

Supplementary information

Towards edible robots and robotic food

**In the format provided by
the authors and unedited**

Supplementary Information for: Towards Edible Robots and Robotic Food

Dario Floreano^{1*}, Bokeon Kwak¹, Markéta Pankhurst¹, Jun Shintake², Mario Caironi³, Valerio F. Annese³, Qiukai Qi⁴, Jonathan Rossiter⁴, Remko Boom⁵

¹Laboratory of Intelligent Systems, Institute of Mechanical Engineering, École Polytechnique Fédérale de Lausanne, Station 11, Ecublens, 1015, Switzerland

²Shintake Research Group, School of Informatics and Engineering, The University of Electro-Communications 1-5-1 Chofugaoka, Chofu, Tokyo 182-8585, Japan

³Center for Nano Science and Technology, Istituto Italiano di Tecnologia, Via R. Rubattino, 81, Milano, 20134 Italy

⁴School of Engineering Mathematics and Technology, University of Bristol, Bristol, BS8 1TW UK & Bristol Robotics Laboratory, Bristol, BS16 1QY UK

⁵Laboratory of Food Process Engineering, Wageningen University, Bornse Weiland 9, 6708, WG, Wageningen, the Netherlands

*corresponding author

References consulted to extract data shown in Figure 1

- [SR1] Ashby, M. F. *Materials Selection in Mechanical Design*. Butterworth Heinemann (1999).
- [SR2] Unt, A., Piili, H., Hirvimäki, M., Manninen, M., Salminen, A. Laser scribing of stainless steel with and without work media. *International Congress on Applications of Lasers & Electro-Optics (ICALEO)*, 1012–1021 (2010). <https://doi.org/10.2351/1.5061932>.
- [SR3] AZO Materials, www.azom.com (Feb. 2023).
- [SR4] MatWeb Material Property Data, www.matweb.com (Feb. 2023).
- [SR5] Kępczak, N., Kaczmarek, Ł., Pawłowski, W. Cast Iron and Mineral Cast Applied For Machine Tool Bed - Dynamic Behavior Analysis. *Archives of Metallurgy and Materials*, **60**, 1023–1029 (2015). <https://doi.org/10.1515/amm-2015-0254>.
- [SR6] Kępczak, N., Pawłowski, W. Application of Mineral Casting for Machine Tools Beds. *Mechanics and Mechanical Engineering*, **17**, 285–289 (2013).
- [SR7] Magryta, P., Pietrykowski, K., Skiba, K. FEM simulation research of natural frequency vibration of crankshaft from internal combustion engine. *ITM Web of Conferences*, **15**, Art. No. 07004 (2017). <https://doi.org/10.1051/itmconf/20171507004>
- [SR8] Chen, T.-C., Chen, Y.-J., Hung, M.-H., Hung, J.-P. Design analysis of machine tool structure with artificial granite material. *Advances in Mechanical Engineering*, **8**, 1–14 (2016). <https://doi.org/10.1177/16878140166565>
- [SR9] Material Properties, <https://material-properties.org/> (Feb. 2023).
- [SR10] Li, M., Zinkle, S. J. Physical and Mechanical Properties of Copper and Copper Alloys in *Comprehensive Nuclear Materials* (ed: Konings, R. J. M.). Elsevier Science, **4**, 667–690 (2012). <https://doi.org/10.1016/B978-0-08-056033-5.00122-1>
- [SR11] Uddin, M. M., Mondal, D., Herrington, P. D. Finite Element Simulation of Backward Micro Extrusion for Annealed Copper. *ASME International Mechanical Engineering Congress and Exposition*. IMECE2018-86755, V002T02A043 (2018). <https://doi.org/10.1115/IMECE2018-86755>.
- [SR12] Maina, M. R., Okamoto, Y., Inoue, R., Nakashiba, S.-I., Okada, A., Sakagawa, T. Influence of Surface State in Micro-Welding of Copper by Nd:YAG Laser. *Applied Sciences*, **8**, Art. No. 2364 (2018). <https://doi.org/10.3390/app8122364>.
- [SR13] Titanium physical properties, <https://www.kobelco.co.jp/> (Feb. 2023).
- [SR14] Glass material properties, www.sonelastic.com (Feb. 2023)
- [SR15] Karazi, S. M., Ahad, I. U., Benyounis, K. Y. Laser Micromachining for Transparent Materials in Reference Module in *Reference Module in Materials Science and Materials Engineering*, 2017. <https://doi.org/10.1016/B978-0-12-803581-8.04149-7>

