بسم الله الرحمن الرحيم

مجلة جامعة الملك عبدالعزيز: علوم الأرصاد والبيئة وزراعة المناطق الجافة، ٣٣ ع١، ٩٩ صفحة (٢٠٢٤م)
ردمد ١٠٣٩ – ١٣١٩
رقم الإيداع: ١٤/٠٢٩٨

مجـــلة
جامعة الملك عبدالعزيز

علوم الأرصاد والبيئة
وزراعة المناطق الجافة

المجـلد ٣٣ العدد ١

٢٠٢٤م

مَركز النشر العلمي
جَامعَة الملك عبـد العزيـز
ص ب : ٨٠٢٠٠ ـ جـدة : ٢١٥٨٩
[illegible]

المحتويات

﴿ القسم العربي ﴾

صفحة

نظرة شاملة على أصناف اللوز (Prunus dulcis) ومتطلباتها والممارسات البستانية

عائشة عبدالله الغامدي[١،٢]، راشد مساعد السبيحي[١]
١قسم علوم الأحياء، كلية العلوم، جامعة الملك عبد العزيز
٢ قسم علوم الأحياء، كلية العلوم والآداب بالمخواة ، جامعة الباحة

مستخلص. تتواجد أشجار اللوز (*Prunus dulcis*) في دول البحر الأبيض المتوسط وتقتصر زراعتها على المناطق ذات مناخ البحر الأبيض المتوسط. اللوز هي أحد أنواع الجوزيات، التي تعرف بأنها وجبة خفيفة صحية ومصدر جيد للبروتين والكربوهيدرات والدهون ومضادات الأكسدة. تحتوي بذور اللوز على مركبات الفلافونويدات ، فيتامين E ، الريبوفلافين ،الأحماض الأمينية ،المعادن الأساسية ، المنغنيز، المغنيسيوم ،النحاس والفوسفور. يحدث الإزهار عندما يتم استيفاء متطلبات البرودة والحرارة بالكامل. عند زراعة أصناف غير متوافقة ذاتيًا، من المهم توزيع الملقحات بشكل صحيح، حيث يستحسن أن يحتوي البستان على ٣٠% على الأقل من الملقحات لضمان التلقيح الأمثل. بناءً على خصائص القشرة يتم تصنيف اللوز إلى أصناف ذات قشرة ناعمة وصلبة. كما يتم تصنيف اللوز أيضا إلى فئتين، الحلو والمر. تتأثر كمية المياه التي تستخدم في بساتين اللوز بشكل كبير بالطقس بما في ذلك الرطوبة ودرجة الحرارة والوقت من اليوم. يعتبر التسميد أمرًا بالغ الأهمية للتطور السليم للوز والإثمار المنتظم والمحصول عالي الجودة. ولقد أتاحت طرق إكثار اللوز من خلال التطعيم تحسين اختيار الطعوم التي سيتم إكثارها. كما يجب أن تتمتع الأصول الجديدة المستخدمة في التطعيم بالصفات المرغوبة التالية: تحمل التربة الجيرية و/أو غيرها من التربة الفقيرة؛ سهولة التكاثر باستخدام العقل الخشبية و/أو التكاثر الدقيق وكذلك تمتعها بنمو قوي. أصبحت زيادة التحمل للتربة الثقيلة والمشبعة بالماء هدفًا مهمًا للأصناف الهجن الجديدة. حيث يتم انتخاب الطرز الجينية الجديدة المتكيفة محلياً وإكثارها بطرق الإكثار الخضري ، مما يؤدي إلى التعرف على مئات الأصناف وإكثارها في مناطق إنتاج محددة. بالإضافة إلى ذلك، فقد تم إجراء العديد من الدراسات الجزيئية التي تسهل نقل تلك الصفات المرغوبة. وبشكل عام، فإن هذه المقالة تركز على كيفية إدارة الحقول ابتداءً من اختيار الأصناف وحتى الحصاد بهدف الوصول إلى محصول لوز بجودة وكمية عالية.

217. Vázquez-Araújo L, Enguix L, Verdú A, García-García E, Carbonell-Barrachina AA. 2008. Investigation of aromatic compounds in toasted almonds used for the manufacture of turrón. *European Food Research and Technology*. 227(1):243–254.
218. Verma MK. 2014. Almond Production Technology. In: Training Manual on Teaching of Post-Graduate Courses in Horticulture (Fruit Science), October; pp. 274–280.
219. Vivaldi GA, Strippoli G, Pascuzzi S, Stellacci AM, Camposeo S. 2015. Olive genotypes cultivated in an adult high-density orchard respond differently to canopy restraining by mechanical and manual pruning. *Sci. Hortic.* 192:391–396.
220. Wang Y, Georgi LL, Zhebentyayeva TN, Reighard GL, Scorza R, Abbott AG. 2002. High-throughput targeted SSR marker development in peach (*Prunus persica*). *Genome*. 45:319–328.
221. Weinberger JH. 1950. Chilling requirements of peach varieties. Proceedings of the American Society for Horticultural Science. 56:122–128.
222. William FR. 1999. Depositional History of Franchthi Cave, Fascicle 12: Sediments, Stratigraphy, and Chronology. Indiana University Press, Bloomington, Indiana.
223. Williams RR. 1970. The effect of supplementary pollination on yield. In: Williams RR, Wilson RR, editors. Towards Regulated Cropping. Grower Books; pp. 7–10.
224. Wirthensohn MG, Chin WL, Franks TK, Baldock G, Ford CM, Sedgley M. 2010. Investigation of flavour compounds from sweet, semi-bitter and bitter almond kernels. Options Méditerranéennes. 94:117-122.
225. Wood MN. 1925. Almond Varieties in the United States. USDA Bulletin 1282, United States Department of Agriculture, Washington DC.
226. Wood MN. 1938. Two New Varieties of Almond: The Jordanolo and Harpareil. USDA Circular 542. USDA, Washington DC, p. 2.
227. Wünsch A, Hormaza JI. 2002. Cultivar identification and genetic fingerprinting of fruit tree species using DNA markers. Euphytica. 125(1):56–67.
228. Xiloyannis C, Dichio B, Tuzio AC, Kleinhentz M, Salesses G, Gómez-Aparisi J, Rubio-Cabetas MJ, Esmenjaud D. 2007. Characterization and selection of Prunus rootstocks resistant to abiotic stresses: waterlogging, drought and iron chlorosis. Acta Horticulturae. 732:247–251.
229. Yalchi T. 2011. Determination of Digestibility of Almond Hull in Sheep. African Journal of Biotechnology. 10(15):3022-3026. DOI:10.5897/AJB10.1631.
230. Zalom FG, Núñez E, Baldwin RA. 2017. ALMOND pests. In: Socias i Company R, Gradziel TM, editors. Almonds: Botany, *Production and Uses*. pp. 375.
231. Zalom FG, Haviland DR, Symmes EJ, Tollerup K. 2015. Insects and mites. In: UC IPM Pest Management Guidelines for Almonds. University of California, Division of Agriculture and Natural Resources, Publication 3431, Oakland, California.
232. Zohary D, Hopf M. 1993. Domestication of Plants in the Old World. Clarendon Press, Oxford, UK.

197. Socias i Company R, Alonso JM, Gómez Aparisi J. 2005. Evaluation of almond selections for fruit set under field conditions. *Options Méditerranéennes, Serie A*. 63:133–139.

198. Socias i Company R, Kodad O, Alonso JM, Felipe AJ. 2008a. 'Mardía' almond. *HortScience*. 43(8):2240–2242.

199. Socias i Company R, Kodad O, Alonso JM, Felipe AJ. 2008b. 'Mardía' almond. *HortScience*. 43:2240–2242.

200. Sodjinou E, Glin LC, Nicolay G, Tovignan S, Hinvi J. 2015. Socioeconomic determinants of organic cotton adoption in Benin, West Africa. *Agriculture & Food Security*.3(1).https://doi.org/10.1186/s40100-015-0030-9

201. Sosinski B, Gannavarapu M, Hager LD, Beck LE, King GJ, Ryder CD, Rajapakse S, Baird WV, Ballard RE, Abbott AG. 2000. Characterization of microsatellite markers in peach (*Prunus persica* (L.) Batsch). *Theoretical and Applied Genetics*. 101:421–428.

202. Soundararajan P, Won SY, Kim JS. 2019. Insight on Rosaceae Family with Genome Sequencing and Functional Genomics Perspective.

203. Spiegel-Roy P. 1976. L'amandier en Israel. *Options Méditerranéennes*. 32:92–95.

204. Stojanova MT, Djukic D, Stojanova M, Ivanovski I, Şatana A. 2022. Effect of Foliar Fertilizing on the Yield of Some Almond Cultivars Grown in North Macedonia. *Plant Physiology and Soil Chemistry*. 2(1):08-11. https://doi.org/10.26480/ppsc.01.2022.08.11

205. Stojanova TM. 2017. *Plant Nutrition*. Practicum, Academic Press, Skopje.

206. Stojanova TM. 2018. *Plant Nutrition*. Textbook, Academic Press, Skopje.

207. Stojanova TM. 2020. *Nutrition of Fruit Plants*. Textbook, Academic Press, Skopje.

208. Stylianides DC. 1976. La culture de l'amandier en Grèce. *Options Méditerranéennes*. 32:72–74.

209. Suvedi M, Ghimire R, Kaplowitz M. 2017. Farmers' participation in extension programs and technology adoption in rural Nepal: A logistic regression analysis. *Journal of Agricultural Education and Extension*. 23(4):351–371. https://doi.org/10.1080/1389224X.2017.1323653

210. Terdoo F, Adekola O. 2014. Assessing the role of climate-smart agriculture in combating climate change, desertification, and improving rural livelihood in Northern Nigeria. *African Journal of Agricultural Research*.9(15):1180-1191. https://doi.org/10.5897/AJAR2013.7665

211. Testolin R, Marrazzo T, Cipriani G, Quarta R, Verde I, Dettori MT, Pancaldi M, Sansavini S. 2000. Microsatellite DNA in peach (*Prunus persica* L. Batsch) and its use in fingerprinting and testing the genetic origin of cultivars. *Genome*. 43:512–520.

212. Testolin R, Messina R, Lain O, Marrazo T, Huang G, Cipriani G. 2004. Microsatellites isolated in almond from an AC-repeat enriched library. *Molecular Ecology Notes*. 4(3):459–461.

213. Thapa GB, Rattanasuteerakul K. 2011. Adoption and extent of organic vegetable farming in Mahasarakham province, Thailand. *Applied Geography*. 31(1):201–209.https://doi.org/10.1016/j.apgeog.2010.04.004

214. Thomas D. 2019. Managing Almond Production in a Variable and Changing Climate. Hort Innovation.

215. Valverde M, Madrid R, Garcı´a AL. 2006. Effect of the Irrigation Regime, Type of Fertilization, and Culture Year on the Physical Properties of Almond (cv. Guara). *J. Food Eng.* 76:584–593.

216. Varela P, Chen J, Fiszman S, Povey MJW. 2006. Crispness assessment of roasted almonds by an integrated approach to texture description: Texture, acoustics, sensory and structure. *Journal of Chemometrics*. 20(6–7):311–320.

grown in Morocco. *Scientia Horticulturae*. 316:112014.
177. Sakar EH, Yamani ME, Rharrabti Y. 2019. Geometrical traits in almond fruit as affected by genotypic and environmental variations in northern Morocco. *Erwerbs-Obstbau*. 61:103–112.
178. Sánchez-Pérez R, Del Cueto J, Dicenta F, Martínez-Gómez P. 2014. Recent advancements to study flowering time in almond and other Prunus species. *Frontiers in Plant Science*. 5(334):1-7. https://doi.org/10.3389/fpls.2014.00334.
179. Sánchez-Pérez R, Dicenta F, Gradziel TM, Arús P, Martínez-Gómez P. 2004. Application of molecular markers in almond breeding programmes. *Nucis-Newsletter*. 12:9–12.
180. Sánchez-Pérez R, Ortega E, Duval H, Martínez-Gómez P, Dicenta F. 2007. Inheritance and relationships of important agronomic traits. *Euphytica*. 155:381–391.
181. Sanden B. 2007. Fall Irrigation Management in a Drought Year for Almonds. *University of California Cooperative Extension Kern Soil and Water*, Bakersfield.
182. Schiril A. 2005. Analisi Economiche Della Produzione e del Mercato del Mandorlo e del Nocciolo in Sicilia. Coreras: Catania, Italy; pp. 1–141.
183. Schirra M. 1997. Postharvest technology and utilization of almonds. *Horticultural Reviews*. 20:267–292.
184. Schueler S, Tusch A, Schuster M, Ziegenhagen B. 2003. Characterization of microsatellites in wild and sweet cherry – markers for individual identification and reproductive processes. *Genome*. 46(1):95–102.
185. Schwankl L, Prichard T, Hanson B. 2007. Soil Intake Rates and Application Rates in Sprinkler-Irrigated Orchards. *University of California Division of Agriculture and Natural Resources Publication 8216*, Oakland, California.
186. Shackel KA, Edstrom J, Fulton A, Lampinen B, Schwankl L. 2011. Drought Survival Strategies for Established Almond Orchards on Shallow Soil. *2011–2012 Annual Report to the Almond Board of California*, Modesto, California.
187. Shirmohammadi M, Fielke J. 2017. Conditioning reduces kernel damage when impact shelling almonds. *International Journal of Food Engineering*. 13(8):20160324.
188. Socias i Company R, Felipe AJ. 1992. Almond: A diverse germplasm. *HortScience*. 27:863–869.
189. Socias i Company R. 1998. Fruit tree genetics at a turning point: the almond example. *Theoretical and Applied Genetics*. 96:588–601.
190. Socias i Company R. 2002. The relationship of Prunus webbii and almond revisited. *Nucis-Newslett*. 11:17–19.
191. Socias i Company R, Felipe AJ. 1988. Self-compatibility in almond: transmission and recent advances in breeding. *Acta Horticulturae*. 224:307–317.
192. Socias i Company R. 1990. Breeding self-compatible almonds. *Plant Breed. Rev.* 8:313–338.
193. Socias i Company R, Alonso JM, Kodad O, Gradziel TM. 2012. Almond. In: Badenes ML, Byrne D (Eds.), *Fruit Breeding, Handbook of Plant Breeding 8*, Springer Verlag, Heidelberg, pp. 697–728.
194. Socias i Company R, Ansón JM, Espiau MT. 2017. Taxonomy, botany and physiology. In: *Almonds: Botany, Production and Uses*, pp. 1–42. CABI.
195. Socias i Company R, Felipe AJ, Gómez Aparisi J. 2003. Almond bloom in a changing climate. *Journal of the American Pomological Society*. 57(2):89–92.
196. Socias i Company R, Felipe AJ, Gómez Aparisi J. 2003. Almond bloom in a changing climate. *Journal of the American Pomological Society*. 57(2):89–92.

traditional Prunus dulcis (Mill.) cultivars under rain-fed conditions. *Sci. Hortic.* 229:226-232.

161. Özdemir B, Okay FY, Sarikamiş G, Yüksel Özmen C, Kibar U, Ergül A. 2021. Crosstalk between flowering and cold tolerance genes in almonds (Amygdalus spp.). Turkish Journal of Agriculture and Forestry45(4):484-494. https://doi.org/10.3906/tar-2103-101.

162. Palacio-Bielsa A, Cambra M, Martínez C, Olmos A, Pallás V, López M, Adaskaveg J, Förster H, Cambra MA, Duval H, Esmenjaud D. 2017. ALMOND diseases. In: Socias i Company R, Gradziel TM, editors. Almonds: Botany, Production and Uses. Publisher, p. 321.

163. Pascuzzi S. 2017. Analysis of the Almond Harvesting and Hulling Mechanization Process : A Case Study. https://doi.org/10.3390/agriculture7120100.

164. Potter D, Eriksson T, Evans RC, Oh S, Smedmark JEE, Morgan DR, Kerr M, Robertson KR, Arsenault M, Dickinson TA et al. 2007. Phylogeny and classification of Rosaceae. *Plant Systematics and Evolution*. 266:5–43.

165. Powell W, Morgante M, Andre C, Hanafey M, Vogel J, Tingey S, Rafalski A. 1996. Comparison of RFLP, RAPD, AFLP and SSR (microsatellite) markers for germplasm analysis. *Molecular Breeding*. 2(3):225–238.

166. Queirós F. 2020. *Manual de Boas Práticas de Fruticultura—Amendoeira*. Retrieved June 14, 2023, from https://www.iniav.pt/divulgacao/publicacoes-bd/manual-de-boas-praticas-de-fruticultura-amendoeira.

167. Rice RE, Barnett WW, Van Steenwyk RA. 1996. Insect and mite pests. In: Almond Production Manual, University of California, Publ. 3364, pp. 202–213.

168. Richardson EA, Seeley SD, Walker RD. 1974. A model for estimating the completion of rest for Red Haven and Elberta peach. *HortScience*. 9:331–332.

169. Rikhter AA. 1972. Biological Basis for the Creation of Almond Cultivars and Commercial Orchards (in Russian). Akademiya Nauk SSSR, Glavnyj Botanicheskij Sad, Moscow, Russia.

170. Rikhter AA. 1972. *Biological Basis for the Creation of Almond Cultivars and Commercial Orchards* (in Russian). Akademiya Nauk SSSR, Glavnyj Botanicheskij Sad, Moscow, Russia.

171. Romero P, Botía P. 2006. Daily and seasonal patterns of leaf water relations and gas exchange of regulated deficit-irrigated almond trees under semiarid conditions. *Environmental and Experimental Botany*. 56:158–173.

172. Rosati A, Metcalf SG, Buchner RP, Fulton AE, Lampinen BD. 2006. Physiological effects of kaolin applications in well-irrigated and water-stressed walnut and almond trees. *Annals of Botany*. 98:267–275. https://doi.org/10.1093/aob/mcl100.

173. Rosengarten FJ. 1984. *The Book of Edible Nuts*. Walker and Co., New York.

174. Saberi-Moghadam M, Hassan-Beygi SR, Aboonajmi M. 2015. Moisture dependent physical and mechanical properties of Mazafati date pit. *Agricultural Engineering International: CIGR Journal*. 17(2):228-242. https://doi.org/10.3965/j.issn.19346344.2010.04.0-0.

175. Sakar EH, El Yamani M, Boussakouran A, Rharrabti Y. 2019. Codification and description of almond (*Prunus dulcis*) vegetative and reproductive phenology according to the extended BBCH scale. *Scientia Horticulturae*. 247:224–234.

176. Sakar EH, El Yamani M, Boussakouran A, Rharrabti Y. 2023. Reproductive phenology calendar and its correlation with air temperature in five Mediterranean almond (*Prunus dulcis* (Mill.) D.A. Webb) cultivars

142. Martínez-Gómez P, Sánchez-Pérez R, Dicenta F, Howad W, Arús P. 2007. Almond. In Fruit Breeding, pp. 275-307. https://doi.org/10.1007/978-3-540-34533-6.

143. Martínez-Gómez P, Sozzi GO, Sánchez-Pérez R, Rubio M, Gradziel TM. 2003b. New approaches to Prunus tree crop breeding. Journal of Food, Agriculture & Environment, 1(1), 52–63.

144. Meith C, Micke WC, Rizzi AD. 1974. Almond Pollination. University of California Cooperative Extension AXT-29. Berkeley (California), USA.

145. Meliá Massiá A, Almajano Contreras A. 1972. La ‘orugueta’ del almendro (Aglaope infausta L.) en la provincia de Huesca durante 1972. Biología y ensayo de lucha. Boletín Informativo de Plagas, 99, 67–77.

146. Mengel K, Kirkby EA, Kosegarten H, Appel T. 2001. Principles of Plant Nutrition: 5th edition. Springer.

147. Messina R, Lain O, Marrazo T, Cipriani G, Testolin R. 2004. New set of microsatellite loci isolated in apricot. Molecular Ecology Notes. 4(3):432–434.

148. Micke WC. 1994. Almond Orchard Management. Division of Agricultural Sciences Publication 3364, University of California, Berkeley, California.

149. Mnejja M, Garcia-Mas J, Howad W, Badenes ML, Arús P. 2004. Simple-sequence repeat (SSR) markers of Japanese plum (Prunus salicina Lindl.) are highly polymorphic and transferable to peach and almond. Molecular Ecology Notes. 4(1):163–165.

150. Moen J, Yang C, Zhang B, Hennessy K, Chen P, Ruan R. 2008. Catalytic Microwave-Assisted Pyrolysis of High-diversity Grassland Perennials. In: The 30th Biotech for Chemicals and Energy Symposium. New Orleans, LA.

151. Mori A, Lapsley K, Mattes R. 2011. Almonds (Prunus dulcis). In: Nuts and Seeds in Health and Disease Prevention. Elsevier, London (UK), pp. 167–173.

152. Mouaffak Y, Zegzouti F, Boutbaoucht M, Najib M, El Adib A, Sbihi M, Younous S. 2013. Cyanide poisoning after bitter almond ingestion. Annals of Tropical Medicine and Public Health. 6(6):679.

153. Mushtaq A, Khaliq M, Saeed A, Azeem MW, Ghania JB. 2015. Almond (*Prunus amygdalus* L.): A review on health benefits, nutritional value and therapeutic applications. *International Journal of Chemical and Biochemical Sciences*. 8:103-106.

154. Navarro A, Álvarez S, Castillo M, Bañón S, Sánchez-Blanco MJ. 2009. Changes in tissue-water relations, photosynthetic activity, and growth of Myrtus communis plants in response to different conditions of water availability. *Journal of Horticultural Science and Biotechnology*. 84:541–547.

155. Neuhoff D, Tashi S, Rahmann G, Denich M. 2014. Organic agriculture in Bhutan: Potential and challenges. *Organic Agriculture.* 4(3):209–221. https://doi.org/10.1007/s13165-014-0075-1.

156. New World Encyclopedia. 2008. Almond. Retrieved from www.google.com on September 11, 2008, at 1:31 PM.

157. Nwosu FO, Dosumu OO, Okocha JOC. 2008. The Potential of Terminalia Catappa (Almond) and Hyphaene Thebaica (Dum Palm) Fruits As Raw Materials for Livestock Feed. *African Journal of Biotechnology* 7(24): 4576-4580.

158. Alonso Segura JM, Socias i Company R, Kodad O. 2017. Late-blooming in almond: A controversial objective. *Scientia Horticulturae* 224: 61–67. https://doi.org/10.1016/j.scienta.2017.05.036

159. Of R, Diversity G, In S. 2011. Review of genetic diversity studies in almond. Acta Agronomica Hungarica 59(4): 379–395. https://doi.org/10.1556/AAgr.59.2011.4.9.

160. Oliveira I, Meyer A, Alfonso S, Gonçalves B. 2018. Compared leaf anatomy and water relations of commercial and

Tocopherol Content in Almond. 1–9. https://doi.org/10.3390/antiox7010006.
124. Kostadinov K, Kostadinova S. 2014. Nitrogen efficiency in eggplants (Solanum Melongena L.) depending on fertilizing. Bulgarian Journal of Agricultural Science, 20, 287-292.
125. Ladizinsky G. 1999. On the origin of almond. Genetic Resources and Crop Evolution, 46(2), 143–147.
126. Laghezali M. 1985. L'amandier au Maroc. Options Méditerranéennes CIHEAM/IAMZ 85/I, 91–96.
127. Lampinen B, Michalaides T. 2008-2009. Almond stockpile monitoring for aflatoxin potential; Final research report 08-AFLA2-Lampinen. Almond Board of California: Modesto, CA, U.S.A.
128. Lang BA, Early JD, Martin GC, Darnell RL. 1987. Endo-, para-, and eco-dormancy physiological terminology and classification for dormancy research. HortScience 22(3):371–377.
129. Lansari A, Iezzoni AF, Kester DE. 1994. Morphological variation within collections of Moroccan almond clones and Mediterranean and American cultivars. Euphytica 43:313–322.
130. Ledbetter CA, Sisterson MS. 2013. Distinguishing nonpareil marketing group almond cultivars through multivariate analyses. Journal of Food Science 78(9). https://doi.org/10.1111/1750-3841.12179.
131. Lepsch HC, Brown PH, Peterson CA, Gaudin AC, Khalsa SDS. 2019. Impact of organic matter amendments on soil and tree water status in a California orchard. Agric WaterManag222:204–212. https://doi.org/10.1016/j.agwat.2019.06.002.
132. Manetto G, Cerruto E. 2013. Vibration risk evaluation in hand-held harvesters for olives. J Agric Eng 44:705–709.
133. Manetto G, Cerruto E, Pascuzzi S, Santoro F. 2017. Improvements in citrus packing lines to reduce the mechanical damage to fruit. Chem Eng Trans 58:391–396.
134. Maranz S, Wiesman Z. 2004. Influence of climate on the tocopherol content of shea butter. J Agric Food Chem 52(10):2934–2937.
135. Marcone C, Jarausch B, Jarausch W, Dosba F. 2011. European stone fruit yellows phytoplasma. In: Hadidi A, Barba M, Candresse T, Jelkmann W, editors. Virus and Virus-Like Diseases of Pome and Stone Fruits. APS Press. p. 233–241.
136. Mark GD, Huxlen AJ. 1992. The New Royal Horticultural Society Dictionary of Gardening. Macmillan Press. London. ISBN 0-333-47494-95.
137. Marsh MM, McKenry MV, Micke WC, Prather TS, Teviotdale BL, Zalom FG. 2002. Integrated Pest Management for Almonds, 2nd edn. University of California, Division of Agriculture and Natural Resources, Publication 3308, Oakland, California.
138. Martínez-García P, Rubio M, Dicenta F, Gradziel TM. 2004. Resistance to Plum Pox Virus (Dideron isolate RB3.30) in a group of California almonds and transfer of resistance to peach. J Am Soc Hort Sci. 129:544–548.
139. Martínez-Gómez P, Arulsekar S, Potter D, Gradziel TM. 2003. An extended interspecific gene pool available to peach and almond breeding as characterized using simple sequence repeat (SSR) markers. Euphytica. 131(3):313–322.
140. Martínez-Gómez P, Arulsekar S, Potter D, Gradziel TM. 2003. Relationships among peach and almond and related species as detected by SSR markers. Journal of the American Society for Horticultural Science. 128(5):667–671.
141. Martínez-Gómez P, Prudencio AS, Gradziel TM, Dicenta F. 2017. The delay of flowering time in almond: A review of the combined effect of adaptation, mutation and breeding. Euphytica. 213:197. https://doi.org/10.1007/s10681-017-1974-5.

basin. *Agricultural Water Management* 222:72–81. https://doi.org/10.1016/j.agwat.2019.05.031.

104. Hagen LS, Chaib J, Fad B, Decrocq V, Bouchet P, Lambert P, Andergon JM. 2004. Genomic and cDNA microsatellites from apricot (Prunus armeniaca L). Molecular Ecology Notes 4(3):432–434.

105. Hamby K, Wang Gao L, Lampinen B, Gradziel T, Zalom F. 2011. Hull split date and shell seal in relation to navel orangeworm (Lepidoptera: Pyralidae) infestation of almonds. Journal of Economic Entomology 104(3):965-969.

106. Hansen J, Renfrew JM. 1978. Palaeolithic-Neolithic seed remains at Franchthi Cave, Greece. Nature 271:349–352.

107. IPM Manual Group, University of California, Davis. 1985. Integrated Pest Management for Almonds. Pub. 3308. Berkeley: University of California, Division of Agriculture and Natural Resources.

108. Jafari S, Alizadeh A, Imani A. 2011. Nutritive Value of Different Varieties of Almond (Prunus Dulcis) Hulls. Research Opinions in Animal & Veterinary Sciences. 1(11):734-738.

109. Jain SM, Priyadarshan PM, editors. 2009. Breeding Plantation Tree Crops: Tropical Species (Vol. 84). New York, NY, USA: Springer.

110. Jain SM, Priyadarshan PM, editors. 2009. Breeding Plantation Tree Crops: Tropical Species (Vol. 84). New York, NY, USA: Springer.

111. Janick J. 2007. Fruits of the Bible. HortScience. 42:1072–1076.

112. Janick J. 2005. Breeding intractable traits in fruit crops: dream the impossible dream. Introduction. HortScience 40:1944.

113. Javaid T, Mahmood S, Saeed W, Alam M. 2019. A Critical Review on Varieties and Benefits of Almond (Prunus dulcis). Acta Scientific Nutritional Health. 3(6):70-72. https://doi.org/10.31080/ASNH.2019.03.0489.

114. Jin Y, Chen B, Lampinen BD, Brown PH. 2020. Advancing Agricultural Production With Machine Learning Analytics: Yield Determinants for California's Almond Orchards. Frontiers in Plant Science. 11:290.

115. Karaat FE, Denizhan H. The effects of different particle film applications on almond trees. Cienc. Rural. 2023;53:1–9.

116. Kalita S, Khandelwal S, Madan J, Pandya H, Sesikeran B, Krishnaswamy K. 2018. Almonds and cardiovascular health: a review. Nutrients. 10(4):468.

117. Kazantzis I, Nanos GD, Stavroulakis GG. 2003. Effect of harvest time and storage conditions on almond kernel oil and sugar composition. Journal of the Science of Food and Agriculture. 83(4):354–359. https://doi.org/10.1002/jsfa.1312

118. Kermanshah A, Ziarati P, Asgarpanah J, Qomi M. 2014. Food values of two endemic wild almond species from Iran. International Journal of Plant, Animal and Environmental Sciences. 4(3):380–388.

119. Kester DE, Gradziel TM. 1996. Almonds. In: Janick J, Moore JN, editors. Fruit Breeding. Vol. III. Wiley, New York. pp. 1–97.

120. Kester DE, Gradziel TM, Grasselly C. 1990. Almonds (Prunus). Acta Horticulturae. 290:699–758.

121. Kester DE, Gradziel TM, Grasselly C. 1991. Almonds (Prunus). In: Moore JN, Ballington HJ, editors. Genetic resources of temperate fruit and nut crops. International Society of Horticulture and Science, The Netherlands. p. 701–758.

122. Kodad O, Estopañán G, Juan T, Alonso JM, Espiau MT. 2014. Oil content, fatty acid composition and tocopherol concentration in the Spanish almond genebank collection. Scientia Horticulturae. 177:99–107.

123. Kodad O, Socias R, Alonso JM. 2018. Genotypic and Environmental Effects on sequence repeats in peach [Prunus persica (L.) Batsch]. Theor. Appl. Genet., 105, 1151–1158.

82. Girona J, Mata M, Marsal M. 2005. Regulated deficit irrigation during kernel filling period and optimal irrigation rates in almond. Agric Water Manag., 75, 152–167. https://doi.org/10.1016/j.agwat.2004.12.008.

83. Glintic M, Krstic Z. 1990. Plant nutrition and protection, Sabac, Republic of Serbia.

84. Godini A. 2002. Almond fruitfulness and role of self-fertility. Acta Horticulturae, 591, 191–203.

85. Goldhamer DA, Viveros M, Salinas M. 2006. Regulated deficit irrigation in almonds: Effects of variations in applied water and stress timing on yield and yield.

86. Gómez Aparisi J, Felipe AJ. 1984. Surgreffage d'amandiers. Options Méditerr. CIHEAM/ IAMZ 1984/II: 41–49.

87. Goor A, Nurock M. 1968. The Fruits of the Holy Land. Israel University Press, Jerusalem.

88. Gradziel TM. 2009. Almond (Prunus dulcis) breeding. In: Jain SM, Priyadarshan PM (Eds.), Breeding Plantation Tree Crops: Temperate Species. Springer. pp. 1–31.

89. Gradziel TM. 2017. History of cultivation. In: Socias i Company R, Gradziel TM (Eds.), Almonds: Botany, Production and Uses. pp. 43.

90. Gradziel TM, Martínez-Gómez P. 2013. Almond breeding. Plant breeding reviews, 37, 207-258.

91. Gradziel TM, Wang DC. 1994. Susceptibility of California almond cultivars to aflatoxigenic Aspergillus flavus. HortScience, 29, 33-35.

