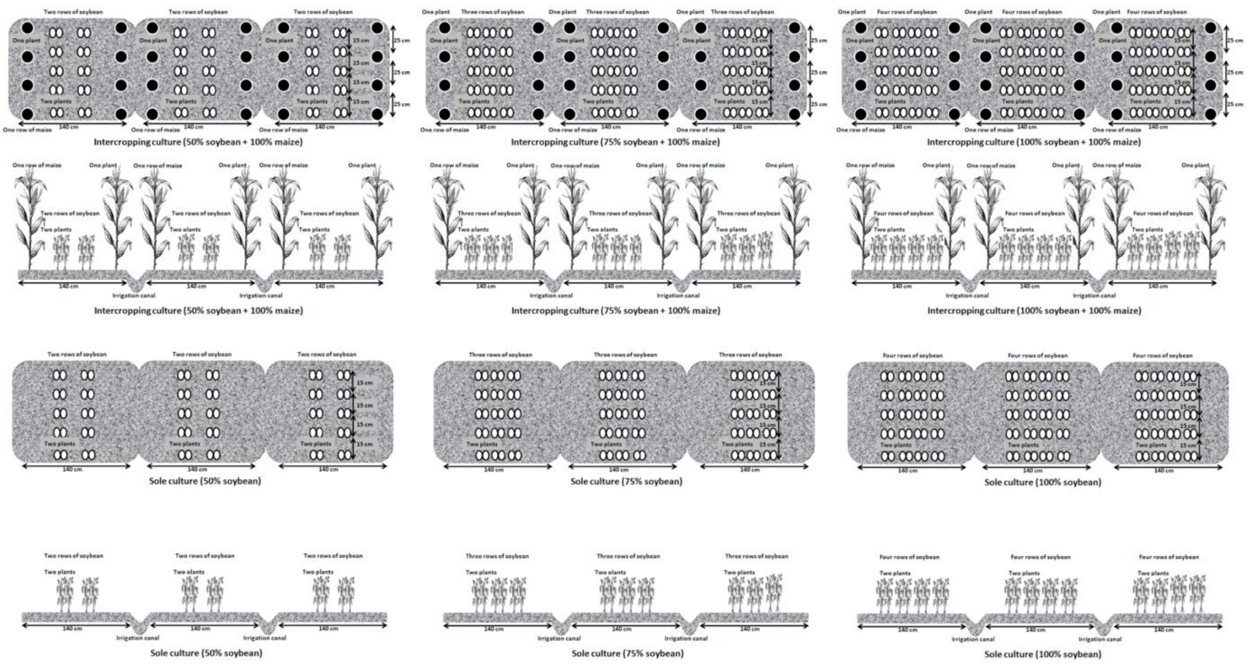


Fig. 1. Plant density of soybean cultivars under intercropping and sole plantings

Observation of viral -infected soybean plants:

Visual observation depending on symptoms:

Samples of three soybean cultivars naturally displaying symptoms of viral infection were determined at every row in each plot. Observation of naturally infected plants started from the sixth week after the planting date, in the middle and end of the season. Plants that had been infected had labels on. By visually examining viral symptoms, the percentage of infection was calculated. The number of virally infected plants divided by the total number of plants in the plot was used to determine the percentage of infected soybean plants. For serological detection, the obtained samples were placed in labeled plastic bags and sent to the serology lab of the Department of Plant Virus and Phytoplasma Research, Plant Pathology Research Institute, Agricultural Research Center, Giza.

Serological detection:

The Double Antibody Sandwich Enzyme-Linked Immunosorbent Assay (DAS-ELISA) test was applied according to the strategy presented by Clark and Adams. (1977). Throughout the two seasons, 130 samples were collected and divided into groups according to different symptoms (mosaic, mottling, vein banding, crinkle, necrotic local lesions (N.L.L.), chlorotic local lesions (C.L.L.), and vein clearing). DAS-ELISA is used for the detection of soybean viruses using specific polyclonal antibody complete kits (LOEWE®, Germany) for SMV, *Cucumber Mosaic Virus* (CMV), *Tomato Ringspot Virus* (ToRSV), *Alfalfa Mosaic Virus* (AMV), and *Pea Seed- borne Mosaic Virus* (PSbMV). While antiserum specific to *Broad Bean Mottle Virus* (BBMV) was previously prepared in the Virus and Phytoplasma Research Department at the Agriculture Research Centre, Giza, Egypt. In the second season, samples were tested for SMV, AMV, and BBMV due to the low incidence of infection with other viruses in the first season. ELISA readings were recorded in a microplate reader (CLINDIAG Systems Co. Ltd.) at an absorbance value of 405 nm.

Aphid population:

Throughout both seasons, the susceptibility of different soybean cultivars to aphid infestation was tested. Samples were taken weekly beginning 45 days after soybeans were planted and for six weeks. Aphid population was recorded by randomly selecting three soybean plants, representing the sample, from each plot's diagonals. The plant leaflets were detached carefully with the visiting aphids in closed plastic bags in the early morning and transferred into the lab and examined.

Determination of jasmonic acid (JA) content in soybean leaflets:

Jasmonic acid (JA) content in soybean cultivars was determined in plants grown under intercropping and sole plantings (µg/100 g) after 60 days from seeding according to Huang *et al*. (2015). These analyses were done by the Food Technology Research Institute, Agricultural Research Center, Giza, Egypt.

Sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS–PAGE) protein analysis:

Studying the effect of intercropping and cropping density on the formation of new proteins compared with sole plantings. Sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS–PAGE) was used to study the banding patterns of the studied soybean cultivars (Giza 21, Giza 82, and Giza 111). Fresh and young leaflets were collected from all treatments for this analysis. Protein fractionation was performed on a vertical slab (16.5 cm x 18.5 cm, Hoefer E600, Amersham Pharmacia Biotech) according to the method of Laemmli (1970) as modified by Studier (1973). This analysis was performed in Cairo University Research Park, Faculty of Agriculture, Cairo University, Giza, Egypt.

Agronomic and seed traits:

Ten soybean plants were randomly taken from each subplot at harvest to record plant height, number of pods plant^{-1}, and seed yield plant^{-1} (g). Seed yield ha^{-1} (t) was determined from seed weight of each subplot and converted to t ha^{-1}.

Statistical analysis:

Data were statistically treated using the analysis of variance (ANOVA) for randomized complete block design, and the least significant difference (LSD) was used for mean separation ($P \leq 0.05$) to compare between soybean cultivars under intercropping and sole plantings. Simple correlations were calculated between the aphid population and SMV incidence recorded at the end of both seasons. All obtained data were subjected to statistical analysis of variance according to Snedecor and Cochran (1980), and the least significant differences (LSD) at the 5% level of significance, were tested according to Freed (1991).

RESULTS

Incidence of naturally virus-infected soybean plants:

Visual inspection:

General viral disease symptoms observed on checked soybean cultivars during the maturity stage under field conditions were mosaic, mottling, vein banding, crinkle, necrotic local lesions, and chlorotic local lesions (**Figure 2**).

Serological test:

Soybean plants showing symptoms (10-15 plants per symptom) were serologically tested by the DAS-ELISA test. Table (1) shows the variation in the infected plants by some viruses (SMV, AMV, BBMV, PSbMV, CMV, and ToRSV). *Soybean mosaic virus* (SMV) was present in almost all samples. As in both seasons, the percentage of SMV in tested samples was 100%.

