A Literature Review and Design Considerations Towards a Gripper for Tomato Harvesting

Original
A Literature Review and Design Considerations Towards a Gripper for Tomato Harvesting / Malyshev, D., Filice, L., Mirabelli, G., Longo, F., Bernardi, B., Carbone, G., Rybak, L.. - 157:(2024), pp. 553-563. (33rd International Conference on Robotics in Alpe-Adria-Danube Region, RAAD 2024 rou 2024) [10.1007/978-3-031-59257-7_55].

Published
DOI: http://doi.org/10.1007/978-3-031-59257-7_55

The final published version is available online at:https://link.springer.com/chapter/10.1007/978-3-031-

A Literature Review and Design Considerations Towards a Gripper for Tomato Harvesting

Dmitry Malyshev[1,2], Luigino Filice[1], Giovanni Mirabelli[1], Francesco Longo[1],
Bruno Bernardi[3], Giuseppe Carbone[1], Larisa Rybak[2]

[1]Dept. of Mechanical, Energy, and Management Eng., Università della Calabria, Rende, Italy
[2]Belgorod State Technological University Named After V. G. Shukhov, Belgorod, Russia
[3]Dept. of Agricultural Sciences, Università Mediterranea di Reggio Calabria, Italy
giuseppe.carbone@unical.it

Abstract. The paper reviews current commercial and research solutions in the field of grippers for automated tomato harvesting. The gripping devices are classified according to the method of harvesting tomatoes, namely individual fruits and branches. The requirements that the design of a gripping device for harvesting tomatoes must satisfy are formulated also based on preliminary laboratory tests. The requirements include the mechanical properties of the tomatoes and the required characteristics of the gripping device. A preliminary design concept is also proposed for harvesting tomatoes with a specific focus onthe large-size tomato varieties.

Keywords: Tomato Harvesting, Gripper, Harvesting Robots.

1 Introduction

Tomato harvesting is a very important task requiring extensive manual work. Several companies, including Priva, Octiva, and Xihelm, are actively developing automation and robotics for tomato cultivation. Xihelm is focused on robotic solutions for tomato harvesting, but no implementation has been documented yet. Floating Company Robotics offers a commercial robot specifically designed for efficient cherry tomato harvesting. However, concerns arise regarding thecareful placement of branches, potentially impacting fruit shelf life. Metomotion provides a commercial robot capable of harvesting various tomato varieties using scissor-shaped grippers. Inaho has developed a unique cherry tomato-picking robot with parallel modules resembling a soft conveyor belt, although multiple attemptsmay be needed for harvesting, posing potential fruit damage. Pioneering research in tomato harvesting emerged in Japan in the 1980s [1] with contributions from Tateshi Fujira and collaborations with Naoshi Kondo [2]. Some papers present only schematic designs without further development [3,4]. A solar-powered robotic system using artificial balls for experiments is condered in [5]. However, it is still an open problem to provide an adaptable grasping solution for small productions of large size tomatoes.

2 Review of existing solutions

Literature review has been made as based on the procedure, which consisted of searching for sources dedicated to robotic tomato harvesting in Scopus, Researchgate and Google. An analysis was carried out of the source, as well as other sources on same topic found in connection with this source (citations, references, the same authors). Within the framework of the current paper, a filtered part of the found sources relating to the development of entire robotic systems or their gripping devices is cited.

Some of the earliest development of tomato grippers, along with other robotic components, began in Japan [6]. To date, researchers from around the world have developed several different gripping devices for harvesting tomatoes. They may have a different number of fingers and a different way of grasping and tearing off the fruit. Let's analyze existing solutions, grouping them by the type of object being grasped.

Mobile platform chassis for tomato harvesting robots were developed in [7-9], but these seem applicable to a broader range of fruits and vegetables. A post-harvest device on a mobile platform for safely moving tomatoes to a basket is developed in [9]. A system using a movable cart to control manual tomato harvesting is considered in [10]. Kinematics and workspace for manipulators considering the required harvesting area are considered in [11]. Manipulator for tomato harvesting, its simulation, checking design parameters, force-torque calculations, and developing a control system, excluding the gripping device aspect are considered in [12].

