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Computational Fluid Dynamics Simulation of Air Flow Around Grasshopper

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Abstract

Grasshoppers and locusts are one of the most dangerous and harm full plagues for crops that in each swarm can destroy 35000 people's food. Grasshoppers and locusts swarm control in different ways. In this study, some grasshopper aerodynamic properties in the wind tunnel have been investigated for the design and manufacture of a locust collection machine. For this purpose, some dead and live grasshopper with grasshopper maquettes were placed in a wind tunnel. Also, a grasshopper in ANSYS software was modeled and analyzed by CFD analysis and extracted velocity, static, and dynamic pressure. According to the experiments that have been done, live grasshoppers were suspended at 6.3 m s -1 wind velocity and in the ANSYS model, the drag force of grasshopper for a throw or suction grasshopper in 6.5 m s -1 was calculated with contours that obtained.

Key words: grasshopper, CFD analysis, aerodynamic properties, wind velocity

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Introduction

Human life has been affected by locusts and grasshopper swarms throughout history [9]. Grasshoppers and locusts are one of the most dangerous and harm full plagues for crop and agricultural lands that harmed many plants due to their invasion and attacks. According to the FAO report, one-tenth of the world population's live hood can be damaged by this harmful pest. Grasshopper and locust swarms can be destroyed 35000 people's food, 20 camels, and 6 elephants in a day. One km2 swarm size contains about 40 million locusts [4.5]. In a single swarm, the number of insects can contain up to 10 billion and their weight approximately 30000 tones [10]. Grasshoppers and locusts infestation cause problems such as famine and drought, economical problems, and migration of humans to different parts of the region [6].

According to various studies, grasshoppers and locusts are controlled in different ways, which are generally divided into three categories: chemical, biological, and mechanical management. Among these control management, chemical management is a common method that can be said to be used all over the world.

In chemical management method, uses various pesticides and insecticides to manage grasshoppers and locusts population, and various studies have been conducted in this area. ULV method is a new technology and efficient that uses for spraying pesticide and insecticide in a zone that grasshoppers and locusts attack there. This method has been done in the form of portable, mounted on four-wheeled vehicles and airplanes or helicopters. According to different studies, chemical control is a more efficient control method [2, 7, 8, and 16]. In the biological method for control and manage grasshoppers and locusts population, natural enemies of this insect used to hunt them; but control artificially this method is too difficult for humans [11]. These natural enemies are divided into vertebrates (rodents, reptiles, hornbill, storks, egrets, raptors, and rollers) and invertebrate (scorpions, solifugids, and ground beetles) [13]. The mechanical control that is used to control grasshopper and locust swarms is very old and traditional. The methods used in mechanical control are digging trenches, beating, and burning [3]. In another study mechanical control management that reduced grasshoppers densities divided into three treatment: contour furrowing, rangeland scalping, and scalping and inter seeding [1]. Also, eliminate sites where grasshoppers and locusts deposit their eggs is one way of mechanical management method to control the grasshopper population [12].

Desert locusts, locusts, red locusts, migratory locusts, locust meals, grasshopper, and grasshopper meal are the common names of this insect. For example, desert locusts, red locusts, migratory locusts, and brown locusts are commonly eaten in Africa [10].

Due to the increase in the world population and their need for food, insects have been added to the human diet recently. Grasshoppers and locusts are some of these edible insects used by people in various parts of Asia, South America, and Africa. Also, due to the high nutritional value of locusts and preventing the reduction of pastures, they can be used to feed livestock and poultry [10 and 15]. Grasshoppers and locusts that swarm to an area can be used for this purpose, but these are should not be contaminated with different pesticides and insecticides; therefore, the chemical control method should not be used for locusts that are intended to be used in livestock and poultry feed.