92. Gradziel TM, Mahoney N, Abdallah A. 2000. Aflatoxin production among almond genotypes is not related to either kernel composition or Aspergillus flavus growth rate. *HortScience*, 34(6), 937–939.

93. Gradziel TM. 2001. Almond species as sources of new genes for peach improvement. *Acta Hort*. 592:81–88.

94. Gradziel TM, Kester DE. 1994. Breeding for resistance to Aspergillus flavus in almond. Acta Hort. 373:111–117.

95. Gradziel TM, Martínez-Gómez P, Dicenta F, Kester DE. 2001. The utilization of related almond species for almond variety improvement. J. Amer. Pomol. Soc. 55:100–108.

96. Gradziel TM, Martínez-Gómez P, Dandekar A, Uratsu S, Ortega E. 2002. Multiple genetic factors control self-fertility in almond. *Acta Hort*. 591:221–227.

97. Gradziel TM, Martínez-Gómez P, Dicenta F, Kester DE. 2001b. The utilization of related almond species for almond variety improvement. J. Am. Pomol. Soc. 55:100–109.

98. Grasselly C, Crossa-Raynaud P. 1980. *The Almond Tree*. Techniques agricoles et productions méridionales. G. P. Maisonneuve-Larose. Paris. 446 p. (in French)

99. Grigorian V. 1976. Description de la situation de l'amandier en Iran. *Options Méditerranéennes* 60:77–79.

100. Gupta PK, Balyan HS, Sharma PC, Ramesh B. 1996. Microsatellites in plants: a new class of molecular markers. *Current Science* 70(1):45–54.

101. Gurdian RJ, Biggs RH. 1964. Effect of low temperature on terminating bud dormancy of Okinawa, Flordawon, Flordahome and Nemaguard peaches. *Proceedings of the Florida State Horticultural Society* 77:370–379.

102. Gustafson WA, Morrissey TM, Bishop C. 1989. Plant Exploration and Germplasm Collection of Cold Hardy Woody Plants for Nebraska from the People's Republic of China. Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, Nebraska.

103. Gutiérrez-Gordillo S, Durán-Zuazo VH, García-Tejero I. 2019. Response of three almond cultivars subjected to different irrigation regimes in Guadalquivir river

64. Estelrich P. 1907. El almendro y su cultivo en el mediodía de España e Islas Baleares. Hijos de J. Cuesta, Madrid - Antonio López, Barcelona.
65. Evreinoff VA. 1952. Quelques observations biologiques sur l'Amandier. Revue Internationale de Botanique Appliée et d'Agriculture Tropicale, 32, 442–459.
66. Evreinoff VA. 1958. Contribution à l'étude de l'amandier. Fruits et Primeurs d'Afrique, 28, 99–104.
67. Farouque MG, Sarker MA. 2018. Farmers' knowledge and practice of organic vegetable cultivation: A field-level study of two villages from Bangladesh. *Journal of Agricultural Extension and Rural Development*,10(5),99–107. https://doi.org/10.5897/JAERD2018.0948
68. Farrand WR. 1999. Depositional History of Franchthi Cave, Fascicle 12: Sediments, stratigraphy, and chronology. Indiana University Press, Bloomington, Indiana.
69. Felipe AJ. 2000. El almendro. I Material vegetal. Mira Editores SA. Zaragoza, Spain.
70. Fernandes de Oliveira A, Mameli MG, De Pau L, Satta D. 2023. Almond Tree Adaptation to Water Stress: Differences in Physiological Performance and Yield Responses among Four Cultivar Grown in Mediterranean Environment. Plants, 12, 1131.
71. Fishman S, Erez A, Couvillon GA. 1987a. The temperature dependence of dormancy breaking in plants: computer simulation of processes studied under controlled temperatures. *Journal of Theoretical Biology*, 126, 309–321.
72. Food and Agriculture Organization of the United Nations. 1995. Edible Nuts. Retrieved on November 19, 2014 from www.fao.org.
73. Food and Agriculture Organization of the United Nations. 2023. Edible Nuts. Retrieved on September 9, 2023 from https://www.fao.org.
74. Free JB. 1970. Insect Pollination of Crops. Academic Press, London, UK.
75. Freitas TR, Santos A, Silva AP. 2023. Reviewing the Adverse Climate Change Impacts and Adaptation Measures on Almond Trees (Prunus dulcis).
76. Galindo A, Collado-González J, Gri˜nán I, Corell M, Centeno A, Martín-Palomo MJ, Girón IF, Rodríguez P, Cruz ZN, Memmi H, Carbonell-Barrachina AA, Hernández F, Torrecillas A, Moriana A, Pérez-López D. 2020. Deficit irrigation and emerging fruit crops as a strategy to save water in Mediterranean semiarid agrosystems. *Agricultural Water Managemen*t, 202, 311–324.
77. Gao Z, Zhuang W, Wang L, Shao J, Luo X, Cai B, Zhang Z. 2012. Evaluation of chilling and heat requirements in Japanese apricot with three models. *HortScience* 47, 1826–1831.
78. García-Tejero IF, Hernández A, Rodríguez VM, Ponce JR, Ramos V, Muriel JL, Durán ZVH. 2015. Estimating almond crop coefficients and physiological response to water stress in semiarid environments (SW Spain). *J. Agric. Sci. Technol.*, 17, 1255–1266.
79. García-Tejero IF, Moriana A, Rodríguez Pleguezuelo CR, Durán Zuazo VH, Egea G. 2018a. Sustainable deficit-irrigation management in almonds (Prunus dulcis L.): different strategies to assess the crop water status. In: García Tejero, I. F., Durán Zuazo, V. H. (Eds.), Water Scarcity and Sustainable *Agriculture in Semiarid Environmen*t.
80. Garcia-Perez, P., Xiao, J., Munekata, P. E., Lorenzo, J. M., Barba, F. J., Rajoka, M. S. R., ... & Simal-Gandara, J. (2021). Revalorization of almond by-products for the design of novel functional foods: An updated review. Foods, 10(8), 1823.
81. Georgi L, Wang Y, Yvergniaux D, Ormsbee T, Iñigo M, Reighard G, Abbott A. 2002. Construction of a BAC library and its application to the identification of simple

study of Abruzzo, Italy. *Journal of Horticultural Science and Biotechnology*. 93(2):209–215.

47. Diallo A, Donkor E, Owusu V. 2020. Climate change adaptation strategies, productivity, and sustainable food security in southern Mali. *Climatic Change*. 159(3):309-327. https://doi.org/10.1007/s10584-020-02684-8.

48. Dicenta F, García J.E. 1993a. Inheritance of self-compatibility in almond. *Heredity* 70:313–317.

49. Dicenta F, García J.E. 1993b. Inheritance of the kernel flavour in almond. *Heredity* 70:308–312.

50. Dicenta F, García J.E. 1992. Phenotypical correlations among some traits in almond. *Journal of Genetics and Breeding* 46:241–246.

51. Dicenta F, Egea J, Ortega E, Martínez-Gómez P, Sánchez-Pérez R, Rubio M, ... Cremades T. 2016. Almond breeding: Important issues and challenges for research. *Options Méditerranéennes, A, Mediterranean Seminars* 119:23–28.

52. Dirlewanger E, Graziano E, Joobeur T, Garriga-Caldré F, Cosson P, Howad W, & Arús P. 2004. Comparative mapping and marker-assisted selection in Rosaceae fruit crops. *Proceedings of the National Academy of Sciences of the United States of America* 101(27):9891–9896.

53. Doll D. 2017. ALMOND water requirement. In R. Socias i Company & T. M. Gradziel (Eds.), *Almonds: Botany, Production and Uses* (pp. 279).

54. Doll D, Shackel K. 2015. *Drought Management for California Almonds*. University of California Division of Agriculture and Natural Resources Publication 8515, Oakland, California

55. Downey SL, Iezzoni AF. 2000. Polymorphic DNA markers in black cherry (Prunus serotina) are identified using sequences from sweet cherry, peach, and sour cherry. *J Amer Soc Hort Sci* 125:76–80.

56. Durán-Zuazo VH, Cárceles B, Gutiérrez-Gordillo S, Bilbao Benítez M, Cermeño Sacristán P, Pérez Parra JJ, García-Tejero IF. 2020. Rethinking irrigated almond and pistachio intensification: A shift towards a more sustainable water management paradigm. Revista de Ciências Agrárias 43:24–49.

57. Dzamič R, Stevanović D. 2000. Agrochemistry. Faculty of Agriculture, Belgrade.

58. Egea G, Nortes PA, Domingo R, Baille A, Perez-Pastor A, Gonzalez-Real MM. 2013. Almond agronomic response to long-term deficit irrigation applied since orchard establishment. *Irrig Sci* 31:445-454. https://doi.org/10.1007/s00271-012-0322-8

59. Egea G, Nortes PA, González-Real MM, Baille A, Domingo R. 2010. Agronomic response and water productivity of almond trees under contrasted deficit irrigation regimes. *Agric Water Manag* 97:171–181.

60. Egea J, Ortega E, Martı´ınez-Gómez P, Dicenta F. 2003. Chilling and heatrequirements of almond cultivars for flowering. *Environ Exp Bot* 50:79–85. http://dx.doi.org/10.1016/S00988472(03)00002-9.

61. El Yaacoubi A, Oukabli A, Legave JM, Ainane T, Mouhajir A, Zouhair R, Hafidi M. 2019. Response of almond flowering and dormancy to Mediterranean temperature conditions in the context of adaptation to climate variations. *Scientia Horticulturae* 257:108687.

62. Erez A, Couvillon GA. 1987. Characterization of the influence of moderate temperatures on rest completion in peach. *Journal of the American Society for Horticultural Science* 112:677–680.

63. Espadafor M, Orgaz F, Testi L, Lorite IJ, González-Dugo V, Fereres E. 2017. Responses of transpiration and transpiration efficiency of almond trees to moderate water deficit. *Sci. Hortic.*, 225, 6–14.

Varieties (3rd ed.). ASHS Press, Alexandria, Virginia.
29. Byrne DH. 1990. Isozyme variability in 4 diploid stone fruits compared with other woody perennial plants. *J Hered.* 81:68–71.
30. Campoy JA, Ruiz D, Egea J. 2011. Dormancy in temperate fruit trees in a global warming context: A review. Scientia *Horticulturae*.130(2):357–372. doi:10.1016/j.scienta.2011.07.011.
31. Cantini C, Iezzoni AF, Lamboy WF, Boritzki M, Struss D. 2001. DNA fingerprinting of tetraploid cherry germplasm using simple sequence repeats. *J Amer Soc Hort Sci.* 126:205–209.
32. Carbó JLE, Connell JH. 2017. Almond harvesting. In: Socias i Company R, Gradziel TM, editors. *Almonds: Botany, Production and Uses.* CRC Press. [Page range of chapter].
33. Cecchini M, Contini M, Massantini R, Monarca D, Moscetti R. 2011. Effects of controlled atmospheres and low temperature on storability of chestnuts manually and mechanically harvested. *Postharvest Biol Technol.* 61:131–136.
34. Cipriani G, Lot G, Huang WG, Marrazzo MT, Peterlunger E, Testolin R. 1999. AC/GT and AG/CT microsatellite repeats in peach [Prunus persica (L) Batsch]: isolation, characterisation and cross-species amplification in Prunus. *Theor Appl Genet.* 99:65–72.
35. Clodoveo ML, Camposeo S, de Gennaro B, Pascuzzi S, Roselli L. 2014. In the ancient world virgin olive oil has been called “liquid gold” by Homer and the “great healer” by Hippocrates. Why is this mythic image forgotten? *Food Res In*t. 62:1062–1068.
36. Columella LJM. 1988. De re rustica. Spanish edition by A. Holgado Redondo, MAPA, Madrid.
37. Connell JH, Colbert F, Kreuger W, Cudney D, Gast R, Bettner T, Dallman S. 2001. Vegetation management options in almond orchards. *Hort Technology*. 11:254–257.
38. Connell JH, Krueger WH, Buchner RP, Niederholzer F, DeBuse CJ, Klonsky KM, DeMoura RL. 2012. Sample costs to establish an orchard and produce almonds, Sacramento Valley. University of California, Cooperative Extension. Department of Agricultural and Resource Economics. Davis, California.
39. Cortés V, Talens P, Barat JM, Lerma-García MJ. 2018. Potential of NIR spectroscopy to predict amygdalin content established by HPLC in intact almonds and classification based on almond bitterness. *Food Control*. 91:68–75.
40. Cultifort. (n.d.). Almond Cultivation: Crop Demands, Plant Material and Nutrition. Retrieved April 4, 2023, from https://www.cultifort.com/en/almond-cultivation-crop-plant-nutrition/
41. Datnoff LE, Elmer WH, Huber DM. 2007. *Mineral nutrition and plant disease.* American Phytopathological Society.
42. DeJong TM. 1996. Photosynthesis and respiration. In: Micke W (ed.) *Almond Production Manual.* ANR Publication 3364. University of California, Davis, California, pp. 103–106.
43. Denisov VP. 1988. Almond genetic resources in the USSR and their use in production and breeding. *Acta Horticulturae*. 224:299–306.
44. Desvignes JC. 1999. Virus Diseases of Fruit Trees. CTIFL.
45. Dhar AR, Islam MM, Jannat A, Ahmed JU. 2018. Adoption prospects and Implication problems of practicing conservation agriculture in Bangladesh: A socioeconomic diagnosis. *Soil Tillage Research.*176:77-84**.** https://doi.org/10.1016/j.still.2017.11.003.
46. Di Lena B, Farinelli D, Palliotti A, Poni S, DeJong TM, Tombesi S. 2018. Impact of climate change on the possible expansion of almond cultivation area pole-ward: A case

Ryder C, Testolin R, Abbott A, King GJ, Iezzoni AF, Arús P. 2003. A set of simple-sequence repeat (SSR) markers covering the *Prunus* genome. *Theor Appl Genet*. 106:819–825. covering the Prunus genome. Theor. Appl. Genet., 106, 819–825.

12. Arquero O. 2013. Manual del almendro. Consejeria de Agricultura, Junta de Andalucia, Seville, Spain.

13. Arquero O, Jarvis-Shean K. 2017. Orchard management. In: Socias i Company R, Gradziel TM, editors. *Almonds: Botany, Production and Uses*. p. 240.

14. Arquero O, Lovera M, Navarro A, Viñas M, Salguero A, Barranco D, Serrano N. 2008. Hábitos de vegetación y respuesta a la intensidad de poda de formación de las principales variedades de almendro. Consejería de Agricultura, Junta de Andalucía, Sevilla, Spain. p. 192.

15. Arús P, Gradziel T, Oliveira MM, Tao R. 2009. Genomics of almond. In: Folta KM, Gardiner SE, editors. Genetics and Genomics of Rosaceae, Vol. 6. p. 187–219. Springer.

16. Arya A, Monaco C. 2007. Seed borne diseases: *Ecofriendly management.* p. 326.

17. Asai WK, Micke WC, Kester DE, Rough D. 1996. The evaluation and selection of current varieties. In: *Almond production manua*l. p. 52–60. University of California 3364.

18. Ashcroft GL, Richardson EA, Seeley SD. 1977. A statistical method of determining chill unit and growing degree hour requirements for deciduous fruit trees. *HortScience. 12:347–348.*

19. Ayfer M. 1975. Varietal selection of almond for central and southern Anatolia. In: II Colloque GREMPA, 8–11 September, Montpellier-Nîmes, France. IAMZ, Zaragoza, Spain. p. 7.

20. Badenes ML, Byrne DH. 2012. Almond. In: *Fruit Breeding*. [Internet]. [cited Year Month Day]. doi: 10.1007/978-1-4419-0763-9.

21. Bailey LH, Bailey EZ, the staff of the Liberty Hyde Bailey Hortorium. 1976. Hortus third: *A concise dictionary of plants cultivated in the United States and Canada. Macmillan.*

22. Barreales D, Fernandes Â, Barros L, Capitão S, Castro Ribeiro A. 2023. Effects of regulated deficit irrigation and foliar kaolin application on quality parameters of almond (Prunus dulcis (Mill.) DA Webb). *J Sci Food Agric.*

23. Barreca D, Nabavi SM, Sureda A, Rasekhian M, Raciti R, Silva AS, Süntar I. 2020. Almond (Prunus dulcis Mill. DA Webb): A source of nutrients and health-promoting compounds. *Nutrients.* 12(3):672.

24. Bartolozzi F, Warburton ML, Arulsekar S, Gradziel TM. 1998. Genetic characterization and relatedness among California almond cultivars and breeding lines detected by randomly amplified polymorphic DNA (RAPD) analysis. *J Am Soc Hort Sci.* 123(3):381–387.

25. Benmoussa H, Ghrab M, Ben M, Luedeling E. 2017. Chilling and heat requirements for local and foreign almond (Prunus dulcis Mill.) cultivars in a warm Mediterranean location based on 30 years of phenology records. *Agric For Meteorol*. 239:34–46.

26. Bianchi B, Tamborrino A, Santoro F. 2013. Assessment of the energy and separation efficiency of the decanter centrifuge with regulation capability of oil water ring in the industrial process line using a continuous method. *J Agric Eng.* 44:278–282.

27. Brewer RF. 1978. Frost protection in almonds. In: Micke WC, Kester D, editors. *Almond Orchard Management* (Publication 4092). Division of Agriculture Sciences, University of California, Davis (California), USA. p. 2–67.

28. Brooks RM, Olmo HP. 1997. *The Brooks and Olmo Register of Fruit and Nut*

potential for diverse genomic and epigenetic interactions.. Clonal propagation enables the preservation of rare and superior genotypes for future plantings and genetic improvement through bud sport transformations or favourable recombinations. Molecular markers can provide a quick, precise, and environment-independent way to evaluate seedlings, which offers valuable opportunities for increasing selection efficiency. The selection of trees with desired traits is easier through molecular markers. This is especially useful for crops like almond, which have a long juvenile period and for evaluating traits that are difficult to measure, such as biotic or abiotic stress resistance. Marker-assisted selection can cut the number of generations required to remove undesirable donor genes dramatically in backcrossing programs once enough mapping information is available (Gradziel & Martínez-Gómez 2013).

14. Conclusion :

Several previous researchers have elucidated the almond characteristics, growth habits, production, nutritional and economic importance of almonds and their role in improving health. Previous research has indicated that the farming methods used in almond cultivation impact the quality of the crops. Molecular studies and their different approaches have also been said to help and make it easier to transfer traits that were found to be desirable through breeding programmes.

15. References

1. [UCANR] University of California Agriculture and Natural Resources [UCANR]. 1996. *Almond Production Manual*. Oakland: Regents of the University of California Division of Agriculture and Natural Resources. Pp 52–61, 90–97.

2. [UCANR] University of California Agriculture and Natural Resources**.** 2002. *Integrated Pest Management for Almonds*. 2nd ed. Oakland: Regents of the University of California Division of Agriculture and Natural Resources. Pp 160–166.

3. Ahmad M, McNeil DL, Sedcole JR. 1997. Phylogenetic relationships in *Lens* species and their interspecific hybrids as measured by morphological characters. *Euphytica*. 1997;94:101-111.

4. Akubude VC, Nwaigwe KN. 2016. Economic importance of edible and non-edible almond fruit as bioenergy material: a review. *Am J Energy Sci*. 3(5):31-39.

5. Alonso Segura JM, Socias i Company R, Kodad O. 2017. Late-blooming in almond: A controversial objective. *Sci Hort*. 224:61–67.https://doi.org/10.1016/j.scienta.2017.05.036.

6. Alonso JM, Anson JM, Espiau MT, Socias i Company R. 2005. Determination of endodormancy break in almond flower buds by a correlation model using the average temperature of different day intervals and its application to the estimation of chill and heat requirements and blooming date. *J Am Soc Hort Sci*. 130:308–318.

7. Álvarez S, Gómez-Bellot MJ, Acosta-Motos JR, Sánchez-Blanco MJ. 2019. Application of deficit irrigation in *Phillyrea angustifolia* for landscaping purposes. *Agric Water Manag*. 218:193–202.

8. Álvarez S, Núñez L, Martín H, Barajas E, Mirás-Avalos JM. 2023. Differences in Growth and Water Use Efficiency in Four Almond Varieties Grafted onto Rootpac-20. *Horticulturae*. 9(3):295.

9. Anderson JL, Richardson EA, Kesner CD. 1986. Validation of chill unit and flower bud phenology models for Montmorency sour cherry. *Acta Horticulturae*. 184:71–78.

10. Aranzana MJ, Garcia-Mas J, Carbó J, Arús P. 2002. Development and variability analysis of microsatellite markers in peach. *Plant Breeding*. 121:87–92.

11. Aranzana M, Pineda A, Cosson P, Dirlewanger E, Ascasibar J, Cipriani G,

have been used for various purposes, such as analyzing variability, determining pedigrees, and identifying cultivars (Wünsch & Hormaza 2002, Martínez-Gómez et al 2003b, Sánchez-Pérez et al 2004a). Some markers, such as isozymes, restriction fragment length polymorphisms (RFLPs), and simple sequence repeats (SSRs), allow for the comparison of variability among homologous regions of the same or different species derived from specific genome sequences (Martínez-gómez et al 2007).

In almond studies, the essential molecular markers utilized are isozymes, restriction fragment length polymorphisms (RFLPs), randomly amplified polymorphic DNAs (RAPDs), simple sequence repeats (SSRs), and markers derived from distinct DNA sequences (Martínez-gómez et al 2007, Jain & Priyadarshan 2009).

Through the study of isozymes, researchers have discovered that almond plants have vast amounts of diversity, thus, The identification of most genotypes has been made possible through this process. In 1990, Byrne conducted a study to compare the variability of isozymes in Prunus. The study showed that almond and Japanese plum, which have a solid self-incompatibility system, exhibited higher variability than apricot and peach, which have different degrees of self-compatibility. The use of isozymes is restricted as conventional enzyme staining methods can only analyze a limited number of loci. Additionally, there is low variation at most loci, as observed by Martínez-Gómez et al 2007, Jain & Priyadarshan 2009.

PCR-based markers have expanded prospects for diversity studies and trait mapping by substituting isotope detection with widely available amplification of PCR. The RAPD method amplifies random locations in the genomic DNA using short arbitrary primers, resulting in dominant markers with variable repeatability (Of et al 2011). Additionally, PCR amplification of arbitrary primers for RAPDs is a valuable method for characterizing germplasm diversity (Bartolozzi et al 1998, Martins et al 2003).

Another essential point Microsatellite markers, also known as SSR markers, based on PCR, are ideal for genetic studies in plants. as a result of their highly polymorphic and abundant, and allow for assessing variability and genetic correlations (Gupta et al 1996, Powell et al 1996, Martínez-Gómez et al 2003a, Jain & Priyadarshan 2009). They are used to identify cultivars (Martínez-Gómez et al 2003b, Martins et al 2003), and to create maps (Dirlewanger et al 2004).

In different Prunus species, SSR markers encompassing nearly the complete genome have been obtained, including peach, apricot, Japanese plum, cherry, and almond (Cipriani et al 1999, Downey & Iezzoni 2000, Sosinski et al 2000, Testolin et al 2000, Cantini et al 2001, Dirlewanger et al 2002, Georgi et al 2002, Wang et al 2002, Yamamoto et al 2002, Aranzana et al 2002, 2003, Clarke & Tobutt 2003, Decroocq et al 2003, Schueler et al 2003, Hagen et al 2004, Messina et al 2004, Mnejja et al 2004).

Recently, Testolin et al (2004) published the initial group of almond SSRs, which have been effectively employed for the identification and characterization of almond cultivars (Martínez-Gómez et al 2003a, Testolin et al 2004) and related Prunus species (Martínez-Gómez et al 2003c).

13. Future progress:

The challenge in breeding cultivars for commercial success lies in optimizing numerous essential traits. Selection of exceptional almond cultivars has been ongoing for hundreds to thousands of years in quest of uncommon individuals with great

Encouraging and exploring conventional breeding and biotechnological approaches for developing almond cultivars resistant to graft-transmissible pathogens can prevent diseases in the future (Palacio-Bielsa et al 2017).

Detecting and diagnosing viruses in almonds, viroids, and phytoplasmas has traditionally relied on biological assays for decades. 'GF 305' or 'Nemaguard' peach seedlings can be inoculated through chip budding grafts, or the cherry indicator 'Shirofugen' which is quite sensitive. can be used for the genus Ilarvirus (Desvignes 1999, Marcone et al 2011).

In Europe's Mediterranean region, the *Aglaope infausta L.*, also known as the almond-tree leaf skeletonizer, is a moth from the Zygaenidae family that can cause significant damage to almond trees. When it feeds on the foliage and young fruit, it becomes a major pest, resulting in extensive losses of fruit and foliage during the earliest part of the season (Meliá & Almajano 1972).

In California orchards, pests such as leaf-footed plant bugs (belonging to the Coreidae family) and stink bugs (belonging to the Pentatomidae family) can cause significant economic damage by feeding on developing almonds before the shells harden. The leaf-footed plant bugs that are commonly found in this region include *Leptoglossus clypealis Heidenmann*, *Leptoglossus occidentalis Heidenmann*, and *Leptoglossus zonatus* (Dallas), as reported by (Zalom et al 2015).

Various types of mites belong to different Acari families, which are known to be harmful to almond crops. Tetranychus web-spinning spider mites are the most destructive globally, but the significance of each Tetranychus species varies depending on the location, as pointed out by (Marsh et al 2002).

Burrowing rodents, such as ground squirrels, pocket gophers, voles, and various rat and mouse species, are among the most destructive vertebrates. In addition, the harm caused by birds can be linked to the environment they inhabit and whether it provides them with nesting areas, places to rest, or a sufficient food supply. This damage can begin when the almonds are still in their infancy and persist until harvest time, as noted by the University of California Statewide IPM Project in 2002. In general, solutions to bird-related issues are not specific to one species and often involve methods of scaring them away. As a result, birds that harm almond crops are addressed as a collective group rather than individually. Additionally, shooting and trapping are less commonly used methods that have also been discussed (Zalom et al 2017).

12. Almond molecular studies

In the past, almond cultivars were identified and characterized based on their physical traits. However, this method had limitations as it was not always possible to analyze these traits, which may be affected by environmental changes. Additionally, physical traits could only be observed in mature samples, which prolonged the analysis process. Fortunately, molecular markers have provided a solution to these issues (Martínez-gómez et al 2007).

Molecular markers are specific variations in a particular region of DNA that exhibit Mendelian inheritance. Markers can be genes or sections of the genome that have no known function. DNA-based markers are rapid, accurate, discriminative, stable, and allow for early trait selection. Crucial for breeding programs, early selection helps identify specific traits linked to markers. Almonds use markers to identify cultivars and genetic variations (Of et al 2011).

They offer a steady, rapid, accurate, and highly discriminative test in varying environmental conditions. These markers and pests can significantly reduce production costs. The most prevalent severe diseases that affect almond foliage are shot holes caused by *Stigmina carpophila* (also known as *Coryneum beijerinkii*), travelure (*Fusicladium amygdali*), polystigma (*P. ochraceum*), fusiccocum (*Fusicocum amygdali*), and anthracnose (*Gloeosporium* amygdalinum and *Colletotrichum acutatum*) (Gradziel & Martínez-Gómez 2013).

Blossom and twig blight, a fungal disease that limits crops worldwide, as a result of *Monilinia laxa* and *Monilinia cinerea*. These fungi pose a threat to flowers, particularly during rainy bloom seasons. *Botrytis cinerea* can also be an issue in the same conditions (Özdemir et al 2021).

Infections of the kernel by the aflatoxin-producing *Aspergillus flavus* are a serious issue. In particular, this applies to areas that experience frequent insect damage. (Gradziel & Kester 1994, Gradziel & Wang 1994, Gradziel et al 2000, Dicenta et al 2003). Although fungicides have been successful in disease control, it is crucial to consider natural resistance due to the ongoing loss of agrochemicals (Martínez-García et al 2004).

When nuts are harvested in California, the peach tree borer (*Anarsia lineata*) and navel orangeworm (*Paramyelois transitella*) can seriously harm the nuts (Rice et al 1996). According to Gradziel & Martinez-Gomez (2002), this issue is caused by the susceptibility to delicate, paper-shelled, and inadequately sealed sutures that are typical of California cultivars, including "Nonpareil," "Ne Plus Ultra," "Winters," and "Merced." Integrated pest management, particularly orchard cleanliness, can achieve partial control (IPM Manual Group of University of California at Davis 1985). Some cultivars, including "Carmel," "Mission," and "Butte," have been shown to exhibit resistance through better-sealed shells (Hamby et al 2011). Because of the significant cultivars' distinctively thick, complex, and well-sealed shells, this issue is not severe in the Mediterranean region.

The Pacific spider mite (*Tetranychus pacificus*), the two-spotted spider mite (*T. urticae*), the European red mite (Panonycusulmi), and the brown almond mite (*Bryobia rubriculus*) In certain areas, production can be negatively affected by various factors, which may have a significant impact, especially in situations when there is of high moisture stress. Variable cultivars have varied susceptibilities (Gradziel & Martínez-Gómez 2013).

Almond graft-transmissible pathogens, such as viruses, viroids, and phytoplasmas, are responsible for spreading diseases globally and regionally. Some of these diseases, especially those caused by multiple infections, can have a significant economic impact when they reduce almond production or cause almond trees to decline.in addition, The long-distance exchange of infected plant material is the main reason for pathogen distribution in the almond industry. Depending on the cultivar's susceptibility, the strain of the pathogen, and environmental factors, the yield of common single graft-transmissible infections can be reduced by 10% to 25%. As a result, if these pathogens are prevalent in the crop, economic losses cannot be ignored. Insects, nematodes, and other vectors naturally disseminate some infections. Thus, the use of unnoticed infected trees in nurseries for grafting or propagation considerably helps their spread (Palacio-Bielsa et al 2017).

Currently, many nurseries routinely use in vitro propagation and appropriate cultivation in glasshouse or screen house facilities to reduce infection risks. Thermotherapy, meristem tip culture, and micro-shoot-tip grafting have been used for sanitation.

dry and dehiscent, with minimal nut fall before maturity, to ensure maximum efficiency of harvesting machines (Carbó & Connell 2017). The harvesting process involves using machines to shake, sweep, collect nuts, and transport them to a processing location. To ensure that no nuts are left behind during harvest, a small amount of manual raking is necessary. The harvest costs associated with in-field operations account for 18% of the total direct production expenses (Connell et al 2012).

The ideal method for harvesting involves shaking the tree with a precise oscillation and frequency balance that prevents harm to the trunk, branches, leaves, and root system to a lesser extent. Trunk shakers have prompted the development of better nut collection systems, The nut removal rate typically ranges from 85% to 95%, depending on the orchard and how the harvest is managed. Mesh and inverted umbrellas have been improved to collect more nuts. An efficient way to harvest nuts in the Mediterranean region is by using a trunk shaker with an attached inverted umbrella (Carbó & Connell 2017).

The mechanized gathering of nuts significantly lowers the requirement for manual labour and reduces costs. Advancements in agronomics, such as cultivating varieties for mechanical harvesting, trimming for vibration transmission, and increasing production, will make almond farming more profitable (Carbó & Connell 2017).

It is common for hailstorms to cause almonds to drop earlier than expected before they are harvested. This condition allows for an evaluation of the performance and feasibility of the mechanised collection operation during the harvesting process. A horizontal cylindrical cage consisting of equally spaced steel rods (2.87 m x 0.30 m) was used for hulling. The hulling machine consisted of a spinning shaft with moulded steel rods that separated the hull from the grain (Pascuzzi 2017).