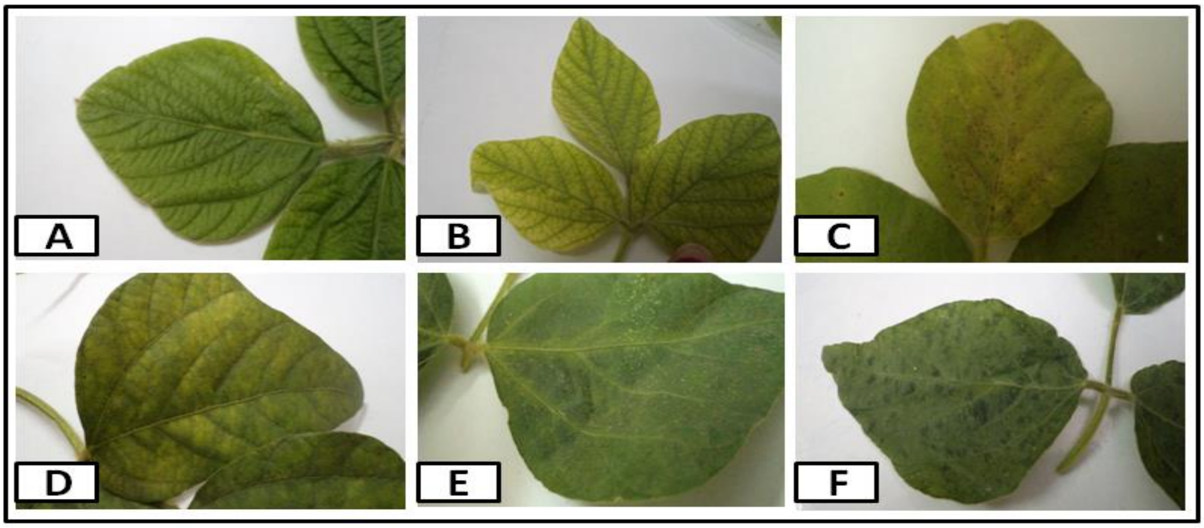


Fig. 2. Symptoms of soybean viral diseases: A (crinkle), B (vein banding), C (necrotic local lesions, N. L. L.), D (mosaic), E (chlorotic local lesions, C. L. L., and vein clearing), and F (mottling)

Table 1. Number of virus-infected soybean plants as indexed by DAS-ELISA test during both seasons (2022-2023)

Symptoms	First season						Second season		
	SMV	AMV	BBMV	PSbMV	CMV	ToRSV	SMV	AMV	BBMV
mottling	15/15*	0/15	10/15	5/15	5/15	5/15	10/10	0/10	10/10
crinkle	15/15	10/15	15/15	5/15	0/15	0/15	10/10	5/10	5/10
mosaic	15/15	0/15	0/15	0/15	5/15	0/15	15/15	0/15	0/15
C.L.L. and vein clearing	10/10	0/10	10/10	10/10	0/10	0/10	5/5	0/5	5/5
Vein banding	10/10	10/10	0/10	0/10	0/10	0/10	10/10	10/10	0/10
N.L.L.	10/10	10/10	0/10	0/10	0/10	0/10	5/5	5/5	0/5
% infected samples	100%	40%	46.6%	26.6%	13.3%	6.6%	100%	36.4%	36.4%

* No. of virus-infected plants/No. of tested plants (showing external symptoms)

Susceptibility of soybean cultivars to infection with SMV under different plant densities of soybean:

Infected plants per subplot showed a range of SMV infection in the first season (2.6 to 37.3%) and the second season (2.0 to 41.5%) **(Figures 3 and 4**). With respect to soybean *cv*. Giza 21, the incidence of SMV at intercropping planting recorded 12.53, 9.63, and 4.93% as the mean of the first season and 17.4, 15.2, and 9.9% as the mean of the second season at low, mid, and high plant densities, respectively. The sole planting recorded SMV infection 31.9, 22.8, and 16.8% as the mean of the first season and 27.3, 24.0, and 19.0% as the mean of the second season at low, mid, and high plant densities, respectively. These results indicate that intercropping soybean *cv*. Giza 21 with maize reduced infection with SMV by 62.1% in the first season and 39.5% in the second season compared with sole planting. Also, high density of intercropping *cv*. Giza 21 reported the lowest SMV infection compared with the other plant densities.

With respect to soybean *cv*. Giza 82, the intercropping planting recorded SMV incidence was 10.1, 17.0, and 20.4% as the mean of the first season and 9.1, 15.9, and 20.4% as the mean of the second season at low, mid, and high soybean plant densities, respectively. The SMV incidence at sole planting recorded 23.1, 26.9, and 28.8% as the mean of the first season and 28.4, 30.2, and 30.4% as the mean of the second season at low, mid, and high soybean plant densities, respectively. These results reveal that intercropping soybean *cv*. Giza 82 with maize reduced infection with SMV by 39.7% in the first season and 48.9% in the second season compared with sole planting. Also, the low plant density of intercropping soybean *cv*. Giza 82 reported the lowest SMV infection compared with the other plant densities.

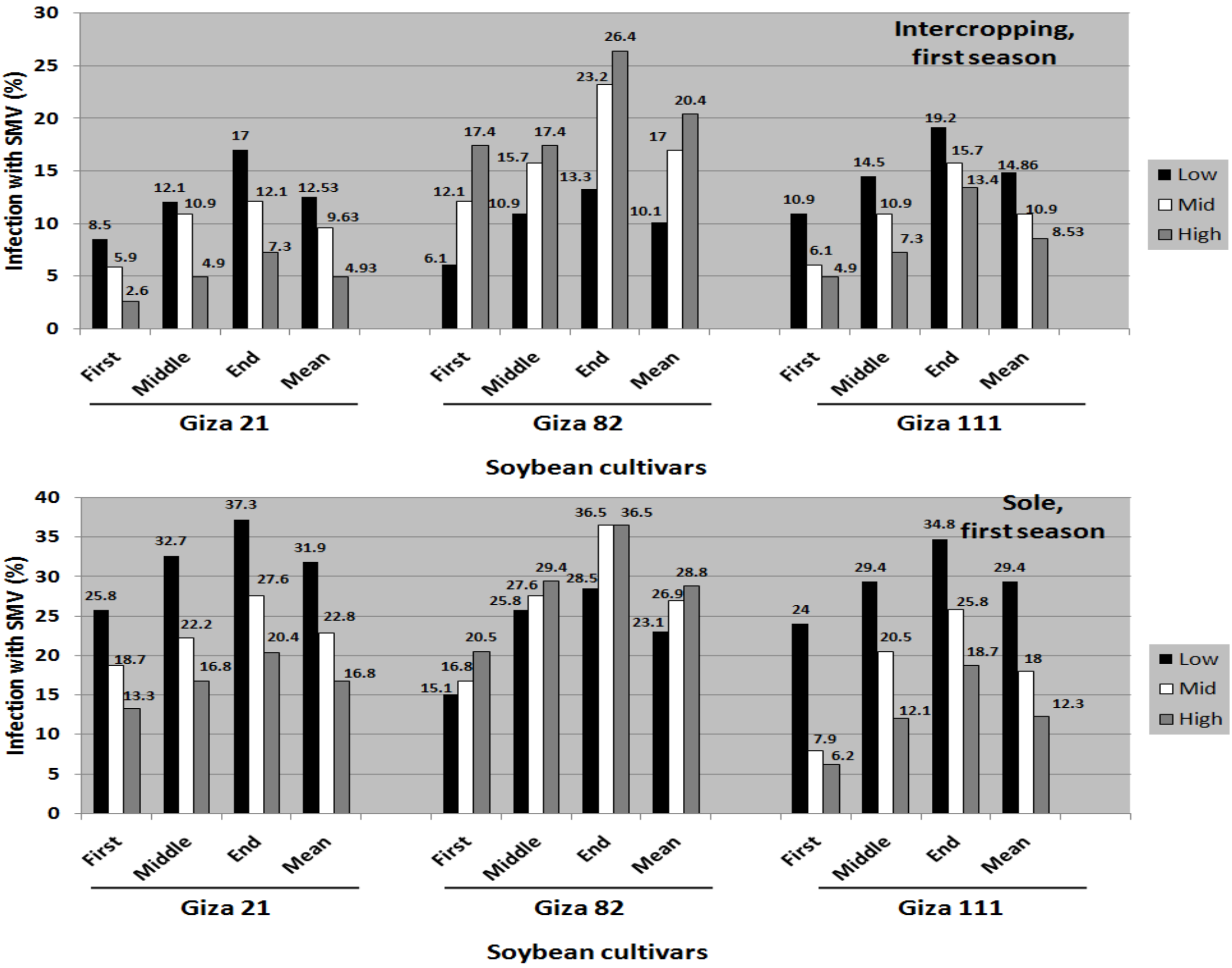
With respect to soybean *cv*. Giza 111, the intercropping planting, SMV incidence recorded 14.86, 10.9, and 8.53 % as the mean of the first season and 18.4, 10.9, and 5.5% as the mean of the second season at low, mid, and high soybean plant densities, respectively. The sole planting SMV incidence recorded 29.4, 18.0, and 12.3% as the mean of the first season and 34.5, 24.3, and 23.1% as the mean of the second season at low, mid, and high soybean plant densities, respectively. These results indicate that intercropping soybean *cv*. Giza 111 with maize reduced infection with SMV by 42.56% in the first season and 57.5% in the second season compared with sole soybean plantings. Also, the high density of intercropping *cv*. Giza 111 reported the lowest SMV infection compared with the other plant densities.

