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LABORATORY EVALUATION OF A SOFT ROBOTIC GRIPPER FOR TOMATOES HARVESTING

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Abstract: One of the main challenges in robotic harvesting of tomatoes is related to the development of end-effectors that can handle delicate fruits without causing damage. Soft grippers have emerged as a promising solution, due to their ability to adapt to the geometry of the fruit while applying reduced mechanical stress. This paper presents laboratory experiments carried out at INMA Bucharest for the evaluation of a soft gripper intended for tomato harvesting. The research focused on correlating gripping forces with the applied working pressure (0.5–1 bar nominal) and on assessing possible damage to the fruits. The tests demonstrated that the gripper ensures stable tomato handling over the entire pressure range investigated, without causing negative effects on the harvested fruits. These results confirm the feasibility of using soft grippers in agricultural robotics applications, particularly for tomato harvesting

Keywords: tomatoes, robotic harvesting, soft grippers, tomato handling, laboratory experiments

INTRODUCTION

The development of robotic grippers for agricultural applications has advanced significantly in recent years, with a particular focus on soft pneumatic solutions. These devices have the ability to adapt to the geometry of delicate products and to distribute the gripping force uniformly, reducing the risk of mechanical damage. Comparative studies confirm that soft grippers outperform rigid counterparts in tasks that require compliance and adaptability [1].

Tomato harvesting represents one of the most demanding applications for robotic grippers, due to the fruits' fragility and variability in size. Several approaches have been analyzed in recent reviews dedicated to robotic harvesting of Solanaceae crops in protected environments, which underline the importance of specialized grippers for safe handling [2].

The gripping of delicate agricultural products, such as tomatoes, is always influenced by the force applied by the harvesting system. This force could be applied mechanically by rigid grippers or pneumatically by soft grippers. The effect of this force, meaning the stability of the grip and the possible damage on the tomato surface, is completely determined by the gripping force and the contact area. This is the reason why, through gripping force analysis, it could be determined the working pressure range, which assures a safe harvesting process. The effect depends on the tomato characteristics and the knowledge of the gripping force behavior will allow for the optimization of robotic harvesting systems.

It is considered that the end-effector is characterizing the functioning state of a harvesting robot. Grippers with rigid fingers could apply excessive local pressure, leading to skin cracks or bruises. Many times, even reduced forces could damage the fruit surface, leading to quality loss and reduced storage time. In most cases, fruit damage is unwanted, because it causes dramatic shortening of the shelf life and reduces the market value of the harvested product. This is the reason why it is considered that if a gripper does not affect the tomato surface, it will be suitable for long-term use in agricultural robotics, while if the one which produces damage is left without taking measures, it will not be feasible for practical applications.

Each type of tomato, depending on its size and shape, will require a gripping force in a specific range. Knowing the correlation between working pressure and gripping force, it could be determined the optimal conditions for safe harvesting. The main source of fruit damage for classical grippers is the concentration of mechanical stress on reduced contact areas. For this reason, solutions are sought for force distribution, like using soft pneumatic actuators which adapt their shape to the fruit geometry and absorb part of the pressure.

Advantages of soft grippers are multiple: adaptability to different sizes and shapes, reduced risk of mechanical damage, simplicity in control, possibility to be integrated in automated robotic systems. Disadvantages arise from the need for a pneumatic supply system, a slower actuation speed compared to rigid systems, and possible wear of the flexible materials after long-term use.

Research efforts have produced a wide range of soft gripper designs, from multifunctional prototypes that integrate different gripping modes [3], to designs optimized through material selection and structural analysis [4]. New models are also being reported for their improved performance in handling spherical or irregular fruits, including tomatoes, by combining compliance with sufficient gripping force [5].

In addition to conventional pneumatic soft grippers, alternative strategies have been proposed, such as prestressed designs for food handling [6] or hybrid solutions that integrate active palm control to improve adaptability [7]. Experimental validations have shown that soft grippers can be successfully applied in real harvesting tasks, with robust prototypes being tested for apple harvesting under field conditions [8].

Despite these developments, there is still limited quantitative reporting on the correlation between working pressure, gripping force, bending behavior and payload capacity, particularly in multi-finger configurations. In this context, the present paper reports on laboratory experiments performed at INMA Bucharest with a commercial soft gripper (RM-SOFT 00M). The objective was to evaluate gripping force, bending angle, payload capacity and fruit damage for both 3-finger and 4-finger configurations, in order to provide a reliable assessment of the gripper's potential for tomato harvesting.

MATERIAL AND METHOD

The experiments were carried out at INMA Bucharest using a commercial soft gripper, pneumatically actuated. The soft gripper used in the experiments was designed for both mobile robotic platforms and collaborative robot (cobot) applications. The kit includes a control unit with built-in pumps and valves, two gripper bases with silicon fingers, spacers, pneumatic accessories, and the necessary mounting hardware. It does not require an external pneumatic supply, as the control box integrates the needed drive system.

