Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)
Available online at www.inia.es/sjar

Spanish Journal of Agricultural Research 2011 9(2), 389-394
ISSN: 1695-971-X
eISSN: 2171-9292

Physico-mechanical characteristics of rose petals dealing with the pneumatic harvest of *Rosa damascena*

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Abstract

For the design of harvesting machines is important the study of characteristics dealing with the harvest of crops. This study focused on some physico-mechanical characteristics of rose petals, which are important for pneumatic harvest mechanization of *Rosa damascena* Mill. These characteristics are terminal velocity, picking force, mass, projection area, density, and drag coefficient of rose petals. The petals were handpicked at 06:30 a.m. (S1), 08:30 a.m. (S2), 10:30 a.m. (S3), and 12:30 p.m. (S4) at four different dates in 2009, June 5 (H1), June 11 (H2), June 17 (H3), and June 23 (H4), covering the potential flowering period. Terminal velocity of rose petals varied between 1.572 and 1.257 m s^{-1}; the picking force from 0.501 to 1.005 N; the mass measured from 0.049 to 0.122 g; projection area from 13.830 cm^2 for H1S4 to 7.071 cm^2 for H4S1; drag coefficient from 0.790 for H2S1 to 0.287 for H1S4. The results of the study indicate that as far as terminal velocity of rose petals is concerned the harvest of *R. damascena* should be executed towards the end of H4 and S4. On the other hand, the magnitude of the picking force, the density, and the drag coefficient of rose petals decrease when the harvesting hour increases from H1 to H4 and the harvesting date increases from S1 to S4, which makes necessary to increase aspiration pressure.

Additional key words: physico-mechanical properties; pneumatic harvest; rose mechanical harvest.

Resumen

Características físico-mecánicas de los pétalos de rosa importantes para la recogida neumática de *Rosa damascena*

Para diseñar máquinas cosechadoras es importante el estudio de algunas características relacionadas con la cosecha de los cultivos. Este trabajo se centró en algunas de las características físico-mecánicas de los pétalos de la flor, importantes para mecanizar la recogida neumática de *Rosa damascena* Mill. Estas características son velocidad terminal, fuerza de recogida, masa, área de proyección, densidad y coeficiente de arrastre de los pétalos de rosa. Los pétalos fueron recogidos manualmente a las 06:30 (S1), 08:30 (S2), 10:30 (S3), y 12:30 (S4) en cuatro fechas diferentes de 2009, 5 de junio (H1), 11 de junio (H2), 17 de junio (H3), y 23 de junio (H4), que abarcan todo el periodo potencial de floración. La velocidad terminal de los pétalos varió entre 1,572 y 1,257 m s^{-1}; la fuerza de recogida entre 0,501 y 1,005 N; la masa entre 0,049 y 0,122 g; el área de proyección entre 13,830 cm^2 para H1S4 y 7,071 cm^2 para H4S1; el coeficiente de arrastre entre 0,790 para H2S1 y 0,287 para H1S4. Los resultados indican que en relación a la velocidad terminal de los pétalos la cosecha de *R. damascena* debe realizarse hacia el final de H4 y S4. Por otro lado, la magnitud de la fuerza de la recogida, la densidad, y coeficiente de arrastre disminuyeron cuando la hora y fecha de la cosecha aumentan de H1 a H4 y de S1 a S4, respectivamente, lo que hace necesario aumentar la presión de aspiración.

Palabras clave adicionales: cosecha neumática; propiedades físico-mecánicas; recolección mecánica de las rosas.

Introduction

The genus *Rosa* includes 200 species and 18,000 cultivars (Gudin, 2000). Although there are 25 rose species in Turkey, *R. damascena* Mill. (Damask rose, oil-bearing rose, pink rose) is the most important species, producing a high-value aromatic oil, which is used in the pharmaceutical, flavorings and fragrance industries (Ercisli, 2004). The main producers of oil-bearing rose in the world are Turkey, Bulgaria, Morocco, Commonwealth of Independent States, Mexico, Iran, India, South Africa, Saudi Arabia, and Egypt (Demircan, 2005). Turkey produces annually approx. 1.5 tons of

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Received: 02-06-10; Accepted: 28-04-11.

rose oil and 7 tons of rose concrete (annual world rose oil and concrete production are 4.5 and 13 tons, respectively). Approximately all the rose oil produced in Turkey is exported and contribute to the substantial amount of essential oil exports of Turkey. The value of essential oil exports reached about US $ 19 million in 2007, 48.9% of which is met by rose oil (Igeme, 2008).