- [SR16] Ashby, M. F. *Materials and the Environment: Eco-informed Material Choice*, Butterworth-Heinemann (2013). <https://doi.org/10.1016/C2010-0-66554-0>
- [SR17] Borosilicate glass properties, www.imetra.com (Feb. 2023)
- [SR18] Becker, J., Jacobs, L. J., Qu, J. Characterization of Cement-Based Materials Using Diffuse Ultrasound. *Journal of Engineering Mechanics*, **129**, 1478–1484 (2003). [https://doi.org/10.1061/\(ASCE\)0733-9399\(2003\)129:12\(1478\)](https://doi.org/10.1061/(ASCE)0733-9399(2003)129:12(1478)).
- [SR19] Ceramic properties, <https://top-seiko.com/> (Feb. 2023).
- [SR20] Karabulut, M., Melnik, E., Stefan, R., Marasinghe, G. K., Ray, C. S., Kurkjian, C. R., Day, D. E. Mechanical and structural properties of phosphate glasses. *Journal of Non-Crystalline Solids*, **288**, 8–17 (2001). [https://doi.org/10.1016/S0022-3093\(01\)00615-9](https://doi.org/10.1016/S0022-3093(01)00615-9)
- [SR21] Abbood, I. S., Odaa, S. A., Hasan, K. F., Jasim, M. A. Properties evaluation of fiber reinforced polymers and their constituent materials used in structures – A review. *Materials Today: Proceedings*, **43**, 1003–1008 (2021). <https://doi.org/10.1016/j.matpr.2020.07.636>.
- [SR22] Carbon rod properties, www.tapplastics.com (Feb. 2023).
- [SR23] Andena, L., Caimmi, F., Leonardi, L., Nacucchi, M., Pascalis, F. D. Compression of polystyrene and polypropylene foams for energy absorption applications: A combined mechanical and microstructural study. *Journal of Cellular Plastics*, **55**, 49–72 (2019). <https://doi.org/10.1177/0021955X18806794>
- [SR24] Rumianek, P., Dobosz, T., Nowak, R., Dziewit, P., Aromiński, A. Static Mechanical Properties of Expanded Polypropylene Crushable Foam. *Materials*, **14**, Art. No. 249 (2021). <https://doi.org/10.3390/ma14020249>
- [SR25] Weingart, N., Raps, D., Kuhnigk, J., Klein, A., Altstädt, V. Expanded Polycarbonate (EPC)—A New Generation of High-Temperature Engineering Bead Foams. *Polymers*, **12**, Art. No. 2314 (2020). <https://doi.org/10.3390/polym12102314>
- [SR26] Sadler, R., Panduranga, R. Feasibility Study of Endo- and Exo-skeletal Framed Structures with Envelopes for LTA Platforms. *Defense Technical Information Center*, ADA547119 (2011).
- [SR27] Polyethylene terephthalate Key Properties in *Phoenix Technologies International LLC* (2008),
- [SR28] PET properties, <https://polymerdatabase.com/> (Feb. 2023).
- [SR29] Dharmadasa, B. Y., McCallum, M., Jimenez, F. L. Characterizing and modeling the viscoplastic behavior of creases in Kapton polyimide films. *AIAA SciTech Forum*, 2020-2165 (2020). <https://doi.org/10.2514/6.2020-2165>.
- [SR30] Courbat, J. Gas Sensors on Plastic Foil with Reduced Power Consumption for Wireless Applications. ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE, 4710 (2010). <https://doi.org/10.5075/epfl-thesis-4710>.
- [SR31] Nylon 6 Properties, <https://designerdata.nl/> (Feb. 2023).
- [SR32] Nylon Properties, <http://www.substech.com/> (Feb. 2023).
- [SR33] Mansy, H. A., Grahe, J. R., Sandler, R. H. Elastic properties of synthetic materials for soft tissue modeling. *Physics in Medicine & Biology*, **53**, 2115 (2008). <https://doi.org/10.1088/0031-9155/53/8/008>.
- [SR34] Wang, Z., Volinsky, A. A., Gallant, N. D. Crosslinking effect on polydimethylsiloxane elastic modulus measured by custom-built compression instrument. *Journal of Applied Polymer Science*, **131**, 41050 (2014). <https://doi.org/10.1002/app.41050>
- [SR35] Hocheng, H., Chen, C.-M., Chou, Y.-C., Lin, C.-H. Study of novel electrical routing and integrated packaging on bio-compatible flexible substrates. *Microsystem Technologies*, **16**, Art. No. 423 (2010). <https://doi.org/10.1007/s00542-009-0930-2>
- [SR36] Yirmibeşoğlu, O. D., Oshiro, T., Olson, G., Palmer, C., Mengüç, Y. Evaluation of 3D Printed Soft Robots in Radiation Environments and Comparison With Molded Counterparts. *Frontiers in Robotics and AI*, **6**, Art. No. 40 (2019). <https://doi.org/10.3389/frobt.2019.00040>.
- [SR37] Kladovasilakis, N., Sideridis, P., Tzetzis, D., Piliounis, K., Kostavelis, I., Tzovaras, D. Design and Development of a Multi-Functional Bioinspired Soft Robotic Actuator via Additive Manufacturing. *Biomimetics*, **7**, Art. No. 105 (2022). <https://doi.org/10.3390/biomimetics7030105>.
- [SR38] An, H. J., Kim, M. S., Kim, J., Son, J., Choi, C. H., Park, J. M., Kim, J.-I. Geometric Evaluation of Patient-Specific 3D Bolus from 3D Printed Mold and Casting Method for Radiation Therapy. *Progress in Medical Physics*, **30**, 32–38 (2019). <https://doi.org/10.14316/pmp.2019.30.1.32>.
- [SR39] Silicone rubber products, www.smooth-on.com (Feb. 2023).
- [SR40] Boonvisut, P., Çavuşoğlu, M. C. Estimation of Soft Tissue Mechanical Parameters from Robotic Manipulation Data. *IEEE/ASME Transactions on Mechatronics*, **18**, 1602-1611 (2012). <https://doi.org/10.1109/TMECH.2012.2209673>.
- [SR41] Fortunato, M., Bellagamba, I., Tamburrano, A., Sarto, M. S. Flexible Ecoflex®/Graphene Nanoplatelet Foams for Highly Sensitive Low-Pressure Sensors. *Sensors*, **20**, Art. No. 4406 (2020). <https://doi.org/10.3390/s20164406>.