The fingers are made of silicone, and the recommended operating pressure range given by the manufacturer is 0.5 to 1.0 bar, with an expected grip force of 5 N per finger at nominal pressure. The device is rated for over 10 million cycles at 1.0 bar and 0.5 Hz, indicating a high durability.

The gripper was operated using a pump control box. The device provides an adjustable output pressure in the range –0.5 to 2.0 bar, using compressed air according to ISO 8573-1:2010 standards. The system includes an M12 8-pin connector for valve and pump control, with digital signal input 21.6–26.4 V DC, 500 mA. The operational temperature range is 0–50 °C. We also calibrated the system using the artificial tomato method (described above) to derive the relationship between input pressure and actual gripping force. To verify real performance, the gripper was tested on actual tomato samples across multiple cycles, assessing grip success rate and damage. In order to assess the gripping performance of the gripper under different configurations, two setups were tested: a 3-finger arrangement and a 4-finger arrangement. The same experimental protocol was applied in both cases, including gripping force calibration with the artificial tomato and repeated tests on real tomato fruits (cherry, plum and round type). For each configuration and pressure level, 100 gripping cycles were performed.

The gripper was supplied from a compressed air system, fitted with a precision regulator that allowed continuous adjustment of the working pressure in the range 0.5–1 bar. The actual pressure delivered to the gripper was measured with a digital manometer with an accuracy of ±0.01 bar.

For determining the gripping force, an artificial tomato was designed and manufactured in the laboratory. The artificial fruit consisted of a silicone elastic membrane connected to a miniature pump and a digital pressure sensor. The membrane was filled with air, the initial internal pressure being equal to atmospheric pressure. When the gripper applied compression, the membrane deformed, resulting in an increase of the internal air pressure. This pressure variation was continuously recorded using a National

Instruments data acquisition system, at a sample rate of 100 Hz, and processed with LabVIEW software.

A calibration procedure was performed prior to testing, by applying known weights on the artificial tomato and recording the corresponding internal pressure values. Based on this calibration curve, the gripping force corresponding to each working pressure level of the gripper was determined. This indirect method assured good repeatability and eliminated the need of placing load cells between the gripper fingers and the object.

Damage assessment was performed on fresh tomato samples of uniform ripeness, collected from a local greenhouse. For each working pressure step, 100 gripping cycles were carried out. After each cycle, the fruit surface was inspected visually and by gentle manual rotation under uniform light. Damage was classified on a five-step scale:

0 – no visible effect,
1 – superficial marks without structural damage,
2 – minor bruises,
3 – moderate bruises or cracks,
4 – severe cracks,
5 – fruit completely damaged.

Figure 1. Gripper mounting on the test stand

The test stand is presented in Figure 1, showing the artificial tomato, the pneumatic supply system, and the gripper mounted on a fixed support. The methodology allowed a clear correlation between the input parameter (working pressure) and the output parameters (gripping force and fruit damage), providing a complete evaluation of the gripper performance in tomato harvesting applications.

RESULTS

The gripper was tested in the manufacturer's recommended pressure range of 0.5–1.0 bar. The gripping force was determined using the artificial tomato method, in both 3-finger and 4-finger configurations.

The results showed a quasi-linear increase of the gripping force with the supply pressure. The 4-finger configuration generated higher gripping forces compared to the 3-finger one, due to the larger contact surface and the additional point of support. Figure 2 illustrates the relationship between working pressure and gripping force for the two configurations.

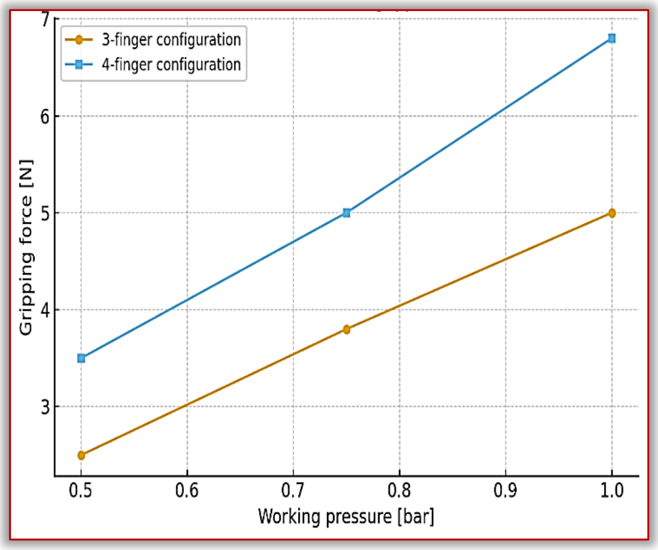

Figure 2. Correlation between working pressure and gripping force for 3-finger and 4-finger configurations of the gripper

The response time of the gripper was also measured. For both configurations, the average response time was under 0.5 s at 0.5 bar, and around 0.7–0.8 s at 1.0 bar, values that are suitable for robotic harvesting applications.

Tests performed on real tomatoes (cherry, plum and round types) confirmed that both configurations assured stable gripping, with slightly better stability for large round tomatoes when using the 4-finger setup. After 100 gripping cycles at each pressure level, no cracks, bruises, or surface marks were observed. The damage score was 0 in all cases.