Aphid population:

In both seasons, *A. gossypii* was predominated, although other aphid species were present in smaller quantities *A. gossypii* had higher distribution on soybean plants in the second season than the first season and had lower distribution in intercropping plantings than sole plantings (Tables 2 and 3).

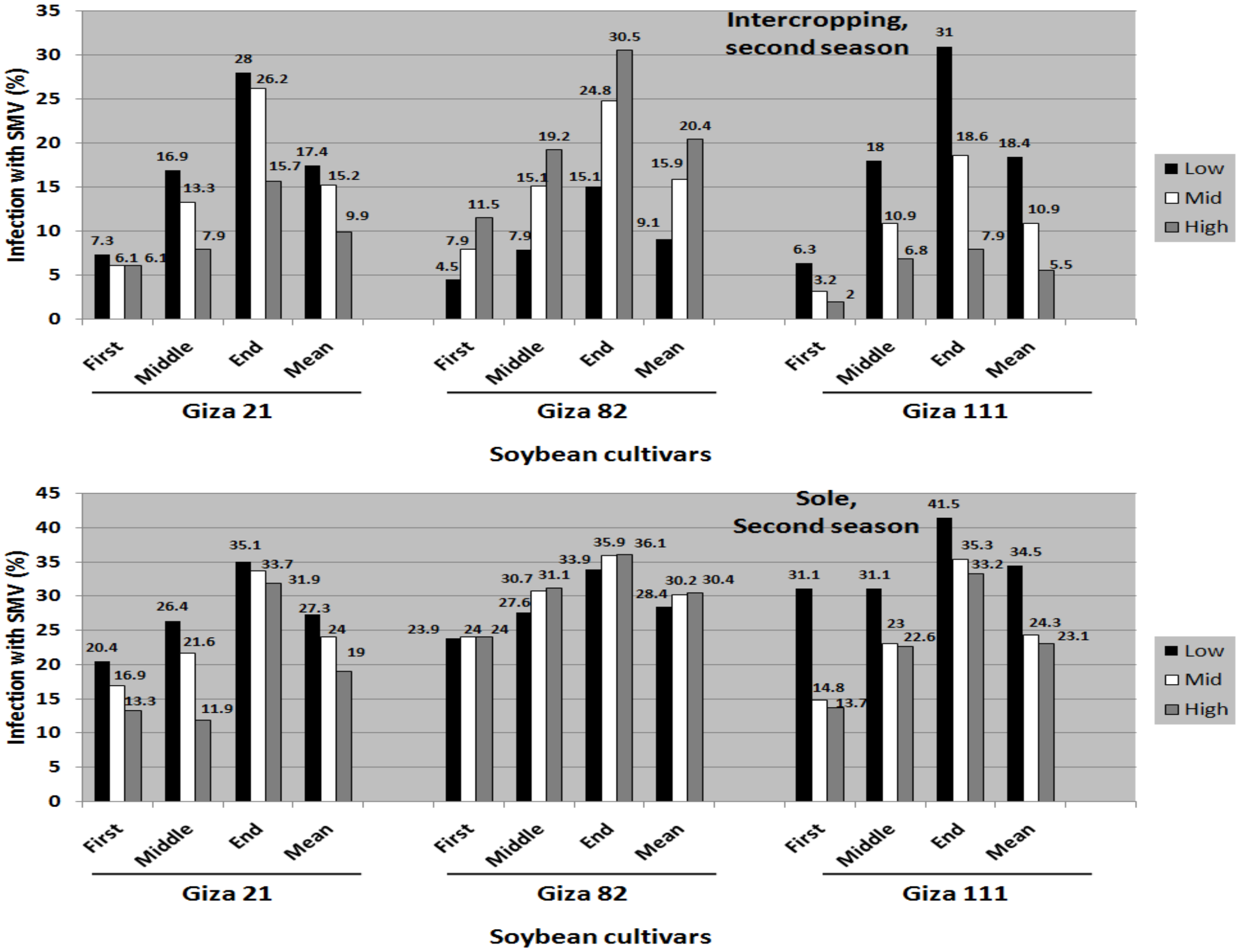
The results showed that the evaluated soybean cultivars' sensitivity to the aphid infestation varied statistically based on the density of soybean plants. Intercropping plantings, soybean *cv*. Giza 21 recorded the lowest aphid population with increasing soybean plant density in the second season, while there was little to no significant impact of plant density on aphid population in the first season. The soybean *cv*. Giza 82 had the maximum population of aphids by increasing the density of soybean plants from low to mid in the first season and from low to high in the second season. While in the case of soybean *cv*. Giza 111, raising plant density from low to high had no significant effect on the population of aphids throughout the first and second seasons.

Furthermore, in the sole plantings, by increasing soybean plant density in the second season, soybean *cv*. Giza 21 had the lowest aphid population. In contrast, there was no significant effect of soybean plant density on aphid population in the first season. Aphid population was maximum in soybean *cv*. Giza 82, with increasing plant density from low to high in the first and second seasons. Meanwhile, for soybean *cv*. Giza 111, increasing plant density from low to high had no significant effect on the population of aphids throughout the first and second seasons.



LSD 5%	Intercropping				Sole			
	First	Middle	End	Mean	First	Middle	End	Mean
Giza 21	-	-	4.4	2.4	5.1	5.1	4.7	4.4
Giza 82	6.2	-	9.3	5.9	-	-	3.6	-
Giza 111	-	3.7	1.7	1.9	13.0	10.0	7.2	3.8

Fig. 3. Percentage of infection of soybean cultivars by SMV virus under density of soybean plants in intercropping and sole plantings in the first season (2022)



LSD 5%	Intercropping				Sole			
	First	Middle	End	Mean	First	Middle	End	Mean
Giza 21	-	4.3	4.9	3.1	1.3	4.6	0.8	1.3
Giza 82	-	4.8	7.5	-	0.6	0.4	0.3	0.6
Giza 111	-	0.6	3.6	-	10.7	-	-	6.7

Fig. 4. Percentage of infection of soybean cultivars by SMV virus under density of soybean plants in intercropping and sole plantings in the second season (2023)

Table 2. Effect of density of soybean plants and soybean cultivars on the population of aphids under intercropping and sole plantings in the first season

Treatments	Mean number of aphids /plant /week						Mean
	First week	Second week	Third week	Fourth week	Fifth week	Sixth week	
Intercropped soybean *cv*. Giza 21 Low*	2.5±2.0	2.5 ±1.7$_b$	2.1±1.0	1.5±1.0	0.5±0.0	0.5±0.0	1.6±0.9
Mid	1.5±1.0	1.5±1.0$_b$	2.0±1.3	1.0±0.3	1.0±0.3	0.5±0.0	1.2± 0.3
High	1.5±1.0	7.5±1.0$_a$	1.8±1.1	1.8±0.5	0.5±0.0	0.5±0.0	2.2±0.5
LSD 5%	-	4.0	-	-	-	-	-
Intercropped soybean *cv*. Giza 82 Low	0.5±0.0$_b$	0.5±0.0$_b$	2.1±0.6	0.5±0.0	1.1±1.2	0.5±0.0	0.8±0.3
Mid	3.5±1.7$_a$	4.2±0.6$_a$	2.8±0.6	1.5±1.0	1.5±1.0	0.5±0.0	2.3±0.5
High	4.5±0.0$_a$	3.5±1.0$_a$	2.1±1.1	2.1±1.5	0.5±0.0	2.1±1.5	2.4 ±0.4
LSD 5%	3.117	2.272	-	-	-	-	-
Intercropped soybean *cv*. Giza 111 Low	4.8±1.5	1.0±0.33$_c$	1.5±1.0	0.5±0.0	0.5±0.0	0.5±0.0	1.4 ±0.1
Mid	6.8±3.2	6.2±1.2$_b$	1.8±0.6	1.1±1.1	1.0±0.33	0.5±0.0	2.9±0.9
High	4.8±3.5	7.8±1.2$_a$	1.0±0.3	1.2±0.6	0.5±0.0	0.5±0.0	2.6±0.6
LSD 5%	-	2.011	-	-	-	-	-
Sole soybean *cv*. Giza 21 Low	2.5±2.0	2.5 ±1.7$_b$	2.1±1.0	1.5±1.0	0.5±0.0	0.5±0.0	1.6±0.9
Mid	1.5±1.0	1.5±1.0$_b$	2.0±1.3	1.0±0.3	1.0±0.3	0.5±0.0	1.2± 0.3
High	1.5±1.0	7.5±1.0$_a$	1.8±1.1	1.8±0.5	0.5±0.0	0.5±0.0	2.2±0.5
LSD 5%	-	4.0	-	-	-	-	-
Sole soybean *cv*. Giza 82 Low	2.4±1.5$_b$	5.0±0.0$_b$	2.5±1.0	1.1±1.1	0.5±0.33	1.0±0.3	2.0±0.5$_b$
Mid	5.8±1.5$_a$	12.2±3.1$_a$	0.5±0.0	0.8±0.0	1.0±0.33	0.5±0.0	3.4±0.5$_a$
High	6.2±1.2$_a$	8.5±0.0$_a$	2.8±2.5	0.5±0.0	0.5±0.0	0.5±0.0	3.1±0.8$_a$
LSD 5%	3.72	4.49	-	-	-	-	1.295
Sole soybean *cv*. Giza 111 Low	3.8±1.5	2.8±1.5$_c$	1.5±1.0	1.0±0.33	1.0±0.33	0.5±0.0	1.7±0.3
Mid	3.5±2.8	5.1±1.5$_a$	3.7±1.8	1.0±0.33	1.0±0.33	0.5±0.0	2.4±1.1
High	2.8±0.6	4.1±1.9$_b$	2.5±1.7	0.5±0.0	0.5±0.0	0.5±0.0	1.8±0.5
LSD 5%	-	0.83	-	-	-	-	-