Rose plant is harvested daily since it has asynchronous flowering period (Kazaz, 1997). Harvesting of rose flowers in Turkey is performed at 40 days flowering period, from the middle of May to the end of June. The yield of *R. damascena* decreases through the end of harvest season. Roses are pulled between the fingers from ovary point so the entire blossom pops off into the hand. Picking begins before the sun rises and stops around 10:30 a.m. (Baydar, 2006). Baydar (2009) reported that the yield of rose oil varies depending on the time of day of flower harvesting. While the yield of rose oil from flowers collected at the early hours of the morning was 0.04% (1 kg of rose oil is obtained from 2.5 tons of rose flower), that of picked at the evening hours was 0.02% (1 kg of rose oil is obtained from 5 tons of rose flower). Likewise, Kazaz (1997) reported that although the roses picked at 5 a.m. contained essential oil as high as 0.06%, that of roses picked at 17 p.m. contained only 0.014%.

Harvest mechanization of *R. damascena* is much demanded because it depends mostly on labour force (Akbolat *et al*., 2006). Hand picking of rose flowers every day during the harvest season and necessity of its harvest at specific time (5:00 a.m.-10:30 a.m.) lead to difficulties in maintaining required labour. Therefore, rose growing in Turkey is a family run type production. Asynchronous flowering period, morphology of rose plants (thorny and much branched), and the importance of picking point of rose flowers from rose plants for oil yield make the harvest mechanization of roses difficult (Akbolat *et al*., 2004). Hence, mechanization of rose plants should be investigated, developed, and put into application. Nowadays, different harvest systems for various types of crops are utilized. Mechanic, hydraulic and pneumatic harvest systems are the most important types among the harvest systems. Pneumatic harvest systems are simple and can work at various conditions. Yılmaz (2008) stated that firstly, the physico-mechanical properties of a specific crop should be determined, previous to the design of a harvest system for the specified crop. Researches concerning the pneumatic harvest systems for various crops (Coşkun, 2002; Tabak *et al*., 2002; Kılıckan and Guner, 2006; Eissa, 2009; Zeinali *et al.,* 2009) were conducted. However, a detailed study dealing with the physico-mechanical properties of *R. damascena* required for its pneumatic harvest mechanization has not been reported so far. Thus, the objective of this study was to determine some harvest design variables (the physico-mechanical properties of petals) required for pneumatic harvest mechanization of *R. damascena.* These design variables are terminal velocity, picking force required to separate petals from ovary point (the picking force of rose petals), weight, projection area, density, and drag coefficient.

Material and methods

Flowers of *R. damascena* were handpicked from the rose garden located at the experimental site of Rose and Rose Products Research and Implementation Center at Süleyman Demirel University, Isparta (latitude 37° 45' N, longitude 30° 33' E, altitude 997 m). The flowers were manually picked at 06:30 a.m. (S1), 08:30 a.m. (S2), 10:30 a.m. (S3), and 12:30 p.m. (S4) at four different dates, June 5 (H1), June 11 (H2), June 17 (H3), and June 23 (H4), covering potential flowering period in 2009.

Aerodynamic properties of agricultural materials are used in the handling and processing of various agricultural products (Song and Litchfield, 1991). The basic design variables for harvest, separation and cleaning of crops are terminal velocity, drag coefficient, weight, vertical and horizontal projection area, density, and breaking force (Güzel *et al*., 1996). Terminal velocity is one of the most important properties for the separation, pneumatic transport and cleaning of crops. Terminal velocities of the rose petals were measured by using an air column at Laboratory of Agricultural Engineering, Süleyman Demirel University. This system consists of an axial fan supplying air, an AC drive adjusting the fan speed, a PVC pipe which air can move vertically, and a sight glass to observe the movement of materials. A hot wire anemometer installed above the sight glass was used to determine terminal velocity of rose flowers (Mohsenin, 1986). Accuracy of the hot wire anemometer was 0.1 m s^{-1}.