- [SR42] Kumar, K. A. A., Sreekala, M. S., Arun, S. Studies on Properties of Bio-Composites from Ecoflex/Ramie Fabric-Mechanical and Barrier Properties. *Journal of Biomaterials and Nanobiotechnology*, **3**, 396–404 (2012). <http://dx.doi.org/10.4236/jbnt.2012.33039>.
- [SR43] Park, Y.-L., Majidi, C., Kramer, R., Bérard, P., Wood, R. J. Hyperelastic pressure sensing with a liquid-embedded elastomer. *Journal of Micromechanics and Microengineering*, **20**, Art. No. 125029 (2010). <https://doi.org/10.1088/0960-1317/20/12/125029>.
- [SR44] Vaicekauskaite, J., Mazurek, P., Vudayagiri, S., Skov, A. L. Mapping the mechanical and electrical properties of commercial silicone elastomer formulations for stretchable transducers. *Journal of Materials Chemistry C*, **8**, 1273–1279 (2020). <https://doi.org/10.1039/C9TC05072H>.
- [SR45] Khaleed, H. M. T., Badruddin, I. A., Saquib, A. N., Addas, M. F., Kamangar, S., Khan, T. M. Y. Novel Approach to Manufacture an AUV Propeller by Additive Manufacturing and Error Analysis. *Applied Sciences*, **9**, Art No. 4413 (2019). <https://doi.org/10.3390/app9204413>.
- [SR46] Kang, S.-C. A Study of Creep Characteristics of ABS (Acrylonitrile Butadiene Styrene) for Different Stress Levels and Temperatures. *Journal of the Korean Society for Precision Engineering*. **29**, 1137–1143 (2012). <https://doi.org/10.7736/KSPE.2012.29.10.1137>.
- [SR47] Naik, J. B., Mishra, S. The Compatibilizing Effect of Maleic Anhydride on Swelling Properties of Plant-Fiber-Reinforced Polystyrene Composites. *Polymer-Plastics Technology and Engineering*. **45**, 923–927 (2007). <https://doi.org/10.1080/03602550600723522>
- [SR48] Swallowe, G. M., Lee, S. F. Quasi-static and dynamic compressive behaviour of poly(methyl methacrylate) and polystyrene at temperatures from 293 K to 363 K. *Journal of Materials Science*, **41**, 6280–6289 (2006). <https://doi.org/10.1007/s10853-006-0506-9>.
- [SR49] Sastri, V. R. Commodity Thermoplastics: Polyvinyl Chloride, Polyolefins, and Polystyrene in *Plastics in Medical Devices*, William Andrew, 73–119 (2010). <https://doi.org/10.1016/B978-0-8155-2027-6.10006-6>.
- [SR50] Pinto, V. C., Ramos, T., Alves, S., Xavier, J., Tavares, P., Moreira, P. M. G. P., Guedes, R. M. Comparative Failure Analysis of PLA, PLA/GNP and PLA/CNT-COOH Biodegradable Nanocomposites thin Films. *Procedia Engineering*, **114**, 635–642 (2015). <https://doi.org/10.1016/j.proeng.2015.08.004>.
- [SR51] Soud, W. A., Baqer, I. A., Ahmed, M. R. Experimental Study of 3D printing Density Effect on the Mechanical Properties of the Carbon-Fiber and Polylactic Acid Specimens. *Engineering and Technology Journal*, **37**, 128–132 (2019). <https://doi.org/10.30684/etj.37.4A.3>.
- [SR52] Balakrishnan, H., Hassan, A., Imran, M., Wahit, M. U. Toughening of Polylactic Acid Nanocomposites: A Short Review. *Polymer-Plastics Technology and Engineering*, **51**, 175–192 (2012). <https://doi.org/10.1080/03602559.2011.618329>.
- [SR53] Reverte, J. M., Caminero, M. Á., Chacón, J. M., García-Plaza, E., Núñez, P. J., Becar, J. P. Mechanical and Geometric Performance of PLA-Based Polymer Composites Processed by the Fused Filament Fabrication Additive Manufacturing Technique. *Materials*, **13**, Art. No. 1924 (2020). <https://doi.org/10.3390/ma13081924>.
- [SR54] Mai, T. D. T., Thu, T. P. T., Thi, T. N., Thu, P. N., Thi, N. P., Thu, T. N. T., Jun, S.-P., Thai, H. Effects of Porogen on Structure and Properties of Poly Lactic Acid/Hydroxyapatite Nanocomposites (PLA/HAp). *Journal of Nanoscience and Nanotechnology*, **16**, 9450–9459 (2016). <https://doi.org/10.1166/jnn.2016.12032>.
- [SR55] Aloyaydi, B. A., Sivasankaran, S. Low-Velocity Impact Characteristics of 3D-Printed Poly-Lactic Acid Thermoplastic Processed by Fused Deposition Modeling. *Transactions of the Indian Institute of Metals*, **73**, 1669–1677 (2020). <https://doi.org/10.1007/s12666-020-01952-6>.
- [SR56] Nguyen, T. K., Hwang, C. J., Lee, B.-K. Numerical investigation of warpage in insert injection-molded lightweight hybrid products. *International Journal of Precision Engineering and Manufacturing*, **18**, 187–195 (2017). <https://doi.org/10.1007/s12541-017-0024-5>.
- [SR57] Sundaram, B. M., Tippur, H. V. Dynamic mixed-mode fracture behaviors of PMMA and polycarbonate. *Engineering Fracture Mechanics*, **176**, 186–212 (2017). <https://doi.org/10.1016/j.engfracmech.2017.02.029>.
- [SR58] Abdel-Wahab, A. A., Ataya, S., Silberschmidt, V. V. Temperature-dependent mechanical behaviour of PMMA: Experimental analysis and modelling. *Polymer Testing*, **58**, 86–95 (2017). <https://doi.org/10.1016/j.polymertesting.2016.12.016>.
- [SR59] Briscoe, B. J., Fiori, L., Pelillo, E. Nano-indentation of polymeric surfaces. *Journal of Physics D: Applied Physics*, **31**, 2395–2405 (1998). <https://doi.org/10.1088/0022-3727/31/19/006>.
- [SR60] Acrylic material properties, <https://www.lehighvalleyplastics.com/> (Feb. 2023).
- [SR61] Hedayati, R., Ziaei-Rad, S., Eyvazian, A., Hamouda, A. M. Bird strike analysis on a typical helicopter windshield with different lay-ups. *Journal of Mechanical Science and Technology*, **28**, 1381–1392 (2014). <https://doi.org/10.1007/s12206-014-0125-3>.