Note: Means followed by the different letters are significantly different from each other

*Low = 50% of soybean plant density, Mid = 75% of soybean plant density, High = 100% of soybean plant density

Table 3. Effect of density of soybean plants and soybean cultivars on the population of aphids under intercropping and sole plantings in the second season

Treatments	Mean number of aphids /plant /week						Mean
	First week	Second week	Third week	Fourth week	Fifth week	Sixth week	
Intercropped soybean *cv.* Giza 21 Low*	3.8±0.6$_{a}$	2.2±0.6$_{a}$	2.5±0.0	2.2±0.6$_{a}$	2.5±0.0$_{a}$	0.5±0.0	2.2±0.2$_{a}$
Mid	1.2±0.6$_{b}$	0.5±0.0$_{b}$	1.5±0.0	0.5±0.0$_{b}$	0.8±0.6$_{b}$	0.5±0.0	0.8±0.1$_{b}$
High	4.5±1.0$_{a}$	4.2±2.1$_{a}$	2.5±2.0	0.5±0.0$_{b}$	0.5±0.0$_{b}$	0.5±0.0	2.1±0.4$_{a}$
LSD 5%	3.251	3.224	-	1.256	1.256	-	0.978
Intercropped soybean *cv.* Giza 82 Low	0.8±0.6$_{b}$	1.5±0.0$_{b}$	2.2±0.6	1.6±0.0	1.6±0.0	0.5±0.0$_{b}$	1.3±0.3$_{b}$
Mid	3.5±1.7$_{a}$	5.5±1.7$_{a}$	2.8±0.6	1.5±1.0	1.5±1.0	0.5±0.0$_{b}$	2.5±0.5$_{a}$
High	4.5±0.0$_{a}$	4.2±1.0$_{a}$	1.8±1.5	2.2±1.5	2.0±0.5	2.1±0.6$_{a}$	2.8±0.5$_{a}$
LSD 5%	3.062	3.117	-	-	-	1.699	1.090
Intercropped soybean *cv.* Giza 111 Low*	2.8±1.5	0.8±0.6$_{b}$	1.5±1.0	0.5±0.0	0.5±0.0	0.5±0.0	1.1±0.1
Mid	4.5±1.0	6.2±1.1$_{a}$	1.8±0.6	1.8±1.1	0.8±0.6	0.5±0.0	2.6±0.3
High	4.8±1.5	6.2±2.5$_{a}$	0.8±0.6	1.1±0.6	0.8±0.6	0.5±0.0	2.3±0.9
LSD 5%		4.807	-	-	-	-	-
Sole soybean *cv.* Giza 21 Low	2.5±1.7	8.5±0.6$_{a}$	1.8±1.1	1.8±1.1	1.8±1.1	0.8±0.6	2.8±0.7$_{a}$
Mid	1.8±1.1	2.5±0.8$_{b}$	1.5±1.0	1.5±1.0	1.5±1.0	0.5±0.0	1.5±0.5$_{b}$
High	1.8±0.6	6.2±2.1$_{a}$	2.2±1.1	1.2±0.6	1.2±0.6	1.2±0.6	2.3±0.9$_{ab}$
LSD 5%	-	2.868	-	-	-	-	1.522
Sole soybean *cv.* Giza 82 Low	2.8±1.5$_{b}$	3.2±0.6$_{b}$	3.2±1.5$_{a}$	2.5±1.0	1.5±0.0	2.1±0.1	2.5±0.7$_{b}$
Mid	6.2±1.2$_{ab}$	13.2±3.1$_{a}$	1.1±0.3$_{b}$	2.2±1.0	1.1±0.3	1.5±0.0	4.2±0.8$_{a}$
High	9.5±2.6$_{a}$	8.2±2.3$_{ab}$	4.2±1.5$_{a}$	1.2±0.6	2.1±0.2	2.1±0.2	4.5±0.7$_{a}$
LSD 5%	4.933	6.852	2.075	-	-	-	2.148
Sole soybean *cv.* Giza 111 Low	2.5±1.0	5.5±1.7	1.8±0.6	1.1±0.3	1.5±0.0$_{a}$	1.1±0.3	2.2±0.2
Mid	4.2±1.4	5.5±1.0	4.2±2.8	1.1±0.3	0.5±0.0$_{b}$	1.1±0.3	2.7±0.5
High	3.8±1.5	4.2±0.6	2.5±1.7	1.1±0.3	1.2±0.6$_{ab}$	1.1±0.3	2.3±0.7
LSD 5%	-	-	-	-	1.256	-	-

Note: Means followed by the different letters are significantly different from each other
*Low = 50% of soybean plant density, Mid = 75% of soybean plant density, High = 100% of soybean plant density

Simple correlation between aphid population and SMV incidence on soybean cultivars under intercropping and sole plantings:

Data in **Fig. 5** indicate that there was a significant correlation between aphid population and SMV incidence for soybean cultivar Giza 82 under intercropping planting (R2 = 0.83 and 0.81) and sole planting (R2 = 0.96 and 0.84) in the first and second seasons, respectively. Meanwhile, there was no significant correlation between aphid population and SMV incidence for *cv.* Giza 21 or *cv.* Giza 111 under intercropping and sole planting in the first and second seasons.

Otherwise, **Fig. 6** shows the differences among soybean cultivars for infection with SMV under intercropping and sole plantings. Under intercropping planting, soybean *cv*. Giza 82 had higher SMV incidence (15.83% in the first season and 15.16% in the second season) than those of soybean *cv*. Giza 111 (11.43% in the first season and 11.63% in the second season) and *cv*. Giza 21 (9.03% in the first season and 14.16% in the second season). Under sole planting, soybean *cv*. Giza 82 had higher SMV incidence (26.30% in the first season and 29.68% in the second season) than those of soybean *cv*. Giza 111 (19.93% in the first season and 27.36% in the second season) and *cv*. Giza 21 (23.86% in the first season and 23.46% in the second season). There were no significant differences between the soybean *cvs*. Giza 111 and Giza 21 and SMV incidence under intercropping planting in the two seasons. Regardless of soybean cultivars, intercropping reduced the percentage of SMV by 48.24 and 49.12% in the first and second seasons, respectively.