The behavior of grasshoppers and locusts when they swarm in an area, makes them easy to harvest for human food or feed to the animals without using chemical pesticides [10]. Since the grasshoppers and locusts swarm to different countries such as our country in previous years and also this year, we seek to manage and control their swarm so that can use for livestock and poultry feed. The mechanical methods used for grasshopper and locust swarm management are not suitable and efficient. Various researches about grasshopper and locusts have been done, but in the field of mechanical management, extensive studies have not been done; therefore, we decided to design and manufacture grasshopper and locust machine to collect them. For this purpose, in this study, some grasshopper aerodynamic properties in the wind tunnel have been investigated for the design of a locust collection machine. First of all, the grasshopper with a real average dimension of grasshoppers in the wind tunnel was modeled in ANSYS (fluid flow fluent) software. Extracted velocity and pressure contours with grasshopper modeling and calculated the grasshopper suspending velocity. After modeling the grasshopper in a wind tunnel and extract their suspending velocity, put live and dead grasshopper with their maquette in a wind tunnel and investigated the ANSYS model answers.

Material and Methods

The present study was conducted to obtain and investigate some aerodynamic properties of grasshopper. For this purpose, a grasshopper with an approximate dimension of the average grasshopper's dimensions inside the wind tunnel in Ansys software was modeled and simulated then examined and analyzed in different wind velocities. Then the number of locusts in the alive and dead form with their maquette put in the wind tunnel and examined in different fan speeds and wind velocities of wind tunnel device.

To analyze the model during the simulation, the input and output side of the wind tunnel model in Ansys software chose as inlet and outlet respectively. Also, the wind tunnel wall and grasshopper model were selected as the wall in Ansys fluid flow fluent. Then the model was meshed and finally extracted velocity and pressure contours.

A grasshopper modeled with the average size of a real grasshopper in Ansys software in the fluid flow fluent part (figure 1) and placed inside the designed wind tunnel. By used CFD analyses, extracted velocity, and pressure contours. The drag force and the gravity force reduced by the buoyant effect of grasshopper calculated by the data extracted from ANSYS model results.

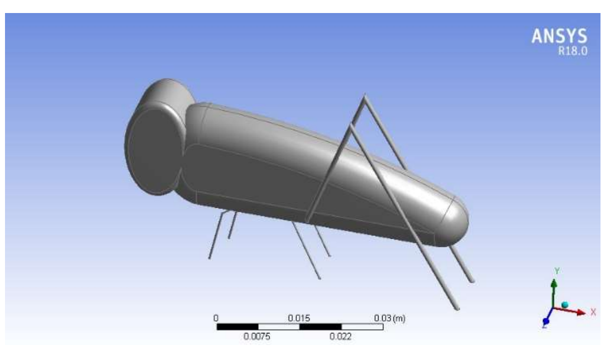


Figure 1. The grasshopper that modeled in ansys software

It should be noted, when the grasshoppers suspend that the drag force and the gravity force reduced by buoyant effect be equal. These two forces are calculated by information of velocity contour data.

The static pressure, dynamic pressure, and velocity contour and vector extracted from model analyses and calculated the drag force and the gravity force reduced by buoyant effect for obtained the velocity that throws or suction the grasshoppers. The drag force is calculated with equation1 [14].

$$F_d = C_d A_b \rho \frac{{V_r}^2}{2} \quad (1)$$

In equation1, C_d is the drag coefficient (dimensionless), A_b is the area perpendicular to the airflow direction (m^2), ρ is the density of air (kg/m^3), and V_r is the relative terminal velocity (m/s).

The gravity force is reduced by the buoyant effect calculated with equation 2 [14].

$$F_g = g m_b \frac{\rho_b - \rho}{\rho_b} \quad (2)$$

In equation2, g is gravity acceleration (m/s^2), m_b is mass of grasshopper (kg), ρ_b is density of grasshopper (kg/m^3), and ρ is density of air (kg/m^3). The density of grasshopper calculated with equation 3:

$$\rho_b = \frac{m}{v} \quad (3)$$

To check and investigate the ANSYS model accuracy, practical experiments have done. To carry out practical experiments, the number of dead and alive locusts with their maquette made by sponge was placed inside the wind tunnel. This device has a motor with a power of 4 kW and a maximum rotation speed of 2890 rpm and the fan speed adjusted with an inverter.