During the growth cycle of almonds, harvesting is the most labour-intensive stage. Even today, it is often done manually by knocking the nuts out of the tree with long sticks during hull dehiscence and then collecting them in nets that are spread out on the ground. It is worth noting that an average of 13-17% of the total commercial value of the almond crop is attributable to the harvest alone (Schiril 2005). Traditionally, hulling and drying are done away from the farm. The usage of trunk shakers in olive harvesting, on the other hand, shows that they can also be employed for almonds (Manetto & Cerruto 2013, Vivaldi et al 2015). The use of trunk shakers increases productivity, and self-propelled shakers with a reversed-umbrella interceptor further improve it (Manetto et al 2017,Bianchi et al 2013).This solution seems most effective for managing almond orchards. The work chain consists of only two or three units, which reduces costs by 20% (Clodoveo et al 2014, Cecchini et al 2011).
Almonds bloom in February, mature into July, and can be harvested as late as October, depending on the variety, with the trees dormant from November to January (UCANR 1996). Almonds are harvested by shaking the trees, sweeping the fallen nuts into windrows, and collecting them from the orchard floor. Weeds on the orchard ground can interfere with equipment and reduce harvest efficiency. Therefore, many growers use intensive herbicide programs to keep the ground bare prior to harvest. (Connell et al 2001, UCANR 2002).

11.6 Pests and diseases

Genetic improvements in scions and rootstocks that increase resistance to diseases

(Stojanova 2018). Foliar nutrition and soil positively impact almond growth, ultimately improving production quality and quantity (Stojanova et al 2022)

In any cultivation system, the plant's nutrient availability is affected by the type and quantity of fertilizer applied, timing of application, and solubility in water (Lester 2007). Furthermore, agricultural irrigation has a considerable impact on plant productivity, last structure, and physical attributes of the fruit (Valverde et al 2006).

Organic fertilizer has enormous potential due to its versatility and advantages in business, environment, and society. Among many other advantages, it helps to improve lives, food safety, resilience to climate change, raise yields, lower financial risks, open up new markets, improve the environment and health, and stop desertification (Terdoo & Adekola 2014, Diallo et al 2020). Although organic farming has the potential to improve soil, ecological, and human wellness and also increase the farmers' revenue, farmers' adoption of organic fertiliser has been gradual due to a lack of information about organic farming(Farouque & Sarker 2018).

The current low agricultural productivity is mainly due to poor soil fertility, as well as other factors such as inadequate input supply, low-quality seeds, lack of knowledge and techniques, inefficient management, labor shortage, and insufficient infrastructure (Neuhoff et al 2014).

The effectiveness of organic fertilizer in crop growth is influenced by several factors, including the level of awareness among farmers about the environmental benefits of using organic fertilizer and their knowledge of its application(Thapa & Rattanasuteerakul 2011). Farmers need to understand the importance of improving soil quality and utilizing organic fertilizers for sustainable agriculture(Dhar et al 2018). According to Sodjinou et al (2015), the use of organic fertilizer requires frequent communication between farmers and extension officers/agents because of its knowledge-intensive nature. For farmers to be educated on the technical aspects of organic farming, a functional extension system is critical. This system would also help in distributing information and open discussion forums (Suvedi et al 2017).

11.5. Harvesting

In traditional Mediterranean almond cultivation, manual harvesting accounts for 30-35% of direct production costs. Due to the increasing difficulty in finding part-time seasonal workers, this operation has become more challenging. The percentage of conventional orchards that remain unharvested is on the rise due to a shortage of labour, low productivity, and physical difficulties such as unevenly grown trees and difficult terrain. The use of harvest mechanisation provides numerous advantages for orchard management, including a safer working environment for employees, reduced labour requirements and production costs, and the production of high-quality fruit. To achieve the desired results, it is essential to operate the various harvesting machines, and It is vital to control harvesting costs for profitability and meet future demands in all countries that produce almonds (Carbó & Connell 2017).

Almond harvesting usually starts in mid-July for early-ripening varieties and lasts until mid-October for later-ripening ones. The majority of almonds are sold as dry fruits, as they need to fully ripen before being harvested. Green almonds are commercially available only in France and North Africa during May and June (Carbó & Connell 2017).

In the Mediterranean region, almonds should be harvested when their hulls are relatively systems, often result in higher irrigation efficiency because of faster water movement from the field's beginning to its end. Sprinklers, drips, and micro-sprinklers are examples of pressurized systems that distribute water according to design characteristics such as the type and size of the nozzle, riser height, and operating pressure. Pressurized systems require more maintenance and filtration than surface-based systems. However, water is distributed via pressurized systems such as sprinklers, drippers, and micro-sprinklers based on several design considerations such as nozzle size and type, riser height, and operational pressure. Compared with surface-based systems, pressurized systems require more maintenance and filtration (Doll 2017).

After the sprouting, plants experience a period of rapid growth. The objective of this phase is to develop shoots and leaves to carbohydrate reserves for future yields and establish fruiting positions. Water requirements are low at first, but increase as the canopy grows. Water requirements for trees begin low and gradually increase as the leaves expand and the canopy grows. During cooler temperatures, shorter days, and higher humidity, trees need less water and can rely on stored soil water from winter rains. This typically results in relatively stress-free growth until full leaf expansion around 4-5 weeks after bloom (Doll & Shackel 2015).

Micro-irrigation systems minimize water losses due to evaporation and apply water frequently in smaller amounts. Proper maintenance is necessary for the distribution of water. Soil intake rates should not be exceeded (Schwankl et al 2007). Reducing water applications in flood or furrow irrigation systems is difficult because they require a minimum amount of water to move across the field. The only option is to increase the interval between irrigation (Doll 2017).

Irrigation timing should consider the impact of rising temperatures and wind speeds on evaporative losses. Thus, it is recommended to start irrigation in the evening and finish in the late morning to minimize evaporative losses (Doll 2017). The optimal run time for micro-sprinkler systems should be at least 6 hours to minimize water loss due to evaporation, but not exceed the soil intake rates or water-holding capacity (Doll 2017). Drip systems require less run time because of the reduced wetted area (Doll 2017).

11.4. Fertilization

In the fruit industry, it is crucial to maintain a balanced ratio of micronutrients and macronutrients for the reproductive and vegetative development of fruit plants (Datnoff et al 2007). Furthermore, the fruit yield and quality are influenced by the biological characteristics of the variety, appropriate soil and climatic conditions, and controlled plant nutrition (Dzamič & Stevanović 2000, Glintic & Krstic 1990).

Nutrition is essential for the proper growth and development of almonds, including healthy flowering, fruiting, and high-quality yield.This is achieved by replenishing the essential elements in the soil (Mengel et al 2001). However, determining the proper doses, types, time, and method of fertilizer application depends on the soil’s nutrient content. Frequently, soil application does not yield the expected results due to physical properties or dryness (Saric et al 1986; Šaciragic and Jekic1988). Foliar feeding or applying fertilizers through the leaf is therefore crucial for the successful production of almonds. Foliar fertilisation is a method that allows for prompt correction of acute nutrient deficiencies. Both macro and micro components are present in foliar fertilizers (Kostadinov & Kostadinova 2014, Stojanova 2017, Stojanova 2018, Stojanova 2020). The advantage of foliar fertilizing is its rapid effects and ability to be performed multiple times during vegetation growth shoots while pruning one major branch or shoot. Remove the terminus of an existing branch to make a heading cut. This triggers the growth of multiple buds just below the cut, resulting in a dense and robust area of new branches (Arquero & Jarvis-Shean 2017).

Various tools can be used. Pole saws and long-handled loppers are the most commonly used tools for cutting almond limbs. They come in manual, electric, or air-powered varieties. Handsaws and chainsaws are also frequently used, with both air-powered and mechanical options and electric and combustion engine models available. These tools are designed to fit different sizes of almond limbs and cutting points, so they are suitable for various cutting needs. Choosing the appropriate equipment is crucial based on the size of the orchard (Arquero & Jarvis-Shean 2017). It is important to use clean and sharp equipment while ensuring that they do not touch the ground. (Arquero &Jarvis-Shean 2017).

11.3. irrigation

Almond trees in the Mediterranean region have been traditionally grown without irrigation (Espadafor et al 2017, Oliveira et al 2018). Because of the higher output, the setting up of irrigation systems in freshly planted orchards has raised water demand in these areas. (Romero & Botía 2006, Durán-Zuazo et al 2020). Assessing the water requirements of crops and their efficiency in water usage is becoming more crucial, particularly in regions with scarce water availability, such as the Mediterranean Basin (Navarro et al., 2009). As a result, sustainable irrigation methods have been introduced in some Mediterranean regions. (Egea et al 2010). Selecting plant materials such as rootstock and scion genotypes with less water needs or enhanced water use efficiency (WUE) is critical for water-lacking areas' sustainable agriculture. (Álvarez et al 2019). It is crucial to understand the water requirements of each cultivar to choose the appropriate plant material and prevent underestimating irrigation needs. This can lead to increased costs, water waste, and negative environmental impact, particularly in water-scarce regions such as the Mediterranean Basin, where some crops may not receive sufficient water (García-Tejero et al 2015, Álvarez et al 2023).

Although almond trees have a high tolerance to water stress, irrigation is generally considered essential to improve crop performance. Effective irrigation is the most critical factor impacting almond yield and quality among agricultural practices. (Lipan et al 2018). Egea et al (2013), García Tejero et al (2018a) also support this claim. According to research, trees in California typically produce between 137-147 cm of water, while they can survive on as little as 19 cm (Shackel et al 2011; Sanden 2007). This increase in growth and yield is caused by higher rates of photosynthesis and respiration resulting from reduced water stress, leading to increased productivity (Doll 2017). Different techniques have been conducted worldwide to control irrigation water utilisation and crop production, such as deficiencies irrigation, orchard vegetation management, mulches, and foliar implementation of reflective or anti-transpirant film protection (Girona et al 2005, Rosati et al 2006, García-Tejero et al 2018a, Lipan et al 2018, Guti´errez-Gordillo et al 2019, Lepsch et al 2019, Galindo et al 2020). It is known that almond trees are highly productive with water (García-Tejero et al 2018a), and have strong drought tolerance (Goldhamer et al 2006). Deficit Irrigation (DI) was established for almond trees along with other crops such as olive trees and vineyards (Barreales et al 2023).

Two of the most common methods for watering an almond plantation are surface irrigation and pressurized systems. Surface irrigation systems, such as flood and furrow moisture of the roots from the time they are removed from the nursery until they are planted in the soil. Potted plants with soil around their roots can be planted at any time; however, autumn may be the best season to do so if there is no risk of frost. Spring planting should be done before May-June, long before the high summer heat (Arquero & Jarvis-Shean 2017).

11.1.3. Planting distance

The growth of plants depends on various factors, including the strength of climatic conditions and plant material (both scion and rootstock). For orchards with high density, it is crucial to select plant material that is not excessively vigorous. Additionally, to avoid overshadowing and limitations in machinery transit, it is recommended to increase the planting distance (particularly between lines) under optimal environmental and management conditions, such as irrigation. Currently, irrigated commercial orchards have rows that are 7–8 m apart and tree distances within the rows of 5-7 meters. This results in planting densities of 179 to 286 trees per hectare, based on the plant material, environmental and growing conditions, and type of harvesting equipment (Arquero 2013).

11.1.4. Pollination

When growing self-incompatible cultivars, it is important to properly design pollinizers. It is advisable to have a minimum of 30% pollinizers to ensure the best possible pollination outcomes. It is also advised to avoid exceeding two consecutive rows of the same self-incompatible cultivar. To make mechanical harvesting easier, it is advisable to have two rows of the same cultivarThere is no need for another cultivar if the cultivar is self-compatible. The orchard may include only one variety. It may be beneficial to have two cultivars in large orchards but in lower percentages than for self-incompatible cultivars. The blooming time is the most important factor to consider when choosing a polliniser. It is important to take into account the ripening time in order to ensure that it concurrency with the main cultivar. Pollinators should have agronomic and productive value as cultivars, as they take up valuable space in the orchard (Arquero & Jarvis-Shean 2017).

11.2. Pruning

Pruning is typically done to assist with cultural practices, such as spraying and harvesting, and to remove dead and diseased wood. Throughout history, pruning has also been utilized to stimulate tree growth. However, studies conducted over a long period have revealed that trees that are slightly pruned (pruned for cultural practices and eliminated of diseased twigs) produce similar or better yields than those that are pruned more heavily. The intensity of pruning required primarily depends on each cultivar's vegetative pattern, as explained by Arquero et al. (2008). The way an orchard is pruned depends on various factors such as the density of planting, the growth habits of the cultivar, the strength of the trees, the irrigation system, how the orchard is managed, the harvesting method, and the availability and cost of labor and equipment (Arquero & Jarvis-Shean 2017).

Pruning cuts are classified into two types: thinning cuts and heading cuts. Each variety causes a varied growth response and should be used for different purposes. Thinning cuts are made to direct development in a specific area and/or to eliminate dead or diseased wood. To do this, the limb or branch should be completely removed by cutting it at the branch collar where it originates from the parent limb (Arquero & Jarvis-Shean 2017). When making heading cuts, the aim is to promote healthy and plentiful growth immediately below the cut. This was accomplished by growing multiple new

Mini-chip budding on small in vitro propagated rootstocks is becoming increasingly common. This strategy, as opposed to just planting bare-root plants during inactive seasons, allows for the creation of plants in pots, table-budding operations, quick plant growth in greenhouses, sale of plants in containers, and the potential of field planting over a longer period of time. Appropriate irrigation and fertilization promote strong growth of the scion bud in T-budding, allowing for the development of a marketable tree in only one season of growth. Mini-chip budding decreases production time to 3-4 months and can be performed year-round (Badenes & Byrne 2012).

In all budding approaches, the shoot above the placed bud is eliminated once it begins to grow. The most convenient rootstocks are those with red leaves for this operation because they allow for easy distinction between the scion and rootstock (Badenes & Byrne 2012).

Almond has been found to be more challenging than other species for micropropagation and callus regeneration (Kester & Gradziel 1996), stifling the development of other propagation mechanisms. In vitro propagation is widely utilised to create almond peach hybrid rootstocks. with many plants in Mediterranean countries and California being propagated in this manner (Badenes & Byrne 2012).

11. Almond orchard management

Selecting the appropriate spacing for plants and performing tree planting tasks are crucial. Any mistake made during this phase can significantly impact the orchard's output throughout its entire commercial lifespan. Even if the error can be corrected, it comes at a substantial expense (Arquero & Jarvis-Shean 2017).

11.1. Field practices

11.1.1. Ploughing

It is recommended to perform deep ploughing of at least 50 cm before planting to encourage root growth and enhance water absorption in the soil. One of two main types of ploughing machinery may be used for this task: the soil or subsoiling is turned over by a deep plough, which is the most effective way to break through the lower soil layers. In the first type, the placement of the various soil profiles is somewhat altered. As a result, the second ploughing, which should be done cross-directionally when the soil is dry, is advised. To remove weeds and prepare the soil for planting, shallow ploughing may be performed later. This can be performed using various tools, such as disc or spur harrows, cultivators, or rakes. It is important to clear out any previous plant material and stones, modify the soil, set up irrigation and create access roads before starting any planting operations (Arquero & Jarvis-Shean 2017).

11.1.2. Planning to plant trees

When planning to plant trees, three important factors must be considered: the environment, the growth potential of the trees, and the machinery needed for maintenance. It is essential to ensure that each tree has sufficient soil to obtain all the water and nutrients it needs. When the soil quality is low, more space is necessary between trees to accommodate larger soil volumes. In orchards without irrigation and with poor soil quality, it is best not to plant more than 150 trees per hectare to avoid potential drought problems (Arquero 2013).

At present, almond orchards are established through the use of grafted plants, which are grown in nurseries and sold either as bare-root specimens or with soil. Planting bare-root plants should only be done between December and February, when the plants are dormant. It is important to maintain the other almond species belonging to Sections Euamygdalus and Spartiodes. Even though hybridization with Section Lycioides is also possible, it may be more challenging, and crosses with Chamea-mydalus are even more difficult to achieve. Despite both physical and differences in development, *P. persica*, which is the cultivated peach, and its wild relatives, *P. mira* and *P. davidiana*, can be easily crossed with P. dulcis. These crosses have been discovered to be valuable as rootstocks and sources of commercially useful characteristics (Gradziel et al 2001 , Gradziel 2001).

Incorporating breeding material from other places improves breeding choices for desirable qualities such as self-fertility and disease resistance. *P. dulcis* and other almond species have commonly hybridised, resulting in introgression (Godini 2002).

10. Propagation

Seed propagation is still standard in many regions, including the Middle East and Central Asia (Kester et al 1990). Conventional seed propagation resulted in substantial genetic heterogeneity due to almond's self-incompatible nature (Kester et al 1990, Socias i Company & Felipe 1992). A localized ecotype or landrace may have limited genetic diversity, resulting in efficient reshuffling that still produces genetic variability. Over the last century, the replacement of native cultivars and landraces with commercially chosen breeding releases has resulted in a severe reduction in overall crop variety. In Europe, many countries have replaced their cultivars with Puglia and French 'Ferragnès' cultivars that bloom later in the season (Grasselly & Crossa-Raynaud 1980).

Early almond production was concentrated in particular areas, and regional varieties developed because of selection for good local adaptability. Local genotypes with considerable variation proliferated because of seedling propagation. However, because they came from a small pool of germplasm, they frequently needed a large amount of genetic variety. This condition is common in remote regions such as the Mediterranean islands, solitary valleys, and the Canary Islands. The most promising seedlings were handpicked for clonal propagation, including several centuries-old choices (Estelrich 1907).

Furthermore, the peach and almond peach hybridization rootstocks have good graft compatibility with almonds. Clonal hybrids of almonds and peaches are becoming increasingly common in Europe. Tolerance to calcareous and/or other poor soils; ease of multiplication by hardwood cuttings and/or micro-propagation; ability to distinguish rootstock growth from scions (i.e., red leaves) to identify unsuccessful scion bud growth; and high vigour are all desirable qualities in new rootstocks. It is becoming increasingly vital to develop hybrids with greater tolerance to heavy and water-saturated soils (Xiloyannis et al 2007).

Grafting was used to propagate almonds in the first century AD, allowing for a better selection of scions for clonal multiplication (Columella 1988). Clonal cultivar selection was insignificant until graft and bud propagation became popular in the past 150 years. Clonal propagation is used to identify and propagate hundreds of cultivars in specific production locations, capturing regionally adapted elite genotypes (Estelrich 1907, Kester et al 1990).

Most nurseries use rootstocks planted the previous year for late spring or early autumn budding. T-budding is typically accomplished by separating the scion cultivar bud from the inner woody tissue, which is actively growing and, hence, easily separated. Chip budding is typically done when growth is insufficient to ensure easy separation of the bark from the inside of the wood (Gómez Aparisi & Felipe 1984).

ongoing efforts to breed self-compatible almond varieties over the long term.

Improving the quality of almonds has become a primary goal in breeding (Socias i Company et al 2008). Defining an ideal kernel quality is a challenging task due to the fact that consumer preferences vary greatly (Janick 2005). Kernel quality should consider both the chemical composition that determines the specific taste and the physical attributes that affect usability. Therefore, the preferred shell type varies according to regional customs. In Mediterranean countries, a hard shell is preferred, in California and other similar areas with a developing system, a soft shell is preferred (Badenes & Byrne 2012).

Because of its favourable impacts on human health, the chemical composition of almond kernels is significant for breeding. These benefits are attributed to the almond's antioxidant compounds, high oleic acid content, and desirable nutrient and fiber levels. While newly released almond varieties do not yet include these aspects, they are gaining attention from breeders, growers, processors, and consumers (Gradziel & Martínez-Gómez 2013). A recent summary by Socias i Company et al 2008a) reviews almond quality components and their heritability.

The primary objectives of breeding are genetic improvement and cultivar development. The former aims to transfer self-compatibility to local genetic backgrounds, while cultivar development involves large commercial plantings for profitability. Commercial success requires the absence of deficiencies in multiple characteristics, not just superior performance in one or a few traits. This task entails optimising numerous important breeding goals, which are classified as genetic improvement and cultivar development. In locally adapted genetics, genetic enhancement improves specialised features such as disease resistance. Substantial commercial plantings during the lengthy production period necessary for commercial viability indicate cultivar development success. Rather than outstanding performance in a few qualities, cultivar success is determined by the absence of defects in several fruit and tree attributes required for commercial viability (Gradziel & Martínez-Gómez 2013).

The biggest challenge in breeding strategies for almond crops is optimizing numerous essential traits simultaneously; this includes using molecular-based techniques and other marker-assisted selection (MAS) (Gradziel & Martínez-Gómez 2013).

9.2. Breeding through Interspecific Hybridization

Researchers are incorporating breeding material from other regions to increase genetic variability for desirable characteristics like self-fertility and resistance to diseases (Kester & Gradziel 1996, Socias i Company 1998, Martínez-Gómez et al 2003). Many of these cultivars may have originated from different species (Kester et al 1991, Ladizinsky, 1999; Socias i Company, 2002).

Certain features of *P. dulcis* may have been improved by natural hybridisation by the transfer of genes from other almond species. *P. webbii* grows throughout the Mediterranean region and naturally hybridises with cultivated almonds in Italy (particularly Sicily), Spain, and Greece, resulting in introgression and self-fertility (Gradziel & Martínez-Gómez 2013). According to a (2002) study by Godini, *P.webbii* is believed to be the source of these characteristics in the Italian region of Apulia. Gradziel et al (2001b) and Gradziel (2001) have reported that controlled crosses can be used to breed hybrids between *P. dulcis* and

sensitivity rises until the petals fall off (Brewer 1978). Therefore, early flowering, when the spring cold and late spring frosts occur, may damage reproductive organs and reduce productivity (Sakar et al 2019).
The process of flowering only occurs after the end of the dormant period. Endo-dormancy refers to the state in which a tree is unable to initiate the process of bud rupture for flowers or vegetation even when the temperature is moderate. Endo-dormancy is followed by eco-dormancy, which happens in late winter and early spring as a result of temperatures that are not favourable to growth (Lang et al 1987, Campoy et al 2011, Sánchez-Pérez et al 2007).
It is essential to grow at least two cross-compatible almond cultivars with overlapping flowering periods on the same orchard to ensure good pollination and higher commercial yield since most almond cultivars are self-incompatible. (Martínez-García et al 2012). According to Williams (1970), wind doesn't have a significant impact on pollination. However, effective pollen transfer from an anther to receptive stigmas can be achieved with the help of pollinating insects. Among them, honeybees are considered to be the most effective (Socias i Company et al 2017). It is recommended to place 2.5–5 hives per hectare in almond orchards during blossoming to enhance flower visits and improve pollination (Free 1970, Rikhter 1972, Meith et al 1974). Identifying the susceptibility of yield to frosts is crucial for flowering time, which has low heritability (0.20) and is closely associated with temperature (Dicenta et al 1993).
Flowering time varies significantly among different almond cultivars. Moreover, varieties with an early or medium flowering time have a long flowering period, This can be regarded as advantageous for two reasons. First, the long blossoming time helps to avoid the damaging impacts of frost and potentially devastating weather. (Socias i Company 1998).

Second, it is a desirable characteristic. regarding the early ripening of fruits (Dicenta & García1992). Late-flowering cultivars have a shorter flowering period, which is one of the primary goals of almond breeding and is considered a desirable characteristic in frost-prone areas (Socias i Company et al 2003, Socias i Company et al 2012 , Dicenta et al 2016).

9. The almond breeding aspects.

9.1.Breeding objectives

Breeding objectives often fall into one of the following three categories: raising yield, raising market quality, or lowering production costs. Inadequate cross-pollination is typically a significant factor in determining commercial production because almond is self-sterile (Asai et al 1996, Micke 1994).

A key gene regulates self-compatibility and self-incompatibility.(Dicenta & Garcia 1993b), Modifier genes are also essential (Gradziel et al 2002, Socias i Company et al 2005). While several almond species can self-pollinate, only the self-compatible genes from *P. mira*, *P. persica*, and *P. webbii* have resulted in fruit set above the commercially desirable 30% (Gradziel et al 2001b).

Breeding populations resulting from crosses between different species segregate for self-compatibility in accordance with the expected Mendelian ratios, which are governed by a single gene (Socias i Company & Felipe 1988, 1992, Dicenta & García 1993a, Gradziel et al 2001). *P. mira*, which exhibits high levels of self-pollination, displays the highest selfing percentages when crossed with almond after the self-compatibility gene was introduced. In 1990, Socias i Company conducted a review of the accumulating enough chilling hours, the plant initiates its reproductive process, which becomes apparent through the emergence of inflorescence (Sakar et al 2019). In Prunus species, flower buds develop before leaf buds (Sakar et al 2019). Bloom season typically begins in late January for early varieties and lasts until April for ultra-late varieties (El Yaacoubi et al 2019; Di Lena et al 2018). In addition, the process of flowering in plants is highly influenced by weather conditions, particularly the air temperature and the occurrence of spring frosts (Sakar et al 2023). Research conducted by Martínez-Gómez et al (2017) suggests that exposure to temperatures of -3°C for a duration of 30 minutes can be harmful to plants. Moreover, temperatures of -2°C and -0.5°C can cause damage to flowers and fruits, respectively.

Various methods have been created to determine the necessary amount of chilling and heat. The chilling hours model (Weinberger, 1950), the Utah model (Richardson et al, 1974), and the dynamic model (Fishman et al 1987a, 1987b) are some of the most commonly used chilling models. In addition, the Growing Degree Hours Model (Anderson et al 1986) is the standard model used for estimating heat requirements. Multiple studies have elucidated the dormancy process and predicted the necessary amounts of chilling and heat required for almonds.

Alonso et al developed a model (2005) that used data from multiple years to calculate the mean transition date from endodormancy to eco-dormancy for 44 different almond cultivars that covered the entire almond bloom range. They conducted a study to investigate the relationship between dormancy temperatures and the timing of full bloom in almond cultivars. The research revealed that the chilling requirements of the different cultivars ranged from 400 to 600 Chill Units, while their heat needs varied from 5500 to 9300 GDH. The optimal temperature for chilling varies depending on genetic variability. Some studies have suggested that cultivars with a low chill factor need higher temperatures to accumulate enough chill units than those with a high chill factor (Gurdian and Biggs 1964). Furthermore, each cultivar may react differently to abrupt temperature changes, such as extreme temperatures or alternating cold and warm temperatures in temperate locations during spring (Couvillon & Erez 1985, Erez & Couvillon 1987).

8. Almond flowering and flowering time:

The almond is the species of *Prunus* that blooms the earliest in comparison to all cultivated species (Alonso Segura et al 2017).

One of the most important agronomical characteristics of almonds is flowering. The phenological phase of almond flowering is caused by the consecutive application of two temperature stimuli: To begin, the flower bud remains dormant until it has had sufficient exposure to cold temperatures. When it hits a certain threshold. Second, flowering within the bud is triggered and progresses at a temperature-dependent rate until the bud blooms (Ashcroft et al 1977).

Flowering occurs only when the plant has received the necessary amount of both cooling and heating, meeting the specific requirements (Sánchez-Pérez et al 2014, Alonso Segura et al 2017, Martnez-Gómez et al 2017). This makes almond trees in more temperate growing areas susceptible to spring frosts and limits their planting to more temperate, almost subtropical but arid climates (Mori et al 2011). Almond blossom buds are able to resist cold temperatures and can tolerate temperatures as low as -7°C. (Socias i Company et al 2017). When flower buds open and display their petals, their the 15°C to 35°C range can negatively impact tree growth (Queirós 2020, Karaat & Denizhan 2023). The mesocarp detaches from the kernel shell under ideal environmental circumstances, disclosing the stone during fruit development. (Freitas et al 2023).

The level of tocopherol homologues present in nut crops can be influenced by temperature and drought during the growth of the fruit or nut (Maranz & Wiesman, 2004). Thus, temperature is a significant factor that affects the accumulation of tocopherol in different species, including almonds (Kodad et al 2018).

Various environmental factors can affect the pollination behaviour of bees, including wind, low temperatures, and rain. Pollination activity is observed to be the highest when the temperature ranges from 15 to 30 degrees Celsius. However, when the temperature drops to 10 to 12 degrees Celsius and there is precipitation, pollination activity is hampered. Bees become less active or may even stop their activity altogether in such conditions (Socias i Company et al 2017, Cultifort 2023, Thomas 2019).

Seeds are susceptible to mould development during maturity, harvesting, and storage due to high humidity and temperature fluctuations (Arya & Monaco 2007). Before processing, large stockpiles of almonds, including their hulls and shells, are stored under tarps. However, this can increase humidity levels, leading to fungal growth and aflatoxin production caused by Aspergillus fungi (Lampinen & Michalaides 2008).

It is crucial to consider the impact of high temperatures and humidity on the quality and safety of almonds during transportation. it is important to keep in mind that almonds that have been peeled are more susceptible to damage compared to those that are still inside their shells. The protective barrier provided by the shells helps to prevent moisture and oxygen exchange. Hence, peeled almonds are more likely to undergo changes in their water content and lipid oxidation, which can lead to faster spoilage when compared to almonds still inside their shells (Kazantzis et al 2003).

7.2. Photoperiod:

Many fruit crops are affected by the amount of daylight they receive, which can impact both their flowering and growth patterns leading up to the dormant season. For deciduous plants in the Prunus family, flower buds can appear along with new shoots that emerge throughout the year. As autumn arrives, the photoperiod becomes a crucial factor in slowing down the growth process, allowing the plant to prepare for leaf shedding, increase cold resistance, and eventually enter dormancy (Alonso 2017).

In most almond leaves, the rate of photosynthesis reaches its maximum at about half of full sunlight because the photosynthetic apparatus becomes 'light-saturated' at this point. (DeJong 1996).

In recent times, various studies have emphasized the importance of light in enhancing the productivity of stone fruit crops. The energy balance of a plant and the photosynthetic capacity of its leaves are influenced by solar radiation. Moreover, it can also impact particular photomorphogenic or photoperiodic responses (Alonso 2017).

7.3. Chilling unit:

Almonds have specific environmental requirements that need to be met in order to end their dormancy. Chilling is required to end endodormancy, while a certain amount of heat is necessary for flowering (Egea et al 2003). Estimating the chilling requirements is crucial for selecting appropriate tree cultivars, maintaining profitable plantations, and minimizing the detrimental impact of climate change (Gao et al 2012). After

6. The nutritional value of almonds and their health importance

Table (2) displays the composition of almonds (Kalita et al 2018)

Nutrients	Units	Value per 100 g Whole Almonds
Proximates		
Calories	kcal	579
Water	g	4.41
Protein	g	21.15
Lipids (total)	g	49.93
Dietary fiber (Total)	g	12.5
Sugars (Total)	g	4.35
Ash	g	2.97
Minerals		
Calcium	mg	269
Iron	mg	3.71
Magnesium	mg	270
Phosphorus	mg	481
Potassium	mg	733
Sodium	mg	1
Zinc	mg	3.12
Copper	mg	1.03
Manganese	mg	2.18

Almonds have natural properties that make them healthy. They contain high amounts of fiber, unsaturated fatty acids, antioxidants and phytochemicals which help protect the body. When consumed, almonds have either neutral or positive effects on glycemia/insulinemia and satiety. More studies are needed to determine the effects on gut peptides. (Mori et al 2011b). Almonds are also traditionally used to heal wounds, anemia, insomnia, headaches, sore throats, brain infections, kidney diseases, urinary tract infections, uteralgia, pityriasis, and hysteria(Mushtaq et al 2015). The main pharmacological properties of almonds include hepatoprotective, antidepressant, antioxidant, memory-enhancing and anti-aging effects (Mushtaq et al 2015).

Almonds are high in magnesium, which helps control blood sugar; It lowers blood sugar levels and improves insulin functions and helps lower blood pressure. Obesity and high blood pressure can be caused by a lack of magnesium (Javaid et al 2019). Almonds are high in protein, fiber and healthy fats. They can help reduce hunger and calorie intake(Javaid et al 2019).

Consuming almonds in higher quantities has been linked to a reduced risk of cancer. Research indicates that those who consume more almonds have a 2 to 3 times lower risk of breast cancer. Additionally, studies on rats have shown that almonds may reduce the risk of colon cancer. In humans, consuming almonds has been linked to increased levels of HDL cholesterol and reduced levels of LDL cholesterol (Javaid et al 2019).