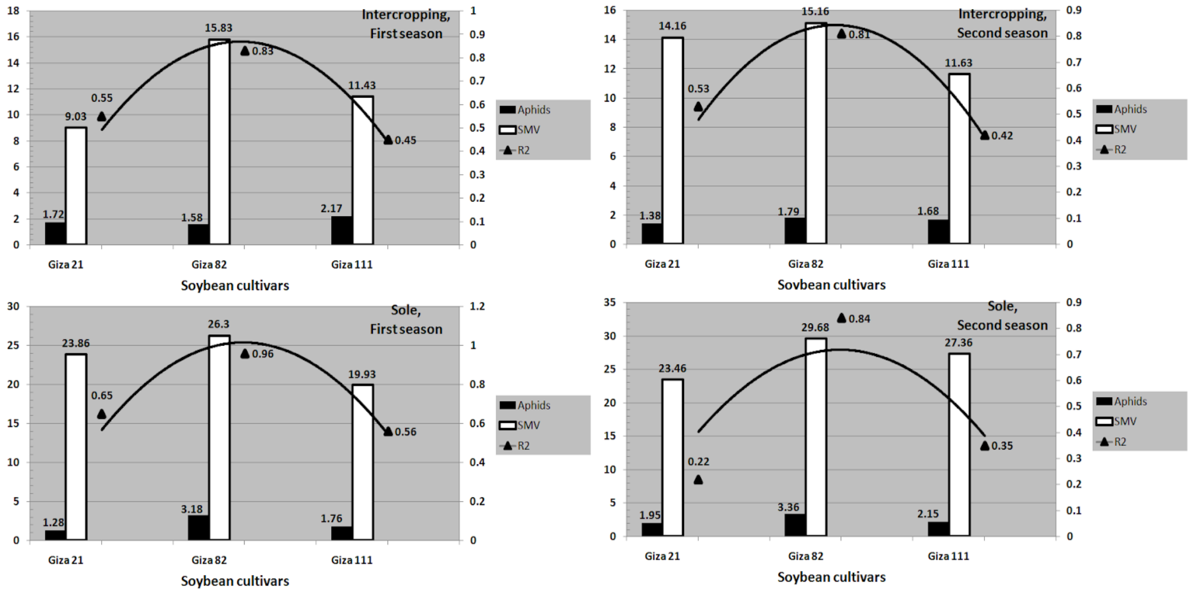
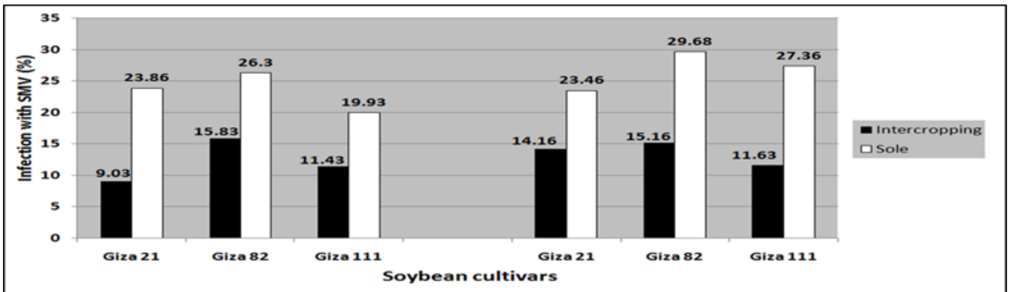


Fig. 5. Simple correlation (R2) between aphid landing rate and SMV incidence in both seasons



Treatments	First season			Second season		
	Intercropping	Sole	F test	Intercropping	Sole	F test
Giza 21	9.03	23.86	8.97	14.16	23.46	3.79
Giza 82	15.83	26.30	3.82	15.16	29.68	2.88
Giza 111	11.43	19.93	7.33	11.63	27.36	3.54
LSD 5%	4.35	3.61	-	3.07	2.76	-

Fig. 6. Soybean cultivars Infection natural with SMV under intercropping and sole plantings in both seasons (2022 and 2023)

Jasmonic acid content in soybean leaflets:

Table (4) shows jasmonic acid (JA) content in soybean leaflets of the three soybean cultivars under all the studied treatments after 60 days from sowing. The content of jasmonic acid in soybean leaflets of the three soybean cultivars increased in the intercropping plantings compared to the sole plantings. Also, the content of jasmonic acid in the *cvs*. Giza 21 and Giza 111 increased as the crop density increased. In contrast, the content of jasmonic acid in *cv*. Giza 82 increased with decreasing crop density in both intercroppings and sole plantings.

Table 4. jasmonic acid (JA) contents in leaflets of three soybean cultivars under three plant densities by intercropping and sole plantings after 60 days from sowing

Soybean cultivars	Density of soybean plants	JA (µg/100 g)	
		Intercropping planting	Sole planting
Giza 21	**High***	411	396
	Mid	382	379
	Low	366	362
Giza 82	**High**	295	293
	Mid	332	322
	Low	366	355
Giza 111	**High**	419	409
	Mid	398	388
	Low	383	370

*Low = 50% of soybean plant density, Mid = 75% of soybean plant density, High = 100% of soybean plant density

Sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS–PAGE) protein analysis:

Protein markers related to intercropping planting:

To assess genotypic variation between intercropping and sole planting system under varying plant densities, total soluble proteins were analyzed using the SDS-PAGE method (Table 5 and 6) and **(Fig. 7 and 8)**. The primary variables considered were the presence or absence of specific protein bands. A total of twelve protein bands with molecular weight ranging from 241 to 7 kDa, were identified across both intercropping and sole planting systems.

Soybean cultivars Giza 111 and Giza 21 had the greatest number of total protein bands, and the least amount of total protein bands was reported in soybean *cv*. Giza 82 (**Table 5 and Figure 7**). The various bands appeared only at low and mid density of soybean *cvs*. Giza 21 (7 kDa) and Giza 111 (59 kDa). Six novel protein bands with molecular weights of 31, 71, 96, 131, 176, and 241 kDa were formed in *cv.* Giza 21 at high density, while one protein band (7 kDa) was found to be absent. Two protein bands with molecular weights of 31 and 71 kDa vanished at a high density in *cv*. Giza 82 in contrast to the other plant densities. Among the various densities in *cv.* Giza 111, a single protein band with a molecular weight of 71 kDa was produced under high density.

Table 5. Effects of density of soybean plants and cultivars on leaflet protein banding patterns under intercropping planting

Band number	Molecular weight (kDa)	Giza 21			Giza 82			Giza 111		
		Soybean density			Soybean density			Soybean density		
		Low*	Mid	High	Low	Mid	High	Low	Mid	High
1	241	0	0	1	0	0	0	1	1	1
2	176	0	0	1	0	0	0	1	1	1
3	131	0	0	1	0	0	0	1	1	1
4	96	0	0	1	0	0	0	1	1	1
5	71	0	0	1	1	1	0	0	0	1
6	59	0	0	0	0	0	0	1	1	0
7	44	1	1	1	1	1	1	1	1	1
8	31	0	0	1	1	1	0	1	1	1
9	21	1	1	1	1	1	1	1	1	1
10	16	1	1	1	1	1	1	1	1	1
11	13	1	1	1	0	0	0	1	1	1
12	7	1	1	0	0	0	0	0	0	0
Total		5	5	10	5	5	3	10	10	10
New bands Molecular Wight		0	0	6 31, 71, 96 131, 176	0	0	0	0	0	1 71

(1) presence of band; (0) absence of band;

*Low = 50% of soybean plant density, Mid = 75% of soybean plant density, High = 100% of soybean plant density

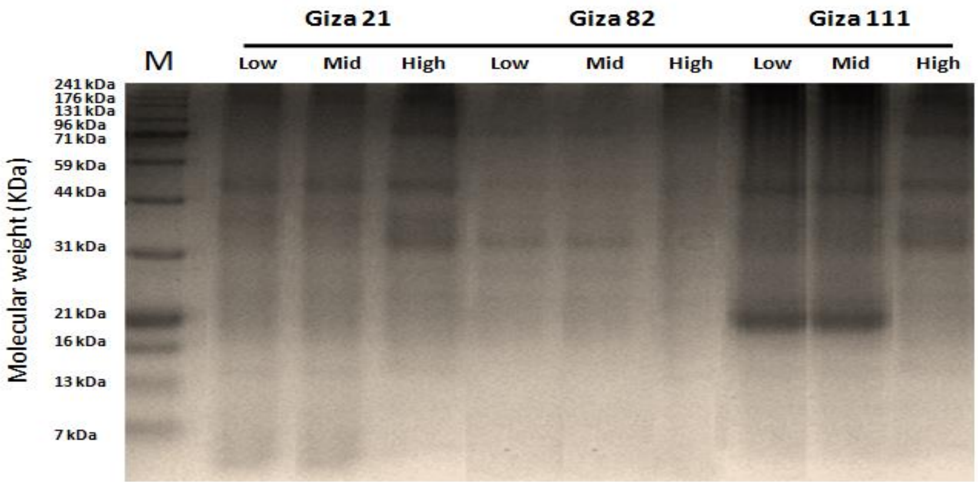


Fig. 7. SDS-PAGE of proteins of Giza 21, Giza 82, and Giza 111 under intercropping planting
Low = 50% of soybean plant density, Mid = 75% of soybean plant density, High = 100% of soybean plant density

Protein markers related to sole planting:

In cultivar Giza 21; unique protein bands were observed at 241, 176, 131, and 96 kDa under low and mid density conditions but were absent at high density. Similarly, in *cv.* Giza 111; unique protein bands were detected at 71, 31, 21, 16, 13, and 7 kDa under low and mid density but were absent at high density. A protein band at 44 kDa was observed at mid- and high-density at *cvs.* Giza 21 and Giza 111, while one protein band (59 kDa) is present at all three cultivars and densities (**Table 6 and Figure 8**).