The dimensionless aerodynamic drag coefficient (Cd) characterizes the interaction between rose petals and airflow and is expressed by the formula (Tabak and Wolf, 1998; Tabak *et al*., 2002):

$$Cd = \frac{2\ m\ g}{V_{cr^2}\ A\ \rho_a}$$

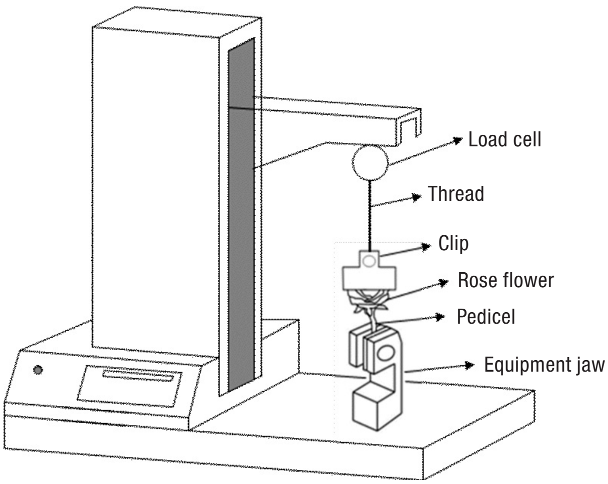

Figure 1. Determination of picking force of rose petals with a universal testing machine.

where m = the mass of rose petal (kg), g = the acceleration of gravity (m s^{-2}), V_{cr} = the terminal velocity of rose petals (m s^{-1}), A = the projection area of rose petal (m^2), ρ_a = the air density (kg m^{-3}).

A balance reading to 0.001 g was used to obtain the mass of rose petals. The projection area of rose petals was calculated by Global Lab Image software (version 2.0, Data Translation Company). The density of petals defined as mass per unit volume was determined by ASTM D1555 (2010).

A universal testing machine with a load cell was used to measure the picking force required to separate petals from ovary point (the picking force of rose petals). Ovary point of the rose flowers was connected to the jaw of the universal testing machine and then petal of flowers attached to a clip with load cell of machine was pulled upward to determine the picking force of rose petal (Fig. 1). All the tests were carried out with a speed 100 mm min^{-1}.

For each test above mentioned, a sample of 30 rose flowers was randomly selected from the rose field. A 4 × 4 randomized block design was applied for the experiment. Where statistical differences ($p < 0.01$ and $p < 0.05$) were detected, Duncan's LSD test was applied in order to compare the means.

Results and discussion

Some harvest design variables required for pneumatic harvest of *R. damascena* are given in Table 1. All the values of design variables in this table are presented as average with a standard deviation. Terminal velocity of rose petals as depending on harvesting hours and dates is given in Table 1 and ranged from 1.257 to 1.572 m s^{-1}. These values are close to those of wheat straw (0.75-5.25 m s^{-1}) oat straw (0.74-3.86 m s^{-1}) and barley straw (0.67-3.1 m s^{-1}) (Güzel *et al*., 1996). The effects of harvesting hours and dates on terminal velocity are given in Figure 2a. It can be seen from Figure 2a and Table 1 that terminal velocity of rose petals slightly decreased with harvest dates from H1 to H4. This finding is supported by the study of (Baydar and Baydar, 2005). On the other side, at a given specific harvesting date, *e.g.* H1, as harvesting hours goes from S1 to S4, the magnitude of terminal velocity of rose petals decreased slightly. The highest and lowest terminal velocity measured was for H1 and H4, respectively. Ayık (1995) reported that terminal velocity of a crop decreases as weight decrease. Besides, Misra *et al*. (2002) pointed out that as light intensity in the morning increases with time leads to decrease in rose oil content. Therefore, it is reasonable to expect a decrease in terminal velocity of the rose petals at the harvesting hours from early in the morning (S1) to the midday (S4) since the contents of essential oil of petals decreases as time proceeds in morning (Baydar and Baydar, 2005). Statistical analyses showed that the effects of harvesting hours and dates on terminal velocity were statistically different ($p < 0.01$) (Table 1).