- [SR62] Yasui, K., Shiokawa, A., Watanabe, M., Kinoshita, H., Morita, C. Temperature deformation characteristics of acrylic windows used for tide embankments. *AIMS Materials Science*, **8**, 932–951 (2021). <https://doi.org/10.3934/matensci.2021057>.
- [SR63] Pestka, K. A. II. Young's Modulus of a Marshmallow. *The Physics Teacher*, **46**, 140–141 (2021). <https://doi.org/10.1119/1.2840976>.
- [SR64] Density table, www.aqua-calc.com (Feb. 2023).
- [SR65] 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. *American Journal of Primatology*, **67**, 329–346 (2005). <https://doi.org/10.1002/ajp.20189>.
- [SR66] Ross, C. F., Washington, R. L., Eckhardt, A., Reed, D. A., Vogel, E. R., Dominy, N. J., Machanda, Z. P. Ecological consequences of scaling of chew cycle duration and daily feeding time in primates. *Journal of Human Evolution*, **56**, 570–585 (2009). <https://doi.org/10.1016/j.jhevol.2009.02.007>.
- [SR67] International Network of Food Data Systems (INFOODS), <https://www.fao.org/> (Feb. 2023).
- [SR68] Lewis, M. J. Physical Properties of Foods and Food Processing Systems. *Woodhead Publishing* (1990).
- [SR69] Agrawal, K. R., Lucas, P. W. The mechanics of the first bite. *Proceedings of the Royal Society B*, **270**, 1277–1282 (2003). <https://doi.org/10.1098/rspb.2003.2361>.
- [SR70] Ak, M. M., Gunasekaran, S. Stress-Strain Curve Analysis of Cheddar Cheese under Uniaxial Compression. *Journal of Food Science*, **57**, 1078–1081 (1992). <https://doi.org/10.1111/j.1365-2621.1992.tb11268.x>.
- [SR71] Iezzi, R., Locci, F., Mucchetti, G. Cheese True Density Prediction by Linear Equations. *Journal of Food Processing Engineering*, **36**, 462–469 (2013). <https://doi.org/10.1111/jfpe.12008>.
- [SR72] Boots, J. N. M., Humblet-Hua, N. P. K., Tonneijck, L., Fokkink, R., Gucht, J. V. D., Kodger, T. E. Characterization of the local mechanical texture of animal meat and meat replacements using multi-point indentation. *Journal of Food Engineering*, **300**, Art. No. 110505 (2021). <https://doi.org/10.1016/j.jfoodeng.2021.110505>.
- [SR73] Baik, O.-D., Mittal, G. S. Determination and Modeling of Thermal Properties of Tofu. *International Journal of Food Properties*, **6**, 9–24 (2003). <https://doi.org/10.1081/JFP-120016621>.
- [SR74] Babarinsa, F. A., Ige, M. T. Young's Modulus for Packaged Roma Tomatoes under Compressive Loading. *International Journal of Scientific & Engineering Research*, **3**, 1–7 (2012).
- [SR75] Jahanbakhshi, A., Sharabiani, V. R., Heidarbeigi, K., Kaveh, M., Taghinezhad, E. Evaluation of engineering properties for waste control of tomato during harvesting and postharvesting. *Food Science & Nutrition*, **7**, 1473–1481 (2019). <https://doi.org/10.1002/fsn3.986>.
- [SR76] Wasala, W. M. C. B., Dharmasena, D. A. N., Dissanayake, T. M. R., Thilakarathne, B. M. K. S. Physical and Mechanical Properties of Three Commercially Grown Banana (*Musa acuminata* Colla) Cultivars in Sri Lanka. *Tropical Agricultural Research*, **24**, 42–53 (2015). <http://doi.org/10.4038/tar.v24i1.7988>.
- [SR77] Karimi, N. Moisture-Dependent Physical Properties of Seedless and Seeded Raisin (*Vitis Vinifera* L.) Varieties. *Cercetări Agronomice în Moldova*, **48**, 5–16 (2015).
- [SR78] Hartstone-Rose, A., Parkinson, J. A., Criste, T., Perry, J. M. G. Brief Communication: Comparing Apples and Oranges—The Influence of Food Mechanical Properties on Ingestive Bite Sizes in Lemurs. *American Journal of Biological Anthropology*, **157**, 513–518 (2015). <https://doi.org/10.1002/ajpa.22726>.
- [SR79] Boukouvalas, Ch. J., Krokida, M. K., Maroulis, Z. B., Marinou-Kouris, D. Density and Porosity: Literature Data Compilation for Foodstuffs. *International Journal of Food Properties*, **9**, 1473–1481 (2006). <https://doi.org/10.1080/10942910600575690>.
- [SR80] Perry, J. M. G., Bastian, M. L., St Clair, E., Hartstone-Rose, A. Maximum ingested food size in captive anthropoids. *American Journal of Biological Anthropology*, **158**, 92–104 (2015). <https://doi.org/10.1002/ajpa.22779>.
- [SR81] Rodríguez-Ramírez, J., Méndez-Lagunas, L., López-Ortiz, A., Sandoval Torres, S. True Density and Apparent Density During the Drying Process for Vegetables and Fruits: A Review. *Journal of Food Science*, **77**, R146–R154 (2012). <https://doi.org/10.1111/j.1750-3841.2012.02990.x>.
- [SR82] Ogawa, Y., Matsuura, M., Yamamoto, N. Young's Modulus and Poisson's Ratio Changes in Japanese Radish and Carrot Root Tissues during Boiling. *International Journal of Food Properties*, **18**, 1006–1013 (2015). <https://doi.org/10.1080/10942912.2013.879388>.
- [SR83] Khan, M. I. H., Patel, N., Mahiuddin, M., Karim, M. A. Characterisation of mechanical properties of food materials during drying using nanoindentation. *Journal of Food Engineering*, **291**, Art. No. 110306 (2021). <https://doi.org/10.1016/j.jfoodeng.2020.110306>.
- [SR84] Qiu, J., Khalloufi, S., Martynenko, A., Dalen, G. V., Schutyser, M., Almeida-Rivera, C. Porosity, Bulk Density, and Volume Reduction During Drying: Review of Measurement Methods and Coefficient Determinations. *Drying Technology*, **33**, 1681–1699 (2015). <https://doi.org/10.1080/07373937.2015.1036289>.