The locusts used in this study were collected from corn fields located in Khoshnam village of Mallard city in Tehran province by the traditional method and then transferred to a room that was built to store grasshopper. This room has a 2×2 square meters area and 2 meters height that is made with MDF wooden frame. Transparent nylon was also used for its walls. To feed the grasshopper, the green wheat germ was prepared for this purpose, which was placed inside the building.

Four live grasshoppers with different dimensions were randomly selected and weighed by an electronic balance. The values of the weights measured are presented in Table 1. Each locust was weighed five times and finally, their average was calculated.

Table1. The grasshopper weighted values

Grasshopper number	1	2	3	4	5	Average (gr)
Grasshopper_numer1	1	1.2	1.05	1.1	1.2	1.11

Grasshopper_numer2	1.15	0.95	0.75	0.9	0.85	0.92
Grasshopper_numer3	0.25	0.25	0.45	0.25	0.4	0.32
Grasshopper_numer4	2	1.8	1.8	1.8	1.8	1.84
						1.0475

According to the number of dead grasshoppers, the grasshopper maquettes were made with the compressed sponge and iron wires were used inside the maquettes to equal their weight with the grasshopper weight.

Before started experiments, wind velocities were measured at different fan rotational speeds by an anemometer. This step has been done for the calibration of wind velocities in the wind tunnel. The measured data analyzed in excel software and extracted a regression model for wind velocities and fan rotational speeds.

After calibration wind velocities and fan rotational speeds and before placed grasshoppers on the wind tunnel and done required experiments, first the grasshopper maquettes placed inside the wind tunnel without dead and alive grasshopper (figure 2). It was observed that at different fan rotational speeds and different wind velocities extracted from the wind velocities and fan rotational speeds regression model, each of the grasshopper maquettes had a different behavior, and eventually, they all reached a common behavior.

Figure 2. The grasshopper maqutte that placed in wind tunnel

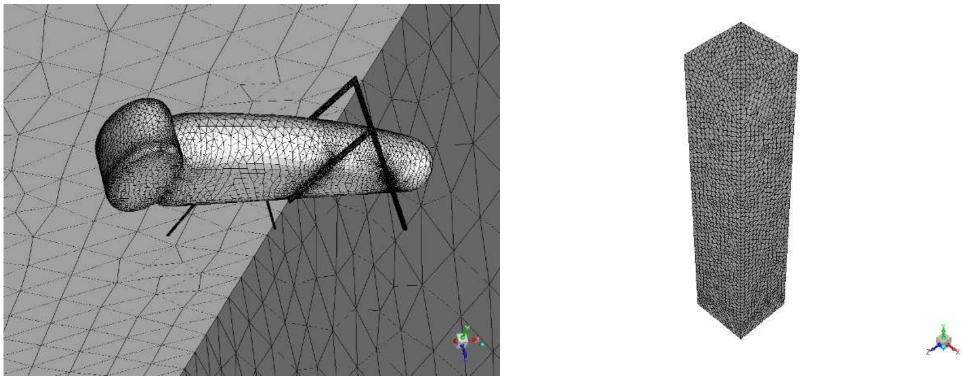
Then the grasshopper maquette with dead and alive grasshoppers placed in a wind tunnel (figure 3). The grasshopper maquette with dead grasshoppers showed in figure 4. Also at this stage, the wind velocities and rotational fan speeds were measured and these values input into excel software and extracted a regression model for wind velocities and fan rotational speeds, too. The grasshopper in each wind velocities and rotational fan speeds exhibited different behaviors.