It is worth noting the competition for robotic tomato picking, which has been held in the city of Kitakyushu (Japan) annually since 2014 [13]. The competition takes place in a greenhouse at the Kitakyushu Research & Science Park. Its dimensions are 10 x 20 m. The greenhouse is equipped with IoT sensors that measure temperature, humidity, soil pH and light. The competition mainly involves teams from the city of Kitakyushu, but teams from other universities also participate. To pick tomatoes, robotsneed to adapt to lighting conditions, which brings the task closer to real-life conditions. The team from the HAYAHI-LAB laboratory won the competition the most times. Over the years of the competition, several scientific results were obtained, and published in papers [14], [15].

2.1. Gripping devices for individual fruits

It is worth noting that as a result of the review, not a single commercial solution was identified that uses individual fruit harvesting. However, most of the research work is devoted specifically to individual fruit harvesting.

Some of the agricultural grips can be combined into a group of flexible grips, printed using a 3D printer using flexible materials. One of these grips, designed specifically forharvesting tomatoes, is discussed in [16]. A similar grip, but used for various objects, including tomatoes, is discussed in [17].

A three-finger gripper made of ABS+ plastic with force sensors, based on a crank-slider mechanism, is proposed in [18]. The influence of gripper motor parameters such as input current and motor speed on the shrinking process anddeformation of tomatoes was investigated in [19]. A recently popular AI tool Chat GPT, was used during the design development in [20]. The gripper design consists of two hemispheres, similar to the design proposed earlier in [21]. A device for harvesting tomatoes is proposed in [22], based on drawing tomatoes with air and cutting off the fruit. There are also many other grippers designed for tomatoes [23-33].

2.2. Gripping devices for branches with fruit

All commercial solutions found for harvesting tomatoes use branch picking or other methods of group harvesting. Descriptions of commercial solutions are described in introduction. The number of research solutions for branch gripping is extremely limited [34-35].

3 Requirements and Challenges

The advancement of robotic technologies for tomato picking necessitates thorough planning and execution of field experiments. They are based on the measurement of theresponse to mechanical stresses of controlled compression and penetration under controlled deformation conditions, i.e. the conditions to be monitored when harvesting operations are planned to be mechanized in order not to damage the product.

3.1 Tomatoes properties

Table 1 shows the properties of tomatoes that should be taken into account whendesigning gripping devices.

Table 1. Tomatoes properties

Property	Min value	Max value	Comment
Weight	14 g (Grape)	454 g (Beefsteak and Heirloom)	Based on the size of tomatoes of different varieties
Size	10 mm (Cherry)	150 mm (Beefsteak and Heirloom)	Based on the size of the tomatoes of different varieties
Young’s Modulus	2.32	4.07	According to [18,36-38]
Poisson’s Ratio	0.55	0.74	According to [18,36-38]
Shape	spherical	ellipsoid/irregular	According to [23,39,40]
Stiffness	3 N/mm (mature)	30 N/mm (green)	According to [23,39,40]
Grasping plane	horizontal	±15 deg from horizontal	According to [23,39,40]
Surface	smooth and dry	dusty and wed	According to [23,39,40]
Pose altitude	300 mm	1500 mm	According to [23,39,40]
Stalk orientation	vertical	±30 deg from vertical	According to [23,39,40]

3.2 Compression and penetration tests

To assess the firmness of the tomatoes, a series of compression and penetration tests were carried out on different tomato varieties. The aim was to establish action thresholds for the gripper so as not to damage the fruit. The tests were carried out at room temperature using a TA-TX Plus texture analyzer (Fig. 1). The different cultivars of tomatoes chosen were: Piccadilly tomatoes, Cherry Tomatoes, Rib Tomatoes, Oxheart Tomatoes, and Grape Tomatoes. Three ripening indices were considered: unripe tomato, medium ripe tomato, and fully ripe tomato. Compression tests involved loading the sample between two plates, applying a force and recording the deformation. The cycle included compression, decompression and a second compression, revealing changes in the structure of the sample. This assessed material behavior under compressive pressures, plastic flow and ductile fracture limits. Penetration tests used cone penetrometers to measure stress-strain properties by inserting a metal cone into the specimen at a constant speed and force. The probes were applied in triplicate with a 100mm dish and 5mm tip, a test speed of 2mm/sec and a trigger force of 5 grams. Compression indices varied for different samples (10 mm for Piccadilly, 20 mm for others), while penetration tests maintained a 10 mm index. The thresholds found during the tests (Fig. 2-3) ranged from 9.29 - 28.13 N for penetration (on fully ripe grape tomatoes and unripe cherry tomatoes respectively), while for compression these values were 30.16 - 302.89 N (on medium ripe Piccadilly tomatoes and unripe cherry tomatoes respectively).