- [SR85] Nowak, K. W., Markowski, M., Daszkiewicz, T. Ultrasonic determination of mechanical properties of meat products. *Journal of Food Engineering*, **147**, 49–55 (2015). <https://doi.org/10.1016/j.jfoodeng.2014.09.024>.
- [SR86] Kadowaki, R., Kimura, H., Inou, N. New Estimation Methods of Young's Modulus and Rupture Strength of Snack Foods Based on Microstructure. *Journal of Texture Studies*, **47**, 3–13 (2016). <https://doi.org/10.1111/jtxs.12154>.
- [SR87] Molenda, M., Stasiak, M. Determination of the elastic constants of cereal grains in a uniaxial compression test. *International Agrophysics*, **16**, 61–65 (2002).
- [SR88] Food material density, www.chemicalbook.com (Feb. 2023).
- [SR89] Leuangsukrerk, M., Phupoksakul, T., Tananuwong, K., Borompichaichartkul, C., Janjarasskul, T. Properties of konjac glucomannan–whey protein isolate blend films. *LWT - Food Science and Technology*, **59**, 3–13 (2014). <https://doi.org/10.1016/j.lwt.2014.05.029>.
- [SR90] Strnad, S., Oberhollenzer, Z., Šauperl, O., Kreze, T., Zemljič, L. F. Modifying Properties of Feather Keratin Bioplastic Films using Konjac Glucomannan. *Cellulose Chemistry and Technology*, **53**, 1017–1027 (2019). <https://doi.org/10.35812/CelluloseChemTechnol.2019.53.100>.
- [SR91] Haekal, M. H., Mawarani, L. J. The Effect of CMC, Agar, and Konjac on the Characteristics of Durian Seed Starch Edible Film. *IOP Conference Series: Materials Science and Engineering*, **833**, Art. No. 012011 (2020). <https://doi.org/10.1088/1757-899X/833/1/012011>.
- [SR92] Severa, L. Deformation and fracture properties of dark chocolate. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, **56**, 115–122 (2008). <https://doi.org/10.11118/actaun200856020115>.
- [SR93] Banks, H. The Density of Chocolate. *H&D Fitzgerald Ltd.* (2012).
- [SR94] Zhao, H., Li, B., James, B. J. Structure-fracture relationships in chocolate systems. *LWT*, **96**, 281–287 (2018). <https://doi.org/10.1016/j.lwt.2018.05.045>.
- [SR95] Tremeac, B., Hayert, M., Le-Bail, A. Mechanical properties of Tylose gel and chocolate in the freezing range. *International Journal of Refrigeration*, **31**, 867–873 (2015). <https://doi.org/10.1016/j.ijrefrig.2007.10.005>.
- [SR96] Chen, Y.-Y., Zhou, X.-Y., Qian, S.-H., Yu, J.-H. Effect of Sugar and Milk Powder Addition on the Mechanical Properties and Texture of Chocolate. *Journal of Oleo Science*, **71**, 1577–1589 (2022). <https://doi.org/10.5650/jos.ess22148>.
- [SR97] Filli, K., Sjöqvist, M., Öhgren, C., Stading, M., Rigdahl, M. Development and Characterization of Extruded Biodegradable Foams based on Zein and Pearl Millet Flour. *Annual Transactions the Nordic Rheology Society*, **19**, 139–145 (2011).
- [SR98] Kasemsiri, P., Dulsang, N., Pongsa, U., Hizioglu, S., Chindaprasirt, P. Optimization of Biodegradable Foam Composites from Cassava Starch, Oil Palm Fiber, Chitosan and Palm Oil Using Taguchi Method and Grey Relational Analysis. *Journal of Polymers and the Environment*, **25**, 378–390 (2017). <https://doi.org/10.1007/s10924-016-0818-z>.
- [SR99] Zhang, X., Teng, Z., Huang, R., Catchmark, J. M. Biodegradable Starch/Chitosan Foam via Microwave Assisted Preparation: Morphology and Performance Properties. *Polymers*, **12**, Art. No. 2612 (2020). <https://doi.org/10.3390/polym12112612>.
- [SR100] Glenn, G. M., Orts, W. J. Properties of starch-based foam formed by compression/explosion processing. *Industrial Crops and Products*, **13**, 135–143 (2001). [https://doi.org/10.1016/S0926-6690\(00\)00060-1](https://doi.org/10.1016/S0926-6690(00)00060-1).
- [SR101] Govedarica, B., Ilić, I., Šibanc, R., Dreu, R., Srčić, S. The use of single particle mechanical properties for predicting the compressibility of pharmaceutical materials. *Powder Technology*, **225**, 43–51 (2012). <https://doi.org/10.1016/j.powtec.2012.03.030>.
- [SR102] Gelberab, M. K., Bhargava, R. Monolithic multilayer microfluidics via sacrificial molding of 3D-printed isomalt. *Lap on a Chip*, **15**, 1736–1741 (2015). <https://doi.org/10.1039/C4LC01392A>.
- [SR103] Isomalt material properties, <https://pharmacentral.com/> (Feb. 2023).
- [SR104] Bolhuis, G. K., Engelhart, J. J. P., Eissens, A. C. Compaction properties of isomalt. *European Journal of Pharmaceutics and Biopharmaceutics*, **72**, 621–625 (2009). <https://doi.org/10.1016/j.ejpb.2009.03.005>.
- [SR105] Gaona-Sánchez, V. A., Calderón-Domínguez, G., Morales-Sánchez, E., Chanona-Pérez, J. J., Arzate-Vázquez, I., Terrés-Rojas, E. Pectin-based films produced by electrospraying. *Journal of Applied Polymer Science*, **133**, Art. No. 43779 (2016). <https://doi.org/10.1002/app.43779>.
- [SR106] Gamboni, J. E., Slavutsky, A. M., Bertuzzi, M. A. Starch-Pectin Films Obtained By Extrusion And Compression Molding. *Journal of Multidisciplinary Engineering Science and Technology*, **6**, 10175–10183 (2019).
- [SR107] Pereira, D. G. M., Vieira, J. M., Vicente, A. A., Cruz, R. M. S. Development and Characterization of Pectin Films with *Salicornia ramosissima*: Biodegradation in Soil and Seawater. *Polymers*, **13**, Art. No. 2632 (2021). <https://doi.org/10.3390/polym13162632>.