Figure 3. The grasshopper maqutte and dead and alive grasshopper that placed in wind tunnel during the test

Figure 4. The grasshopper maqutte and dead grasshopper

Results and discussion

As said, by ANSYS modeling extracted velocity, static and dynamic pressure contours. In figure 5, the meshed model showed.



a b

Figure 5. a) The grasshopper in wind tunnel model meshing, b) The wind tunnel model meshing

The velocity contours in the wind tunnel model showed in figure 6, as showed in this picture the wind velocity in the inlet side of the wind tunnel model is about 6.5 m s^{-1}, and in the outlet side of the wind tunnel model is about 4 m s^{-1}, according to these values and the contours picture the wind velocity across the tunnel decrease.

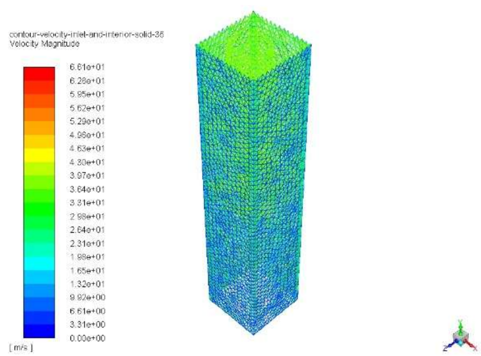


Figure 6. The wind velocity across the wind tunnel

The dynamic and static pressure applied to the interior solid of the model was located in the grasshopper model center of the mass shown in figure 7 and figure 8. With analyzed two same points in these two pictures, dynamic pressures are higher than static pressure. According to the velocity effect on dynamic pressure, this result is acceptable.

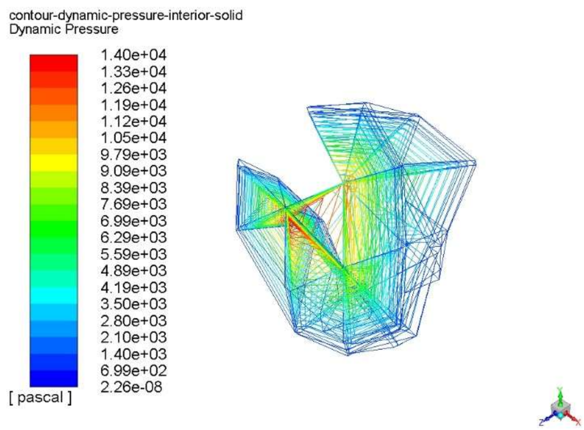


Figure 7. Dynamic pressure that applied to grasshopper center of mass

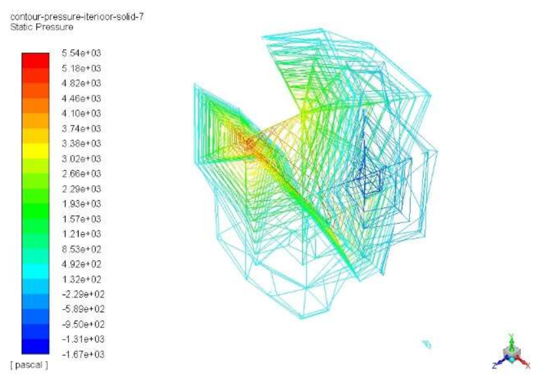


Figure 8. Static pressure that applied to grasshopper center of mass

The velocity contours of the CFD analyze showed in figure 9. According to this picture, wind velocity across the head and legs of the grasshopper is about 6.5 m s -1 that showed the wind velocity across the head and legs of the grasshopper is equal with wind velocity across the wind tunnel model. This result according to the small area of grasshopper legs and the head is logical and acceptable. The wind velocity across the grasshopper body decrease about 3.5 m s -1. in this model, the grasshopper wings did not model, of course across that the velocity like across the grasshopper body decreased. According to Bernoulli laws, the pressure will increase where the velocity decrease.