7. Environment requirement.

7.1. Temperature and humidity.

Climate significantly affects plant physiology and yield production. Temperature, precipitation, humidity, and luminosity are crucial during the phenological stage (Jin et al 2020). Almonds typically grow in regions where the average temperature ranges between 15-20 degrees Celsius annually (Fernandes de Oliveira et al 2023, Queirós 2020).

Photosynthesis is most productive during fruit development when the temperature ranges between 20°C and 30°C (Queirós 2020, Cultifort 2023). Temperatures outside

The almond shells underwent pyrolysis to produce solid char, liquid hydrocarbons, and gases. In addition, a study on the widespread use of bitter almond shells shows that almond shells are suitable feed for the production of activated carbon (Akubude et al 2016).
The use of biomass feedstock as an alternative to fossil fuels has an additional meaning in terms of climate change, as biomass has the potential to be carbon neutral. For example, using biodiesel or its mixes in automobiles produces less gaseous pollutants and emits no net carbon dioxide or sulphur to the atmosphere than normal fuel. Furthermore, producing biodiesel from non-edible almond seeds could serve as a vital poverty alleviation initiative for the rural underprivileged population. This could not only ensure energy security in general and for rural areas in particular but also improve the non-agricultural sector in rural areas. (Akubude et al 2016).

Almond shells were often used to make activated charcoal moreover, sliced almonds were used to make activated charcoal so that, high calorific value of almond residues is almost the same as that of forest residues 18.4 MJ/kg (Nwosu et al 2008). Almond residues have been used directly or after some treatments as absorbents to remove metals and colorings, as animal feed ("New World Encyclopedia" 2008, FAO 1995, Jafari 2011, Yalchi 2011).

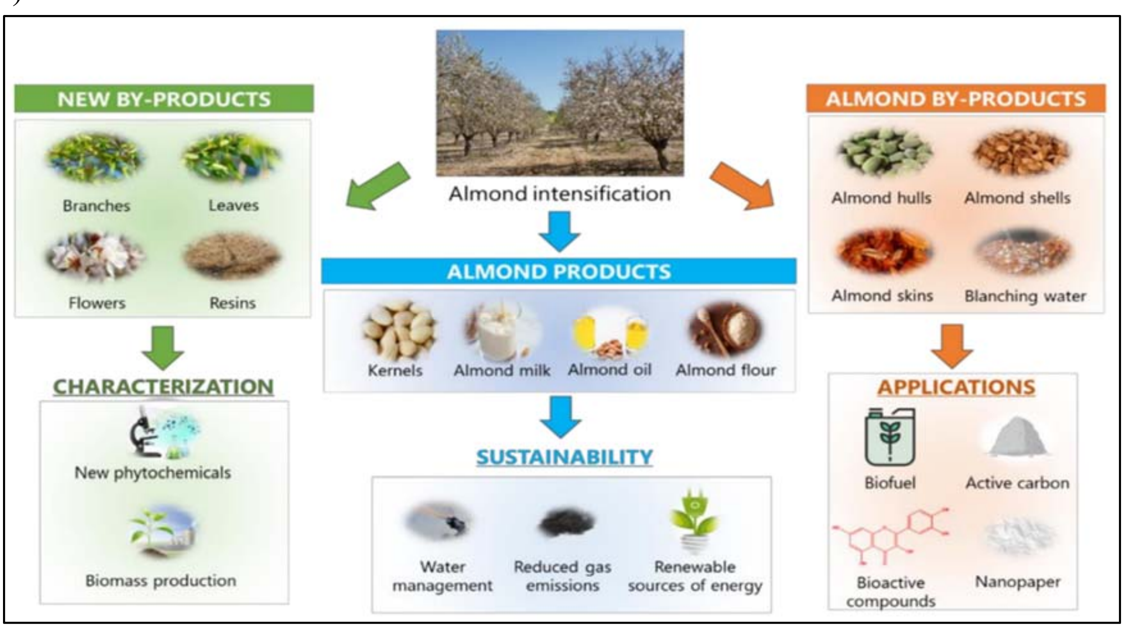


Fig. 3. shows the potential future opportunities for making use of almond products and by-products (Garcia-Perez et al 2021).

The world's largest producer, the United States and the Major producers include Spain, Australia, Turkey, Morocco, and Iran. California produces the most almonds in the United States, making it the state's biggest agricultural export. Afghanistan is also known for producing high-quality almonds (Verma 2014)

Ranking	Country	Production	Unit
1	United States of America	2189040	t
2	Spain	365210	t
3	Australia	285605.05	t
4	Türkiye	178000	t
5	Morocco	169255	t
6	Iran (Islamic Republic of)	163568.2	t
7	Syrian Arab Republic	87768.07	t
8	Tunisia	75000	t
9	Italy	71620	t
10	Algeria	55448	t

Tabe (1): Almond production in the world (**Source:** FAO 2023).

5. The economic importance of almond

Complementary medicine practitioners have long used almond oil, also known as [*Oleum amygdalae*], due to its numerous health benefits (Ahmad 2010). Nowadays, it is extensively used in the cosmetic and pharmaceutical sectors (Felipe 2000, Schirra 1997). Sweet almond oil is extracted from the dried kernel of the almond plant and is known for its anti-inflammatory, immunity-boosting, anti-hepatotoxicity, and massage benefits (Ahmad 2010). Additionally, bitter almond oil is used as a flavoring in foods, soft drinks, and medicines, and as a fragrance in perfumes, soaps, and cosmetics. It is important to note that the hydrocyanic acid, which is responsible for the bitter taste, is removed before the oil is used (Wirthensohn et al 2010). According to some researchers, results of work on almonds indicate that they have high oil yield and are a potential feedstock to produce biofuels and oleo chemicals (Moen et al 2008).

Almond residues are a great source of raw materials for creating energy and value-added products. These residues contain a significant amount of energy that can be transformed into various forms of usable energy by using different commercially available processes. Pyrolysis is considered to be the most suitable process to convert almond residues into liquid fuels, biochar, and activated charcoal (Saberi-Moghadam et al 2015).

Gasification is a high-temperature partial oxidation procedure that turns lingo-cellulosic feedstocks into a combustible gas mixture known as syngas or production gas. The procedure usually takes place between 700 and 1,100 degrees Celsius. The economics of hydrogen production from biomass gasification indicate that hydrogen may be economically produced. Furthermore, studies suggest that almond shells contain approximately 23% syngas (hydrogen and carbon monoxide) and have a low calorific value (LHV) of about 4 MJ/m3. This gas is classified as low to medium value(Akubude et al 2016).

consumed as an edible kernel by the locals(Kermanshah et al 2014).

Spanish varieties

3.3.1. *Marcona*

Spain is known for its diverse range of almond varieties, with the Marcona type being the most widely grown (Varela et al 2006). This variety is usually consumed as a roasted or fried snack or used in the production of turrones. However, the *Marcona* variety is quite costly because of its exceptional taste and low yield (Vázquez-Araújo et al 2008).

3.3.2. *Guara*

Another noteworthy variety is *Guara*, known for its late blooming, ability to self-pollinate, and excellent quality, which has resulted in significant commercial success (Kodad et al 2014).

3.3.3. *Largueta*, *Planeta, Rumbeta, and Desmayo*

Other important Spanish varieties, such as *'Largueta', 'Planeta', 'Rumbeta', and 'Desmayo'* are also produced in large volumes (Cortés et al 2018).

3.4. Indian varieties

3.4.1. *Shalimar*

The Indian variety known as *Shalimar* blooms in the second week of March and can be harvested 143 days after full bloom.The Shalimar tree has a drooping growth habit and produces a light papery shell, which has a high shelling ratio of 50%. It is also qualified for export. Under irrigated conditions, the average productivity of Shalimar is between 2.0-4.0 t/ha. (Verma 2014).

3.4.2. *Makhdoom*

The *"Makhdoom"* tree blooms in the first week of March and is typically harvested 141 days after full bloom. This tree grows in a spreading and drooping manner, and its shells are medium, soft, with a shelling percentage of 42%. This tree has an average production of more than 2.0-3.5 t/ha under irrigated circumstances (Verma 2014).

3.4.3. *Waris*

The Waris cultivar blooms in the third week of March and matures in 145 days. It grows vertically, making it ideal for high-density orcharding. The shell is medium in colour, and the nuts are medium in size, with soft shells and full kernels. The shelling rate is 48%. Under irrigated conditions, the tree yields more than 2.0-3.0 tonnes per hectare (Verma 2014).

3.5. Afghanistan variety

3.5.1. *Satarbai Sufi* (Afghanistan variety)

One of the finest almond varieties in Afghanistan is known as Satarbai Sufi. It hails from the Khulm District in Balkh Province and boasts an early bloom (occurring in the fourth week of February) with a mid-July harvest(Verma 2014).

3.5.2. *Satarbai Bakhmaly* (Afghanistan variety)

Satarbai Bakhmaly is a high-quality export cultivar from Aybak in Samangam Province. It blooms in the first week of March and is harvested in mid-July. This variety is sought by markets that want whole kernels for direct consumption(Verma 2014). This variety is a top choice for export markets seeking whole kernels suitable for direct consumption. It enjoys high demand in India and the Middle East(Verma 2014).

4. Almond production

The global production of almonds during 2021 was approximately 2 million tons (FAO 2023).

Garden, located in Yalta, Crimea, was established under the guidance of A.A. Rikhter in 1972. And Yadrov (1994), has had the second-oldest continuous breeding program for almonds, behind California. These had their origins in Nikolai Vavilov conducted extensive studies in 1930 on collections of species and cultivars, primarily in the Asiatic regions of the former Soviet Union. Ongoing programs continue this work (Denisov 1988).

2. Almond classification

Almonds (*P. dulcis*) belong to the *Rosaceae* family. This family is of great significance in the temperate zone, with many economically important species such as apples, apricots, plums, cherries (both sweet and sour), strawberries, and roses (Arús et al 2009). Almonds belong to the Prunoideae (or Amygdaloideae) subfamily, with a single monocarp-late pistil maturing into a drupe (Soundararajan et al 2019), but they are now classified as their own family, the Prunaceae or Amygdalaceae. Prunus evolved from the Spiraeoideae subfamily, which has recently been discovered (Potter et al 2007).

The classification of almonds has been a challenge because they are considered an outlier within the *Prunus* species. The scientific name most commonly used today is *Prunus dulcis*, which acknowledges its similarities in morphology and genetic makeup with other *Prunus* plants, as well as its reported ability to hybridize with apricot, peach, and some plums. This name has been replaced by the newer name of Prunus dulcis, although some European literature still refers to it as *Prunus amygdalus* (Gradziel 2009). Experts with knowledge of almond species native to Central Asia prefer to classify them under a separate genus called *Amygdalus communis* (Ladizinsky 1999). This is because they believe that the unique botanical structures and development patterns that have evolved in these extreme environments are distinctive enough to warrant a separate genus (Mori et al 2011b).

3. Almond worldwide distribution

Numerous types are available worldwide. However, due to superior export quality, only a few cultivars, varieties, and species dominate the global market.

3.1. Nonpareil (USA variety)

The dominant almond cultivar in California is 'Nonpareil', accounting for 34.8% of total bearing acreage and 38.7% of total tonnage produced. 'Nonpareil'is an old cultivar that was chosen in the 19^{th} century. It is still widely used today because it regularly yields high-quality kernels that are harvested early and fast, processed without harm, and useful for a variety of products (Ledbetter & Sisterson 2013).

3.2. Iran species

3.2.1. *A. lycioides*

A. lycioides, also known as "Badamak", is located in some parts of Iran and is an indigenous species found primarily in the south. This plant has many uses, such as producing edible nutritive oil and kernels after debittering. It is valuable as a food source and has medicinal properties such as being an anti-diabetic, anti-inflammation, antimicrobial, and laxative substance (Kermanshah et al 2014).

3.2.2. *A. wendelboi*

A. wendelboi is an endemic species found only in the southern region of Iran, specifically in the Mountains of Gnow protected area. The fruit of this plant is known locally as "Archen" and is widely used in folk medicine to treat colds, coughs, headaches, and skin burns. In addition to its medicinal uses, it is also and the Madeira Islands. These introductions may have originated from various groups, as numerous trade channels were well-established by this time, including the early ocean traders, the Phoenicians of Asia Minor (Egea & Garcia 1975), and the Greeks, who founded colonies in Sicily, Europe, and North Africa. During the Arab conquest of North Africa around 500 to 600, almonds were introduced into Tunisia and Morocco. Later, they were brought to Spain and Portugal. Before this, the cultivation of almonds was mainly confined to an area of Spain's central plateau and river valley slopes within 50 miles of the Mediterranean coast. This information is based on the research conducted by Jaouani in 1976 and Laghezali in 1985, respectively. It is believed that one of the Silk Road caravan routes passed through north-central Africa, specifically through Timbuktu and into Morocco. This suggests that there may have been an earlier route for the dispersion of goods to North Africa and Western Europe. Some remnants of these pre-Arabic introductions may still exist today in the diverse germplasm, which is only now being recorded in Morocco's and Tunisia's geographically isolated Atlas Mountains. Studies by Laghezali in 1985 and Lansari et al in 1994 provide evidence of this.

The New World was colonised by early European and Asian settlers, which resulted in commercial almond cultivation in Australia,South Africa and North and South America. It is necessary to test different regions and germplasm to successfully cultivate almonds due to their vulnerability to winter cold, spring frosts, and summer rains. California introduced almonds as an extension of Mediterranean culture, using limited European germplasm (Wood 1925).

From 1850 to the present, he has been a representation of the New World stage. However, California's methods of almond cultivation deviated from conventional methods used in the rest of the world.Significant adaptations were made in the production of crops, including the selection of specific cultivars and rootstocks that are vegetatively propagated to increase production. Markets were standardized based on the cultivar used, and growing sites were selected and optimized. New cultural and management techniques were developed, such as increased mechanization, and agrochemical inputs, and supplemental pollination. These enhancements have increased yield while also supporting current industrial and commercial strategies (Kester et al 1990, Micke 1994).

Beginning in the middle of the 1950s, California's population of almond seedlings, which can be found either in orchards made from un-budded almond seedling rootstock 'escapes' or along roadsides and close to commercial orchards became the primary source of new cultivars. Numerous choices from this source have been patent and released as commercial cultivars by individual growers through commercial nurseries since 1957 (Brooks & Olmo 1997).

The majority, including "Merced," "Price," "Carmel," and "Fritz," were utilized to cross-pollinate "Nonpareil." Later blooming varieties like "Thompson" and "Livingston" were combined with "Texas." The cooperative breeding program was established in 1923 at Davis, California, between USDA and University of California following early polling nation and cultivar assessment studies (Wood 1938).

In 1948, this program was divided. Up until 1975, the USDA program was still in effect.

Numerous cultivars and rootstocks have been released as a result of the University of California program's ongoing efforts (Kester & Gradziel 1996). The Nikitsky Botanical

When wild almonds are chewed or crushed, their glycoside amygdalin turns into hydrogen cyanide, making them poisonous. It is important to note that cultivated almonds are entirely safe to eat, as they do not contain amygdalin (Verma 2014).

1. History of Almond Cultivation

The almond tree was one of the earliest trees to be grown by humans because of its nutritious and long-lasting kernels, which remain appetizing even when consumed over an extended period of time. It was first cultivated around the third millennium BCE and has been present in the early range of plant domestication across Asia (Spiegel-Roy 1976) The almond is different from other Prunus crops both botanically and horticulturally. These differences have significant implications for its role in human history and its transmission. Botanically, the part that is consumed is a seed, not a fruit. It is a long-lasting source of propagation and a concentrated, desirable, and relatively non-perishable food item, making it a valuable commodity for trade since ancient times (Gradziel 2017).

During prehistoric times, almonds were a valuable commodity in trade across Asia, North Africa, and Europe. This led to the creation of a market standard. The sweet almond, also known as the "Greek nut," is a distinct species and is currently becoming a developing market standard. Also, it is known as *Prunus amygdalus* Batsch, *Amygdalus communis* L., and *Amygdalus dulcis* Mill, *Prunus dulcis* (Mill.) D.A. Webb (Gradziel 2017).

Around 11,000 BCE, Franchthi cave in southern Greece showed evidence of almond and pistachio, It's possible that lentil farming was practiced before grain farming in Asia Minor, indicating a trend (Hansen & Renfrew 1978, Farrand 1999, William, 1999).

Almonds have been a part of culinary culture since ancient times. They were mentioned in Sumerian banquet menus and were commonly used in Palestine, as shown in biblical references (Rosengarten 1984, Goor & Nurock 1968, Janick 2007).

The cultivation of almonds in the eastern Mediterranean began in the second millennium BCE, as evidenced by the remains found in Tutankhamun's tomb (Zohary & Hopf 1993). There are four stages of almond cultivation and distribution: Asiatic, Mediterranean, Californian, and Southern Hemispheres (Kester et al 1990).

The Asiatic stage is the period in which almonds were first domesticated and subsequently spread over central and southwestern Asia. The Greek naturalist Theophrastus wrote about almonds, which he named Amygdalai, in his dissertation on the history of plants around 300 BCE. Almond cultivation was known in Turkey (Ayfer, 1975), Iran (Grigorian 1976), Syria (Spiegel-Roy 1976), China (Gustafson et al 1989), Pakistan, and north-west India (Singh et al 1977) within a few hundred years. The first almond cultivation took place in Kashgar, Xinjiang Province, after being brought from central Asia across the Tian Shan Mountains to the west (Gustafson et al 1989).

The spread of almond cultivation towards the west in the Mediterranean occurred in two stages. Between 300 and 400 BC, the cultivation of almonds had expanded across the Peloponnesian peninsula and the Greek islands (Stylianides 1976). Almonds gradually spread to all suitable regions of the Mediterranean, including Spain, Portugal, Southern France, Portugal, Northern Africa rapid initial growth, and their ability to tolerate summer heat and drought. Almond trees are the first to flower among temperate latitude trees, but this also means that their production is limited to areas with minimal spring frost risk (Badenes & Byrne 2012).

The almond tree is a deciduous tree that typically grows between 4 and 10 meters tall and can reach over 20 meters in height. Moreover, it lives for 100 years or more, and the trunk diameter reaches 30 cm (Mori et al 2011a).
In the first year of cultivation, the immature/young branches appear green and turn purple when exposed to sunlight; in the second year, the purple colour changes to grey (Mori et al 2011, Mushtaq et al 2015).

Lanceolate leaves are 1.2-4 cm broad and4-13 cm long, featuring a serrate edge and a 2.5 cm petiole. In early spring, individual or paired white or pale pink flowers with five petals measuring 3-5 cm in diameter grow before leaves (Bailey et al 1976, Verma 2014, Mushtaq et al 2015).

Almond is a species that mostly cannot fertilize itself (self-sterile). A single locus controls gametophytic self-incompatibility with multiple codominant alleles. This means that cross-pollination is required, leading to increased genetic diversity and greater adaptability to new environments (Benmoussa et al 2017, Gradziel & Martínez-Gómez 2013).

In addition, the almond fruit is botanically classified as a drupe. It is typically 3.5 to 6 cm long and consists of three parts. Firstly, the edible section of the almond is the kernel, or meat, which consists of two big cotyledons covered by brown skin (exocarp) and protected by an exterior hull and an intermediate shell (Gradziel 2009). Second, a fleshy, leathery green-grey coat with a thin hull (mesocarp) expands slightly during development before becoming dry, leathery, and dehiscing at maturity. Third, depending on genotypes, the mature endocarp in the separate hardened shell (endocarp) ranges from hard to soft and papery (Jain & Priyadarshan 2009, Badenes & Byrne 2012a, Mushtaq et al 2015, Barreca et al 2020).

Almonds can be classified into soft- and hard-shell varieties based on their shell characteristics. For instance, In Australia and California, most almond cultivars have soft shells, but most varieties in Spain have hard shells (Shirmohammadi & Fielke 2017).

Fig. 1. Different parts of almond nut in the late-stage of growth.

Almonds begin to bear an economic crop in the third year after planting the trees. Trees achieve their full potential five to six years after planting, depending on varieties and growing conditions. Fruits ripen in the autumn, around 6-7 months after blossoming (Mark & Huxley 1992).

There are two categories in which almonds are classified: sweet and bitter. Sweet almonds are edible, whereas bitter almonds are harmful. Bitter almonds are somewhat more extensive and shorter than sweet almonds. The fixed oil in sweet almonds is 50%. Hydrogen cyanide is produced by bitter almonds (Mouaffak et al 2013).

JKAU: Met., Env. & Arid Land Agric. Sci., Vol. **33** No. 1, pp: 63 - 99 (2024 A.D.)
DOI:10.4197/Met.33-1.5

Almond (*Prunus dulcis*): Comprehensive overview of cultivars, requirements and field Management

Aisha A. Alghamdi [1, 2], Rashed M. Alsabehi[1].

[1] *Department of Biological Sciences, Faculty of Sciences, King Abdulaziz University, 21551 Jeddah, Saudi Arabia*
[2] *Department of Biological Sciences, Faculty of Science and Arts in Almakhwah, Al Baha University, Al Baha, Saudi Arabia*

Abstract. almond [*Prunus dulcis* (Mill.) D.A. Webb, syn. *P. amygdalus* (L.) Batsch] is located in the Mediterranean countries, and its cultivation is restricted to areas that have a Mediterranean climate. Almonds, a type of tree nut, are widely recognised as a healthy snack. They are an excellent source of protein, carbohydrates, antioxidants, and lipids. Almonds also contain flavonoids, vitamin E, riboflavin, amino acids, and minerals such as manganese, magnesium, copper, and phosphorus. Overall, almonds are a nutrient-rich and delicious addition to any diet. Flowering occurs when the requirements for chilling and heat are fully satisfied. When growing self-incompatible cultivars, it is essential to design pollinizers properly. For optimal pollination, it is recommended to have a minimum of 30% pollinizers. Almonds can be classified into soft- and hard-shell varieties based on their shell characteristics. There are two types of almonds: sweet and bitter. The weather, including humidity, temperature, and time of day, heavily influences the water usage of almond orchards. Nutrition is crucial for the proper development of almonds, regular fruiting, and high-quality yields. Almond propagation through grafting has allowed for an improved selection of scions to be clonally propagated. New rootstocks should possess desirable traits such as tolerance to poor soils, including calcareous soil, ease of propagation through hardwood cuttings or micro-propagation, as well as high rootstock vigour. New hybrids with increased tolerance to heavy and water-saturated soils are currently in development. Locally adapted elite genotypes are captured through clonal propagation, resulting in the identification and propagation of hundreds of cultivars in specific production areas. Furthermore, numerous molecular studies have been conducted, facilitating the transfer of these desirable traits. Generally, this article focuses on the process of managing the fields, from selecting cultivars to harvesting, in order to achieve high quality and high-quality almond production.

Keywords: Almond*, Prunus dulcis*, cultivars, requirements, fields Management, production.

INTRODUCTION:

Almond(*Prunus dulcis* (Miller) D. A.Webb syn. *Prunus amygdalus* Batsch., *Amygdalus communis* L., *Amygdalus* dulcis Mill.) is the earliest domesticated nut tree to flower in spring, due to its low chill requirements and quick response to warm temperatures (Javaid et al 2019).

Almonds are commonly grown and consumed in Mediterranean countries, which include regions in California, in the Central Valley of the Middle East, Syria, Turkey, and Iran; Central Asia; the slopes of the Himalayas; and the Southern Hemisphere, including Chile, Argentina, Southern Africa, and Australia (Badenes & Byrne 2012, Javaid et al 2019). Several international breeding programs have spread almond cultivation to colder regions, such as northern Europe and America, by delaying the timing of flowering (Sakar et al 2019).

Almond cultivation is limited to Mediterranean climates with minimal rainfall in late winter, summer, and early fall. Almonds thrive in mild winters and hot, dry summers thanks to their low requirement for cold temperatures to initiate early flowering, their

تقييم الغطاء النباتي الطبيعي في محيط مدينة مكة المكرمة، المملكة العربية السعودية

جمانه عبدالإله عبدالشكور
جامعة الملك عبدالعزيز

مستخلص. مكة المكرمة – المملكة العربية السعودية، هي من أهم المدن التي واجهت انخفاضًا في الغطاء النباتي الطبيعي، بسبب مناخها الجفاف الحار، حيث تتراوح درجة الحرارة العظمى حوالي ٤٠-٤٩ درجة مئوية، وندرة هطول الأمطار، ويتراوح معدل هطول الأمطار بين ٥٠-٨٠ ملم/سنة. من المفترض أن يكون النبات طبيعيا من نباتات المنطقة، بمعنى أن ينمو النبات بشكل طبيعي في منطقة معينة أو نظام بيئي أو موطن معين دون تدخل بشري. الهدف من هذه الدراسة هو تقييم الحياة النباتية الطبيعية حول مدينة مكة المكرمة من خلال اختيار ثمانية مواقع من مناطق مختلفة. وكانت مساحة قطع الأرض حوالي ١٠ × ١٠ أمتار. وكشفت الدراسة أن المواقع الثمانية تمثلت بـ ٢٠ نوعا تنتمي إلى ٨ عائلات، هي الفصيلة البقولية Fabacese والفصيلة الدفلية Apocynaceae بنسبة (٣٤٪)، (٢٥٪) تليها الفصيلة القطيفية Amaranthaceae (١٣٪)،الفصيلة النجيلية Poaceae (١٢٪) ، فصيلة القرعيات Cucurbitaceae (٥٪). ثم تمثلت (الفصيلة الخيمية Apiaceae و الفصيلة النجمية Asteraceae) بنسبة (٤٪)، بينما تمثل الفصيلة الباذنجانية Solanaceae (٣٪) فقط من الغطاء النباتي. أما أشكال الحياة في النباتات المحلية فكانت النباتات البذرية (٤٠٪) هي السائدة بينما كانت النباتات النصف مستترة (He) هي الأقل قيمة في أشكال الحياة (١٠٪). واظهرت الدراسة أن الفئات الزهرية هي الصحراوية العربية (SA) والسودانية الزامبيزية (AZ) هي المهيمنة حيث تمثل (٣٨٪)، في حين كانت فئات البحر الأبيض المتوسط(ME) ، والصحراوية السندية(SSI) ، والاستوائية(TR) ، والإيرانية الطورانية (IT) هي الأقل قيمة وتمثل تقريباً (٦٪).

بالنسبة لأنواع النباتات فلقد ظهر أن نبات *Rhazya stricta* هو الأكثر عددا من الأنواع التي لوحظت في النباتات المحلية في منطقة الدراسة ويمثل (١٧٪)، في حين تم العثور على *Cenchrus biflorus* و *Leptadenia pyrotechnica* و*Lycium shawii* و*Panicum turgidum* و*Senegalia asak* و*Senna italica* و*Stipellula capensis* و*Vachellia frav* و*Vachellia tortilis* . الأدنى بنسبة (٣٪) في جميع المواقع. وأخيراً، فإن هناك نقص في أنواع النباتات في منطقة مكة.

Arabia. *Turkish Journal of Botany*, *37*(5), 894-907.

Lloyd, M., Zar, J. H., & Karr, J. R. (1968). On the calculation of information-theoretical measures of diversity. *American Midland Naturalist*, 257-272.

Meurant, G. (2012). *An Introduction to Numerical Classification*. Elsevier.

Migahid, A. M. (1978). "*Flora of Saudi Arabia*." Riyadh University,Saudi Arabia

Minnesota Department of Natural Resources. (2013). A handbook for collecting vegetation plot data in Minnesota: The relevé method.

Mishra, S., Shrivastava, P., & Dhurvey, P. (2017). Change detection techniques in remote sensing: a review. *International Journal of Wireless and Mobile Communication for Industrial Systems*, 4(1):1-8.

Mosallam, H. A. (2007). Comparative study on the vegetation of protected and non-protected areas, Sudera, Taif, Saudi Arabia. *International Journal of Agriculture and Biology (Pakistan)*

Mueller Dombois, D., & Ellenberg, H. (1974). *Aims and methods of vegetation ecology* (No. 581.5 M8).

Noor, T. H., Noor, A., & Elmezain, M. (2022). Poisonous Plants Species Prediction Using a Convolutional Neural Network and Support Vector Machine Hybrid Model. *Electronics*, *11*(22), 3690.

Osman, A. (2012, September). Seismic hazard analysis and development of ground motion parameters for Makkah region in Saudi Arabia. In *Proceedings of the 15th World Conference on Earthquake Engineering, Lisbon, Portugal* (pp. 24-28).

Pielou, E. C. (1966). The measurement of diversity in different types of biological collections. *Journal of theoretical biology*, *13*, 131-144.

Rahman, M. A., J. S. Mossa, M. S. Al-Said and M. A. Al-Yahya (2004). "Medicinal plant diversity in the flora of Saudi Arabia 1: a report on seven plant families." *Fitoterapia* **75**(2): 149-161.

Raunkiaer, C. (1937). *Plant life forms*. Clarendon press.

Raymond, C. M., Brown, G., & Robinson, G. M. (2011). The influence of place attachment, and moral and normative concerns on the conservation of native vegetation: A test of two behavioural models. *Journal of Environmental Psychology*, *31*(4), 323-335.

Shalaby, A., & Tateishi, R. (2007). Remote sensing and GIS for mapping and monitoring land cover and land-use changes in the Northwestern coastal zone of Egypt. *Applied geography*, *27*(1), 28-41.

Tehrany, M. S., Kumar, L., & Drielsma, M. J. (2017). Review of native vegetation condition assessment concepts, methods and future trends. Journal for Nature Conservation, 40, 12-23.

Torrion, J. A. (2002, February). Land degradation detection, mapping and monitoring in the Lake Naivasha Basin, Kenya. ITC.

Wickens, G.E. 1976. *The flora of Jebel Morra (Sudan Republic) and its geographical affinities*. Kew Bulletin Additional Series V. London: HMSO.

Zahran, M. (1982). Vegetation types of Saudi Arabia. *King Abdel Aziz University Press, Jeddah, Saudi Arabia*.

Zohary, M. (1973). "*Geobotanical foundations of the Middle East*." Vol. 2, Stuttgart, Gustav Fischer Verlag and Asterdam, Netherlands.

Al-Yasi, H. M., Alotaibi, S. S., Al-Sodany, Y. M., & Galal, T. M. (2019). Plant distribution and diversity along altitudinal gradient of Sarrawat Mountains at Taif Province, Saudi Arabia. *Bioscience Research*, *16*(2), 1198-1213.

Ayyad, M. A., & El-Ghareeh, R. E. M. (1982). Salt marsh vegetation of the western Mediterranean desert of Egypt. *Vegetatio*, *49*, 3-19.

Boulos, L. (1997). endemic flora of the Middle east and North Africa. *Reviews in ecology: desert conservation and development. Metropole, Cairo*, 229-260.

Boulos, L. (2005). Flora of Egypt, volume four, Monocotyledons.

Cetin, M., Adiguzel, F., Gungor, S., Kaya, E., & Sancar, M. C. (2019). Evaluation of thermal climatic region areas in terms of building density in urban management and planning for Burdur, Turkey. *Air Quality, Atmosphere & Health*, *12*(9), 1103-1112.

Chaturvedi, R. K., & Sankar, K. (2006). Laboratory manual for the physico-chemical analysis of soil, water and plant. *Wildlife Institute of India, Dehradun*, *97*.

Chaudhary, S. (1999). "*Flora of the Kingdom of Saudi Arabia*: vol. 1." Riyadh: Ministry of Agriculture and Water, National Herbarium, National Agriculture and Water Research Center 691p.-illus. En Icones, Anatomy and morphology, Keys. Geog **2**.

Chaudhary, S. (2000). "*Flora of the Kingdom of Saudi Arabia*: illustrated volume 2 (part 3)." Riyadh: Ministry of Agriculture iii, 432p.