- [SR108] Nisar, T., Wang, Z.-C., Alim, A., Iqbal, M., Yang, X., Sun, L., Guo, Y. Citrus pectin films enriched with thinned young apple polyphenols for potential use as bio-based active packaging. *CyTA - Journal of Food*, **17**, 695–705 (2019). <https://doi.org/10.1080/19476337.2019.1640798>.
- [SR109] Karim, R., Nahar, K., Zohora, F. T., Islam, M., Bhuiyan, R. H., Jahan, M. S., Shaikh, A. A. Pectin from lemon and mango peel: Extraction, characterisation and application in biodegradable film. *Carbohydrate Polymer Technologies and Applications*, **4**, Art. No. 100258 (2022). <https://doi.org/10.1016/j.carpta.2022.100258>.
- [SR110] Zsivánovits, G., Marudova, M., Ring, S. Influence of mechanical properties of pectin films on charge density and charge density distribution in pectin macromolecule. *Colloid and Polymer Science*, **28**, 301–308 (2005). <https://doi.org/10.1007/s00396-005-1378-2>.
- [SR111] Kohyama, K., Hayakawa, F., Kazami, Y., Nishinari, K. Sucrose release from agar gels and sensory perceived sweetness. *Food Hydrocolloids*, **60**, 405–414 (2016). <https://doi.org/10.1016/j.foodhyd.2016.04.003>.
- [SR112] Nayar, V. T., Weiland, J. D., Nelson, C. S., Hodge, A. M. Elastic and viscoelastic characterization of agar. *Journal of the Mechanical Behavior of Biomedical Materials*, **7**, 60–68 (2012). <https://doi.org/10.1016/j.jmbbm.2011.05.027>.
- [SR113] Normand, V., Lootens, D. L., Amici, E., Plucknett, K. P., Aymard, P. New Insight into Agarose Gel Mechanical Properties. *Biomacromolecules*, **1**, 730–738 (2000). <https://doi.org/10.1021/bm005583j>.
- [SR114] Hernández, V., Ibarra, D., Triana, J. F., Martínez-Soto, B., Faúndez, M., Vasco, D. A., Gordillo, L., Herrera, F., García-Herrera, C., Garmulewicz, A. Agar Biopolymer Films for Biodegradable Packaging: A Reference Dataset for Exploring the Limits of Mechanical Performance. *Materials*, **15**, Art. No. 3954 (2022). <https://doi.org/10.3390/ma15113954>.
- [SR115] Resano-Goizueta, I., Ashokan, B. K., Trezza, T. A., Padua, G. W. Effect of Nano-Fillers on Tensile Properties of Biopolymer Films. *Journal of Polymers and the Environment*, **26**, 3817–3823 (2018). <https://doi.org/10.1007/s10924-018-1260-1>.
- [SR116] Wei, D., Zhou, F., Wang, H., Liu, G., Fang, J., Jiang, Y. Effects of Surfactants on Zein Cast Films for Simultaneous Delivery of Two Hydrophilic Active Components. *Materials*, **15**, Art. No. 2795 (2022). <https://doi.org/10.3390/ma15082795>.
- [SR117] Rakotonirainy, A. M., Wang, Q., Padua, G. W. Evaluation of Zein Films as Modified Atmosphere Packaging for Fresh Broccoli. *Journal of Food Science*, **66**, 1108–1111 (2001). <https://doi.org/10.1111/j.1365-2621.2001.tb16089.x>.
- [SR118] Mahajan, K., Chatli, M. K., Mehta, N., Malav, O. P. Quality and Storage Stability of Bioactive Biodegradable Zein Protein Films Impregnated with Coliphages. *International Journal of Current Microbiology and Applied Sciences*, **8**, 964–975 (2019). <https://doi.org/10.20546/ijcmas.2019.808.112>.
- [SR119] Zein material properties, www.drugfuture.com (Feb. 2023).
- [SR120] Chen, G., Chen, Y., Jin, N., Li, J., Dong, S., Li, S., Zhang, Z., Chen, Y. Zein films with porous polylactic acid coatings via cold plasma pre-treatment. *Industrial Crops and Products*, **150**, Art. No. 112382 (2020). <https://doi.org/10.1016/j.indcrop.2020.112382>.
- [SR121] Paramawati, R., Yoshino, T., Isobe, S. Properties of Plasticized-Zein Film as Affected by Plasticizer Treatments. *Food Science and Technology Research*, **7**, 191–194 (2001). <https://doi.org/10.3136/fstr.7.191>.
- [SR122] Kangarlou, S., Haririan, I. Physico-Mechanical Analysis of Free Ethylcellulose Films Plasticized with Incremental Weight Percents of Dibutyl Sebacate. *Iranian Journal of Pharmaceutical Sciences*, **3**, 135–142 (2007).
- [SR123] Narisawa, S., Yoshino, H., Hirakawa, Y., Noda, K. Porosity-Controlled Ethylcellulose Film Coating. I. Formation of Porous Ethylcellulose Film in the Casting Process and Factors Affecting Film-Density. *Chemical and Pharmaceutical Bulletin*, **41**, 329–334 (1993). <https://doi.org/10.1248/cpb.41.329>.
- [SR124] Ghadermazi, R., Hamdipour, S., Sadeghi, K., Ghadermazi, R., Asl, A. K. Effect of various additives on the properties of the films and coatings derived from hydroxypropyl methylcellulose—A review. *Food Science & Nutrition*, **7**, 3363–3377 (2019). <https://doi.org/10.1002/fsn3.1206>.
- [SR125] Shi, S.-C., Chen, T.-H., Mandal, P. K. Enhancing the Mechanical and Tribological Properties of Cellulose Nanocomposites with Aluminum Nanoadditives. *Polymers*, **12**, Art. No. 1246 (2020). <https://doi.org/10.3390/polym12061246>.
- [SR126] Piriyaarasath, S., Sriamornsak, P. Effect of source variation on drug release from HPMC tablets: linear regression modeling for prediction of drug release. *International Journal of Pharmaceutics*, **411**, 36–42 (2011). <https://doi.org/10.1016/j.ijpharm.2011.03.019>.
- [SR127] Parameswara, P., Demappa, T., Mahadevaiah, Prakash, Y., Somashekarappa, H., Byrappa, K., Somashekar, R. Polymeric degradation of water soluble chitosan/HPMC films using WAXS data. *Materials Research Innovations*, **16**, 126–129 (2012). <https://doi.org/10.1179/1433075X11Y.0000000028>.