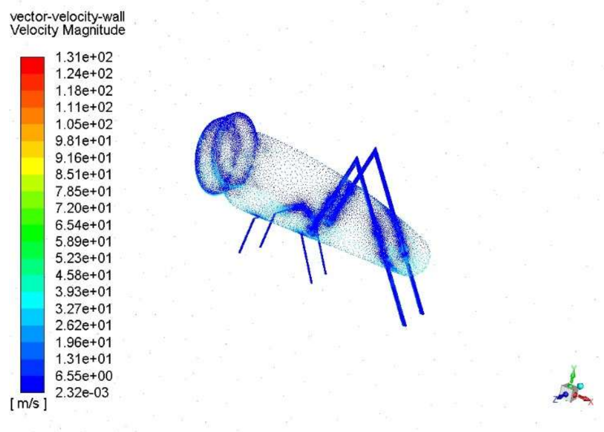


Figure 9. The wind velocity across the grasshopper model

The drag force calculated by equation 1:

$$F_d = C_d A_b \rho \frac{{V_r}^2}{2} = 0.5 \times 0.05 \times 0.01 \times 1.225 \times \frac{6.5^2}{2} = 0.00647\ N \cong 0.01N$$

In the top equation, for this model C_d and A_b were considered with 0.5 and 0.05×0.01 (m^2) values. The density of air is equal to 1.225 (kg/m^3) and according to figure 9, the V_r is equal to 6.5 (m/s). By putting these values in the drag force equation, F_d was obtained 0.00647 N ~ 0.01 N.

The grasshopper gravity force is reduced by buoyant effects calculated with equation 2 but before calculated that it's necessary to calculate the density of grasshopper with equation 3.

Density of grasshopper:

$$\rho_b = \frac{m}{v} = \frac{0.01047}{0.05 \times 0.015 \times 0.015} = 93.06\ kg/m^3$$

The grasshopper gravity force reduced by buoyant effects:

$$F_g = \frac{g m_b (\rho_b - \rho)}{\rho_b} = 10 \times 0.001047 \times \frac{93.06 - 1.225}{93.06} = 0.01033N \approx 0.01N$$

As said, when the grasshopper suspend that the drag force and the grasshopper gravity force reduced by buoyant effects equal to each other. According to the calculation of two forces, their values were equal to 0.01 N. Therefore, in 6.5 (m/s) wind velocity the grasshopper was suspended and obtained the velocity that throws or suction the grasshoppers.

The static pressure contours of model walls that applied to the bottom of the grasshopper model showed in figure 10. According to this picture, about 3000 Pascal applied to the model. This pressure is too higher than the drag force, also this pressure force can throw grasshopper.

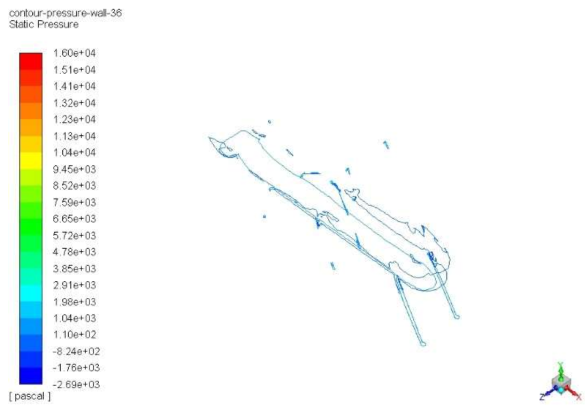


Figure 10. Static pressure contours of grasshopper

Also, the path line of the model was extracted and showed in figure 11.

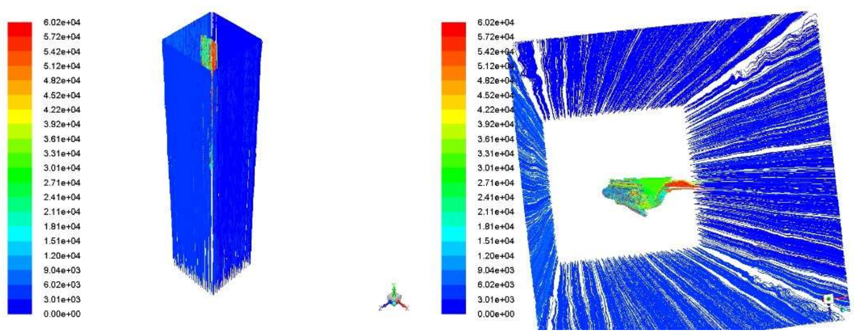


Figure 11. Path line of grasshopper in wind tunnel model

As said, the wind velocities and fan rotational speeds regression model that was extracted for the wind tunnel device which used for this research showed in figure 12. The R-square of this model is equal to 0.9766 and the equation of this model is shown in figure 12.