Table 1: Gripping force for 3-finger and 4-finger configurations

Working pressure [bar]	Avg. force 3-finger [N]	Avg. force 4-finger [N]
0.5	2.5	3.5
0.75	3.8	5
1	5	6.8

The results confirm that the soft gripper adapts to the tomato geometry and distributes the gripping force uniformly over the fruit surface, eliminating the risk of localized stress. The modularity of the gripper allows for different finger configurations, with the 4-finger setup providing slightly higher stability for larger fruits.

The bending angle of the fingers increased with supply pressure. At 0.5 bar, the average bending angle was ~35°, while at 1.0 bar it reached ~75°. The 4-finger configuration provided a more uniform bending profile, contributing to a larger contact area and improved fruit stability.

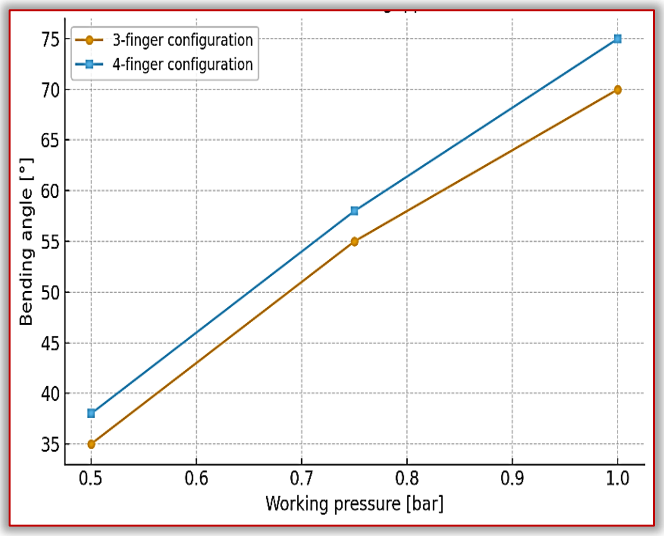

Figure 3. Bending angle of gripper fingers as a function of working pressure

The payload capacity was determined by testing the maximum tomato mass lifted and transported without slippage. In the 3-finger configuration, the gripper could safely handle fruits up to ~120 g, while in the 4-finger configuration it successfully handled fruits up to ~160 g.

CONCLUSIONS

The paper presented laboratory measurements performed for the assessment of the gripping force developed by a commercial soft gripper and its effects on tomato fruits. The evaluation method, based on the use of an artificial tomato equipped with an internal pressure sensor, allowed for the correlation between the gripper working pressure and the gripping force.

The results obtained show that the gripping force increases proportionally with the working pressure, ensuring a stable handling of the fruit over the entire tested range. Tests performed on real tomato samples demonstrated that no visible damage occurred after repeated gripping cycles, confirming that the gripper adapts to the fruit geometry and distributes the force uniformly.

The obtained results prove that the soft gripper can be safely used in tomato harvesting applications without affecting fruit quality. Furthermore, the methodology developed for laboratory evaluation represents a reliable tool for future testing and optimization of robotic harvesting systems

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References

[1] Terrile, S.; Argüelles, M.; Barrientos, A. Comparison of Different Technologies for Soft Robotics Grippers. Sensors 2021, 21, 3253
[2] Matache, M.G., Găgeanu, I., Brăcăcescu, C., Cristea, O.D. and Cristea, R.D. (2025). Robotic harvesting methods for vegetables of the Solanaceae family in greenhouses and solariums using specialized grippers – a review. Acta Hortic. 1433, 323-330
[3] Correia, A.; Charters, T.; Leite, A.; Campos, F.; Monge, N.; Rocha, A.; Mendes, M.J.G.C. Design, Control, and Testing of a Multifunctional Soft Robotic Gripper. Actuators 2024, 13, 476
[4] Meenakshipriya B., Suhas R.M., Shivashankaran D., Dhinesh Kumar M., Raswin K.T., Manoj V.,, "Design and analysis of soft robotic gripper with different materials for object handling," Proceedings of the 15th International Conference on Computing Communication and Networking Technologies (ICCCNT), Kamand, India, pp. 1–8, 2024.
[5] Zhang, H.; Liu, W.; Yu, M.; Hou, Y. Design, Fabrication, and Performance Test of a New Type of Soft-Robotic Gripper for Grasping. Sensors 2022, 22, 5221
[6] Wang Z., Torigoe Y., Hirai S., "A prestressed soft gripper: design, modeling, fabrication, and tests for food handling," IEEE Robotics and Automation Letters, vol. 2, no. 4, pp. 1909–1916, 2017.
[7] Subramaniam V, Jain S, Agarwal J, Valdivia y Alvarado P. Design and characterization of a hybrid soft gripper with active palm pose control. The International Journal of Robotics Research. 2020;39(14):1668-1685
[8] Wang X., Kang H., Zhou H., Au W., Wang M.Y., Chen C., "Development and evaluation of a robust soft robotic gripper for apple harvesting," Computers and Electronics in Agriculture, vol. 204, p. 107552, 2023

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