Chaudhary, S. A. (2001). Flora of the Kingdom of the Saudi Arabia, vol. III. *Ministry of Agriculture and Water, Riyadh, Saudi Arabia*.

Collenette, I. (1998). "A checklist of botanical species in Saudi Arabia." *Burgess Hill, England: International Asclepiad Society 80p.-. ISBN* 953237605.

Collenette, S. (1999). *Wildflowers of Saudi Arabia*. National Commission for Wildlife Conservation and Development (NCWCD).

Elaidarous, A. A., Osman, H. E., Galal, T. M., & El-Morsy, M. H. (2022). Vegetation–environment relationship and floristic diversity of Wadi Al-Sharaea, Makkah Province, Saudi Arabia. Rendiconti Lincei. Scienze Fisiche e Naturali, 33(1), 169-184.

EL-GHANI, M. M., & ABDEL-KHALIK, K. N. (2006). Floristic diversity and phytogeography of the Gebel Elba National Park, south-east Egypt. *Turkish Journal of Botany*, *30*(2), 121-136.

El-Ghanim, W. M., Hassan, L. M., Galal, T. M., & Badr, A. (2010). Floristic composition and vegetation analysis in Hail region north of central Saudi Arabia. *Saudi Journal of Biological Sciences*, *17*(2), 119-128.

Elhag, M., & Bahrawi, J. A. (2016). Consideration of geo-statistical analysis in soil pollution assessment caused by leachate breakout in the municipality of Thermi, Greece. *Desalination and Water Treatment*, *57*(57), 27879-27889.

Franklin, J. (1995). Predictive vegetation mapping: geographic modelling of biospatial patterns in relation to environmental gradients. *Progress in physical geography*, *19*(4), 474-499.

Galal, T. M., Al-Yasi, H. M., & Fadl, M. A. (2021). Vegetation zonation along the desert-wetland ecosystem of Taif Highland, Saudi Arabia. *Saudi Journal of Biological Sciences*, *28*(6), 3374-3383.

Guisan, A., & Zimmermann, N. E. (2000). Predictive habitat distribution models in ecology. *Ecological modelling*, *135*(2-3), 147-186.

Heip, C. H., Herman, P. M., & Soetaert, K. (1998). Indices of diversity and evenness. *Oceanis*, *24*(4), 61-88.

Hunter, P. R., & Gaston, M. A. (1988). Numerical index of the discriminatory ability of typing systems: an application of Simpson's index of diversity. *Journal of clinical microbiology*, *26*(11), 2465-2466.

Keylock, C. J. (2005). Simpson diversity and the Shannon–Wiener index as special cases of a generalized entropy. *Oikos*, *109*(1), 203-207.

KHALIK, K. A., El-Sheikh, M., & El-Aidarous, A. (2013). Floristic diversity and vegetation analysis of wadi Al-Noman, Mecca, Saudi

biodiversity-adapted area. Also, Native plants are the best adapted in the region because their characteristics such as less supplemental watering, aid in regulating precipitation runoff and preserve healthy soil because their deep root systems prevent the compaction of the soil. In Makkah, compared to previous studies the study showed there is a reduction in the number of species. This can be mainly due to the presence of various habitats each with features as regards the soil characteristics, rock type, water resources and grazing.

6. Acknowledgments

First and foremost, I must acknowledge my limitless thanks to Allah.

I owe a deep debt of gratitude to Dr. Amal Al-dhebiani for her motivation and continuous encouragement.

Then all the appreciation and thanks to my family

7. References

Aati, H., El-Gamal, A., Shaheen, H., & Kayser, O. (2019). Traditional use of ethnomedicinal native plants in the Kingdom of Saudi Arabia. *Journal of ethnobiology and ethnomedicine*, *15*, 1-9.

Abbas, A. M., Al-Kahtani, M. A., Alfaifi, M. Y., Elbehairi, S. E. I., & Badry, M. O. (2020). Floristic diversity and phytogeography of Jabal Fayfa: a subtropical dry zone, south-west Saudi Arabia. *Diversity*, *12*(9), 345.

Abd El-Ghani, M. M., & El-Sawaf, N. (2004). Diversity and distribution of plant species in agro-ecosystems of Egypt. *Systematics and Geography of Plants*, 319-336.

Abdelrahman, K., lamri, A. M., Al-Otaibi, N., & Fnais, M. (2020). Geotechnical assessment for the ground conditions in Makah Al-Mukarramah city, Saudi Arabia. *Journal of King Saud University-Science*, *32*(3), 2112-2121.

Abdel khalik, K. A., El-Sheikh, M., & El-Aidarous, A. (2013). Floristic diversity and vegetation analysis of wadi Al-Noman, Mecca, Saudi Arabia. Turkish Journal of Botany, 37(5), 894-907.

Albeshri, A., Baeshen, N. A., Bouback, T. A., & Aljaddawi, A. A. (2021). A review of rhazya stricta decne phytochemistry, bioactivities, pharmacological activities, toxicity, and folkloric medicinal uses. *Plants*, *10*(11), 2508.

Al-Eisawi, D. M., & Al-Ruzayza, S. (2015). The flora of holy Mecca district, Saudi Arabia. *International Journal of Biodiversity and conservation*, 7(3):173-189.

Alfarhan, A. H., Chaudhary, S. A., & Thomas, J. (1998). Notes on the flora of Saudi Arabia. *Journal-King Saud University Science*, *10*, 31-40.

AL-HARTHI, S. T. S., AL-QAHTANI, A. M., & AL-MUNQEDHI, B. M. (2021). Alien plants in Western region, Saudi Arabia.

Aljeddani, G. S., Al-Harbi, N. A., Al-Qahtani, S. M., El-Absy, K. M., Abdullatif, B. M., & Dahan, T. E. (2021). Inventory of some introduced and invasive plant species in some governorates of the Kingdom of Saudi Arabia. *Appl. Ecol. Environ. Res*, *19*, 4373-4388.

Allen, S. E., Grimshaw, H. M., Parkinson, J. A., & Quarmby, C. (1974). *Chemical analysis of ecological materials*. Blackwell Scientific Publications.

Allen, S. E. (1989). Chemical analysis of ecological materials, Black Well Sci. Pub. *Osney*.

AlNafie, A. H. (2008). Phytogeography of Saudi Arabia. *Saudi Journal of Biological Sciences*, *15*.

Al-Namazi, A. A., Algarni, S. M., Wan, J. S., Al Mosallam, M. S., & Alotaibi, F. (2022). Floristic composition of Jandaf Mountain as biodiversity hotspot area in southwestern Saudi Arabia. *Saudi Journal of Biological Sciences*, *29*(5), 3654-3660

Alshareef, A. (1984). Geography of Saudi Arabia South-West of the Kingdom. *Dar Almerikh, Riyadh. Saudi Arabia*, *2*, 1-488.

Al-Sherif, E. A., Ayesh, A. M., & Rawi, S. M. (2013). Floristic composition, life form and chorology of plant life at Khulais region, Western Saudi Arabia. *Pak. J. Bot*, *45*(1), 29-38.

Ashrae H (2005). Design condition for Makkah, Saudi Arabia. *Fundamentals* (SI), 1:1-2.

Al-Yasi, H. M. (2015). Plant Diversity Using Soil Seed Bank Technique in West Region at KSA.

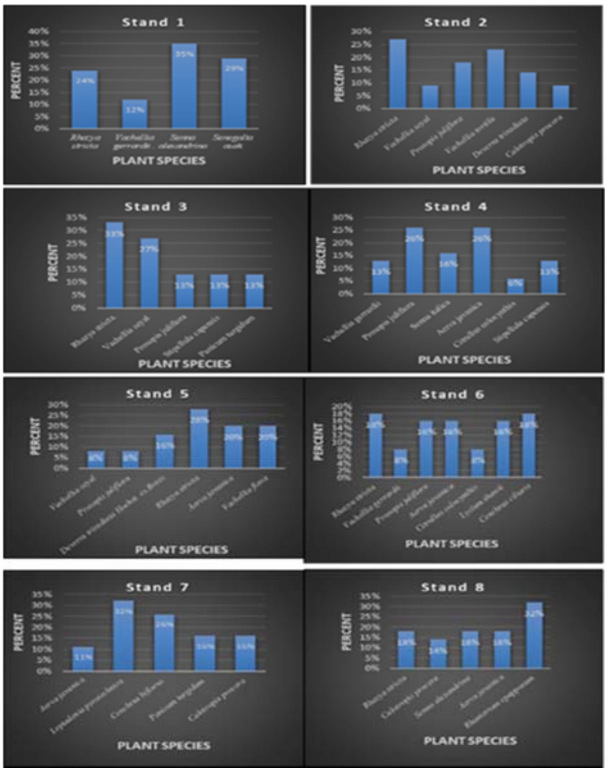


Figure 13. Proportions of plant species among each stand.

4. Discussion

The vegetation is the expression of the environment inside the specified locality within a specified period. It varies from year to year based on environmental conditions especially according to rainfall and temperature circumstances. During the study period in Makkah from December 2021 to February 2022, the precipitation was decreased according to National Center for Meteorology about (20.6 mm). Moreover, the characteristics of the vegetation cover of Makkah has low floristic diversity.

In terms of floristic and vegetation composition in the studied area, the families Fabaceae was represented by the highest number of species (34% which is agreed with Aati *et al*. (2019) who recorded the that Fabiaceae is the most dominating family in Saudi Arabia. Furthermore, this result coincides with Al-Eisawi & Al-Ruzayza (2015) who reported that the common families in the flora of Makkah in 2015 were Poaceae and Fabaceae by (16.94% and 13.11%, respetively); but in this study Fabeaceae was followed by Apocynaceae with 25% as the second dominant family instead of Poaceae as in Al-Eisawi and Al-Ruzazya result.

Moreover, it is well known that Fabaceae constitute the main bulk of plant species in Saudi Arabia as recorded and mentioned in many publications such as (Alfarhan *et al*., 1998; Collentte 1999; Mosallam, 2007; Al-Nafie, 2008 and El-Ghanim *et al*., 2010, Al-Namazi et al., 2022). Correspondingly, similar results were obtained in neighboring countries, such as Egypt (Abd EL-Ghani and Abd El-Khalik, 2006; Abd El-Ghani and El-Sawaf, 2004) and Jebel Marra of the Sudan (Wickens, 1976).

The dominance of Phanerophytes (Ph) life form by 40% was in dispute with the results of Al-Esawi and Al-Ruzazya (2015), this could be due to the changes of the ecological conditions through the years. The followed dominance life forms Therophytes (Th) and Chamaephytes (Ch) (5 species) (25%), are in accordance with Al-Esawin and Al-Ruzazya result. Moreover, it is also in accordance with Abdel Khlik *et al.* (2013).

The most prevalent chorotype was Saharo-Arbian like in most previous studies in Makkah region (Abduel-Khalik et al., 2013; Al-Esawi and Al-Ruzazya, 2015). While the Irano-Turanian was the second common in Al-Esawi and Al-Ruzazya, here it is the least frequent.

Rhazya stricta (Apocynaceae) was the richest species in the study area about 17%. *Rhazya stricta* is one of the most economically significant medicinal plants, found all over the Arabian Peninsula and dry South Asia, leaves are used in the traditional system of medicine to treat syphilis, chronic rheumatism, and body pain (Albeshri *et al*., 2021). *Calotropis procera* was the most dominant species in Makkah region in other studies (Abdel-Khalik et al., 2013). Even though, they are two different species but they belong to the same family Apocynaceae; this could explain why Apocynaceae is the second dominant family in this study.

5. Conclusions and Recommendation

Preservation of the native plant species conservation is important to maintain the

Stand	Species	Density	%	Shannon	Shannon winner value	Simpson	Simpson value
	Aerva javanica (Burm. fil.) Juss.	6	16%	-0.29144632		0.021337127	
	Citrullus colocynthis (L.) Schrader	3	8%	-0.200445306		0.004267425	
	Lycium shawii Roem. & Schult.	6	16%	-0.29144632		0.021337127	
	Cenchrus ciliaris L.	7	18%	-0.311624528		0.029871977	
	Total	38	100%				
7	*Aerva javanica* (Burm. fil.) Juss.	2	11%	-0.236978084	1.1	0.005847953	0.81
	Leptadenia pyrotechnica (Forssk.) Decne.	6	32%	-0.364004056		0.087719298	
	Cenchrus biflorus Roxb.	5	26%	-0.35131607		0.058479532	
	Panicum turgidum Forssk	3	16%	-0.29144632		0.01754386	
	Calotropis procera (Aiton) W.T.Aiton	3	16%	-0.29144632		0.01754386	
	Total	19	100%				
8	*Rhazya stricta* Decne.	4	18%	-0.309954199	1.2	0.025974026	0.82
	Calotropis procera (Aiton) W.T.Aiton	3	14%	-0.271695022		0.012987013	
	Senna alexandrina Mill.	4	18%	-0.309954199		0.025974026	
	Aerva javanica. (Burm. fil.) Juss.	4	18%	-0.309954199		0.025974026	
	Rhanterium epapposum Oliv.	7	32%	-0.364360279		0.090909091	
	Total	22	100%				

Total number of all Species	20
Shannon index value	2.035983198
Simpson index value	0.868175166

Stand	Species	Density	%	Shannon	Shannon winner value	Simpson	Simpson value
	Deverra triradiata Hochst. ex Boiss.	3	14%	-0.271695022		0.012987013	
	Calotropis procera (Aiton) W.T.Aiton	2	9%	-0.217990479		0.004329004	
	Total	22	100%				
3	*Rhazya stricta*. Decne	5	33%	-0.366204096	0.6	0.095238095	0.82
	Vachellia seyal (Delile) P.J.H.Hurter	4	27%	-0.352468224		0.057142857	
	Prosopis juliflora (Sw.) DC.	2	13%	-0.268653736		0.00952381	
	Stipellula capensis (Thunb.) Röser & Hamasha	2	13%	-0.268653736		0.00952381	
	Panicum turgidum Forssk	2	13%	-0.268653736		0.00952381	
	Total	15	100%				
4	*Vachellia gerrardii* (Chaudhary) Ragup., Seigler, Ebinger & Maslin	4	13%	-0.264218431	1.2	0.012903226	0.83
	Prosopis juliflora (Sw.) DC.	8	26%	-0.349560171		0.060215054	
	Senna italica Mill.	5	16%	-0.294282144		0.021505376	
	Aerva javanica (Burm. fil.) Juss.	8	26%	-0.349560171		0.060215054	
	Citrullus colocynthis (L.) Schrader	2	6%	-0.176828389		0.002150538	
	Stipellula capensis (Thunb.) Röser & Hamasha	4	13%	-0.264218431		0.012903226	
	Total	31	100%				
5	*Vachellia seyal* (Delile) P.J.H.Hurter	2	8%	-0.202058292	1.7	0.003333333	0.84
	Prosopis juliflora (Sw.) DC.	2	8%	-0.202058292		0.003333333	
	Deverra triradiata Hochst. ex Boiss.	4	16%	-0.293213034		0.02	
	Rhazya stricta Decne	7	28%	-0.356430389		0.07	
	Aerva javanica (Burm. fil.) Juss.	5	20%	-0.321887582		0.03333333	
	Vachellia flava (Forssk.) Kyal. & Boatwr.	5	20%	-0.321887582		0.03333333	
	Total	25	100%				
6	*Rhazya stricta* Decne.	7	18%	-0.311624528	1.8	0.029871977	0.087
	Vachellia gerrardii (Chaudhary) Ragup., Seigler, Ebinger & Maslin	3	8%	-0.200445306		0.004267425	
	Prosopis juliflora (Sw.) DC.	6	16%	-0.29144632		0.021337127	

17	*Vachellia flava (Forssk.) Kyal. & Boatwr.*	Fabaceae	Ph	S
18	*Vachellia gerrardii* (Chaudhary) Ragup., Seigler, Ebinger & Maslin	Fabaceae	Ph	S
19	*Vachellia seyal* (Delile) *P.J.H.Hurter*	Fabaceae	Ph	
20	*Vachellia tortilis* (Forssk.) Galasso & Banfi	Fabaceae	Ph	

Table 4. The density of plant taxa represented in 8 stands around Makkah city.

Plant Species	Total N=190	
	Density	%
Aerva javanica (Burm. fil.) Juss.	25	13%
Calotropis procera (Aiton) W.T.Aiton	8	4%
Cenchrus biflorus Roxb.	5	3%
Cenchrus ciliaris L.	7	4%
Citrullus colocynthis (L.) Schrader.	10	5%
Deverra triradiata Hochst. ex Boiss.	7	4%
Leptadenia pyrotechnica (Forssk.) Decne.	6	3%
Lycium shawii Roem. & Schult.	6	3%
Panicum turgidum Forssk	5	3%
Prosopis juliflora (Sw.) DC.	18	9%
Rhanterium epapposum Oliv.	7	4%
Rhazya stricta Decne.	33	17%
Senegalia asak (Forssk.) Kyal. & Boatwr.	5	3%
Senna alexandrina Mill.	10	5%
Senna italica Mill.	5	3%
Stipellula capensis (Thunb.) Röser & Hamasha	6	3%
Vachellia flava (Forssk.) Kyal. & Boatwr.	5	3%
Vachellia gerrardii (Chaudhary) Ragup., Seigler, Ebinger & Maslin	9	5%
Vachellia seyal (Delile) P.J.H.Hurter	8	4%
Vachellia tortilis (Forssk.) Galasso & Banfi	5	3%

Table 5. Analysis of the plant taxa represented in each stand around Makkah city.

Stand	Species	Density	%	Shannon	Shannon winner value	Simpson	Simpson value
1	*Rhazya stricta* Decne.	4	24%	-0.340451525	1.32	0.044117647	0.76
	Vachellia gerrardii.	2	12%	-0.25177249		0.007352941	
	Senna alexandrina Mill.	6	35%	-0.367571956		0.110294118	
	Senegalia asak (Forssk.) Kyal. & Boatwr.	5	29%	-0.35993395		0.073529412	
	Total	17	100%				
2	*Rhazya stricta* Decne.	6	27%	-0.354349905	1.7	0.064935065	0.81
	Vachellia seyal (Delile) P.J.H.Hurter	2	9%	-0.217990479		0.004329004	
	Prosopis juliflora (Sw.) DC.	4	18%	-0.309954199		0.025974026	
	Vachellia tortilis (Forssk.) Galasso& Banfi	5	23%	-0.336728305		0.043290043	
	Deverra triradiata Hochst. ex Boiss.	3	14%	-0.271695022		0.012987013	

Figure 11. The Shannon index among each stand.

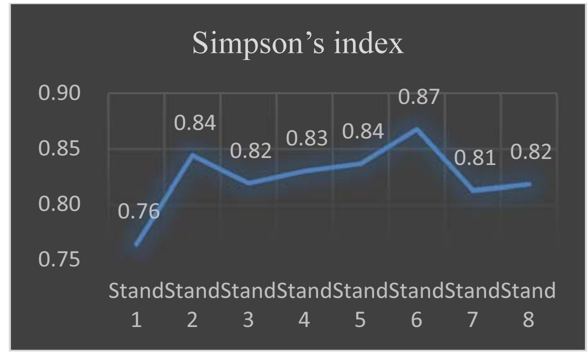


Figure 12. The Simpson's index among each stand.

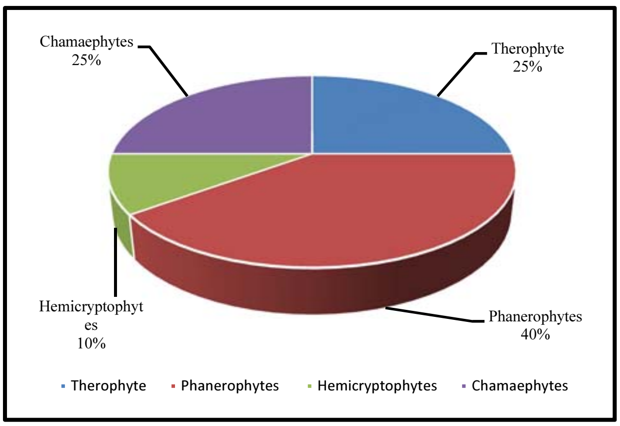
Table 3. The list of plant species in 8 represented stands around Makkah city including life-form, growth and floristic categories.
Categories: ME= Mediterranean, SA= Saharo-Arabian, SSi= Saharo-Sindian, TR= Tropical, SZ = Sudano-Zambezian, and IT = Irano-Turanian

	Plant species	Family	Life form	Growth	loristic categories
1	*Aerva javanica.* (Burm. fil.) Juss.	Aramanthaceae	Th	Herbs	TR
2	*Calotropis procera* (Aiton) W.T.Aiton	Apocynaceae	Ph	Shrubs	SA
3	*Cenchrus biflorus* Roxb.	Poaceae	Th	Grass	TR
4	*Cenchrus ciliaris* L.	Poaceae	He	Grass	SA+SZ
5	*Citrullus colocynthis* (L.) Schrader.	Cucurbitaceae	Th	Herbs	SZ+SA+IT+ME
6	*Deverra triradiata* Hochst. ex Boiss.	Apiaceae	Ch	Shrubs	SA
7	*Leptadenia pyrotechnica* (Forssk.) Decne.	Apocynaceae	Ph	Shrubs	SA+SZ
8	*Lycium shawii* Roem. & Schult.	Solanaceae	Ch	Shrubs	SA+SZ+IT
9	*Panicum turgidum* Forssk	Poaceae	He	Shrubs	SA+SZ
10	*Prosopis juliflora* (Sw.) DC.	Fabaceae	Ph	Shrubs or small trees	SA+ME+SZ
11	*Rhanterium epapposum* Oliv.	Asteraceae	Th	Shrubs	SA
12	*Rhazya stricta* Decne.	Apocynaceae	Ch	Shrubs or small trees	SA+SZ
13	*Senegalia asak* (Forssk.) Kyal. & Boatwr.	Fabaceae	Ph	Shrubs	SA+SZ
14	*Senna alexandrina* Mill.	Fabaceae	Ch	Shrubs	SSI+SZ
15	*Senna italica* Mill.	Fabaceae	Ch	Shrubs	SA+SZ
16	*Stipellula capensis* (Thunb.) Röser & Hamasha	Poaceae	Th	Geass	SA

The Floristic categories Saharo-Arabian (SA) and Sudano-Zambezian (AZ) were the dominant by (38%), while Mediterranean (ME), Saharo-Sindian (SSI), Tropical (TR), Irano-Turanian (IT) were all represented by (6%) (Fig 8 & Table 3).

Figure 8. The life-form of plant taxa in 8 represented stands around Makkah city.

Figure (9) and Table (4) Showed that Rhazya stricta had the highest number of species in the study area 33 species (17%), followed by Aerva javanica 25 species (13%) and Prosopis juliflora 18 species (9%), While Cenchrus biflorus, Leptadenia pyrotechnica, Lycium shawii, Panicum turgidum, Senegalia asak, Senna italica, Stipellula capensis, Vachellia flava and Vachellia tortilis were represented by only 3% over the stands.



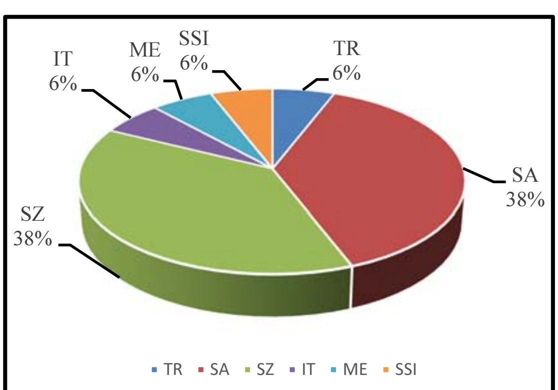


Figure 9. The Floristic categories of the plant taxa in 8 represented stands around Makkah city.

Categories: ME= Mediterranean, SA= Saharo-Arabian, SSi= Saharo-Sindian, TR= Tropical, SZ = Sudano-Zambezian, and IT = Irano-Turanian

Among all studied vegetations, The Shannon index was (2.036), while Simpson's index was (0.868). The values of Shannon index in the study area as follows: 1.2 (stand1), 1.7 (stand2), 0.6 (stand3), 1.2 (stand 4), 1.7 (stand 5), 1.8 (stand 6), 1.1 (stand 7) and 1.2 (stand 8). Which means that stand 6 was the highest in biodiversity while stand 3 was the lowest as shown in Figure 10 and Table 5.

Simpson's Results in the study area showed that the 0.250 (stand1), 0.071 (stand2), 0.333 (stand3), 0.372 (stand 4), 0.111 (stand 5), 0.083 (stand 6), 0 (stand 7) and 0.267 (stand 8). Which means that stands 4 is the highest in biodiversity while the lowest is stand 7 as shown in Figure 11 and Table 5.

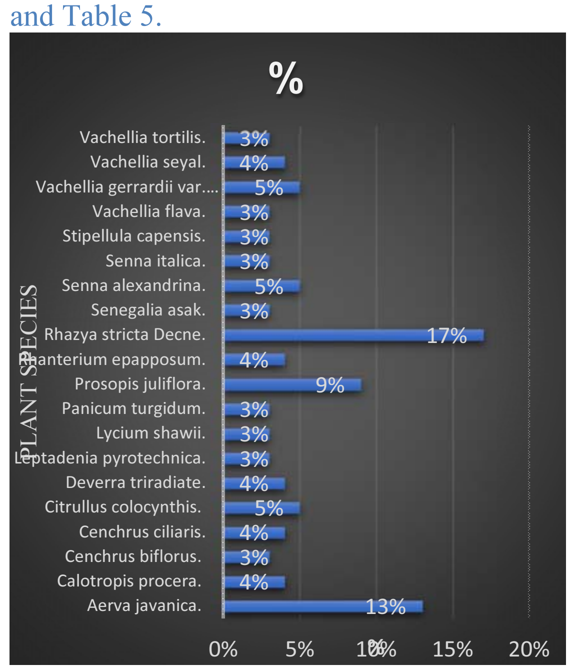


Figure 10. The density of plant vegetation in 8 represented stands around Makkah city.

families; (Abundance 1) The families Fabaceae and Apocynaceae were the dominance by (34%), (25%) respectively, followed by Amaranthaceae (13%), Poaceae (12%) and Cucurbitaceae (5%); then tow families Apiaceae & Asteraceae were represented by (4%), while Solanaceae was represented by only (3%) of the vegetation (Fig 5 & Table2).

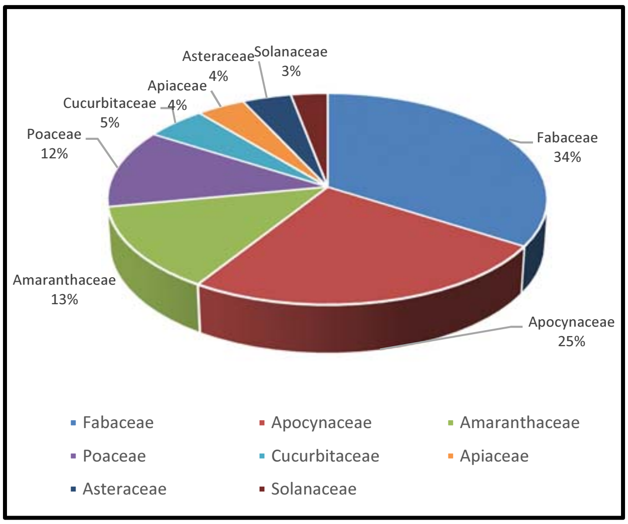


Figure 5. Families of the plant taxa in 8 represented stands around Makkah city.

Table 2. Plant Families among the study aera.

S

H

Shrubs dominated the vegetation growth of the study area by (54%), followed by trees, Grass, Herbs and small trees (17%, 13%, 8% and 8%, respectively) (Fig 6 & Table 3).

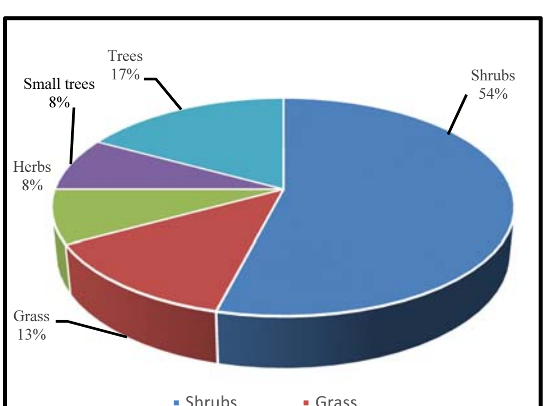


Figure 6. Plant growth form of plant taxa in 8 represented stands around Makkah city.

The life form of the recognized species follows Raunkiaer scale; Raunkiaerin's approach explains and helps in understanding the flora and structure of vegetation in relation to prevailing ecobiological conditions. As shown in (Fig 7 &Table 3), Phanerophytes (Ph) (8 species) by 40% is the dominance life form of the total species over the other life forms, followed by Therophytes (Th) and Chamaephytes (Ch) (5 species) (25%), while Hemicryptophytes (He) was the lowest value of life form (2 species) (10%).

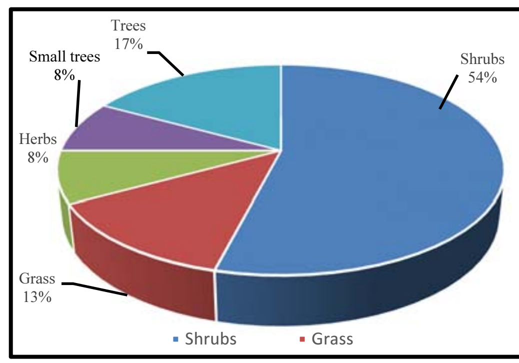


Figure 7. Plant growth form of plant taxa in 8 represented stands around Makkah city.

	Vegetations N=190	
Family	Density (count)	%
Fabaceae	65	34%
Apocynaceae	47	25%
Amaranthaceae	25	13%
Poaceae	23	12%
Cucurbitaceae	10	5%
Apiaceae	7	4%
Asteraceae	7	4%
Solanaceae	6	3%

these species. The global distributions (i.e., floristic regions) are coded as follows:

Analysis of species richness and Density

There are various indices for examining species richness in a region based on estimations of the relative abundance of the species derived from samples (Heip *et al*., 1998). Among these indices are the Shannon–Wiener information function (Lloyd *et al*., 1968), the Simpson's dominance index (Hunter and Gaston, 1988), the Margalef species richness index (Meurant, 2012), and the Pielou evenness index (Pielou, 1966). The first two were used in the current study due to the linkage between a common family of diversity indices and nonadditive statistical mechanics (Keylock, 2005).

The Shannon index.

The main principle of this index is that the diversity of a community is the amount of data in a code. It is calculated as follows.

$$H = -\sum_{i=1}^{S} (p_i \times \ln p_i) = -\sum_{i=1}^{S} \left(\frac{n_i}{N} \times \ln \frac{n_i}{N}\right)$$

In this formula, S is the total number of species.
P = is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N)
ni = number of individuals of species "i"
p = is the proportion
pi = relative abundance of species "I"
N = total number of individuals of all species
$\frac{ni}{N}$ = equivalent to pi, the probability of N finding the i-th species.
H = Shannon Diversity Index

Simpson index

Simpson's approach for assessing species diversity evaluates the dominance of a species relative to the number of species in a sample or

$$D = [\Sigma n_i (n_i - 1)] / N (N - 1)]$$

population (Hunter and Gaston, 1988). It is calculated as follows.

D is the Simpson diversity index, n_i is the number of individuals belonging to i species, and N is the total number of individuals.