- [SR128] Cho, Y. I., No, H. K., Meyers, S. P. Physicochemical Characteristics and Functional Properties of Various Commercial Chitin and Chitosan Products. *Journal of Agricultural and Food Chemistry*, **46**, 3839–3843 (1998). <https://doi.org/10.1021/jf971047f>.
- [SR129] Chitosan material data, <https://www.cd-bioparticles.net/> (Feb. 2023).
- [SR131] Zubair, M., Najeeb, F., Mohamed, M., Saeed, A., M. K., Ramis., M. S., Abdul Mujeeb, Sarojini, B. K. Analysis of Chitosan Polymer Doped with Nano Al₂O₃ and Nano CuO. *American Journal of Polymer Science*, **4**, 40–45 (2014). <https://doi.org/10.5923/j.ajps.20140402.03>.
- [SR132] Elhussieny, A., Faisal, M., D'Angelo, G., Aboulkhair, N. T., Everitt, N. M., Fahim, I. S. Valorisation of shrimp and rice straw waste into food packaging applications. *Ain Shams Engineering Journal*, **11**, 1219–1226 (2020). <https://doi.org/10.1016/j.asej.2020.01.008>.
- [SR133] Fernandez, J. G., Ingber, D. E. Unexpected Strength and Toughness in Chitosan-Fibroin Laminates Inspired by Insect Cuticle. *Advanced Materials*, **24**, 480–484 (2012). <https://doi.org/10.1002/adma.201104051>.
- [SR134] Badwan, A. A., Rashid, I., Omari, M. M. H. A., Darras, F. H. Chitin and Chitosan as Direct Compression Excipients in Pharmaceutical Applications. *Marine Drugs*, **13**, 1519–1547 (2015). <https://doi.org/10.3390/md13031519>.
- [SR135] Frolova, Y., Sobolev, R., Kochetkova, A. Influence of oil combinations on the structural properties of oleogels. *International Conference on Advances in Agrobusiness and Biotechnology Research*, **285**, Art. No. 05009 (2021). <https://doi.org/10.1051/e3sconf/202128505009>.
- [SR136] Patel, A. R., Dewettinck, K. Comparative evaluation of structured oil systems: Shellac oleogel, HPMC oleogel, and HIPE gel. *European Journal of Lipid Science and Technology*, **117**, 1772–1781 (2015). <https://doi.org/10.1002/ejlt.201400553>.
- [SR137] Frolova, Y., Sarkisyan, V., Sobolev, R., Makarenko, M., Semin, M., Kochetkova, A. The Influence of Edible Oils' Composition on the Properties of Beeswax-Based Oleogels. *Gels*, **8**, Art. No. 48 (2022). <https://doi.org/10.3390/gels8010048>.
- [SR138] Wettlaufer, T., Flöter, E. Wax based oleogels and their application in sponge cakes. *Food & Function*, **13**, 9419–9433 (2022). <https://doi.org/10.1039/D2FO00563H>.
- [SR139] Sobolev, R., Frolova, Y., Sarkisyan, V., Makarenko, V., Kochetkova, A. Effect of beeswax and combinations of its fractions on the oxidative stability of oleogels. *Food Bioscience*, **48**, Art. No. 101744 (2022). <https://doi.org/10.1016/j.fbio.2022.101744>.
- [SR140] Olmos-Oropeza, G., Aguilar-Zárate, M., Saavedra-Leos, M. Z., Martínez-Juárez, L. G., Toro-Vazquez, J. F., Sánchez-Macías, A., López-Martínez, L. A. Development of Candelilla Wax Oleogels as a Medium of Controlled Release of Phosphorus in an In Vitro Model. *Applied Science*, **11**, Art. No. 3815 (2021). <https://doi.org/10.3390/app11093815>.
- [SR141] Obradovic, J., Petibon, F., Fardim, P. Preparation and Characterisation of Cellulose-Shellac Biocomposites. *BioResources*, **12**, 1943–1959 (2017). <https://doi.org/10.15376/biores.12.1.1943-1959>.
- [SR142] Hindi, S. S., Dawoud, U. M., Asiry, K. A. Bioplastic Floss of a Novel Microwave-Thermospun Shellac: Synthesis and Bleaching for Some Dental Applications. *Polymers*, **15**, Art. No. 142 (2023). <https://doi.org/10.3390/polym15010142>.
- [SR143] Thombare, N., Kumar, S., Kumari, U., Sakare, P., Yogi, R. K., Prasad, N., Sharma, K. K. Shellac as a multifunctional biopolymer: A review on properties, applications and future potential. *International Journal of Biological Macromolecules*, **215**, 203–223 (2022). <https://doi.org/10.1016/j.ijbiomac.2022.06.090>.
- [SR144] Hossain, M. E., Ketata, C., Islam, M. R. Experimental Study of Physical and Mechanical Properties of Natural and Synthetic Waxes using Uniaxial Compressive Strength Test. *Proceedings of the Third International Conference on Modeling, Simulation and Applied Optimization*, Art. No. 41-44246 (2009).
- [SR145] Craig, R. G., Eick, J. D., Peyton, F. A. Strength properties of waxes at various temperatures and their practical application. *Journal of Dental Research*, **46**, 300–305 (1967). <https://doi.org/10.1177/00220345670460013101>.
- [SR146] Tinto, W. F., Elufioye, T. O., Roach, J. Waxes in Pharmacognosy: Fundamentals, Applications and Strategies (eds: Badal, S., Delgoda, R.), Academic Press (2016). <https://doi.org/10.1016/B978-0-12-802104-0.00022-6>.
- [SR147] Carnauba wax material property, <https://www.chemsrc.com/> (Feb. 2023).
- [SR148] Zhang, Y., Adams, M. J., Zhang, Z., Vidoni, O., Leuenberger, B. H., Achkar, J. Plasticisation of carnauba wax with generally recognised as safe (GRAS) additives, *Polymer*, **86**, 208–219 (2016). <https://doi.org/10.1016/j.polymer.2016.01.033>.
- [SR149] Ramos, K.J., Bahra, D.F. Mechanical behavior assessment of sucrose using nanoindentation, *Journal of Materials Research*, **22**, 2037–2045 (2007). <https://doi.org/10.1557/jmr.2007.0249>.
- [SR150] Godshall, M. A., Eggleston, G., Thompson, J., Kochergin, V. Sugar in *Kirk-Othmer Encyclopedia of*