One of the most important design variables for pneumatic harvest mechanization of *R. damascena* is the picking force of rose petals, which is supposed to be equal or lower than the aspiration force which pneumatic harvest systems should develop (Coskun, 2002). The picking force of rose petals varied between 1.005 and 0.501 N (Table 1 and Fig. 2b). The response of harvesting hours ($p < 0.01$) and dates ($p < 0.05$) on the picking force of rose petals was found to be statistically significant. The highest picking force of rose petals was measured for the petals gathered at the harvesting hour of S1 and dates of H1. Baydar (2009) reported that depending on the harvesting hour in a day properties of rose petals decrease in strength, which is in agreement with the result of this study. Although the lowest force requirement (measured at the harvesting hours of S4) for pneumatic harvest system is desirable, the contents of rose oil at this hour diminishes (Baydar, 2009) leading to decrease in harvest field efficiency of the pneumatic harvest system.

Mass of rose petals has influence on harvest design variables required for pneumatic harvest of *R. damascena* such as terminal velocity, picking force, and aero-

Table 1. Some design variables of rose oil for pneumatic harvesting

	S1**	S2**	S3**	S4**	Average
Terminal velocity (m s⁻¹)					
H1**	1.572 ± 0.029	1.565 ± 0.025	1.560 ± 0.019	1.548 ± 0.015	1.561[a]
H2**	1.536 ± 0.023	1.377 ± 0.018	1.367 ± 0.014	1.353 ± 0.017	1.408[b]
H3**	1.378 ± 0.021	1.329 ± 0.018	1.311 ± 0.015	1.258 ± 0.012	1.319[c]
H4**	1.370 ± 0.018	1.320 ± 0.023	1.301 ± 0.018	1.257 ± 0.016	1.312[c]
Average	1.464[a]	1.398[b]	1.385[b]	1.354[c]	
Picking force (N)					
H1*	1.005 ± 0.109	0.873 ± 0.082	0.668 ± 0.039	0.539 ± 0.064	0.772[a]
H2*	0.905 ± 0.023	0.796 ± 0.047	0.775 ± 0.057	0.564 ± 0.042	0.760[a]
H3*	0.787 ± 0.077	0.761 ± 0.081	0.564 ± 0.038	0.515 ± 0.039	0.657[b]
H4*	0.752 ± 0.033	0.751 ± 0.049	0.554 ± 0.030	0.501 ± 0.043	0.640[b]
Average	0.862[a]	0.796[ab]	0.640[bc]	0.530[b]	
Mass (g)					
H1**	0.122 ± 0.003	0.076 ± 0.003	0.073 ± 0.004	0.062 ± 0.004	0.083[a]
H2**	0.094 ± 0.001	0.069 ± 0.002	0.068 ± 0.002	0.059 ± 0.002	0.072[ab]
H3**	0.061 ± 0.003	0.057 ± 0.003	0.056 ± 0.003	0.053 ± 0.003	0.057[b]
H4**	0.056 ± 0.003	0.052 ± 0.002	0.050 ± 0.002	0.049 ± 0.002	0.052[b]
Average	0.083[a]	0.063[ab]	0.062[ab]	0.056[b]	
Projection area (cm²)					
H1**	11.793 ± 0.431	12.005 ± 0.511	13.499 ± 0.577	13.830 ± 0.463	12.782[a]
H2**	7.674 ± 0.403	8.086 ± 0.276	8.286 ± 0.424	10.716 ± 0.462	8.690[b]
H3**	7.407 ± 0.257	7.778 ± 0.241	7.989 ± 0.247	8.697 ± 0.482	7.968[b]
H4**	7.071 ± 0.364	7.470 ± 0.369	7.644 ± 0.256	8.537 ± 0.255	7.680[b]
Average	8.486[b]	8.835[b]	9.354[ab]	10.445[a]	
Density (g mL⁻¹)					
H1**	0.022 ± 0.003	0.018 ± 0.004	0.017 ± 0.002	0.016 ± 0.003	0.018[a]
H2**	0.020 ± 0.002	0.017 ± 0.003	0.015 ± 0.003	0.015 ± 0.002	0.017[ab]
H3**	0.020 ± 0.003	0.016 ± 0.003	0.015 ± 0.003	0.015 ± 0.002	0.016[b]
H4	0.016 ± 0.003	0.015 ± 0.002	0.014 ± 0.003	0.014 ± 0.003	0.015[b]
Average	0.019[a]	0.016[b]	0.015[b]	0.015[b]	
Drag coefficient					
H1**	0.634 ± 0.082	0.392 ± 0.047	0.342 ± 0.056	0.287 ± 0.076	0.414[b]
H2**	0.790 ± 0.053	0.684 ± 0.044	0.663 ± 0.034	0.457 ± 0.055	0.649[a]
H3**	0.663 ± 0.011	0.635 ± 0.016	0.618 ± 0.028	0.584 ± 0.033	0.625[a]
H4**	0.645 ± 0.065	0.604 ± 0.089	0.592 ± 0.021	0.549 ± 0.066	0.598[ab]
Average	0.683[a]	0.579[b]	0.554[b]	0.469[c]	