- *Density analysis*

One of the often-employed techniques is predictive vegetation modeling. It is described as "predicting the distribution of vegetation across a landscape based on the relationship between the spatial distribution of vegetation and certain environmental variables" (Franklin, 1995 &

$$\gamma_{(k)} = \frac{1}{2n\,(k)} \cdot \sum_{i=1}^{2(k)} \left[z_{(x_i)} - z_{(x_i+k)}\right]^2,$$

IT	*Irano-Turanian*
ME	*Mediterranian*
SA	*Saharo-Arabian*
SSI	*Saharo-Sindian*
SZ	*Sudano-Zambezian*
TR	*Tropical*

Guisan and Zimmermann, 2000). Concepts of spatial variations are obtained according to the following equations.

where n(k) is the number of pairs of observation, and Z(xi) is the feature property measured in point x and in point $x + k$.

$$Z \cdot (x_0) = \sum_{i=1}^{n} \lambda_i \cdot z\,(x_i),$$

where $Z \cdot (x0)$ is the interpolated value of variable Z at location, $x0$, $Z(xi)$ represents the values measured at location xi, and λi is the weighed coefficient calculated based on the semi variogram when

$$\sum_{i=1}^{n} \lambda_i = 1.$$

There for, it is possible to obtain non-biased interpolated values; that is, the expected value $E\ [Z \cdot (x0) - Z(x0)] = 0$ and the estimated variance $\text{Var.}[Z{\cdot}(x0) - Z(x0)]$= minimum (Elhag and Bahrawi, 2016).

3.Result

A total of 190 plant specimen in the 8 stands were represented by 20 species belonging to 8

N o.	Longitude	Latitude	Slope	The aspect
1	39°59'27"E	21°30'53"N	˚3.4143996	Northeast
2	39°38'09"E	21°31'52"N	˚0.7359542	Northwest
3	39°39'55"E	21°20'36"N	˚3.4144068	Southwest
4	39°56'48"E	21°20'40"N	˚23.1043825	Southeast
5	39°48'55"E	21°17'36"N	˚22.5860828	South
6	39°59'52"E	21°25'N	˚3.4166964	East
7	39°39'41"E	21°25'41"N	˚3.4166964	West
8	39°48'02"E	21°35'47"N	˚3.4166465	North

Ehlenberg (Mueller-Dombois and Ellenberg, 1974). Using relevés for vegetation study involves two broad considerations. One is the method by which relevé plots are placed in the study area. The second is how the data on plant species cover are collected in the plot. Both considerations are influenced by the objectives and requirements of the study (Minnesota Department of Natural Resources, 2013).

Figure3. Locations of the study sites.

The study areas were visited from December to February 2021- 2022. According to relevé, the plots were about 10-meter × 10 meters in size (Figure 4) and samples were taken through the winter and spring seasons when taxa were expected to be growing and flowering.

Figure 4. According to relevé, the plots were about 10-meter × 10 meters in size.

The vegetation sampling includes collecting the plants, drying and recording all plants taxa in the plots. Then, the recorded species' identification and name were done in accordance with Migahid, 1978; Chaudhary, 1999; Collenette, 1999 and Boulos, 1999; 2000; 2002; 2005; 2009.

Table 1. The locations of each stand.

Abundance

The abundance of plant species was determined according to Braun- Blanquet cover abundance scale as follows:

SCALE	COVER-ABUNDANCE
5	>75%
4	50 - 75%
3	25 - 50%
2	5 - 25%
1	1 - 5%
+	Few
R	Solitary

Life forms

The life form analysis is supplying supplemental data that makes it easier to comprehend the intricate interactions of plant species with abiotic and biotic elements in the surrounding environment (Ayyad & El-Ghareeb, 1982). The distribution of life forms among plants growing in dry regions is influenced by landforms and topography (Galal *et al*. 2021).

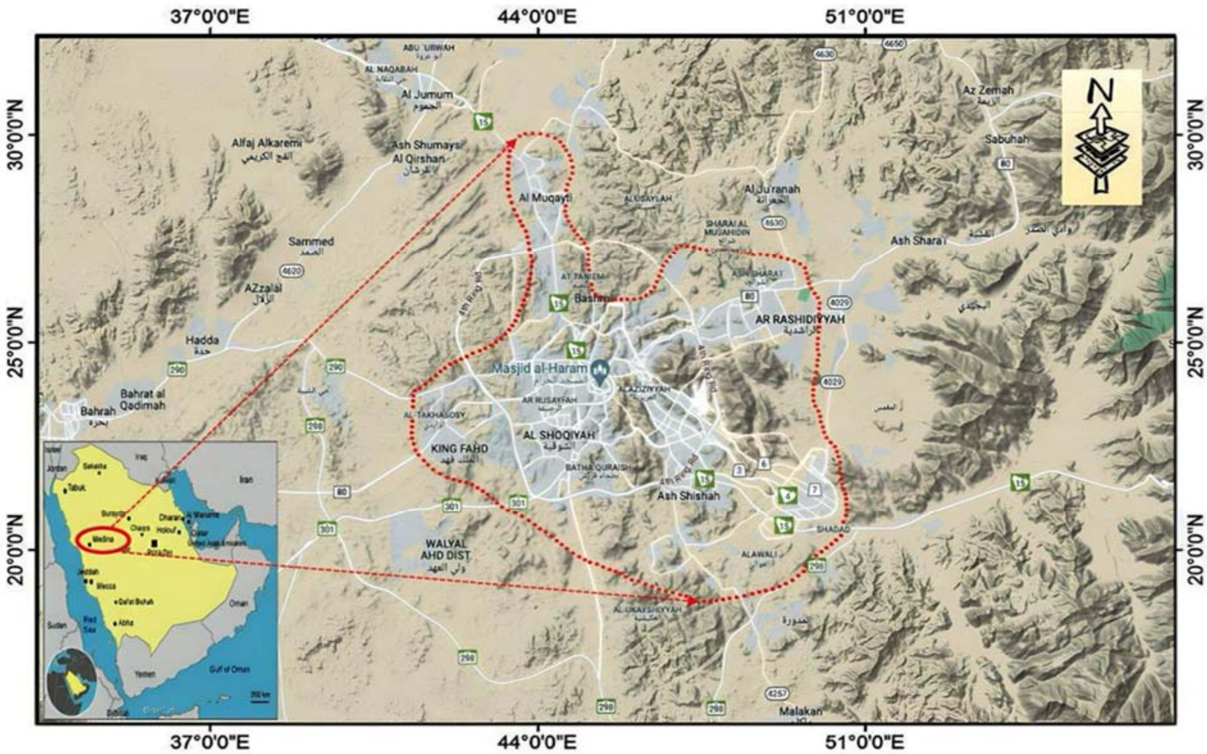


Figure 1. A map of Saudi Arabia (left bottom corner) inside the black box with a zoomed-in map showing The Makkah region.

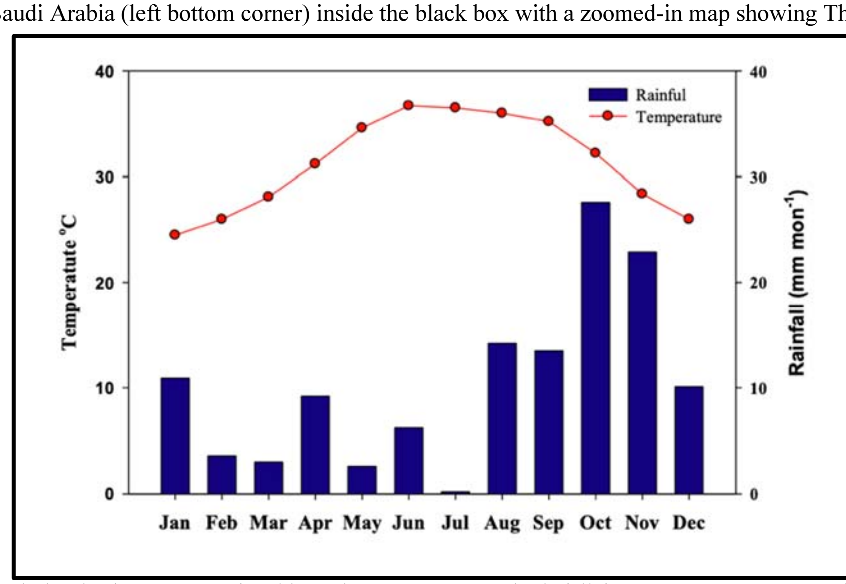


Figure 2. Monthly variation in the average of ambient air temperature and rainfall from 2003 to 2019 according to the data of Meteorological Station at Makkah Al-Mukaramah (Presidency Meteorol ogy and Environment)

Vegetation sampling and Assessment

Locations and samples were selected as an example of a large range of physiographic and environmental variability in every area. Eight stands were studied as showed in table1and (Figure 3). Sample plots in each stand were randomly selected using the relevé process in every site described by Mueller- Dombois and

(Elaidarous, *et al*., 2022). However, xerophytic vegetation is a distinguished feature of the plant life in Saudi Arabia (Zahran, 1982).

Makkah situated in Wadis between the mountainous region of the west of Saudi Arabia with an arid system (Alshareef, 1984 & Khalik *et al*., 2013). In Makkah, there is a reduced in the natural vegetative cover due to the degradation, which shows in hot aridity, with a maximum temperature around 40-49°C, and scarcity of rainfall, the rate of rainfall between 50-80 mm/year, with most of the precipitation falling during the winter (Ashrae, 2005; Al-Eisawi & Al-Ruzayza, 2015; Abdelrahman *et al*., 2020). Climate change and human activity are both important causes in the spread of desertification and drought (Shalaby & Tateishi, 2007; Cetin *et al*., 2019).

Also, the natural vegetation and biodiversity are seriously threatened locally and globally by disturbances to it, such as total clearance, urban expansion, overgrazing, invasive species invasion, soil erosion and salinity, natural disasters, and poor management that result in differences in microclimate and vegetative cover (Tehrany, *et al*., 2017). Because of the importance of biodiversity and the intrinsic relationship between human activities and policies and the state of native vegetation, monitoring and assessment of changes in the condition of natural plants are high-priority tasks for governments (Raymond *et al*., 2011). Moreover, there are several structural, functional, and compositional traits found in natural vegetation. Natural plants are certain species that have a significant environmental tolerance that developed a distinct plant association with unique floristic and structural attributes to adapt to a certain environment.

Subsequently, there is a need to conserve the natural vegetation that can resist these conditions and provide a habitat for terrestrial-based species. The aim of this work is to assess the natural vegetation cover by using field surveys by dividing the area into eight stands (to cover all important sites in Makkah) and collecting the plants. Then, analyze the natural plant composition to assist in the afforestation project of the holy city by the plants originally growing in limitation of resources to reduce the efforts.

2. Materials and Methods

Study area

Eight different study stands were chosen around the city of Makkah to represent all the vegetation and ecological sites. Makkah is a city situated in the middle of the western part of the kingdom of Saudi Arabia within an area called the Arabian shield (longitude 39.826°E and latitude 21.43°N) in a fragile system in Wadis, in Saudi Arabia's western mountainous region, 80 km from Jeddah on the Red Sea coast (Al-Eisawi& Al-Ruzayza, 2015; Osman, 2012; Abdel Khalik *et al*., 2013). It is a portion of Al Hejaz Hill, which stretches parallel to the Red Sea from the Kingdom's borders to the Al-Sarwat Mountains in the south. It is surrounded by the regions of Al Medina in the north, Riyadh in the east, Abha in the south, and the Red Sea in the west as obviously in (Fig 1).

Climate of the study area

The climate in Makkah is tropical and arid. The monthly average of meteorological conditions showed that the monthly average ambient air temperatures ranged between 24.5°C and 36.7 °C during January and June, respectively from 2003 to 2019 according to the data of Meteorological Station at Makkah Al-Mukaramah (Presidency Meteorology and Environment) (Fig 2).

JKAU: Met., Env. & Arid Land Agric. Sci., Vol. **33** No. 1, pp: 47 - 62 (2024 A.D.)
DOI:10.4197/Met.33-1.4

Assessment of natural vegetation cover at the vicinity of Makkah city, Saudi Arabia

Jumanah A Abdulshakur
King Abdulaziz University
jabdulshakur@stu.kau.edu.sa

Abstract. makkah - Saudi Arabia, is one of the most important cities, which faced a reduction in natural vegetative cover, due to the hot aridity, with a maximum temperature around 40-49°C, and scarcity of rainfall, the rate of rainfall is between 50-80 mm/year. A plant is supposed to be native if it has occurred naturally in a particular region, ecosystem, or habitat without human intervention. The aim of this study was to study the flora around Makkah city by choosing eight stands from different localities. The field work included relevé, the plots were about 10 × 10 meters in size. The study revealed that the eight stands were represented by 20 species belong to 8 families, Fabaceae and Apocynaceae were dominant by (34%), (25%) followed by Amaranthaceae (13%), Poaceae (12%) and Cucurbitaceae (5%); then (Apiaceae & Asteraceae) were represented by (4%), while Solanaceae was represented by only (3%) of the vegetation. Phanerophytes (40%) were the dominant while Hemicryptophytes (He) were the lowest value of life form (10%). The Floristic categories Saharo-Arabian (SA) and Sudano-Zambezian (AZ) were the dominant (38%), while Mediterranean (ME), Saharo-Sindian (SSI), Tropical (TR), Irano-Turanian (IT) were lowest value (6%). *Rhazya stric*ta has a high number of species that were observed in native plants in study area (17%), while *Cenchrus biflorus, Leptadenia pyrotechnica, Lycium shawii, Panicum turgidum, Senegalia asak*, Senna *italica*, *Stipellula capensis, Vachellia flava* and *Vachellia tortilis* were the lowest with 3% over the stands. Finally, the diversity in species deficiency in Makkah.
Keywords: Vegetation, Shannon, Simpson, indices, families, western region.

INTRODUCTION:

Around 2,250,000 km^2, or nearly 80% of the total area of the Arabian Peninsula, is occupied by the Kingdom of Saudi Arabia. Which is located between 15.2° and 32.6° north and 34.1° and 55.5° east. A vast area of semi-arid, arid, and hyper-arid regions covers Saudi Arabia, and it is characterized by many ecosystems that differ in their plant diversity (Al-Yasi *et al*., 2019& Elaidarous, *et al*., 2022). According to Al-Sherif *et al*. (2013) and Al-Yasi (2015), there are several physiographical regions, such as mountains, Valleys (Wadis), sandy and rocky deserts, salt planes (Sabkhahs) and lava areas (Harrats), etc. The flora of Saudi Arabia is one of the most diverse in the Arabian Peninsula, with plentiful original resources for agriculture and medicinal plants (Rahman *et al*., 2004). The flora of Saudi Arabia is intricate, sharing similarities with the floras of North Africa, East Africa, the Mediterranean, and Irano-Turanian nations. About 137 families and 2284 species including naturalized and alien plants have been reported from various habitats of Saudi Arabia (Aljeddani *et al*., 2021). Although there are many wild plants in Saudi Arabia, there are fewer species per square kilometer than there are elsewhere, particularly in the Central, Eastern, and Northern regions; the regions along the northwestern and southwestern regions have dense vegetation and contain the highest number of species (Al-Eisawi, & Al-Ruzayza, 2015& Noor *et al*.,2022). Around 80% of Saudi Arabia's total flora is found in the south-western regions, which also have the largest number of species (Abbas *et al*., 2020). Desert vegetation is majority and distinctive type of natural plant life and covers large areas mostly with xerophytic sub-shrubs and shrubs

استخدام تقنيات مختلفة للحفاظ على جودة اللحم ومدة صلاحيته، دراسة مرجعية محدثة

نوف حسن الجيزاني[١] ، منال عصام شفي[٢]

١- قسم العلوم البيولوجية، علم الحيوان، جامعة الملك عبدالعزيز، جدة، ٢١٥٨٩، المملكة العربية السعودية

البريد الالكتروني: naljizani0003@stu.kau.edu.sa

٢- المجموعة البحثية لاستدامة الإنتاج الزراعي، قسم العلوم البيولوجية، علم الحيوان، جامعة الملك عبدالعزيز، جدة، ٢١٥٨٩، المملكة العربية السعودية

البريد الالكتروني: Meshafi@kau.edu.sa

مستخلص. تعتبر الأسماك والمنتجات السمكية ضرورية لصحة الإنسان، حيث توفر بروتينات عالية الجودة وفيتامينات أساسية ومعادن وأحماض دهنية صحية متعددة غير مشبعة. علاوة على ذلك، فقد ارتبطت الأهمية الغذائية الكبيرة لهذه المواد بالعديد من الفوائد الصحية التي تمتد من نمو الجنين قبل الولادة وحتى البلوغ. ومع ذلك، يمكن أن تتدهور الأسماك بسرعة بعد الحصاد بسبب عوامل بيئية خارجية مثل نوعية المياه (النفايات التي تتحول إلى أمونيا ونترات ونتريت، ودرجة الحموضة، وكمية الأكسجين المذاب ودرجة الحرارة) والعوامل الفسيولوجية الداخلية مثل الميكروبات والبكتيريا، مما يزيد من فرصة تدهورها وفقدان قيمتها الغذائية. ولذلك، من الضروري استخدام تقنيات تربية الأحياء المائية التي تتطور باستمرار، مع التركيز على نوع وحالة الأسماك وتطبيق التقنيات المناسبة للأسماك المستزرعة، مع الأخذ في الاعتبار مدة النقل. بالإضافة إلى ذلك، هناك تقنيات مختلفة تستخدم في حفظ الأسماك بما في ذلك التقنيات التقليدية مثل التمليح، التجفيف، التدخين والتخليل أو التتبيل، وتشمل تقنيات معالجة الأسماك الغير التقليدية التبريد، التجميد والتعبئة المفرغة من الهواء. وأيضا لتحديد مدى نضارة الأسماك مثل الخصائص الحسية والتحليلات الميكروبية وتقييمات التحليل الفيزيائي والكيميائي. تشمل تقنيات تجهيز الأسماك المنهجيات والإجراءات المستخدمة منذ الحصاد حتى وصولها إلى المستهلك في شكلها النهائي. تتناول هذه المراجعة أهم تقنيات حفظ الأسماك المستخدمة وتأثيرها على الجودة الشاملة. بالإضافة إلى تحقيق إنتاج مستدام ذو محتوى غذائي وتحسين الإنتاجية المربحة، وكذلك للحد من الآثار الصحية السلبية على المستهلكين والخوف على السلامة الغذائية للغذاء لتحقيق رفاهية الانسان وفقاً لمحوري اقتصاد مزدهر ومجتمع لرؤية المملكة ٢٠٣٠.

الكلمات المفتاحية: تقنيات معالجة الأسماك، الفساد، الطازجة، تقنيات الحفظ، الاستزراع السمكي، جودة الأسماك، مدة الصلاحية.

method (QIM) sensory scheme and study of shelf-life of ice-stored blackspot seabream (Pagellus bogaraveo). LWT-Food Science and Technology, 44(10), 2253-2259.

73. Sheng, L., & Wang, L. (2021). The microbial safety of fish and fish products: Recent advances in understanding its significance, contamination sources, and control strategies. Comprehensive Reviews in Food Science and Food Safety, 20(1), 738-786.

74. Shumilina, E., Slizyte, R., Mozuraityte, R., Dykyy, A., Stein, T. A., & Dikiy, A. (2016). Quality changes of salmon by-products during storage: Assessment and quantification by NMR. Food chemistry, 211, 803-811.

75. Sigurgisladottir, S., Ingvarsdottir, H., Torrissen, O. J., Cardinal, M., & Hafsteinsson, H. (2000). Effects of freezing/thawing on the microstructure and the texture of smoked Atlantic salmon (Salmo salar). *Food Research International*, *33*(10), 857-865.

76. Sikorski, Z. E., & Kolakowska, A. (2020). Freezing of marine food. In Z. E. Sikorski (Ed.), Seafood: resources, nutritional composition, and preservation (pp. 111–124). Boca Raton: CRC Press.

77. Smida, M. A. B., Bolje, A., Ouerhani, A., Barhoumi, M., Mejri, H., & Fehri-Bedoui, R. (2014). Effects of Drying on the Biochemical Composition of Atherina boyeri from the Tunisian Coast. Food and Nutrition Sciences, 5(14), 1399.

78. Tahiluddin, A., & Kadak, A. E. (2022). Traditional fish processing techniques applied in the Philippines and Turkey. Menba Kastamonu Üniversitesi Su Ürünleri Fakültesi Dergisi, 8(1), 50-58.

79. Teklu, D., & Lema, A. (2015). Optimization of time and temperature for smoking of Nile tilapia for a better preservation of protein and gross energy value. Journal of Nutrition and Food Sciences, 5(1), 1-9.

80. Wu, T. H., & Bechtel, P. J. (2008). Ammonia, dimethylamine, trimethylamine, and tri- methylamine oxide from raw and processed fish by-products. Journal of Aquatic Food Product Technology, 17, 27–38.

81. Yerlikaya, P., & Gökoğlu, N. (2010). Effect of previous plant extract treatment on sensory and physical properties of frozen bonito (Sarda sarda) filllets. Turkish Journal of Fisheries and Aquatic Sciences, 10(3).

82. You, Y., Kang, T., & Jun, S. (2021). Control of ice nucleation for subzero food preservation. Food Engineering Reviews, 13(1), 15-35.

83. Yu, D., Regenstein, J. M., & Xia, W. (2019). Bio-based edible coatings for the preservation of fishery products: A review. Critical reviews in food science and nutrition, 59(15), 2481-2493.

84. Yu, D., Wu, L., Regenstein, J. M., Jiang, Q., Yang, F., Xu, Y., & Xia, W. (2020). Recent advances in quality retention of non-frozen fish and fishery products: a review. Critical Reviews in Food Science and Nutrition, 60(10), 1747-1759.

85. Zhan, X., Sun, D.-W., Zhu, Z., & Wang, Q.-J. (2018). Improving the quality and safety of frozen muscle foods by emerging freezing technologies: a review. Critical Reviews in Food Science and Nutrition, 58(17), 2925-2938.

57. Melgosa, R., Marques, M., Paiva, A., Bernardo, A., Fernández, N., Sá-Nogueira, I., & Simões, P. (2021). Subcritical water extraction and hydrolysis of cod (Gadus morhua) frames to produce bioactive protein extracts. Foods, 10(6), 1222.
58. Mengistu, S. B., Mulder, H. A., Benzie, J. A., & Komen, H. (2020). A systematic literature review of the major factors causing yield gap by affecting growth, feed conversion ratio and survival in Nile tilapia (Oreochromis niloticus). Reviews in Aquaculture, 12(2), 524-541.
59. Modibbo, U. U., Osemeahon, S. A., Shagal, M. H., & Halilu, M. (2014). Effect of moisture content on the drying rate using traditional open sun and shade drying of fish from Njuwa Lake in North Eastern Nigeria. IOSR Journal of Applied Chemistry, 7(1), 41-45.
60. Nie, X., Zhang, R., Cheng, L., Zhu, W., Li, S., & Chen, X. (2022). Mechanisms underlying the deterioration of fish quality after harvest and methods of preservation. Food Control, 135, 108805.
61. Nollet, L. M., & Toldrá, F. (Eds.). (2010). Sensory analysis of foods of animal origin. CRC press.
62. Ntzimani, A., Angelakopoulos, R., Semenoglou, I., Dermesonlouoglou, E., Tsironi, T., Moutou, K., & Taoukis, P. (2023). Slurry ice as an alternative cooling medium for fish harvesting and transportation: Study of the effect on seabass flesh quality and shelf life. Aquaculture and Fisheries, 8(4), 385-392.
63. Odeyemi, O. A., Alegbeleye, O. O., Strateva, M., & Stratev, D. (2020). Understanding spoilage microbial community and spoilage mechanisms in foods of animal origin. Comprehensive reviews in food science and food safety, 19(2), 311-331.
64. Oehlenschläger, J. (2014). Seafood quality assessment. Seafood processing: Technology, quality and safety, 359-386.
65. Oğuzhan, P. (2012). Su Ürünleri Kurutma Teknolojisi. Akademik Gıda, 10(2), 121-124.
66. Petsini, F., Fragopoulou, E., & Antonopoulou, S. (2019). Fish consumption and cardiovascular disease related biomarkers: a review of clinical trials. Critical reviews in food science and nutrition, 59(13), 2061-2071.
67. Rastogi, N. K., Raghavarao, K., Balasubramaniam, V. M., Niranjan, K., & Knorr, D. (2007). Opportunities and challenges in high pressure processing of foods. Critical Reviews in Food Science and Nutrition, 47(1), 69-112.
68. Rifat, M. A., Wahab, M. A., Rahman, M. A., Nahiduzzaman, M., & Mamun, A. A. (2023). Nutritional value of the marine fish in Bangladesh and their potential to address malnutrition: A review. Heliyon.
69. Rodríguez, Ó., Losada, V., Aubourg, S. P., & Barros-Velázquez, J. (2004). Enhanced shelf-life of chilled European hake (Merluccius merluccius) stored in slurry ice as determined by sensory analysis and assessment of microbiological activity. Food Research International, 37(8), 749-757.
70. Rumape, O., Elveny, M., Suksatan, W., Hatmi, R. U., Voronkova, O. Y., & Bokov, D. O. (2022). Study on the quality of fish products based on different preservation techniques: a review. Food Science and Technology, 42, e78521.
71. Samples, S. (2015). The effects of processing technologies and preparation on the final quality of fish products. Trends in Food Science & Technology, 44(2), 131-146.
72. Sant'Ana, L. S., Soares, S., & Vaz-Pires, P. (2011). Development of a quality index

41. Ihekoronye, A. I., & Ngoddy, P. O. (1985). Integrated food science and technology for the tropics. Macmillan.

42. Jeyasanta, K. I., Prakash, S., Carol, G. R., & Patterson, J. (2013). Deterioration due to delayed icing and its impacts on the nutritional quality of M alabar 43amples43 (C arangoides malabaricus). International journal of food science & technology, 48(3), 519-526.

43. Jiang, Q., Huang, S., Ma, J., Du, Y., Shi, W., Wang, M., ... & Zhao, Y. (2023). Insight into mechanism of quality changes in tilapia fillets during salting from physicochemical and microstructural perspectives. Food Chemistry: X, 17, 100589.

44. KADAK, A. E., & ÇELİK, M. (2015). Kitosan eklenmiş hamsi marinatlarının soğuk depolanmasında meydana gelen fiziksel ve duyusal değişimler. Alinteri Journal of Agriculture Science, 28(1), 33-44.

45. Kaminski, A. M., Cole, S. M., Al Haddad, R. E., Kefi, A. S., Chilala, A. D., Chisule, G., ... & Ward, A. R. (2020). Fish losses for whom? A gendered assessment of post-harvest losses in the barotse floodplain fishery, Zambia. Sustainability, 12(23), 10091.

46. Kauffeld, M., Wang, M. J., Goldstein, V., & Kasza, K. E. (2010). Ice slurry applications. International Journal of Refrigeration, 33(8), 1491-1505.

47. Khan, A. Q., Aldosari, F., & Hussain, S. M. (2018). Fish consumption behavior and fish farming attitude in Kingdom of Saudi Arabia (KSA). Journal of the Saudi Society of Agricultural Sciences, 17(2), 195-199.

48. Küçükgülmez, A., Eslem Kadak, A., & Celik, M. (2010). Fatty acid composition and sensory properties of Wels catfish (Silurus glanis) hot smoked with different sawdust materials. International journal of food science & technology, 45(12), 2645-2649.

49. Kulat, M. I., Mohtar, R. H., & Olivera, F. (2019). Holistic water-energy-food nexus for guiding water resources planning: Matagorda County, Texas case. Frontiers in Environmental Science, 7, 3.

50. Lakshmanan, R., Piggott, J. R., & Paterson, A. (2003). Potential applications of high pressure for improvement in salmon quality. Trends in Food Science & Technology, 14(9), 354-363.

51. Lanzarin, M., Ritter, D. O., Novaes, S. F., Monteiro, M. L. G., Almeida Filho, E. S., Mársico, E. T., ... & Freitas, M. Q. (2016). Quality Index Method (QIM) for ice stored gutted Amazonian Pintado (Pseudoplatystoma fasciatum× Leiarius marmoratus) and estimation of shelf life. LWT-Food Science and Technology, 65, 363-370.

52. Lauteri, C., Ferri, G., & Pennisi, L. (2023). A Quality Index Method-based evaluation of sensory quality of red mullet (Mullus barbatus) and its shelf-life determination. *Italian Journal of Food Safety*, *12*(1).

53. Liu, W., Lyu, J., Wu, D., Cao, Y., Ma, Q., Lu, Y., & Zhang, X. (2022). Cutting techniques in the fish industry: A critical review. Foods, 11(20), 3206.

54. Losada, V., Barros-Velázquez, J., Gallardo, J. M., & Aubourg, S. P. (2004). Effect of advanced chilling methods on lipid damage during sardine (Sardina pilchardus) storage. European Journal of Lipid Science and Technology, 106(12), 844-850.

55. Maktabi, S., Zarei, M., & Chadorbaf, M. (2016). Effect of a traditional marinating on properties of rainbow trout fillet during chilled storage. In Veterinary Research Forum (Vol. 7, No. 4, p. 295). Faculty of Veterinary Medicine, Urmia University, Urmia, Iran.