Chemical Technology, John Wiley & Sons (2021).
<https://doi.org/10.1002/0471238961.1618151603151215.a01.pub3>.

[SR151] Eichhorn, S. J., Young, R. J. The Young's modulus of a microcrystalline cellulose, *Cellulose*, **8**, 2037–2045 (2001). <https://doi.org/10.1023/A:1013181804540>.

[SR152] Sun, C. C. True Density of Microcrystalline Cellulose, *Journal of Pharmaceutical Sciences*, **94**, 2132–2134 (2005). <https://doi.org/10.1002/jps.20459>.

[SR153] Gosline, J., Lillie, M., Carrington, E., Guerette, P., Ortlepp C., Savage, K. Elastic proteins: biological roles and mechanical properties. *Philosophical Transactions of the Royal Society B*, **357**, 121–132 (2002). <https://doi.org/10.1098/rstb.2001.1022>.

[SR154] Su, T., Xu, M., Lu, F., Chang, Q. Adipogenesis or osteogenesis: destiny decision made by mechanical properties of biomaterials. *RSC Advances*, **12**, 24501–24510 (2022). <https://doi.org/10.1039/D2RA02841G>.

[SR155] Houten, E. E. W. V., Dooley, M. M., Kennedy, F. E., Weaver, J. B., Paulsen, K. D. Initial In Vivo Experience with Steady-State Subzone-Based MR Elastography of the Human Breast. *Journal of Magnetic Resonance Imaging*, **17**, 72–85 (2003). <https://doi.org/10.1002/jmri.10232>.

[SR156] Moraes, J. O. D., Müller, C. M. O., Laurindo, J. B. Influence of the simultaneous addition of bentonite and cellulose fibers on the mechanical and barrier properties of starch composite-films. *Food Science and Technology International*, **18**, 35–45 (2011). <https://doi.org/10.1177/1082013211427622>.

[SR157] Keetels, C. J. A. M., Vliet, T. V., Walstra, P. Relationship between the Sponge Structure of Starch Bread and its Mechanical Properties. *Journal of Cereal Science*, **24**, 27–31 (1996). <https://doi.org/10.1006/jcscs.1996.0034>.

[SR158] Liu, Z., Scanlon, M. G. Understanding and Modeling the Processing-Mechanical Property Relationship of Bread Crumb Assessed by Indentation. *Cereal Chemistry*, **79**, 763–767 (2002). <https://doi.org/10.1094/CCHEM.2002.79.6.763>.