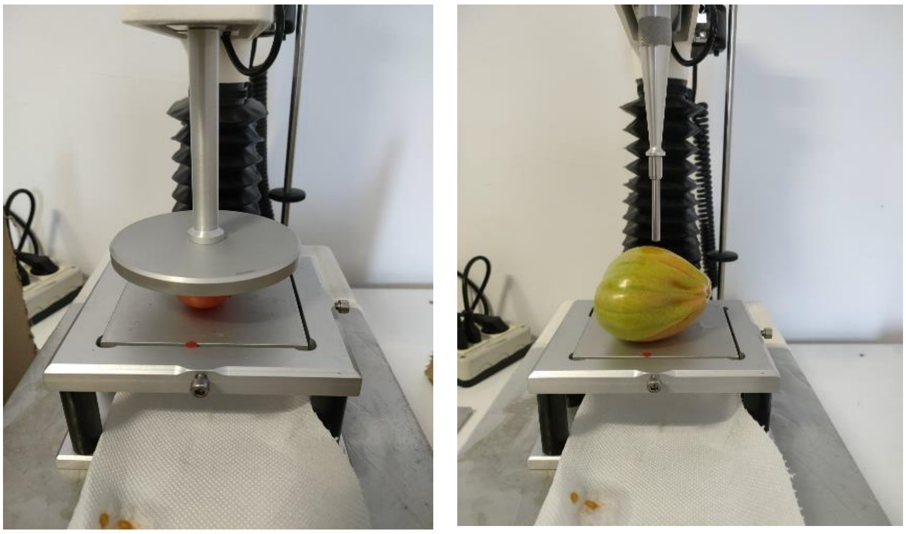

Fig.1. TA-TX Plus Texture Analyzer during tests

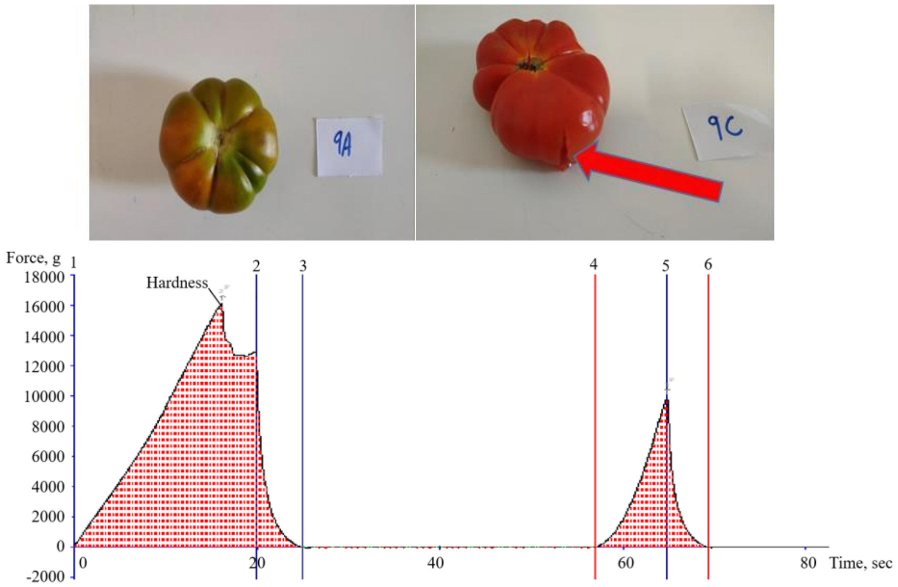

Fig. 2. Example of compressed tomato and its damage (showed by arrow) andmaximum peaks obtained during trials