*,**: Significant at the 5% and 1% probability levels, respectively.

dynamic drag coefficient. Experimentally determined relationship of the mass of rose petals depending on harvesting hours and dates is given in Figure 2c. The mass of rose petals decreased with harvesting hours from S1 to S4 and dates from H1 to H4. This might be due to reduction in the contents of essential oil of rose petals. The similar phenomenon was reported by Baydar (2009). The average mass of the rose petals measured changed from 0.122 g to 0.049 g. The highest and lowest masses of rose petals corresponded to H1S1 and H4S4, respectively. Statistical analyses showed that the effect of harvesting hours and dates on the mass of rose petals was statistically significant ($p < 0.01$). It should be pointed out that the roses having more mass of petals have more essential oil content. Therefore, the more appropriate harvesting hours will be H1S1.

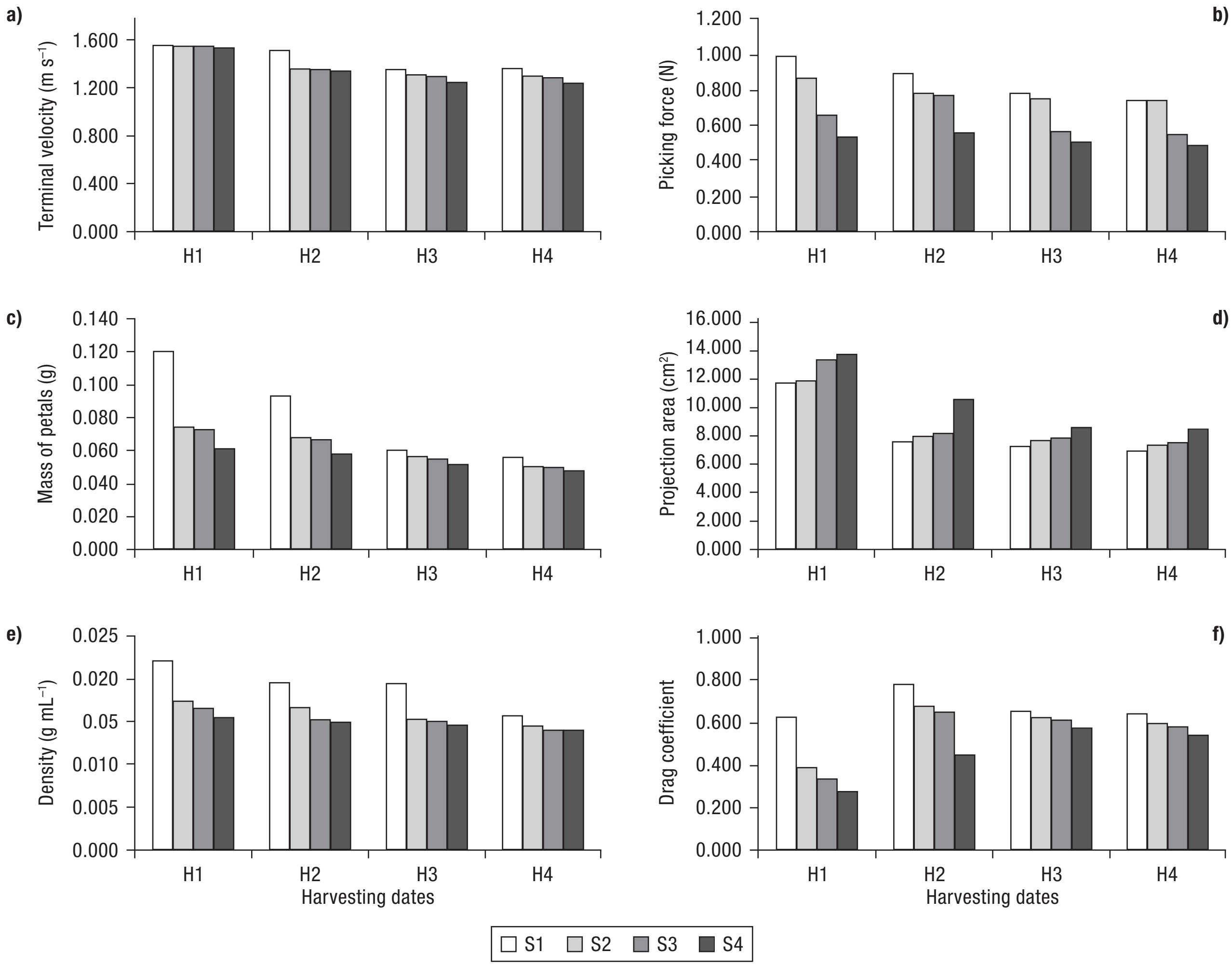

Figure 2. Effect of harvesting hours and dates on the a) terminal velocity of rose petals, b) picking force of rose petals, c) mass of rose petals, d) projection area of rose petals, e) density of rose petals, f) drag coefficient of rose petals

Projection area of the rose petals changed from 13.830 cm^2 for H1S4 to 7.071 cm^2 for H4S1 (Table 1 and Fig. 2d). When the average projection area of petals based on the harvest dates was considered, the highest and lowest projection areas were measured for H1 and H4, respectively. On the other hand, the highest and lowest projection areas were measured for S4 and S1 when the average projection area of petals based on the harvesting hours was considered (Fig. 2d). Visual inspection during the field study showed that the rose petals in the morning were nested with concave shape; however, the flowers were fully open and petals were straighter towards midday. Thus, it is expected that projection area of rose petals measured at midday is higher than that of measured at the morning. Statistical analysis showed that effects of harvesting hours and dates on projection area of rose petals were significant at 0.01 probability level.