Table 6. Effects of density of soybean plants and cultivars on leaflet protein banding patterns under sole planting

Band number	Molecular weight (kDa)	Giza 21			Giza 82			Giza 111		
		Soybean density			Soybean density			Soybean density		
		Low*	Mid	High	Low	Mid	High	Low	Mid	High
1	241	1	1	0	0	0	0	0	0	0
2	176	1	1	0	0	0	0	0	0	0
3	131	1	1	0	0	0	0	0	0	0
4	96	1	1	0	0	0	0	0	0	0
5	71	1	1	1	0	0	0	1	1	0
6	59	1	1	1	1	1	1	1	1	1
7	44	0	1	1	0	0	0	0	1	1
8	31	0	0	0	0	0	0	1	1	0
9	21	0	0	0	0	0	0	1	1	0
10	16	0	0	0	0	0	0	1	1	0
11	13	0	0	0	0	0	0	1	1	0
12	7	0	0	0	0	0	0	1	1	0
Total		6	7	3	1	1	1	7	8	2
New bands Molecular Wight		0	1 44	1 44	0	0	0	0	1 44	1 44

(1) presence of band; (0) absence of band
*Low = 50% of soybean plant density, Mid = 75% of soybean plant density, High = 100% of soybean plant density

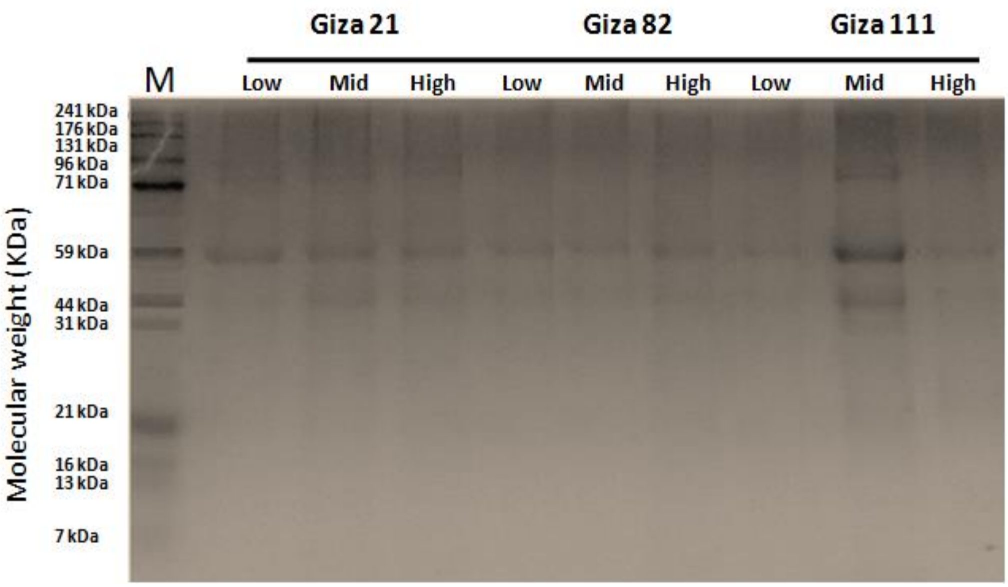


Fig. 8. SDS-PAGE of proteins of Giza 21, Giza 82, and Giza 111 under sole planting
Low = 50% of soybean plant density, Mid = 75% of soybean plant density, High = 100% of soybean plant density

Agronomic and seed traits:

Increasing soybean plant density from low to high in both intercropping and sole plantings resulted in an increase in seed yield and height of plant per hectare, while the yield of seed per plant and the number of pods per plant remained relatively stable **(Tables 7 and 8).** In the first season, plant height increased from 93.16 to 105.40 cm when soybean plant density increased from low to high in intercropping planting. In the meantime, during the second season, this value increased from 87.12 to 100.13 cm. In the first season of the sole planting, the height of the plants increased from 78.13 to 88.03 cm when the plant density was increased from low to high. In the meantime, during the second season, this value increased from 74.39 to 84.38 cm. The seed yield per hectare in the first season of the intercropping planting increased from 1.15 to 2.25 t when soybean plant density was increased from low to high. In the meantime, during the second season, this value increased from 0.89 to 1.95 t. The seed yield per hectare in the first season of the sole planting increased from 2.07 to 3.57 t when the plant density was increased from low to high. In the meantime, during the second season, this value increased from 1.77 to 3.19 t.

The number of pods per plant, plant height, seed yields per plant, and yield of seeds per hectare varied significantly through soybean cultivars in the first and second seasons (**Tables 7 and 8**). In both seasons, the intercropped soybean *cv*. Giza 111 outperformed other cultivars by producing the highest number of pods per plant (47.92 in the first season and 40.20 in the second season) and the highest seed yield per plant (12.19 g in the first season and 11.34 g in the second season), as well as the highest seed yield per hectare (1.92 t in the first season and 1.63 t in the second season). Meanwhile, the intercropped *cv*. Giza 21 exhibited the tallest plant (108.10 cm in the first season and 101.59 cm in the second season) compared to other cultivars in both seasons. Furthermore, in sole planting of *cv*. Giza 111, there were the highest number of pods per plant (87.61 in the first season and 80.98 in the second season) and the highest seed yields per plant (21.03 g in the first season and 19.82 g in the second season) and seed yield per hectare (3.10 t in the first season and 2.78 t in the second season) among all cultivars in both seasons. On the other hand, in sole planting, *cv*. Giza 21 was the tallest plant (91.34 cm in the first season and 87.28 cm in the second season) compared to other cultivars in both seasons.

Plant height, the number of pods per plant, and the seed yield per plant were not influenced by the interaction between plant density and soybean cultivars in the two seasons, as shown in **Tables (9) and (10).** The highest seed yield per hectare was obtained by growing soybean *cv*. Giza 111 at high plant density under intercropping and sole planting systems in the first and second seasons.

Table 7. Seed yield of intercropped soybean cultivars and its attributes under three soybean plant densities in the first and second seasons

Density of soybean plants	Soybean cultivars	First season				Second season			
		Plant height (cm)	Number of pods/ plant	Seed yield / plant (g)	Seed yield / hectare (t)	Plant height (cm)	Number of pods / plant	Seed yield / plant (g)	Seed yield / hectare (t)
High*	Giza 21	115.50	19.76	8.62	1.88	106.82	17.82	7.00	1.55
	Giza 82	97.90	28.11	9.00	2.28	93.44	27.66	8.80	2.01
	Giza 111	102.80	35.22	11.27	2.61	100.13	34.03	10.11	2.30
	Mean	**105.40**	**27.70**	**9.63**	**2.25**	**100.13**	**27.17**	**8.63**	**1.95**
Mid	Giza 21	107.10	26.96	10.54	1.24	101.65	21.05	7.89	1.00
	Giza 82	94.30	36.72	11.63	1.56	87.62	34.16	10.82	1.34
	Giza 111	98.40	51.89	12.57	1.77	94.58	41.48	11.69	1.52
	Mean	**99.93**	**38.52**	**11.58**	**1.52**	**94.61**	**32.23**	**10.13**	**1.28**
Low	Giza 21	101.70	31.14	10.69	0.99	96.32	23.41	8.29	0.72
	Giza 82	85.30	40.63	12.34	1.10	81.15	37.14	11.60	0.88
	Giza 111	92.50	56.66	12.73	1.38	83.91	45.10	12.24	1.08
	Mean	**93.16**	**42.81**	**11.92**	**1.15**	**87.12**	**35.21**	**10.71**	**0.89**
Average	Giza 21	**108.10**	**25.95**	**9.95**	**1.37**	**101.59**	**21.42**	**7.72**	**1.09**
	Giza 82	**92.50**	**35.15**	**10.99**	**1.64**	**87.40**	**32.99**	**10.40**	**1.41**
	Giza 111	**97.90**	**47.92**	**12.19**	**1.92**	**92.87**	**40.20**	**11.34**	**1.63**
LSD 5% Soybean density (A)		**5.44**	**N.S.**	**N.S.**	**0.18**	**8.11**	**N.S.**	**N.S.**	**0.14**
LSD 5% Soybean cultivars (B)		**3.47**	**18.41**	**1.70**	**0.06**	**2.42**	**14.05**	**1.15**	**0.10**
LSD 5% A x B		**N.S.**	**N.S.**	**N.S.**	**0.23**	**N.S.**	**N.S.**	**N.S.**	**0.22**