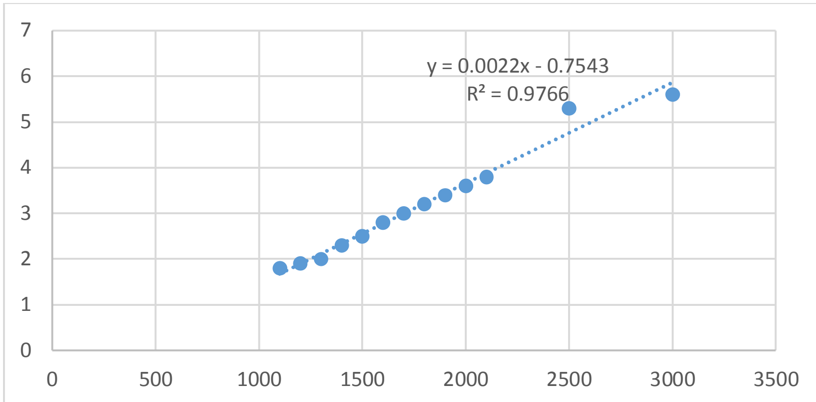


Figure 12. The extracted regression model

The grasshopper maquettes, dead and live grasshoppers had different behavior in each wind velocity that their behavior in each wind velocity explained in table 2. Another regression model extracted from wind velocities and fan rotational speeds for wind tunnel when the maquettes and grasshoppers were placed in it showed in figure 13. The R-square of this model is equal to 0.9858 and the equation of this model is shown in figure 13.

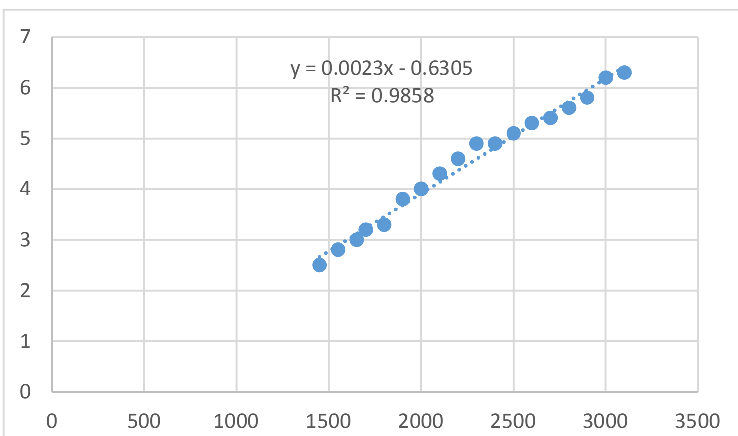


Figure 13. The extracted regression model when maquettes and grasshoppers placed in it

Table2. The explanation of grasshopper maquettes and grasshopper in each wind velocity

Wind Velocity (m s^{-1})	Fan rotational speed (rpm)	Explanation
2.5	1450	The smallest grasshopper raised from the wind tunnel net
2.8 and 3	1550 and 1650	Nothing happened

3.2	1700	The grasshopper maquettes were on raising the threshold
3.3	1800	Dead grasshoppers completely raised from the wind tunnel net and there were suspended
3.8 and 4	1900 and 2000	Dead grasshoppers completely were suspended and the alive grasshoppers clung the net strongly with their legs
4.3 and 4.6	2100 and 2200	one of the alive grasshoppers kept itself on one side of the wind tunnel and one of them moved on the wind tunnel net but strongly clung on it
4.9	2300 and 2400	Again one of the alive grasshoppers kept itself on one side of the wind tunnel and one of them move on the net
5.1	2500	The grasshoppers that kept itself on the one side of the wind tunnel, on that side moved up
5.3	2600	The alive grasshoppers were in raising the threshold and used grasshopper maquettes to fixed their positions
5.4	2700	Two legs of grasshopper that clung to the wind tunnel net detached from it
5.6	2800	That grasshopper completely detached from the wind tunnel net and kept itself on one of the grasshopper maquettes and moved by that
5.8	2900	That grasshopper came back on the wind tunnel net by using grasshopper maquettes
6.3	3000	Alive grasshoppers were suspended