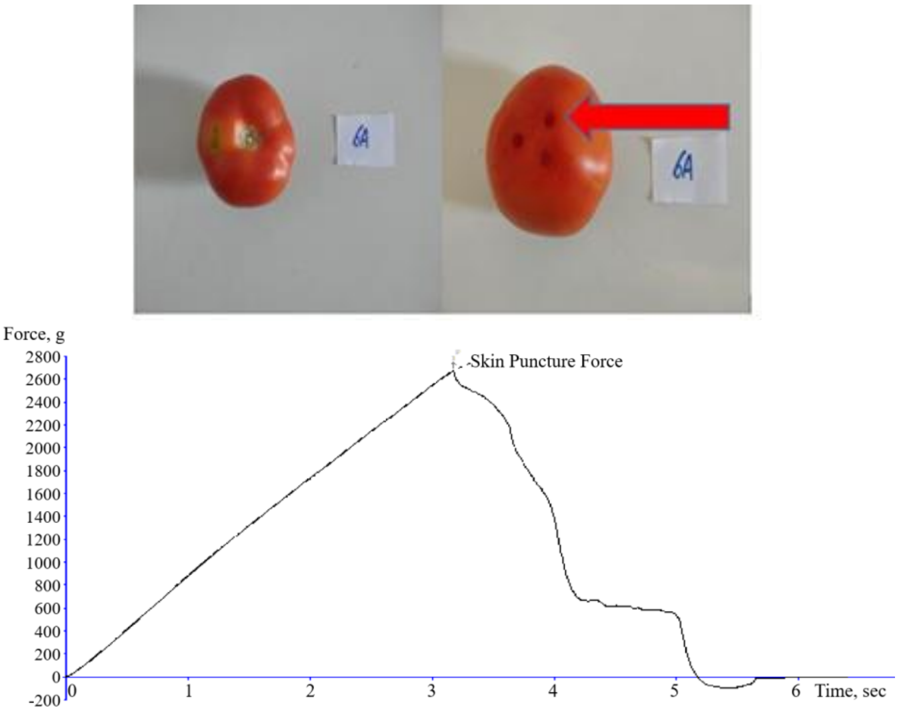

Fig.3. Example of a penetrated tomato and its damage (showed by arrow) and maximum peaks obtained during trials

3.3 Regulatory Considerations

Based on the analysis performed and the sizes of tomatoes of various varieties, requirements have been drawn up that must be met by a tomato gripping device (Table 2).

Table 2. Gripper requirements

Metrics	Value	Comment
Harvesting rate	30 kg/hour	To provide productivity comparable to manual labor [41]
Accuracy	1 mm	Sufficient accuracy based on the size of the tomatoes
Payload	500 g	According to the maximum weight of large types of tomatoes (Beefsteak and Heirloom)
Workspace	150 mm x 150 mm x 150 mm	According to the maximum size of large types of tomatoes (Beefsteak and Heirloom)
Measured Force of Sensor	1-30 N	According to the tomato stiffness range [23,39,40]
Type of Sensors	Piezoresistive, piezoelectric	Suitable for tomatoes
Energy Source of Actuators	Electrical preferable (other suitable options can be used)	Compromise between functionality and energy consumption, enabling its implementation in current agricultural robotics [42]
Control	position control, force feedback	Control algorithms with the stiffness of the object for the handling of fruits [42]
Material	Non-toxic material	Since tomatoes are a food product

4 Possible Gripper Design

Let's consider one of the options for the structure of a gripping device that can be used for harvesting tomatoes. A specific design solution has been identified in this work as the one DOF (degree of freedom) mechanism, which is represented in Figure 4. It is made up of two four-bar mechanisms, ABCL and EFGH. This mechanism is an extension of a design solution that was addressed previously in [43]. This mechanism provides a symmetrical bending of the palm around the revolute joint at point L after adequate dimensional synthesis. The revolute joint in the L joins the palm's two parts. A motor is installed at point E and can actively bend the palm. However, to achieve a passive adjustable palm bending, turn off this actuator and use the k stiffness of a spring attached at point L. Depending on your grasping requirements, you can choose between active and passive palm operation modes. The proposed palm also serves as a base for three fingers that can be attached to it at positions D1, D2, and I. The bending of the palm also results in the rotation of the fingers, which aids in the grasping of an object. The design of the proposed gripper is shown in figure 5[44]. The proposed design of the gripping device allows us to satisfy the requirements formed above. In particular, the design allows the use of electric actuators and the installation of the necessary sensors to implement force feedback. All-round fruit gripping allows for stable gripping of tomatoes weighing 500 grams. The gripper will be non-toxic to products if food-grade plastic is used or has a special coating.