Density of rose petal is one of the most important properties for harvest, transport and storage operations. Density of petals varied between 0.014 g mL^{-1} for H4S3 and H4S4 and 0.022 g mL^{-1} for H1S1 (Table 1 and Fig. 2e). Density decreased with both harvesting hours from S1 to S4 and dates from H1 to H4. The response of harvesting hours and dates on density of petal were statistically significant ($p < 0.01$).

Tabak *et al*. (2002) reported that drag coefficient is affected by shape factor, fuzziness, rotation and oscillation in motion of the rose petals. This coefficient is defined as the resistance of a crop to motion in an airflow used in pneumatic conveying, separation, and drying process. Drag coefficient of rose petal ranged from 0.790 for H2S1 to 0.287 for H1S4 (Table 1 and Fig. 2f). These values are close to those reported for wheat (0.5), barley (0.5), corn (0.5-0.7), soybean (0.45), oat (0.47), and cotton seed (0.52-0.61) (Kılıçkan and Guner, 2006; Guzel *et al.*, 1996). The effect of harvesting hours and dates on drag coefficient of rose petals was found to be statistically significant ($p < 0.01$).

Conclusions

In this study, some harvest design variables required for pneumatic harvest mechanization of *R. damascena* were investigated. It can be concluded that the harvest of *R. damascena* should be executed towards the end of harvesting dates H4 and harvesting hour S4 in terms of terminal velocity, but harvesting hour of S1 is better than S4 because rose oil content decreases from S1 to S4. As far as the picking force, the density and the drag coefficient are concerned, they decrease when the harvesting hour increases from H1 to H4 and the harvesting date increases from S1 to S4, which makes necessary to increase aspiration pressure. The projection area increases when the harvesting hours changes from S1 to S4, but decreases when the harvesting dates changes from H1 to H4 and it should be taken into account not only for pneumatic regulations but also for mechanical harvest of rose petals.

Acknowledgement

This research was supported by TUBİTAK-BİDEB, National Postdoctoral Research Scholarship Programme-2218.

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