According to the grasshopper's behavior in each wind velocity, understood by increasing wind velocity, the wind force can overcome the power of the grasshopper's legs force when clung to a barrier. This point could help to design a machine that harvests grasshoppers and locusts when they were on the crops.

As the explanation of the grasshopper state in table 2, the alive grasshoppers were suspended in 6.3 (m/s) of wind velocity speed. These practical experiments results approved the ANSYS model results. Also by this confirmation, conclude the ANSYS model has the best accuracy.

Conclusion

This study was performed to investigate some aerodynamic properties of grasshopper. For this purpose, a grasshopper with real grasshopper approximate dimension was modeled in Ansys software and analyzed by CFD Analysis. Also to check and investigate the model accuracy some dead and alive grasshopper with grasshopper maquette were placed in a wind tunnel and studied their behavior in each different fan rotational speed and wind velocities. The wind velocity for a throw or suction grasshopper in the ANSYS model extract 6.5 m/s and this value in practical experiments was measured 6.3 m/s. The results showed the modeling answers and experimental results were compatible.

References:

1. Branson, D.H., Joren A., Sword, G.A. 2006. Sustainable management of insect herbivores in grassland ecosystems: New perspectives in grasshopper control. BioScience, 56 (9).
2. Campbell, J.B., Reece, P.E. and Hein, G.L. 1997. NF97-329 a guide to grasshopper control on rangeland. Historical Materials from University of Nebraska-Lincoln Extension. Paper 1065.
3. FAO report. 2001. Desert locust guidelines, control.
4. FAO report. 2015. FAO desert locust information service (DLIS) helps countries to control desert locust.
5. FAO report. 2016. Weather and desert locusts.
6. Gomes, I., Queiroz A.I. and Alves D. 2019. Iberians against locusts: fighting cross-border bio-invaders (1898-1947). Historia Agraria, 78: 127-159.
7. Joffe, S.R. 1995. Desert locust management. The international bank for reconstruction and development/The World Bank.
8. Lecoq, M. 2001. Recent progress in desert and migratory locust management in Africa. Are preventive actions possible?. Journal of Orthoptera Research, 10(2): 277-291.
9. Lecoq, M. 2010. Integrated pest management for locusts and grasshoppers: are alternatives to chemical pesticides credible?. Journal of Orthoptera Research, 19(1): 131-132.
10. Makkar, H.P.S., Tran, G., Heuze´, V. and Ankers, Ph. 2014. State of the art on use of insects as animal feed. Animal feed science and technology, 197: 1-33.
11. Parker J.R. 1939. Grasshopper and their control. Farmers Bulletin No.1828.
12. Patrick C.D. and Davis S.G. Grasshopper and their control. Agrilife extension Texas A&M System.
13. Ritchie J.M. and Dobson H. 1995. Desert locust control operatons and their environmental impacts.
14. Shrivastava S.K., Prakash A., Rao J., Saxena S. and Arif M. 2019. Grsashopper: an untapped halal food source for future India. J. Appl. Zool. Res. 30(2): 93-132.
15. Srivastava, A.K., Goering, C.E., Rohrbach, R.P. and Buckmaster, D.R. 2006. Engineering Principles of agricultural machines. (2nd ed). American society of agricultural and biological engineering, (chapter 13).
16. Zhang L., Lecoq M., Latchininsky A., and Hunter D. 2019. Locust and grasshopper management. Annual review of entomology, 64: 15-34.