*Low = 50% of soybean plant density, Mid = 75% of soybean plant density, High = 100% of soybean plant density

Table 8. Seed yield of sole soybean cultivars and its attributes under three soybean plant densities in the first and second seasons

Density of soybean plants	soybean cultivars	First season				Second season			
		Plant height (cm)	Number of pods/ plant	Seed yield/ plant (g)	Seed yield/ hectare (t)	Plant height (cm)	Number of pods/ plant	Seed yield/ plant (g)	Seed yield/ hectare (t)
High	**Giza 21**	96.65	69.13	16.93	3.01	93.18	59.26	15.30	2.60
	Giza 82	79.11	59.27	17.70	3.71	76.14	55.51	16.91	3.43
	Giza 111	88.32	73.96	20.23	3.99	83.81	72.15	19.75	3.56
	Mean	**88.03**	**67.45**	**18.28**	**3.57**	**84.38**	**62.30**	**17.32**	**3.19**
Mid	**Giza 21**	90.55	81.38	18.87	2.35	86.66	76.70	16.43	2.02
	Giza 82	72.82	57.80	19.73	2.89	70.37	63.00	17.72	2.57
	Giza 111	84.40	90.33	21.15	3.03	78.24	82.87	20.28	2.76
	Mean	**82.59**	**76.50**	**19.92**	**2.76**	**78.42**	**74.19**	**18.14**	**2.45**
Low	**Giza 21**	86.84	82.70	19.22	1.81	82.01	82.70	16.65	1.42
	Giza 82	68.56	60.97	20.15	2.12	66.59	64.65	17.95	1.85
	Giza 111	79.00	98.56	21.71	2.29	74.56	87.91	20.42	2.03
	Mean	**78.13**	**80.74**	**20.36**	**2.07**	**74.39**	**78.42**	**18.34**	**1.77**
Average	**Giza 21**	**91.34**	**77.73**	**18.34**	**2.39**	**87.28**	**72.88**	**15.79**	**2.01**
	Giza 82	**73.49**	**59.34**	**19.19**	**2.90**	**71.03**	**61.05**	**17.19**	**2.61**
	Giza 111	**83.91**	**87.61**	**21.03**	**3.10**	**78.87**	**80.98**	**19.82**	**2.78**
LSD 5% Soybean density (A)		**5.88**	**N.S.**	**N.S.**	**0.08**	**3.61**	**N.S.**	**N.S.**	**0.04**
LSD 5% Soybean cultivars (B)		**3.06**	**13.33**	**2.21**	**0.05**	**3.16**	**16.35**	**2.51**	**0.02**
LSD 5% A x B		**N.S.**	**N.S.**	**N.S.**	**0.13**	**N.S.**	**N.S.**	**N.S.**	**0.09**

*Low = 50% of soybean plant density, Mid = 75% of soybean plant density, High = 100% of soybean plant density

DISCUSSION

It can be deduced that soybeans are the world's fourth-largest crop and a major source of food and feed. It provides a significant source of vegetable oil and vegetable protein for human and animal use. However, various viruses can attack soybean plants. SMV is one of the viruses with a significant economic impact on soybean production (Widyasari, *et al*., 2020; Shelke, *et al*., 2023 and Hasan, *et al*., 2023).

Intercropping, the practice of growing two or more crops together in the same field, has gained attention for its potential to enhance crop productivity and disease resistance. Intercropping a tall crop with a short crop is a prevalent practice in this agricultural strategy. For example, intercropping cereal with legumes (Blessing, *et al*., 2022).

Controlling disease incidence and reducing insect pest attacks are just a few of the many advantages and enormous potential benefits of intercropping planting systems. Other benefits include efficient resource utilization improved soil fertility through the incorporation of legumes to the mix, soil conservation by covering a larger area of ground cover, controlling weed growth, and decreased reliance on chemicals (Maitra, *et al.*, 2019). These practices are essential for promoting sustainable agriculture, minimizing environmental harm, and reducing crop losses.

Promising outcomes have been observed in the reduction of some viral infections by 90% via intercropping with other suitable crops. Studies have demonstrated that intercropping effectively reduces viral infection in the fields of sugar beet, muskmelon, and radish agriculture. Intercropping tall or dwarf sorghums with soybeans has been found to reduce seed mottling from SMV by 50%. (Hill and Whitham, 2014 and Damicone *et al*., 2007).

In the present study, nine treatments were applied, consisting of three soybean plant densities that were expressed as low (50%), mid (75%), and high (100%) of the recommended plant density and three cultivars of soybeans (Giza 21, Giza 82, and Giza 111) that were either planted solely or under intercropping with maize hybrid TWC 321.

Symptomatic soybean leaf samples exhibiting viral disease symptoms were collected during the two seasons and tested by enzyme-linked immunosorbent assay (ELISA) using specific polyclonal antibodies. Virus SMV was more prevalent than all other viruses found in all samples (Golnaraghi, *et al*., 2004). The SMV percentage in the analyzed samples was 100% in both seasons.

Our results showed that intercropping soybean *cv*. Giza 21 with maize reduced infection with SMV by 62.1% in the first season and 39.5% in the second. With *cv*. Giza 82, the SMV infection dropped by 39.7% in the first season and 48.9% in the second. Also *cv*. Giza 111, the infection with SMV was reduced by 42.56% in the first season and 57.5% in the second season compared with sole planting. These results are consistent with Damicone *et al.* (2007), who reported that the intercropping had effects on viral infection that were non persistent. Corn intercropping reduced *Turnip mosaic virus* incidence in radish by 90%, whereas tall or dwarf sorghum intercropping in soybeans decreased *Soybean mosaic virus* (SMV) seed mottling by 50%. Cereal crops have been commercially planted in and near sugar beets in Europe, and this approach has been successful in lowering viral infections. Planting Swiss chard and wheat near or within muskmelon decreased the prevalence of potyviruses by 90%.

The lowest infection rates of SMV were observed at high density of intercropping *cvs*. Giza 21 and Giza 111 and in low density of intercropping *cv*. Giza 82 compared with the other plant densities. These results were attributed to the content of JA in the tested soybean cultivars. The content of JA in the leaflets of all three soybean cultivars was higher in the intercropping plantings than the sole plantings. Also, the content of JA in the *cvs*. Giza 21 and Giza 111 increased as the crop density increased, but the opposite was true in *cv*. Giza 82. The plants employ their hormones to react to biotic and abiotic stress, where JA has a major role in regulating insect infestation, plant development, and defense responses to virus diseases. It increased the synthesis of antioxidants such as POD, SOD, and CAT, which helped plants recover from aphid stress. Also, JA reduced aphid population by 60–70% and improved the wheat plants' tolerance to biotic stress. (Alazem, and Lin, 2015; Zhang, *et al*., 2017; Wu and Ye, 2020; and Aslam, *et al.,* 2022).

Intercropping plantings led to a decrease in the aphid's populations on all three soybean cultivars compared to sole plantings. The results appeared that the evaluated soybean cultivars' sensitivity to the aphid infestation varied statistically based on the density of soybean plants. In the second season of intercropping plantings, soybean *cv*. Giza 21 experienced the lowest aphid population as soybean plant density increased; while in the first season, plant density had minimal impact on aphid population. The *cv*. Giza 82 increased the density of soybean plants from low to mid in the first season and from low to high in the second, resulting in the greatest population of aphids. During the first and second seasons, there was no discernible impact on the aphid population in *cv*. Giza 111 when plant density was raised from low to high. These findings align with Wang and Ghabrial (2002), who noted that increased aphid movement could facilitate greater spread of viruses within and among fields. Maitra *et al*. (2019) reviewed intercropping and found that in 53% of the studies, intercropping decreased the number of pests. There was a decrease in pest incidence in the intercropping of maize, cowpeas, and beans, as well as an increase in the natural enemies' number. Also, cowpea and cotton intercropping effectively prevented thrips and whiteflies from attacking while also producing a good yield. Whereas the population of green stink bug (*Nezara viridula*) and stem borer (*Chilo zacconius*) infestations in rice comparison were low, indicating that intercropping upland rice with ground nut was superior to monoculture of rice in terms of pest control. Ju *et al*. (2019) found that strip intercropping peanuts with maize effectively controlled peanut aphids, by increasing of ladybeetle density (predator), which significantly reduced the number of peanut aphids. Fattah *et al.* (2023) recommended intercropping soybeans and corn at high planting densities (six rows of soybeans and two rows of corn) as an optimal practice for sustainable agricultural production. This approach reduced *Aphis glycines* population while increasing predator numbers, which led to a decrease in the level of crop damage.