56. Martinsdottir, E. (2010). Sensory quality management of fish. Sensor analysis for food and beverage quality control.

Journal of the Fisheries Research Board of Canada, 6, 351–358.
23. Dyer, W. J., & Mounsey, Y. A. (1945b). Amines in fish muscle: II. Development of trimethylamine and other amines. Journal of the Fisheries Research Board of Canada, 6d, 5, 359–367.
24. Einarsdóttir, H., Guðmundsson, B., & Ómarsson, V. (2022). Automation in the fish industry. Animal Frontiers, 12(2), 32-39.
25. Emel, O. Z. (2020). Effects of smoking with different wood chips and barbecuing on some properties of salmon fish. Gıda, 45(1), 1-8.
26. ERDEM, M. E., Bilgin, S., & Çağlak, E. (2005). Tuzlama ve marinasyon yöntemleri ile işlenmiş istavrit baliği'nin (Trachurus mediterraneus, Steindachner, 1868) muhafazasi sirasindaki kalite değişimleri. Anadolu Tarım Bilimleri Dergisi, 20(3), 1-6.
27. Erkan, N. (2011). Iodine content of cooked and processed fish in Turkey. International journal of food science & technology, 46(8), 1734-1738.
28. Espejo-Hermes, J. (1998). Fish processing technology in the tropics. Quezon City (PH): Tawid Publications.
29. Esposito, G., Sciuto, S., & Acutis, P. L. (2018). Quantification of TMA in fishery products by direct sample analysis with high resolution mass spectrometry. Food Control, 94, 162-166.
30. FAO 2021. Food Loss and Waste in Fish Value Chains. www. Fao.org/flw-in-fish-value-chains/en/
31. Foruzani, S., Maghsoudloo, T., & Noorbakhsh, H. Z. (2015). The effect of freezing at the temperature of-18° C on chemical compositions of the body of Lutjanus johnii. Aquaculture, Aquarium, Conservation & Legislation-International Journal of the Bioflux Society (AACL Bioflux), 8(3).
32. Freitas, J., Vaz-Pires, P., & Câmara, J. S. (2019). Freshness assessment and shelf-life prediction for Seriola dumerili from aquaculture based on the quality index method. Molecules, 24(19), 3530.
33. George, R. M. (1993). Freezing 42amples4242 used in the food industry. Trends in Food Science & Technology, 4(5), 134-138.
34. Ghaly, A. E., Dave, D., Budge, S., & Brooks, M. S. (2010). Fish spoilage mechanisms and preservation techniques. American journal of applied sciences, 7(7), 859.
35. Gomez, M. I., Mohammed, B., Li, J., Ballco, P., & Zhang, Y. (2023). Exploring consumer preferences and the willingness to pay for domestically produced finfish in the Kingdom of Saudi Arabia.
36. Goncalves, A. C. (2010). Quality and value in aquaculture. Sensory properties and useful shelf life of fish and bivalve (Doctoral dissertation, 42amples4242y of Lisbon).
37. Guevara, G. (1980). Overview: the fish processing industry of the Philippines. Commemorative Issue.
38. Güngörmez, H., Güzel, Ş., Öksüz, A., & Güzel, S. (2017). Tuz ile Balığın Buluşması: Tuzlu Balık. Journal of the Institute of Science and Technology, 7(2), 149-155.
39. Huidobro, A., López-Caballero, M., & Mendes, R. (2002). Onboard processing of deepwater pink shrimp (Parapenaeus longirostris) with liquid ice: effect on quality. European Food Research and Technology, 214, 469-475.
40. Huidobro, A., Mendes, R., & Nunes, M. (2001). Slaughtering of gilthead seabream (Sparus aurata) in liquid ice: influence on fish quality. European Food Research and Technology, 213, 267-272.

storage. Journal of Microbiology, Biotechnology and Food Sciences, 2, 653–666.
6. Amit, S. K., Uddin, M. M., Rahman, R., Islam, S. M., & Khan, M. S. (2017). A review on mechanisms and commercial aspects of food preservation and processing. Agriculture & Food Security, 6(1), 1-22.
7. AYDIN, C., & Yalçın, K. A. Y. A. (2018). Sıcak Dumanlanmış Balık Ezmesinin Bazı Kalite Parametrelerinin Belirlenmesi. Gaziosmanpaşa Bilimsel Araştırma Dergisi, 7(3), 130-140.
8. Balino-Zuazo, L., & Barranco, A. (2016). A novel liquid chromatography–mass spectrometric method for the simultaneous determination of trimethylamine, dimethylamine and methylamine in fishery products. Food chemistry, 196, 1207-1214.
9. Bellas, I., & Tassou, S. A. (2005). Present and future applications of ice slurries. International Journal of Refrigeration, 28(1), 115-121.
10. Bernardi, D. C., Mársico, E. T., & Freitas, M. Q. D. (2013). Quality Index Method (QIM) to assess the freshness and shelf life of fish. Brazilian archives of biology and technology, 56, 587-598.
11. Boonsumrej, S., Chaiwanichsiri, S., Tantratian, S., Suzuki, T., & Takai, R. (2007). Effects of freezing and thawing on the quality changes of tiger shrimp (Penaeus monodon) frozen by air-blast and cryogenic freezing. Journal of Food Engineering, 80(1), 292-299.
12. Buljo, J. O., & Gjerstad, T. B. (2013). Robotics and automation in seafood processing. In Robotics and automation in the food industry (pp. 354-384). Woodhead Publishing.
13. Cain, M. L. (2019). The Philippines: Fish Preservation Techniques. In Appropriate Technology for Development (pp. 343-357). Routledge.
14. Cakli, S., Kilinc, B., Cadun, A., & Tolasa, S. (2006). Effects of using slurry ice on the microbiological, chemical and sensory assessments of aquacultured sea bass (Dicentrarchus labrax) stored at 4 C. European Food Research and Technology, 222, 130-138.
15. Çetinkaya, H. (2017). Okul yöneticilerinin toksik (zehirli) liderlik davranışları ile öğretmenlerin tükenmişlik düzeyleri arasındaki ilişki [Master Thesis] (Master's thesis, Pamukkale Üniversitesi Eğitim Bilimleri Enstitüsü).
16. Chavan, B. R., Basu, S., & Kovale, S. R. (2008). Development of edible texturised dried fish granules from low-value fish croaker (Otolithus argenteus) and its storage characteristics. Cmu J Sci, 1, 173-182.
17. Cosgrove, W. J., & Loucks, D. P. (2015). Water management: Current and future challenges and research directions. Water Resources Research, 51(6), 4823-4839.
18. Delima, R., Sahira, S., Sumiroyani, S., Kamelia, K., Reskiana, R., Rahmi, K. A., & Marta, E. (2021). The Impact of Using Salt on Drying Rate of Fish. International Journal of Natural Science and Engineering, 5(3), 87-95.
19. Dıaz-Tenorio, L. M., Garcıa-Carreno, F. L., & Pacheco-Aguilar, R. (2007). Comparison of freezing and thawing treatments on muscle properties of whiteleg shrimp (Litopenaeus vannamei). J Food Biochem, 31, 563-576.
20. Doe, P., & Olley, J. (2020). Drying and dried fish products. In Seafood (pp. 125-145). CRC Press.
21. Duarte, C. M., Agusti, S., Barbier, E., Britten, G. L., Castilla, J. C., Gattuso, J. P., ... & Worm, B. (2020). Rebuilding marine life. Nature, 580(7801), 39-51.
22. Dyer, W. J. (1945a). Amines in Fish Muscle I. Colorimetric determination of 41amples4141- lamine as the picrate salt.

1945a). The assessment of spoilage in fish products often relies on the measurement of TVB-N, a crucial characteristic. TVB-N is widely recognized as the predominant chemical indicator for evaluating the spoilage of marine fish (Amegovu et al., 2012; Wu & Bechtel., 2008). Nevertheless, the conventional approach to quantify its concentrations in tissue samples is time-consuming due to the need for meticulous extraction procedures (Esposito et al., 2018).

TMA alone can indicate fish freshness because its level is directly related to product deterioration. The official method for determining the concentration of the substance.

Chemical analysis is a scientific technique used to determine the composition and properties of substances and characteristics of the chemical changes that occur in fish muscle during rotting.

3.4.1 Potential of Hydrogen (pH):

The assessment of deterioration process in fish products can be achieved by measuring pH the despite its limited accuracy and harmful solvents, it is predominantly the analytical approach based on Dyer's method (Dyer., 1945b).

4. Conclusion

Currently, fish farms and aquaculture in the Kingdom of Saudi Arabia operate in a global and competitive market due to increasing human consumption of aquatic resources. To maintain this competitive level, fish processing techniques are integral to reducing concerns about food safety, maintaining the country's economic development, and achieving consumer satisfaction. However, it is hard to harvest and transport due to its rapid susceptibility to spoilage and rot. Therefore, it is suggested to choose one of the fish processing techniques with high precision according to the type and condition of the fish and the way that reaches the consumer, considering the duration of transportation. In addition, it is possible to combine more than one technique to obtain results with long shelf life, abundant nutritional value, and better flesh quality. Furthermore, there are many ways to determine the freshness of fish, ranging from experienced people to less ones.

References

1. Abraha, B., Admassu, H., Mahmud, A., Tsighe, N., Shui, X. W., & Fang, Y. (2018). Effect of processing methods on nutritional and physico-chemical composition of fish: a review. MOJ Food Process Technol, 6(4), 376-382.
2. Abera, G. (2019). Review on high-pressure processing of foods. Cogent Food & Agriculture, 5(1), 1568725.
3. Aldás Guerrero, R. F. (2013). Diseño de un negocio dedicado a la exportación de filete de tilapia en camas frías al mercado canadiense período 2014-2018 (Bachelor's thesis, Quito/UIDE/2013).
4. Alice, E. J., Amanullah, M., Karim, M. A., Hossain, M. A., & Islam, M. T. (2020). Effects of vacuum and modified atmosphere packaging on the biochemical and microbiological quality of sliced goonch fish (Bagarius bagarius) stored at refrigerated condition. Food Research, 4(6), 2256-2264.
5. Amegovu, A. K., Sserunjogi, M. L., Ogwok, P., & Makokha, V. (2012). Nucleotited de- gradation products, total volatile basic nitrogen, sensory and microbiological quality of nile pearch (Lates niloticus) fillets under chilled

structured scale ranging from 10 to 3. Absolute freshness is indicated by a score of 10–9; good quality is indicated by an 8; tastelessness or neutrality is indicated by a 7–6; slight extraneous odors and tastes (initial state of alteration) is indicated by a 5–4; and severe extraneous odors and tastes (putrid product) are indicated by a 3 . When the product's flavor and odor received a sensory QIM score of less than six overall, the samples were declared unfit for consumption.

3.1.3 Quantitative Image Analysis (QIA):

Quantitative Image Analysis (QIA) methods were developed using exterior characteristics such as skin, texture, odor, and the look of eyes, gills, and anus (Freitas et al., 2019).

3.2 Microbiological Analysis:

The presence of microorganisms in aquatic species indicates the bacterial composition of the surrounding environment and the circumstances experienced during handling or processing. In the case of recently processed fish, Single Species Organisms (SSOs) are observed in minimal quantities and represent a minor portion of the microbial community associated with the fish. Under specific storage conditions, such as a particular temperature, SSOs' growth rate is higher than other microflora. This increased growth leads to the production of metabolites that are responsible for off-flavors in the product. Ultimately, these off-flavors result in sensory rejection of the product (Freitas et al., 2019; Oehlenschlager., 2014). The prevailing SSOs found in aquatic species inhabiting temperate seas and subjected to ice preservation at a temperature of 0 °C in the presence of oxygen are *Shewanella* spp and *Pseudomonas* spp. These substances are linked to odors characterized by ammoniacal spoilage and hydrogen sulfide (Sant'Ana et al., 2011).

3.3 Physical Evaluation:

The physical evaluation is a comprehensive assessment of an individual's physical health and well-being. It involves the systematic examination of one often employed method for evaluating electrical measures in fish based on the observation that the cell membranes in fish muscle tissue undergo a gradual disruption caused by autolytic enzymatic degradation and subsequent microbial activity anus (Freitas et al., 2019). This process ultimately results in a reduction in electrical resistance and capacity. Hence, over time, there will be a decrease in the magnitude of the electric impulse recorded (Oehlenschlager., 2014). The alteration in gradient is a result of the dual-phase quality deterioration process elucidated by two distinct degradation mechanisms, namely enzymatic autolysis and microbial activity (Freitas et al., 2019).

3.4 Chemical Analysis: concentration of hydrogen ions, commonly known as pH measurement (Lanzarin et al., 2016). The pH levels of live fish exhibit variation across different species. Thus, the occurrence of a low value, indicated by the QI, signifies an aberrant alteration and elucidates the rapid deterioration of the fish (Freitas et al., 2019).

In addition, the generation of volatile amines, including ammonia, trimethylamine (TMA), dimethylamine (DMA), and methylamine (MA) (Sadok, Uglow, & Haswell, 1996), is sometimes referred to as total volatile basic nitrogen (TVB-N). These organic molecules are formed by bacterial or enzymatic processes, utilizing trimethylamine-n-oxide (TMAO) as a precursor (Dyer & Mounsey., expiration or "best before" date for fresh fish (Freitas et al., 2019).

3.1 Sensory Characteristics:

Sensory character is crucial in determining food quality, influencing consumer acceptance, food selection, and market value. The assessment of aquaculture product quality based on production and post-production characteristics is consistently regarded as a matter of utmost significance (Goncalves., 2010). Sensory analysis demonstrates adaptability across several stages of the supply chain, hence proving its significance in assessing the freshness of fish at different junctures of transactions (Freitas et al., 2019). Sensory analysis tools can significantly improve the overall perception of products in today's highly competitive markets (Bernardi et al., 2013). Also, it is widely recognized as a highly effective method for adequately assessing the freshness and grading of fish or fish products (Freitas et al., 2019).

In sensory evaluation, olfaction played a significant role in discerning the extent of degradation. According to the study by Freitas et al. (2019), the initial characterization of skin and gill odors in cod was classified as reminiscent of seaweed or fresh. However, starting from day 3 of the experiment, these aromas transitioned to a neutral state. Moreover, the perception of unpleasant scents linked to decay was observed on the 11th day; however, the intensity necessary for rejection was only reached on the 12th day. The primary cause of this phenomenon can be attributed to the notable presence of strong scents on both the skin and gills, characterized explicitly by rancidity.

3.1.1 Quality Index Method QIM:

Quality Index Method (QIM) is a grading method used to evaluate the freshness of fish. It is characterized by its efficiency, simplicity, nondestructiveness, and descriptive nature. The integration of fish species differences is achieved through an objective assessment of fish features, such as gill odor (Nollet & Toldra., 2010). Additionally, it offers a dependable and standardized approach to users, including manufacturers, customers, merchants, and resellers. This methodology comprises clear directions and easily comprehensible illustrative materials. This approach is very suitable for instructing individuals with limited expertise and providing training or overseeing the performance of panelists (Bernardi et al., 2013). Attributes are assessed using a scoring system that assigns demerit points ranging from 0 to 3. Additionally, as time elapses, punctuation is more emphasized, resulting in higher scores (Martinsdottir., 2010). However, it is frequently observed that one or more traits do not attain the maximum demerit points due to the lack of significant changes throughout the storage period, which prevents them from achieving such scores (Sant'Ana et al., 2011).

3.1.2 Quality Index (QI):

Quality Index (QI) is derived by aggregating all ratings to predict shelf-life. The possibility of making a forecast relies on establishing a linear correlation between the variable of interest, namely QI, and the duration of storage. However, novel QIM schemes are developed in conjunction with other methodologies. The fish muscle assessment is conducted using the Torry Scale (Freitas et al., 2019). According to Lauteri et al. (2023), the Torry scheme was utilized, and each sample was given a score based on a scientific investigations into applying high pressure for food preservation did not commence until the late 1980s and early 1990s. According to Rastogi et al. (2007), bacteria and enzymes respond similarly under high-pressure conditions. Conversely, elevated pressure levels may lead to cellular harm and distortion, causing structural modifications and impairments. It has been shown that alterations in pressure within the range of 100-300 MPa are generally reversible in most food products, in contrast to modifications induced by variations in temperature. In certain instances, such as with bacterial spores, it has been observed that they can endure elevated pressures, necessitating a minimum of 1,200 MPa for deactivation (Abera., 2019). Consequently, applying high pressure can influence various aspects of food quality, including proteolysis, myofibrillar proteins, and muscle enzymes. Additionally, it is imperative to consider the effects on sensory perception and texture. The relationship between high pressure and color changes and meat tenderization has been shown. (Figure 5). The quality of aquatic goods can be influenced by each stage of the process and any additional components introduced. Customizing the preservation technique according to the specific requirements of a perishable item such as fish, which is vulnerable to bacterial decay and oxidative processes, is imperative. The study conducted by Rumape et al. (2022) highlights the importance of preserving the overall quality, sensory attributes, and textural properties of food products while also maintaining their nutritional value. The findings suggest that employing a combination of storage and preservation techniques in a thoughtful and innovative manner can produce high-quality goods with favorable nutritional characteristics.

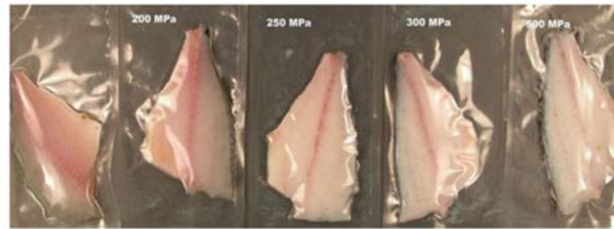


Fig 5. Changes in sea bream (Sparus aurata L.) fillets. (Rumape et al., 2022).

3. Determination of Fish Freshness

The freshness of fish is an important factor to consider due to its limited shelf life as a highly perishable food item. This attribute is important in ensuring safety, nutritional content, availability, and edibility.

It is well acknowledged that not only one method can be deemed entirely dependable in assessing the freshness or quality of fish goods (Martinsdottir., 2010). The assessment of fish freshness and the decision to accept or reject it based on this criterion may be the sole requirement for the industry (Freitas et al., 2019).

The post-mortem changes in fish encompass a range of physical, chemical, sensory, and microbiological features that contribute to the deterioration of food quality. These changes are species-specific and can be influenced by factors such as fishing processing technique, handling practices, and storage temperature (Freitas et al., 2019). Substantial elements serve as indicators of product spoiling (Balino-Zuazo & Barranco, 2016; Shumilina et al., 2016). Nevertheless, due to the absence of the capture date on fish sold by vendors, consumers lack a dependable means of ascertaining the true freshness of the product. Moreover, the existing regulations do not mandate the inclusion of an

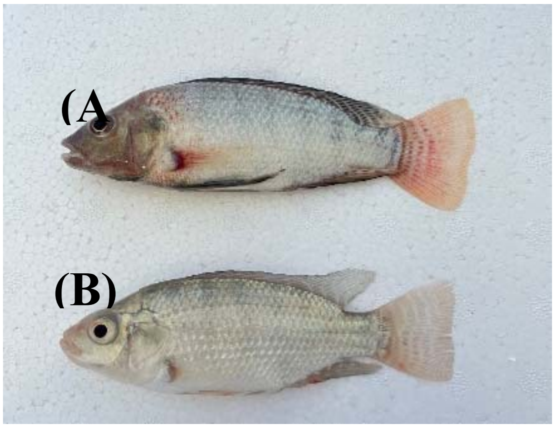


Fig 1. A) None of the techniques were applied to *Oreochromis niloticus* aquaculture. B) Freezing technique was applied using cold water and small pieces

Fig 3. Freezing technique used for *Oreochromis niloticus* aquaculture.

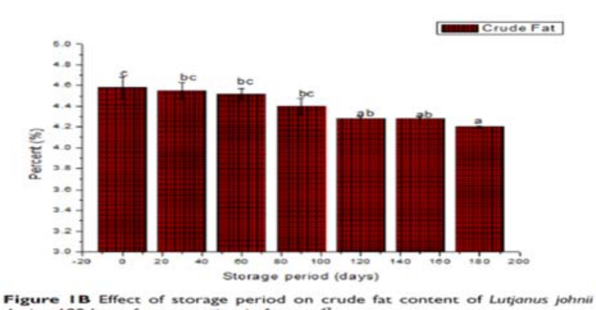


Fig 4B: Effect of storage period on crude fat content of *Lutjanus johnii* during 180dayes of preservation in freezer (Foruzani et al., 2015).

2.2.2.1 Slurry ice

Slurry ice has become a viable method in the post-capture, onboard handling, storage, and transporting of fish (Ntzimani et al., 2023). According to previous studies conducted by Huidobro et al. (2001), Losada et al. (2005), and Rodríguez et al. (2004), it has been observed that slurry ice exhibits the ability to inhibit microbial development and extend the shelf life of many marine species, including salmon, seabream, horse mackerel, and pink shrimp. Additionally, slurry ice can be defined as a biphasic system wherein small spherical ice particles are enveloped by seawater at temperatures below zero degrees Celsius (Cakli et al., 2006). The purported benefits of using cryogenic ice, compared to conventional freshwater ice forms, including flake, tube, and block ice, encompass several aspects. These include a lower temperature, resulting in faster chilling owing to enhanced heat exchange, a reduced likelihood of physical damage, and the presence of spherical tiny particles (Bellas & Tassou, 2005; Kauffeld et al., 2010). According to Kauffeld et al. (2010), the ice slurry's ice concentration can be adjusted to a maximum of 60%, while the salt content can range from 2% to 3%. This adjustment is crucial in achieving optimal preservation outcomes for sensitive fish, as it prevents any potential injury and excessive salt absorption by the fish. Furthermore, the comprehensive application of the slurry ice mixture to the fish surface protects fish tissues against the detrimental effects of oxygen, including lipid oxidation and dehydration (Huidobro et al., 2002).

2.2.3 Vacuum Packing

High pressure's potential to eliminate germs was first documented in 1899. However, et al., 2022). In a study conducted by You et al. (2021), it was observed that a decrease in the freezing rate resulted in the formation of larger ice crystals, leading to pronounced damage to muscle fibers. According to Sigurgisladottir et al. (2000), the size and uniformity of the ice crystals can be enhanced by increasing the speed and homogeneity of the freezing process. It was also noted that the color and texture of the *Oreochromis niloticus* muscles fish did not change when ice was applied immediately after harvesting. As a result, the shelf life was increased, and the general characteristics and nutritional value were maintained. (Figures 1,2 and 3). However, understanding the impact of freezing and thawing on frozen fish's muscle is essential for choosing the best preservation conditions and maintaining the product's texture, which will ultimately determine whether or not consumers will accept it (Dıaz-Tenorio et al., 2007). Additionally, he noted in his research that freezing and thawing conditions as well as holding temperature can have an impact on fish muscle qualities, including their edibility. Freezing can keep a product as fresh as when it was first stored and prolong its shelf life, but it depends on a number of variables, including the fish species' initial condition and the amount of time that passes between harvest and freezing. It can also result in protein denaturation and texture defects (Abraha et al., 2018). Protein denaturation may happen during the freezing fish treatment method (Yerlikaya & Gokoglu., 2010). Since muscle protein is the primary source of textural distinctive features, denatured protein affects the water-holding capacity, flavor, color, and texture of frozen fish and fish products (Abraha et al., 2018). Consequently, there is an increased risk of damage to proteins and loss of important amino acids (Chavan et al., 2008). Yerlikaya & Gokoglu (2010), have reported that the freezing time has an impact on the final quality of frozen fish. According to Lakshmanan et al. (2003), the number of freeze-thawing periods has a direct impact on the nutritional losses of aqua foods. Free fatty acid can have indirect effects on texture changes and flavor deterioration of frozen fish by promoting protein denaturation and enhancing lipid oxidation, respectively. Fish that has been frozen for 180 days can have less crude protein and fat, according to research by Foruzani et al. (2015) (Fig 4A) (Fig 4B).

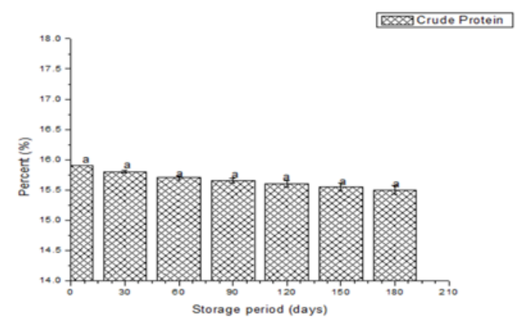


Fig 4A: Effect of storage period on crude protein content of *Lutjanus johnii* during 180dayes of preservation in freezer (Foruzani et al., 2015).

Fig 2. Freezing technique used for *Oreochromis niloticus* aquaculture.

environment, where they can last for several months. (Espejo-Hermes, 1998; Sampels, 2015); (Espejo-Hermes, 1998; Sampels, 2015). An investigation showed that marinating rainbow trout fillets extended their shelf life at 4 ˚C by delaying microbiological spoiling and avoiding deterioration (Maktabi et al., 2016).

2.2 Non- Traditional Techniques

Rumape et al. (2022) advised initiating the cooling process promptly after harvesting the fish. However, Jeyasanta et al. (2013) observed that delaying the application of icing for varying durations of 4, 6, 8, or 10 hours resulted in a decrease in the storage life of Malabar trevally. Specifically, the shelf life was lowered to 14, 10, 6, and 3 days, respectively, compared to the 18-day shelf life observed when icing was applied immediately. The study conducted by Rumape et al. (2022) revealed that the shelf life of rainbow trout *Oncorhynchus mykiss* experienced a reduction from the initial range of 9-11 days to a new range of 5-7 and 1-3 days, respectively, when the process of icing was delayed by either 4 or 8 hours after the fish were captured.

2.2.1 Cooling

Fresh fish is commonly transported and sold on a bed of crushed ice, maintaining a temperature of approximately zero degrees Celsius. The preservation of freshness can be achieved using refrigeration or cooling methods; however, it is important to note that these methods do not possess the capability to eliminate or eradicate microorganisms, nor can they halt enzymatic activity. According to Yu et al. (2019), most biological deterioration processes exhibit a deceleration rate. In a study conducted by Melgosa et al. (2021), it was observed that the rate of hydrolysis in cod exhibited a threefold increase at a temperature of 20°C compared to 0°C. Additionally, microbial growth decelerates at lower temperature conditions. The rate at which food is cooled has a crucial role in determining the overall quality of the final product, encompassing factors such as oxidation, spoilage, and texture. In order to achieve the intended duration of shelf life, it is imperative to maintain sufficient refrigeration throughout transportation and storage (Alice et al., 2020). Shelf-life of *Oreochromis niloticus* after being stored at +1.0 ◦C for 23 days, the microbiological quality of tilapia fillets was still good for eatable. Nonetheless, certain adverse impacts were noted in the samples' texture, color, and drip loss. According to sensory assessment and microbiological counts, the ideal storage periods were 13–15 and 21 days .

2.2.2 Freezing

Freezing has been widely regarded as a viable method for prolonging meat preservation over extended durations (George, 1993). However, it is essential to note that freezing can significantly affect muscle's chemical and structural properties, including the generation of lipid oxidation products (Zhan et al., 2018). According to Yu et al. (2020), freezing is more successful than cold storage in reducing enzymatic and microbiological activity retaining flavor and nutritional properties. The formation of ice crystals during the freezing process is a critical event. It is important to note that larger ice crystals provide a higher risk of membrane rupture and textural damage, which might result in increased oxidation (Sikorski & Kolakowska, 2020). The generation of small ice crystals during the freezing process is crucial in preventing increased oxidation and deterioration in texture after thawing (Rumape

2.1.3 Smoking

Like smoking, preserving food through smoking has been widely employed in numerous underdeveloped nations (Samples., 2015; Espejo-Hermes., 1998). The preservation process of smoking involves the synergistic impact of salting, drying, heat treatment, and chemical deposition resulting from the combustion of wood (Espejo-Hermes., 1998). In general, smoked products acquire a desirable smoky aroma by the combustion of sawdust or wood during manufacturing and by the influence of volatile compounds. This process ultimately extends the shelf life of the smoked products. The process of smoking fish is commonly conducted within a smokehouse facility to effectively regulate the combustion of wood (Küçükgülmez et al., 2010; Espejo-Hermes., 1998). There are two distinct traditional smoking methods employed in the preservation of fishery goods: hot smoking, which involves subjecting the products to elevated temperatures ranging from 70 to 80 degrees Celsius. According to previous studies (Espejo-Hermes., 1998; Aydin & Yalçın., 2018), the final products typically exhibit qualities such as being cooked, juicy, and tasty. Cold smoking involves the process of smoking fishery items at a controlled temperature that does not exceed 30°C. According to previous studies (Espejo-Hermes., 1998; Emel., 2020), smoked items are typically uncooked and may necessitate an additional cooking step. Teklu & Lema., (2015), mentioned that for non-dried fish, *Oreochromis niloticus* was smoked at 80 ± 3°C for two hours, on the other hand, if the fish dried before, the smoke duration was about three hours at 80 ± 3°C. However, If the time, temperature, and wood type are not controlled and chosen in accordance with the regulations throughout the smoking protocol, the smoked fish products' chemical, physical, and nutritional contents will be impacted. Furthermore, the carcinogenic activity may increase and cause various disorders in consumers (Abraha et al., 2018). Fish quality that has been smoked will have a hard texture, turn black instead of golden brown, and lose nutrients that are sensitive to heat (Boonsumrej et al., 2007). Depending on the amount of heat produced during smoking, fish's protein and amino acid denaturation will occur. This changes the protein's chemical and physical characteristics and lowers its biological availability (Ihekoronye & Ngoddy, 1985). According to research by Abraha et al. (2018), overheating can happen in the majority of conventional smoking techniques for fish processing, which greatly lowers the availability of vital amino acids (lysine, tryptophan, and methionine). Chavan et al. (2008) report that smoking also raises the amount of insoluble protein and decreases the amount of more soluble protein, such as sarcoplasmic and myofibrillar contents.

2.1.4 Pickling or Marinating

The preservation actions of pickling or marinating are due to the combined effects of salt and vinegar/acetic acid (Espejo-Hermes, 1998; Sampels, 2015; Kadak & elik., 2015; Cetinkaya, 2017). The presence of vinegar or acetic acid reduces the pH of the product, thereby inhibiting the proliferation of microorganisms that cause spoilage (Sampels., 2015). In addition, higher concentrations of these substances have increased inhibitory effects on enzymes and bacteria (Espejo-Hermes., 1998; Cetinkaya., 2017). However, pickled/marinated products generally have a short shelf life and are therefore considered semi-preserved unless stored in a chilled salt onto the fish through rubbing. On the other hand, wet salting, which includes brining and pickle curing, entails immersing the fish in a solution of salt and water prior to packaging. In the case of wet salting, each layer of fish is sprinkled with salt that has been previously used (Espejo-Hermes., 1998; Erdem et al., 2005; Güngörmez et al., 2017). according to Jiang et al.,(2023), salting at levels greater than 3% for 10 hours in *Oreochromis niloticus* caused myofibers deterioration, shrinking, and microstructure changes.

2.1.2 Drying

Another TTs known as drying. Drying has preserved fishing products since ancient times (Doe & Olley., 2020). Drying is extracting moisture from fishery products, typically accomplished through evaporation or alternative methodologies (Espejo-Hermes, 1998; Oğuzhan., 2012; Samples., 2015). Reducing the moisture content (MC) of fisheries products to below 15% has effectively prevented spoiling caused by various microorganisms. Additionally, drying the products to a moisture content of 10% has been observed to completely inhibit the formation of molds, resulting in a significant extension of the products' shelf-life (Espejo-Hermes., 1998). The drying rate of fishery products during the drying process is affected by several significant parameters, including the thickness of the product, its salt and fat content, the temperature at which drying occurs, the velocity of the surrounding air, and the relative humidity (Samples., 2015). Drying methods for fishery products include contact drying and air drying, also known as sun-drying. Contact drying involves cleaning the products and exposing them directly to sunlight for a specific period, which can range from hours to days, depending on the nature of the products. Alternatively, drying with salts can be employed, whereby the fishery products are cleaned, brined, or dry-salted and subsequently placed under the sun for a specified duration (Espejo-Hermes, 1998; Erkan, 2011; Oğuzhan, 2012). Sun drying *Alestes baremose* fish is a preservation method of creating good quality, quick, and straightforward procedure that yields an acceptable result (Modibbo et al., 2014). On the other hand, Delima et al. (2021), shows that salt amount varies depending on the fish species: two teaspoons for tilapia, one tablespoon for motan and lemongrass fish. Fish drying times are dependent on the intensity of the sun; cloudy weather prolongs drying times. When fish treated with salt were examined for research purposes, the fish's quality held up better than that of fish not treated with salt. Even in terms of flavor, fish prepared with salt is more appetizing or practical for eating. Because the salted fish already has a distinct flavor when cooked, it doesn't need any additional flavorings or seasonings.The flavor of the fish will be dull as opposed to unsalted fish (Table 1).

Table 1. Different fish with the addition of salt

NO	Type of fish	Drying Time	Add salt	Texture	Quality
1	Tilapia	Three days	2 tbsp	Dry	No fishy smell and long-lasting.
2	Motan Fish	Two days	1 tbsp	Dry	No fishy smell and durable
3	Lemongrass Fish	Two days	1 tbsp	Hard	No fishy smell and long-lasting.

In addition, long-term exposure of fish to sunlight can oxidize the lipids in the fish, reducing nutritional quality and raising consumer health risks (Smida et al., 2015). Furthermore, natural drying can dry fish faster and cause the flesh to become hard even though some moisture is still present, slowing down the drying process and promoting protein degradation (Abraha et al., 2018).

Hence, fish Processing Technology (FPT) encompasses a range of methodologies and procedures employed in the post-harvest processing, handling, and commercialization of aquatic goods, spanning from the initial harvesting stage to the ultimate consuming phase (Tahiluddin & Kadak., 2022).

The main focus of applying processing technology to aquatic products is to avoid or slow down spoiling caused by bacteria, enzymes, and improper physical and mechanical handling (Kaminski et al., 2020). For these reasons, good food preservation techniques should prevent microbial spoilage of food without affecting its nutritional value and flesh quality to meet the nutritional needs of this enormous population.

2. Fish Processing Technology (FPT)

Fish Processing technologies have a significant relationship, and this affect the nutrients that fish offer for human health. Accordingly, FPT is crucial in ensuring food security, promoting economic development, and maximizing the nutritional content available to consumers (Tahiluddin & Kadak., 2022). The importance of ensuring the production of high-quality fish products is underscored by the fluctuating demands of consumers and the elevated costs associated with these items (Liu et al., 2022). Furthermore, fish processing processes can be categorized into two distinct groups: traditional methods and non-traditional ways. In summary, the Traditional Techniques (TTs) employed for fish processing are limited to smoking, drying, salting, and canning, whereas chilling, freezing, and vacuum packing are categorized as non-traditional techniques (NTTs) of fish processing (Guevara., 1980; Cain., 2019). Typically, TTs are implemented with limited infrastructure and resources, utilizing affordable equipment commonly found within small-scale fisheries' value chains. On the other hand, NTTs are commonly employed at processing facilities with significant investments and in the context of international trade (FAO, 2021).