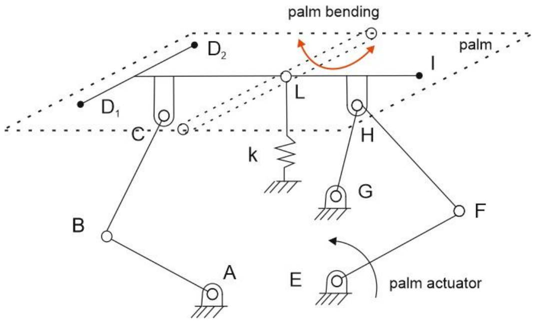

Fig. 4. Kinematic model of the driving mechanism for the proposed palm. [44]

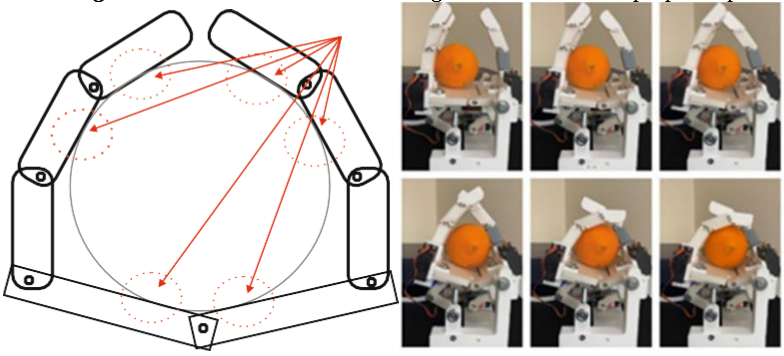

Fig. 5. An example of grasping configuration while holding a cylindrical object: a) scheme, b) real environment

5 Conclusions

Presently, extensive research and various commercial solutions exist for robotic tomato harvesting; however, widespread implementation remains limited. As a result, manual labor is still widely employed for tomato harvesting. An ongoing challenge is the effective integration of recognition and control algorithms, as well as equipment, into real-world environments. Laboratory studies often fall short in addressing all the complexities of real-life conditions. The field of tomato harvesting requires increased automation to overcome existing limitations in the application of robotic systems. This paper delves into current literature, conducting preliminary testing to identify primary design requirements and constraints for achieving a human-like, gentle, and adaptable harvesting process for large tomatoes by proposing a possible design concept. Future investigations will center on designing a novel robotic gripper based on the proposed human-like concept.

Acknowledgments This paper has been partially funded by the PNRR Next Generation EU“TECH4YOU - ECS 00000009, CUP H23C22000370006.

References

1. Kawamura, N., Namikawa, K., Fujiura T.,Ura, M.: Study on Agricultural Robot (Part 1). Journal of the Japanese Society of Agricultural Machinery 46, 353–358 (1984) (in Japanese)
2. Kondo, N., Shibano, Y., Mohri, K., Fujiura, T. and Monta, M.: Request to Cultivation Method from Tomato Harvesting Robot. Acta Hortic. 319, 567-572 (1992)
3. Buemi, F., Massa, M., Sandini, G., & Costi, G.: The AGROBOT project. Advances in Space Research 18(1-2), 185–189 (1996)
4. Jin, Z.M., Sun, W., Zhang, J., Shen, C., Zhang, H.Y., Han, S.Q.: Intelligent Tomato Picking Robot System Based on Multimodal Depth Feature Analysis Method. IOP Conf. Ser. Earth Environ. Sci. 440, 042074 (2020)
5. Miah, I., Sultan, S., Wangchuk, J., Savitha R.: Development of Solar Power Agriculturally Based Fruit Picking Robot. ESP Journal of Engineering & Technology Advancements 3(1) JETA-V3I1P108 (2023)
6. Kawamura, N., Namikawa, K., Fujiura, T., Ura, M., Ogawa, Y.: Prototype production of the hand part of a fruit harvesting robot, Journal of the Japan Society of Agricultural Machinery, 49, 116 (1987) (in Japanese)
7. Su, L., Liu, R., Liu, K., Li, K., Liu, L., Shi, Y.: Greenhouse Tomato Picking Robot Chassis. Agriculture, 13, 532 (2023)
8. Zhu, T., Xiang, J.: Chassis Design of Tomato Picking Robot in the Greenhouse. J. Phys. Conf. Ser. 2136, 012047 (2021)
9. Zu, L.L., Han, M.Z., Liu, J.Q., Liu, P.Z., Li, T., Su, F.: Design and Experiment of Nondestructive Post-Harvest Device for Tomatoes. Agriculture 12, 1233 (2022)
10. Ota, T., Iwasaki, Y., Nakano, A., Kuribara, H., & Higashide, T.: Development of yield and harvesting time monitoring system for tomato greenhouse production. Engineering in Agriculture, Environment and Food 12(1), 40–47 (2019)
11. Li, Z., Liu, J., Li, P., Li, W.: Analysis of Workspace and Kinematics for a Tomato Harvesting Robot. In: Proceedings International Conference on Intelligent Computation Technology and Automation, Changsha, China, pp. 823-827 (2008)
12. Wu, J.H., Zhang, Y., Zhang, S.H., Wang, H.J., Liu, L., Shi, Y.G.: Simulation Design of a Tomato Picking Manipulator. Teh. Vjesn. 28, 1253–1261. (2021)
13. Ishii, K., Matsuo, T., Takemura, Y., Sonoda, T., Sanada, A., Tominaga, M., Nishida, Y., Yasukawa, S., Shirahashi, K., Fujinaga, T., Arita, D., Kawajiri, K., Ohshima, K., Okada, M.: Report on the 8th Tomato-Harvesting Competition toward Smart Agriculture. In: Proceedings of International Conference on Artificial Life and Robotics, pp.486-490 (2023)
14. Ohshige, T., Tominaga, M., Fujinaga, T., Takemura, Y., Ahn, J.: Development of Harvesting Robot for Tomato Robot Competition 2022 and Its Evaluation. In: Proceedings of International Conference on Artificial Life and Robotics, pp. 477-480 (2023)
15. Yaguchi, H., Nagahama, K., Hasegawa, T., Inaba, M.: Development of an autonomous tomato harvesting robot with rotational plucking gripper. In: Proceedings of the 2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Daejeon, Korea, 9–14 October 2016, pp. 652–657 (2016)