There was a significant correlation between aphid population and SMV incidence for *cv*. Giza 82 under intercrop planting and sole planting in the first and second seasons. Meanwhile, there was no significant correlation between aphid population and SMV incidence for *cv*. Giza 21 or *cv*. Giza 111. These results, probably due to variation in the SMV incidence that occurred in the first season versus the second season, were related to differences in the JA content of the tested soybean cultivars, as well as differences in aphid population density under intercropping and sole plantings, as mentioned by Maitra *et al*., (2019) and Wu and Ye (2020).

There is a variance among soybean cultivars in SMV infection sensitivity under intercropping and sole plantings. Where *cv.* Giza 82 was more sensitive to SMV infection than *cvs.* Giza 111 and Giza 21, especially when solely planted compared with intercropping. *cvs*. Giza 111 and Giza 21 were slightly more tolerant to SMV infection than *cv*. Giza 82 in both seasons. In addition, there were no significant differences between the soybean *cvs*. Giza 111 and Giza 21 in SMV incidence under intercropping planting in the two seasons. The results are consistent with Eid *et al*. (2023), who indicated that Giza 21 was moderately tolerant to SMV infection, while Giza 82 was the least tolerant cultivar. Giza 111 was less tolerant.

Regardless of soybean cultivars, intercropping reduced the percentage of SMV by 48.24 and 49.12% in the first and second seasons, respectively. Obviously, maize plants formed a biological barrier to dispersal of the aphids compared with the sole planting that was reflected on the yield potential of the tested soybean cultivars. This corresponds to Nampala *et al*. (2002), Hassan (2009) and Ju *et al*. (2019), who reported that intercropping reduced the aphid population in cowpea and rice more than sole planting.

Increasing soybean plant density from low to high in both intercropping and sole plantings resulted in an increase in seed yield/hectare, and plant height, while the seed yield/plant and number of pods/plants remained relatively stable. This indicates that adjusting plant density could play a crucial role in enhancing soybean yield in various planting systems. These findings are consistent with Rahman *et al.* (2011) who observed that the yield of soybean seeds increased with increasing planting density, and the highest yield was at a density of 80 to 100 plants m^{-2}, depending on the variety and season. Density higher than this led to reduced seed yield. Xu *et al.* (2021), they observed that higher planting densities significantly improved dry matter accumulation in soybean plants, leading to increased soybean yield. They also discovered that high planting density increased soybean plant height by 8.2% compared to standard planting density. Overall, higher plant density led to increased productivity in terms of seed yield/hectare and plant height, highlighting the importance of optimizing plant density for maximizing soybean yield. In this context, increasing planting density is becoming an increasingly important strategy to increase soybean yield.

The number of pods/plants, seed yields/plant, seed yields/hectare, and plant height varied significantly among soybean cultivars during the first and second seasons. Among the cultivars tested, *cv*. Giza 111 in both seasons outperformed other cultivars by producing the most pods/plant and the highest seed yield/plant, as well as seed yield/hectare. Meanwhile, the *cv*. Giza 21 exhibited the highest plant compared to other cultivars in both seasons. The highest seed yield/hectare was obtained by cultivating soybean *cv*. Giza 111 at high plant density under intercropping planting systems during both seasons. Overall, these results suggest that intercropping *cv.* Giza 111 may be more advantageous for seed yield and pod production, while *cv.* Giza 21 may be preferred for those seeking taller plants. These findings underscore the importance of selecting the appropriate cultivar based on specific objectives and environmental conditions (Xu *et al*. 2021). These results are consistent with Metwally *et al.* (2021), who reported that *cv.* Giza 111, followed by Woodworth, Hutcheson, C1, and C34, yielded higher seed yields compared to other varieties in intercropping systems. Similarly, soybean genotypes C1, Woodworth, and *cv.* Giza 111, followed by Hill and Holladay, and then Hutcheson, produced higher seed yields than other genotypes in solid planting. In addition, they found that under intercropping and solid plantings, soybean genotypes such as Woodworth, Dr-101, *cv.* Giza 111, and C34 exhibited higher seed yields per plant and per hectare compared to other genotypes. These results highlight the significant impact of cultivar selection and plant density on seed yield per hectare. Farmers should consider these factors when developing planting strategies to optimize productivity.

CONCLUSION

It can be deduced that this study provided an important first step toward understanding the relationship between SMV and aphid populations resulting from the complex interactions that occur among soybean cultivars, their density, and cropping systems. It is clear from this study that intercropping planting led to a decrease in the number of aphids and a decrease in the rates of SMV infection. There is also a discrepancy between soybean cultivars in their susceptibility to viral infection, as it turned out that the *cvs*. Giza 21 and Giza 111 are more resistant to SMV virus, while the *cv*. Giza 82 is the most sensitive to infection, especially in sole planting. The population density of plants also affects infestation, insect population, and productivity. Where growing soybean *cvs*. Giza 111 and Giza 21 with high soybean plant density had a greater significant effect on lowering aphid population and SMV infection than susceptible *cv*. Giza 82. We recommend planting the *cv*. Giza 21 at intercropping high density if the goal is to obtain taller plants or planting the *cv*. Giza 111 at intercropping high density if the goal is to obtain a higher seed yield, low SMV infection, and low aphid incident. So the correct selection of soybean cultivar with its appropriate plant density decreased the aphid population and made symptoms of SMV much less severe under intercropping planting.

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تأثير تحميل أصناف فول الصويا مع الذرة على الإصابة بفيروس فسيفساء فول الصويا وديناميكية تعداد حشرة المن *Aphis gossypii* (Homoptera: Aphididae)

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يعد فول الصويا من المحاصيل الهامة، وهو بمثابة مصدر مهم للزيت النباتي والبروتين. ومع ذلك، فإن فيروس فسيفساء فول الصويا (SMV) هو أحد مسببات الأمراض واسعة الانتشار التي تؤثر سلبًا على محصول فول الصويا على مستوى العالم. يوفر هذا البحث خطوة أساسية نحو فهم تأثير زراعة أصناف فول الصويا مع الذرة ومع كثافات زراعة مختلفة على الإصابة بفيروس SMV، وعلاقته بتعداد المن والتأثير الناتج على إنتاجية محصول فول الصويا. أجريت الدراسة على مدار موسمين وتضمنت تسع معاملات، جمعت بين ثلاثة أصناف لفول الصويا (جيزة 21، جيزة 82، وجيزة 111)، وثلاثة كثافات زراعية (منخفضة ومتوسطة وعالية)، وزراعة متداخلة أو زراعات منفردة. تم استخدام اختبار DAS-ELISA للكشف عن SMV، في حين تمت فحص تعداد المن أسبوعيًا. تم قياس محتوى حمض الجاسمونيك، وتم استخدام SDS-PAGE لتقييم تخليق البروتينات الجديدة المتأثرة بالزراعة البينية وكثافة الزراعة. كما تم قياس الصفات الزراعية وإنتاجية البذور، وتم تحليل البيانات باستخدام تحليل التباين (ANOVA). أظهرت النتائج أن التحميل أدي إلى انخفاض نسبة SMV بمقدار 48.24 % و 49.12 % في الموسمين الأول والثاني على التوالي مقارنة مع موسمين الزراعة المنفردين. علاوة على ذلك، أدت الكثافة النباتية العالية إلى تقليل حدوث SMV في الصنف جيزة 21 وجيزة 111، بينما كان العكس صحيحًا في جيزة 82. وارتبط حدوث SMV بشكل كبير مع تعداد المن في الصنف جيزة 82 مقارنة بالأصناف الأخرى تحت ظروف التحميل أو الزراعة المنفردة. توصي هذه الدراسة بزراعة صنف فول الصويا جيزة 111 ذو الكثافة النباتية العالية، حيث أظهر انخفاض فى معدل الإصابة بفيروس SMV، وتحمله للإصابة بحشرة المن، وارتفاع إنتاجية البذور عند التحميل.

الكلمات المفتاحية: **SMV**، المن، أصناف فول الصويا، التحميل المحصولى، الكثافة النباتية