16. Guo, T., Zheng, Y., Bo, W., Liu, J., Pi, J., Chen, W., Deng, J.: Research on the Bionic Flexible End-Effector Based on Tomato Harvesting. Journal of Sensors 2022, Article ID 2564952 (2022)
17. Elgeneidy, K., Lightbody, P., Pearson, S., Neumann, G.: Characterising 3D-printed Soft Fin Ray Robotic Fingers with Layer Jamming Capability for Delicate Grasping. In: 2019 2nd IEEE International Conference on Soft Robotics (RoboSoft), Seoul, Korea (South), pp. 143–148 (2019)
18. Russo, M., Ceccarelli, M., Corves, B., Hüsing, M., Lorenz, M., Cafolla, D. and Carbone, G.: Design and test of a gripper prototype for horticulture products. Robot. Comput.-Integ. Manuf. 44, 266–275 (2017)
19. Liu, J., Li, Z., Li, P., Mao, H.: Design of a Laser Stem-cutting Device for Harvesting Robot In: Proceedings of the IEEE International Conference on Automation and Logistics Qingdao, China September 2008, pp. 2370-2374 (2008)
20. Stella, F., Della Santina, C. & Hughes, J.: How can LLMs transform the robotic design process?. Nat Mach Intell 5, 561–564 (2023)
21. Yeshmukhametov, A., Koganezawa, K., Buribayev, Z., Amirgaliyev, Y., Yamamoto, Y.: Development of Continuum Robot Arm and Gripper for Harvesting Cherry Tomatoes. Appl. Sci. 12, 6922 (2022)
22. Fujinaga, T., Yasukawa, S., Ishii, K.: Development and Evaluation of a Tomato Fruit Suction Cutting Device. In: Proceedings of the 2021 IEEE/SICE International Symposium on System Integration (SII), Fukushima, Japan, 11–14 January 2021; pp. 628–633. (2021)
23. Ceccarelli, M., Figliolini, G., Ottaviano, E., Simon Mata, A., and Jimenez Criado, E.: Designing a robotic gripper for harvesting horticulture products. Robotica 18, 105–111 (2000)
24. Taqi, F., Al-Langawi, F., Abdulraheem, H., El-Abd, M.: A cherry-tomato harvesting robot. In: Proceedings of the 2017 18th International Conference on Advanced Robotics (ICAR), Hong Kong, China, 10–12 July 2017, pp. 463–468 (2017)
25. Vu, Q., Ronzhin, A. A.: A Model of Four-Finger Gripper with a Built-in Vacuum Suction Nozzle for Harvesting Tomatoes. In: Smart Innovation, Systems and Technologies, pp. 149–160. Spinger: Berlin/Heidelberg, Germany (2020)
26. Jun, J., Kim, J.; Seol, J., Kim, J., Son, H.: Il Towards an Efficient Tomato Harvesting Robot: 3D Perception, Manipulation, and End-Effector. IEEE Access 9, 17631–17640 (2021)
27. Ling, X., Zhao, Y., Gong, L., Liu, C., Wang, T.: Dual-arm cooperation and implementing for robotic harvesting tomato using binocular vision. Rob. Auton. Syst. 114, 134–143 (2019)
28. Ling, P P, Ehsani, R, Ting, K C, Chi, Y.-T., Ramalingam, N., Klingman, M. H., Draper, C.: Sensing and end-effector for a robotic tomato harvester. In: 2004 ASAE/CSAE Annual International Meeting, Ottawa, Ontario, Canada, 043088. American Society of Agricultural and Biological Engineers, St. Joseph, Michigan (2004)
29. Kondo, N., Monta, M., Shibano, Y., Mohri, K.: Two finger harvesting hand with absorptive pad based on physical properties of tomato, Environ. Control Biol. 31(2), 87–92 (1993)
30. Chiu, Y. C., Yang, P. Y., Chen, S.: Development of the End-Effector of a Picking Robot for Greenhouse-Grown Tomatoes. Applied Engineering in Agriculture 29(6), 1001-1009 (2013)

31. Zhang, F.; Chen, Z.;Wang, Y.; Bao, R.; Chen, X.; Fu, S.;Tian, M.; Zhang, Y.: Research on Flexible End-Effectors with Humanoid Grasp Function for Small Spherical Fruit Picking. Agriculture 13, 123. (2023)
32. Wang, G., Yu, Y., Feng, Q.: Design of End-effector for Tomato Robotic Harvesting. IFAC-PapersOnLine 49-16, 190–193 (2016)
33. Rong, J., Wang, P., Wang, T., Hu, L., Yuan, T.: Fruit pose recognition and directional orderly grasping strategies for tomato harvesting robots. Computers and Electronics in Agriculture 202, 107430 (2022)
34. Feng, Q., Zou, W., Fan, P., Zhang, C., Wang, X.: Design and test of robotic harvesting system for cherry tomato. Int. J. Agric. Biol. Eng. 11, 96–100 (2018)
35. Kondo, N., Yata, K., Iida, M., Shiigi, T., Monta, M., Kurita, M., Omori, H.: Development of an end-effector for a tomato cluster harvesting robot. Eng. Agriculture, Environment Food 3, 20–24 (2010)
36. Gladyszewska, B., Ciupak, A.: Changes in the mechanical properties of the greenhouse tomato fruit skins during storage. Technical Sciences 12(12), 1-8 (2009)
37. Williams, S.H., Wright, B.W., Truong, V.D., Daubert, C.R., Vinyard, C.J.: Mechanical properties of foods used in experimental studies of primate masticatory function, Am. J. Primatol. 67 (3), 329–346 (2005)
38. Babarinsa, F.A., Ige, M.T.: Young’s Modulus for packaged Roma tomatoes under compressive loading, Int. J. Sci. Eng. Res. 3(10), 314–320 (2014)
39. Jimenez, C.E.: Diseno de un organo aprenhensor para la recolecciòn de productos ortofruticolas”, Master Thesis (ETSII, University of Malaga) (1998)
40. Figliolini, G., Gastaldi, L., Sorli, M.: Analisi teorica e sperimentale di un sistema di controllo della pressione in anello aperto con valvole digitali modulate in PWM, XII Congresso Nazionale AIMETA, Napoli, Vol. III, pp. 99–104 (1995)
41. Samuel, D.V.K.: Manually operated tomato harvesting tool for greenhouse. Acta Hortic. 710, 491-496. (2006)
42. Navas, E., Fernández, R., Sepúlveda, D., Armada, M., Gonzalez-de-Santos, P.: Soft Grippers for Automatic Crop Harvesting: A Review. Sensors 21, 2689 (2021)
43. Niola, V., Penta, F., Rossi, C., Savino, S.: An Underactuated Mechanical Hand: Theoretical Studies and Prototyping. International Journal of Mechanics and Control 16(1), 11-19 (2015)
44. Rodinò, S., Lago, F., Malyshev, D., Carbone, G.: Design of a Movable Palmfor a 3-Fingers Robotic Hand. International Journal of Mechanics and Control 24(1), 177–188 (2023)