Fish processing typically commences immediately following the capture of fish. The process encompasses several stages, including the capture of fish, bleeding, chilling, grading, beheading, scaling, filleting, skinning, trimming, portioning, mincing, by-product recycling, and packaging (Aldás, 2013; Buljo & Gjerstad, 2013; Einarsdóttir et al., 2022). The processing operations in question are essential as they encompass several vital procedures, including beheading, filleting, trimming, skinning, and portioning (Liu al., 2022).

2.1 Traditional Techniques

2.1.1 Salting

Salting is classified as one of TTs and is recognized as one of the first techniques employed to preserve fish and other fishery products (Samples., 2015). The preservation mechanism and underlying principles of salting are consistent across all fisheries products, irrespective of the specific method employed. Additionally, dry and wet salting of fish and fishery products is widely implemented globally (Tahiluddin & Kadak., 2022). Osmosis and diffusion are fundamental processes involved in reducing and removing moisture from fishery products, resulting in a decrease in enzymatic and bacterial activities. These ultimately extend salted products' shelf life (Espejo-Hermes., 1998; Erdem et al., 2015; Güngörmez et al., 2017). Dry salting, known as the Kench process, involves directly applying decades. According to Gomez et al. (2023), there has been a significant increase in per capita consumption, which has risen by 200% during a specific period. Specifically, the consumption has gone from 6.4 kg to 11.3 kg. This increase is accompanied by an annual growth rate of 2.9%, which surpasses the global, regional, and sub-regional averages.

As a result of the increase in population and the rising living standards of civil society, there is considerable pressure on fish consumption (Khan et al., 2018). However, many challenges are associated with this massive increase in water resource requirements. Such as high demand and higher efficiency of work to improve productivity (Kulat et al., 2019).

In addition, fish is a rich source of protein, minerals, vitamins, and essential nutrients for human nutrition (Abraha et al., 2018). Moreover, fish are a valuable dietary component due to their provision of essential amino acids, lipid-soluble micronutrients, and highly unsaturated fatty acids (Nie et al., 2022; Petsini et al., 2019; Yu et al., 2020). Furthermore, the significant nutritional significance of these substances has been linked to numerous health advantages spanning from prenatal development through adulthood (Rifat et al., 2023). In summary, a significant correlation exists between fish consumption and enhancing individual well-being and longevity (Rumape et al., 2022).

Given the continuous expansion of the global population and the imperative to effectively store and transport food to areas of demand, food preservation assumes a crucial role in extending its longevity while preserving its nutritional composition, texture, and taste (Ghaly et al., 2010).

Conversely, fish is often seen as a complex culinary commodity owing to its susceptibility to spoiling, oxidation, and the emergence of undesirable tastes resulting from inadequate handling or storage practices. Various factors, including the dietary composition of the fish, how it is handled, and the conditions in which it is stored, significantly influence the preservation of optimal nutritional value in fish (Rumape et al., 2022).

To be specific, fish is known to have a short shelf life after being caught, primarily because of its elevated moisture content, reliance on oxygenated blood supply for cell maintenance, neutral pH, and presence of numerous resident microbiotas. These factors collectively contribute to the spoilage of fish through microbial and biochemical processes (Amit et al., 2017; Odeyemi et al., 2020). The enzymatic and oxidative processes in fish following their harvest give rise to notable alterations in their sensory and nutritional characteristics. These changes have a detrimental impact on the shelf-life of fish and are commonly interpreted by customers as a decline in freshness (Duarte et al., 2020). The adverse effects linked to a decrease in freshness are caused mainly by the degradation of proteins and the oxidation of lipids. These processes result in undesirable alterations in the odor, flavor, and texture of fish and also give rise to significant concerns regarding food safety (Sheng & Wang, 2021).

The contemporary fisheries and aquaculture sectors function within a vast and international marketplace. Given the intensifying competition within the marketplace, the fisheries and fish farming sectors must investigate sophisticated technology interventions to enhance productivity and profitability (Liu et al., 2022).

JKAU: Met., Env. & Arid Land Agric. Sci., Vol. **33** No. 1, pp: 29 - 46 (2024 A.D.)
DOI:10.4197/Met.33-1.3

Using Various Fish Processing Techniques to Maintain Flesh Quality and Shelf Life, An Updated Review

Nouf Hasan Aljizani[1] & Manal E. Shafi[2]

1 Department of Biological Sciences, Zoology, King Abdulaziz University, Jeddah 21589, Saudi Arabia
E-mail: naljizani0003@stu.kau.edu.sa

2 Sustainable Agriculture Production Research Group, Department of Biological Sciences, Zoology, King Abdulaziz University, Jeddah 21589, Saudi Arabia
E-mail: Meshafi@kau.edu.sa
ORCID: 0000-0003-2899-9496

Abstract. fish and fish products are crucial for human health, providing high-quality proteins, essential vitamins, minerals, and healthy polyunsaturated fatty acids. Furthermore, the great nutritional importance of these substances has been linked to numerous health benefits extending from prenatal development of the fetus to puberty .However, fish can deteriorate quickly after harvesting due to external environmental factors such as water quality (waste that turns into ammonia, nitrate, nitrite, pH, amount of dissolved oxygen, and temperature) and internal physiological factors such as microbes and bacteria, which increases the chance of their deterioration and loss of nutritional value. Therefore, it is essential to use techniques for aquaculture fish that are constantly evolving, focusing on the type and condition of the fish and applying appropriate techniques for farmed fish, considering the duration of transport. In addition, there are various techniques used in the preservation of aquaculture fish, including traditional techniques such as salting, drying, smoking, and pickling or marinating; non-traditional fish processing techniques include cooling, freezing, and vacuum packaging. Also, to determine fish freshness such as sensory characteristics, microbial analyses, physical and chemical evaluations. Fish processing techniques include methodologies and procedures used from harvest until reaching the consumer in its final form. This review investigates the most important preservation techniques used for fish and their impact on overall quality. In addition, it aims to achieve sustainable production with nutritional content, improve profitable productivity, and reduce negative health impacts on consumers and fear about the nutritional safety of food to achieve human in line with the Kingdom's Vision 2030's two pillars of a thriving economy and society.

Keywords: fish processing, spoilage, preservation techniques, aquaculture farming, freshness, fish quality, shelf life.

1. INTRODUCTION:

Human fish consumption has increased globally by 3.2% annually since the 1970s (Mengistu et al., 2020). Also, the global population is projected to increase by 2-2.5 billion individuals by 2050. Consequently, there will be a need to ensure food and energy provision for this growing population. Additionally, a significant demand for power remains unmet, affecting approximately one billion people (Cosgrove & Loucks., 2015).

In line with a comparable global pattern, there has been a consistent rise in the demand for fish among consumers in the Kingdom of Saudi Arabia (KSA) throughout the previous few

تأثير سماد النفايات العضوية البلدية على إنتاج الذرة المستدامة في زراعة الأراضي القاحلة

شهدات حسين ١ *، سمير ج. م. السليماني ١، فهد الغباري ١، خرام شاهزاد ٢ محمد رضا كابلي ٣، تشين كينغ ٤ ومحمد رشيد ٢

1 *قسم الزراعة كلية علوم البيئة جامعة الملك عبد العزيز جدة، المملكة العربية السعودية،*
salsolaimani@hotmail.com، falghabari@gmail.com،
2 *مركز التميز في الدراسات البيئية*(CEES) ، *جامعة الملك عبد العزيز، جدة، المملكة العربية السعودية،*
kramzan@kau.edu.sa، irmaliks@gmail.com،
3 *قسم الهندسة الصناعية، جامعة الملك عبد العزيز، جدة، المملكة العربية السعودية،* mkabli@kau.edu.sa
4 *كلية الموارد والعلوم البيئية، جامعة الصين الزراعية، بكين، الصين،* qchen@cau.edu.cn

مستخلص. يعد الاستخدام الفعال للسماد المشتق من النفايات العضوية البلدية (*MOW*) لإدارة مغذيات التربة أمرًا بالغ الأهمية لإنتاج المحاصيل المستدام وحماية البيئة. تعد زراعة الذرة باستخدام سماد *MOW* اقتصادية ومفيدة بيئيًا في جميع أنحاء العالم. تؤدي إضافة سماد *MOW* إلى التربة إلى تحسين إنتاجية الذرة. تم إجراء دراسة ميدانية في عامي ٢٠٢٢ و٢٠٢٣ لتحديد تأثير اثنين من السماد العضوي المصنوع من *MOW* الممزوج بالفيرميكوليت وروث البقر والأسمدة *NPK* على ثلاثة مستويات (٥ و١٠ و١٥ طن/هكتار) على محصول الذرة ومكونات المحصول. ثلاث مكررات التصميم الإحصائي لقطعة الأرض. تحتوي قطع الأراضي الرئيسية على مستويات سماد، بينما تحتوي القطع الفرعية على أربعة سماد نفايات *MOW: MOW*، الفيرميكوليت + *MOW*، روث البقر + *MOW*، و١٢٥ كجم/هكتار من سماد *NPK* مع *MOW*. تحتوي كل قطعة أرض مساحتها ٦ م٢ على مسافة ٥٠ سم من الخط إلى الخط و٣٠ سم من النبات إلى النبات. كان لسماد *MOW* مع سماد *NPK* أكبر الأثر على المحصول والخصائص المرتبطة به، يليه سماد الفيرميكوليت وروث البقر بمعدل ١٥ طن/هكتار. وأخيرًا، كان خلط *MOW* مع *NPK* بمعدل ١٥ طن/هكتار هو الأفضل بالنسبة لجميع خصائص الذرة. لن يلقي هذا التحليل النوعي والكمي ضوءًا جديدًا على تحويل *MOW* إلى سماد في سياق زراعة الأراضي القاحلة فحسب، بل سيمهد الطريق أيضًا لتوسيع كبير ومفيد في إنتاج الذرة.

الكلمة المفتاحية: النفايات العضوية البلدية، الذرة، المواد المضافة، نسبة السماد، الأراضي القاحلة.

Agron. 2020, Vol. 10, Page 1838 10, 1838. https://doi.org/10.3390/AGRONOMY10111838

28. Urra, J., Alkorta, I., Garbisu, C., 2019. Potential Benefits and Risks for Soil Health Derived From the Use of Organic Amendments in Agriculture. Agron. 2019, Vol. 9, Page 542 9, 542. https://doi.org/10.3390/AGRONOMY9090542

29. van Zyl, H.J.J., du Preez, C.C., 2022. Response of wheat cultivars with varying acid tolerances to liming of eastern Free State soils. https://doi.org/10.1080/02571862.2022.2137590 39, 360–369. https://doi.org/10.1080/02571862.2022.2137590

30. Wan, L.J., Tian, Y., He, M., Zheng, Y.Q., Lyu, Q., Xie, R.J., Ma, Y.Y., Deng, L., Yi, S.L., 2021. Effects of Chemical Fertilizer Combined with Organic Fertilizer Application on Soil Properties, Citrus Growth Physiology, and Yield. Agric. 2021, Vol. 11, Page 1207 11, 1207. https://doi.org/10.3390/AGRICULTURE11121207

31. Wang, H., Xu, J., Liu, X., Zhang, D., Li, L., Li, W., Sheng, L., 2019. Effects of long-term application of organic fertilizer on improving organic matter content and retarding acidity in red soil from China. Soil Tillage Res. 195, 104382. https://doi.org/10.1016/J.STILL.2019.104382

32. Zerssa, G.W., Kim, D.G., Koal, P., Eichler-Löbermann, B., 2021. Combination of Compost and Mineral Fertilizers as an Option for Enhancing Maize (Zea mays L.) Yields and Mitigating Greenhouse Gas Emissions from a Nitisol in Ethiopia. Agron. 2021, Vol. 11, Page 2097 11, 2097. https://doi.org/10.3390/AGRONOMY11112097

33. Zhou, Z., Zhang, S., Jiang, N., Xiu, W., Zhao, J., Yang, D., 2022. Effects of organic fertilizer incorporation practices on crops yield, soil quality, and soil fauna feeding activity in the wheat-maize rotation system. Front. Environ. Sci. 10, 1058071. https://doi.org/10.3389/FENVS.2022.1058071/BIBTEX

Liu, Z., Luo, S., Wu, Y., Lyu, J., Yu, J., 2022. Reduced Chemical Fertilizer Combined With Bio-Organic Fertilizer Affects the Soil Microbial Community and Yield and Quality of Lettuce. Front. Microbiol. 13, 863325. https://doi.org/10.3389/FMICB.2022.863325/BIBTEX

16. Köninger, J., Lugato, E., Panagos, P., Kochupillai, M., Orgiazzi, A., Briones, M.J.I., 2021. Manure management and soil biodiversity: Towards more sustainable food systems in the EU. Agric. Syst. 194, 103251. https://doi.org/10.1016/J.AGSY.2021.103251

17. Kousar, S., Ahmed, F., Pervaiz, A., Bojnec, Š., 2021. Food Insecurity, Population Growth, Urbanization and Water Availability: The Role of Government Stability. Sustain. 2021, Vol. 13, Page 12336 13, 12336. https://doi.org/10.3390/SU132212336

18. Lal, R., 2015. Restoring Soil Quality to Mitigate Soil Degradation. Sustain. 2015, Vol. 7, Pages 5875-5895 7, 5875–5895. https://doi.org/10.3390/SU7055875

19. Li, S., Liu, Zhijun, Li, J., Liu, Zhanwei, Gu, X., Shi, L., 2022. Cow Manure Compost Promotes Maize Growth and Ameliorates Soil Quality in Saline-Alkali Soil: Role of Fertilizer Addition Rate and Application Depth. Sustain. 2022, Vol. 14, Page 10088 14, 10088. https://doi.org/10.3390/SU141610088

20. Liu, Z., Yu, N., Camberato, J.J., Gao, J., Liu, P., Zhao, B., Zhang, J., 2019. Crop production kept stable and sustainable with the decrease of nitrogen rate in North China Plain: An economic and environmental assessment over 8 years. Sci. Rep. 9. https://doi.org/10.1038/S41598-019-55913-1

21. Mazloomi, F., Jalali, M., 2019. Effects of vermiculite, nanoclay and zeolite on ammonium transport through saturated sandy loam soil: Column experiments and modeling approaches. CATENA 176, 170–180. https://doi.org/10.1016/J.CATENA.2019.01.014

22. Palaniveloo, K., Amran, M.A., Norhashim, N.A., Mohamad-Fauzi, N., Peng-Hui, F., Hui-Wen, L., Kai-Lin, Y., Jiale, L., Chian-Yee, M.G., Jing-Yi, L., Gunasekaran, B., Razak, S.A., 2020. Food Waste Composting and Microbial Community Structure Profiling. Process. 2020, Vol. 8, Page 723 8, 723. https://doi.org/10.3390/PR8060723

23. Pisa, C., Wuta, M., Muchaonyerwa, P., 2020. Effects of incorporation of vermiculite on carbon and nitrogen retention and concentration of other nutrients during composting of cattle manure. Bioresour. Technol. Reports 9, 100383. https://doi.org/10.1016/J.BITEB.2020.100383

24. Revilla, P., Alves, M.L., Andelković, V., Balconi, C., Dinis, I., Mendes-Moreira, P., Redaelli, R., Ruiz de Galarreta, J.I., Vaz Patto, M.C., Žilić, S., Malvar, R.A., 2022. Traditional Foods From Maize (Zea mays L.) in Europe. Front. Nutr. 8, 683399. https://doi.org/10.3389/FNUT.2021.683399/BIBTEX

25. Roca, L.F., Romero, J., Bohórquez, J.M., Alcántara, E., Fernández-Escobar, R., Trapero, A., 2018. Nitrogen status affects growth, chlorophyll content and infection by Fusicladium oleagineum in olive. Crop Prot. 109, 80–85. https://doi.org/10.1016/J.CROPRO.2017.08.016

26. Rodríguez-Espinosa, T., Papamichael, I., Voukkali, I., Gimeno, A.P., Candel, M.B.A., Navarro-Pedreño, J., Zorpas, A.A., Lucas, I.G., 2023. Nitrogen management in farming systems under the use of agricultural wastes and circular economy. Sci. Total Environ. 876, 162666. https://doi.org/10.1016/J.SCITOTENV.2023.162666

27. Sayara, T., Basheer-Salimia, R., Hawamde, F., Sánchez, A., 2020. Recycling of Organic Wastes through Composting: Process Performance and Compost Application in Agriculture.

https://doi.org/10.1016/J.CITIES.2019.06.001
2. Agegnehu, G., Srivastava, A.K., Bird, M.I., 2017. The role of biochar and biochar-compost in improving soil quality and crop performance: A review. Appl. Soil Ecol. 119, 156–170. https://doi.org/10.1016/J.APSOIL.2017.06.008
3. Al-suhaibani, N., Selim, M., Alderfasi, A., El-hendawy, S., 2021. Integrated application of composted agricultural wastes, chemical fertilizers and biofertilizers as an avenue to promote growth, yield and quality of maize in an arid agro-ecosystem. Sustain. 13, 7439. https://doi.org/10.3390/SU13137439/S1
4. Aziiba, E.A., Qiang, C., Coulter, J.A., 2019. Mechanisms of Nitrogen Use in Maize. Agron. 2019, Vol. 9, Page 775 9, 775. https://doi.org/10.3390/AGRONOMY9120775
5. Chang'a, E.P., Abdallh, M.E., Ahiwe, E.U., Mbaga, S., Zhu, Z.Y., Fru-Nji, F., Iji, P.A., 2020. Replacement value of cassava for maize in broiler chicken diets supplemented with enzymes. Asian-Australasian J. Anim. Sci. 33, 1126. https://doi.org/10.5713/AJAS.19.0263
6. Chen, T., Zhang, S., Yuan, Z., 2020. Adoption of solid organic waste composting products: A critical review. J. Clean. Prod. 272, 122712. https://doi.org/10.1016/J.JCLEPRO.2020.122712
7. Fróna, D., Szenderák, J., Harangi-Rákos, M., 2019. The Challenge of Feeding the World. Sustain. 2019, Vol. 11, Page 5816 11, 5816. https://doi.org/10.3390/SU11205816
8. Giller, K.E., Delaune, T., Silva, J.V., Descheemaeker, K., van de Ven, G., Schut, A.G.T., van Wijk, M., Hammond, J., Hochman, Z., Taulya, G., Chikowo, R., Narayanan, S., Kishore, A., Bresciani, F., Teixeira, H.M., Andersson, J.A., van Ittersum, M.K., 2021. The future of farming: Who will produce our food? Food Secur. 13, 1073–1099. https://doi.org/10.1007/S12571-021-01184-6/FIGURES/6
9. Goldan, E., Nedeff, V., Barsan, N., Culea, M., Panainte-Lehadus, M., Mosnegutu, E., Tomozei, C., Chitimus, D., Irimia, O., 2023. Assessment of Manure Compost Used as Soil Amendment—A Review. Process. 2023, Vol. 11, Page 1167 11, 1167. https://doi.org/10.3390/PR11041167
10. Gupta, K.K., Aneja, K.R., Rana, D., 2016. Current status of cow dung as a bioresource for sustainable development. Bioresour. Bioprocess. 3, 1–11. https://doi.org/10.1186/S40643-016-0105-9/METRICS
11. Han, Y., Lv, F., Lin, X., Zhang, C., Sun, B., Yang, X., Zhang, S., 2022. Crop Yield and Nutrient Efficiency under Organic Manure Substitution Fertilizer in a Double Cropping System: A 6-Year Field Experiment on an Anthrosol. Agron. 2022, Vol. 12, Page 2047 12, 2047. https://doi.org/10.3390/AGRONOMY12092047
12. Heisey, S., Ryals, R., Maaz, T.M., Nguyen, N.H., 2022. A Single Application of Compost Can Leave Lasting Impacts on Soil Microbial Community Structure and Alter Cross-Domain Interaction Networks. Front. Soil Sci. 2, 749212. https://doi.org/10.3389/FSOIL.2022.749212
13. Hua, W., Luo, P., An, N., Cai, F., Zhang, S., Chen, K., Yang, J., Han, X., 2020. Manure application increased crop yields by promoting nitrogen use efficiency in the soils of 40-year soybean-maize rotation. Sci. Reports 2020 101 10, 1–10. https://doi.org/10.1038/s41598-020-71932-9
14. Jiang, Y., Li, K., Chen, S., Fu, X., Feng, S., Zhuang, Z., 2022. A sustainable agricultural supply chain considering substituting organic manure for chemical fertilizer. Sustain. Prod. Consum. 29, 432–446. https://doi.org/10.1016/J.SPC.2021.10.025
15. Jin, N., Jin, L., Wang, S., Li, J., Liu, F.,

Chemical fertilizer is taken up by plants immediately after application and provides nutrients for a short time, boosting crop growth, but organic fertilizers release nutrients slowly, allowing them to meet plant needs in the long run and during the critical yield-forming period (Wan et al., 2021).

Compost treatment at 15 (ton/ha) yielded the highest mean cob yield and other cob-related features, followed by 10. The control treatment (just MOW) had the lowest cob characteristics in both seasons. Compost is becoming increasingly popular to improve soil quality and agricultural outputs (Agegnehu et al., 2017). A study of several different characters discovered that an increase in compost rate led to a rise in maize yield components (Zerssa et al., 2021). Compost enhances soil fertility while also reducing nitrogen loss and stabilizing nitrogen intake and maize yields (Hua et al., 2020). Composting is one example of an organic fertilizer modification technology that, when used properly, can lead to increased crop yields and improved soil fertility status (Chen et al., 2020). Organic amendments have the potential to directly increase crop output because they boost the availability of soil nutrients (Urra et al., 2019).

Cob length, grain rows per cob, and 1000-grain weight enhanced maize production. Tables 2 and 3 show that 15-ton/ha compost yielded the most cobs and had the best qualities for C4, followed by C2 and C3 for both seasons. Organic inputs and compost maintain soil productivity, providing necessary nutrients for crop production. NPK plus compost increased maize grain output more than NPK alone (Han et al., 2022). The NPK fertilizer and manure treatment increased maize crop cob fresh and dry yield ($p > 0.05$) compared to the control treatment, demonstrating that it affected the crop during growth. (Table 3).

Besides biomass and yield, maize crop nitrogen content (%) is crucial. This study indicated that 15 ton/ha of NPK fertilizer with manure enhanced nitrogen content by 1.6 and 2.3% for compost rates of 10 and 5 ton/ha. Roca et al., 2018 found that NPK and manure application increased nitrogen content, supporting that high chlorophyll content may be responsible for the high nitrogen content. Overall, 15 t/ha manure and blended fertilizer (NPK) increased biomass, yield, and protein.

4. Conclusion

Arid land agriculture has gained scholarly attention in the last decade, although little research has examined MOW composting for maize productivity. We used the conversion of MOW to evaluate compost for sustainable crop production and soil amendment resources. Many exciting and relevant properties are likely in MOW composts. These features are valuable and significant in preparing these composts and their application for maize production. In two-year field trials, MOW composts and NPK treatments dramatically altered maize growth, production, and quality in a dry agro-ecosystem.

Acknowledgments

The authors extend their appreciation to the Deputyship for Research & Innovation, Ministry of Education in Saudi Arabia for funding this research work (Project number 397).

Conflict of interest

The authors state that the research had no commercial or financial conflicts of interest.

References

1. Abu Hatab, A., Cavinato, M.E.R., Lindemer, A., Lagerkvist, C.J., 2019. Urban sprawl, food security and agricultural systems in developing countries: A systematic review of the literature. Cities 94, 129–142.

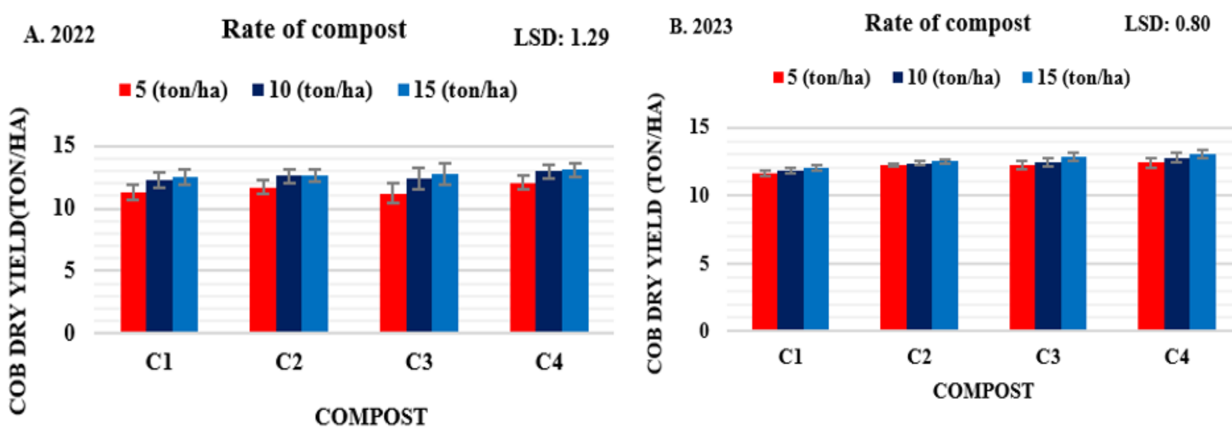


Figure 4. Effect of MOW compost on the cob dry yield of maize during 2022 and 2023
Here C1= only MOW compost (control), C2= 10 % Vermiculite added to MOW compost(w/v), C3= 10% cattle dung added to MOW compost (w/w) and C4= 150 kg/ha NPK + MOW compost

3. Discussion

Analyses of variation (Tables 1 and 2) showed that the treatments C4 (combination of MOW compost and NPK) and C2 (Vermiculite and MOW) induced a considerable increase in different maize parameters over the treatments C2 and C1 (only MOW compost). Most of the evaluated parameters of maize improved in C2 and C3 (Cow manure and MOW) compared to C1 when combined with synthetic fertilizers. Based on the information in both tables, it looks like combining the use of organic composts with a low dose (125 kg/ha) of NPK (C4) could be a good way to keep the growth, productivity, and quality of the maize crop within acceptable ranges, even when the soil quality is low and the weather is dry. These findings are consistent with those of other studies that have found that using a high-level application amount of organic compost or a combination of organic compost and chemical fertilizers is an effective strategy and that this method is being advocated as a viable substitute for the intensified use of chemical fertilizers to improve the growth, production, and quality of a variety of field crops, even in arid environments (Jin et al., 2022).

The combined effect of NPK and manure application increased output for all maize growth, cob fresh weight(g) and cob dry weight (g) and other attributes across all treatments compared to the control ($p > 0.05$). The maize production was greatly improved by the application of mineral fertilizers in addition to manure. At 15 ton/ha compost level, treatment MOW +NPK yielded the maximum cob fresh and dry yield, considerably higher than the control ($p > 0.05$). This confirms the beneficial effect of NPK and organic fertilizer treatment on crop development and yield found in earlier research. These findings support past research suggesting NPK and organic fertilizer applications boost crop growth and productivity. (Wang et al., 2019). Organic matter in composts improves the biological and physical-chemical properties of the soil. This may explain why maize parameters increased a lot when a lot of compost or a combination of organic and chemical fertilizers was used instead of just chemical fertilizers (Zhou et al., 2022). Applying organic and chemical fertilizers together may be beneficial as it improves synchronization and synergy between nutrients and plant needs throughout the growth cycle.

Table 4. Mean values of Leaf area index, cob fresh yield, cob dry yield and nitrogen % of maize under the influence of MOW composts during 2022-2023.

Treatments	Leaf area index (LAI)		Cob fresh yield (ton/ha)		Cob dry yield (ton/ha)		Nitrogen % in grain	
	2022	2023	2022	2023	2022	2023	2022	2023
Compost rate (ton/ha)								
5	1.35c	1.30c	20.79a	21.31a	12.29a	11.93b	0.69c	0.75c
10	1.64b	1.67b	20.82a	21.81a	12.34a	12.44ab	1.49b	1.54b
15	1.83a	1.88a	21.44a	22.04a	12.50a	12.64a	1.79a	1.83a
MOW composts								
C1	0.40b	0.39c	20.98a	20.49b	12.13a	12.18a	1.14c	1.19c
C2	1.63a	1.37b	21.04a	21.93a	12.45a	12.38a	1.30b	1.35b
C3	1.55a	1.30 b	20.25a	21.77a	12.32a	12.36a	1.33b	1.41b
C4	1.69a	1.99a	21.79a	22.69a	12.43a	12.57a	1.52a	1.54a

Values in the column with identical letter(s) do not substantially differ at the 5% level of probability. Here C1= only MOW compost (control), C2= 10 % Vermiculite added to MOW compost(w/v), C3= 10% cattle dung added to MOW compost (w/w) and C4= 150 kg/ha NPK + MOW compost

2.4 Consequences of MOW composts and their levels on maize cob yield

The interaction outcomes between the MOW composts and their levels significantly affected the fresh and dried cob yields of maize. Figure 3 shows that compared to other MOW-derived composts over both seasons, the combination of organic and inorganic fertilizers significantly influenced ($p \leq 0.05$) maize cob fresh yield and cob dry yield production for the two seasons. However, composts with no additives (only MOW) had the lowest values overall yield contributing attributes for both seasons. Figures 3 and 4 also display the results of two growing seasons of using MOW compost coupled with NPK, which are significant ($p \leq 0.05$). Values were lowest in 2022 and 2023 when MOW compost was applied without amendments.

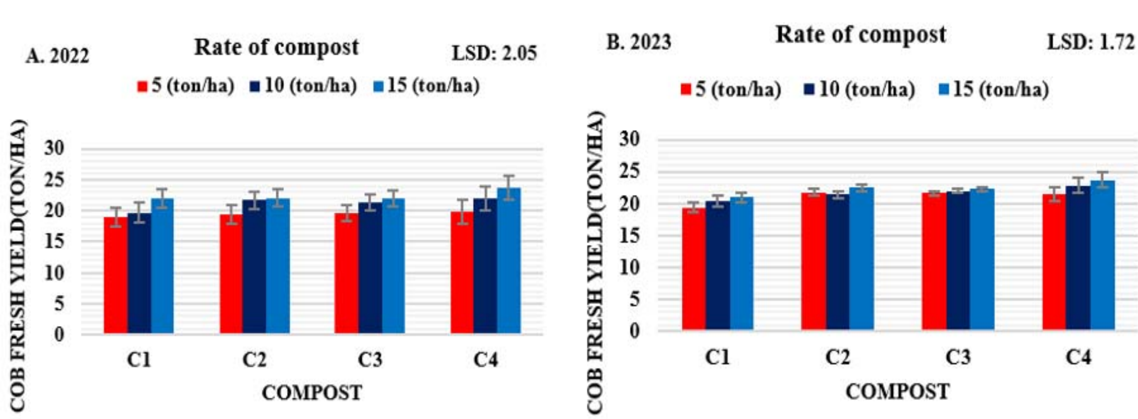


Figure 3. Effect of MOW compost on the cob fresh yield of maize during 2022 and 2023
Here C1= only MOW compost (control), C2= 10 % Vermiculite added to MOW compost(w/v), C3= 10% cattle dung added to MOW compost (w/w) and C4= 150 kg/ha NPK + MOW compost

1000 grain weight (371.20g) were found for the first season at 15 ton/ha level of compost, but only the highest number of seed rows per cob (12.84) was obtained during second season for the same level of compost (Table 2). Among all treatments, maximum mean values for almost all the parameters were obtained for treatment C4 in both seasons, followed by C3 and C2 treatment for the level of 15ton/ha.

Table 3. Effect of MOW composts on maize cob yield attributes during 2022-2023.

Treatments	Cob length (mm)		Cob girth (mm)		Seed rows/ cob		1000 seeds weight (g)	
	2022	2023	2022	2023	2022	2023	2022	2023
Compost rate (ton/ha)								
5	203.79a	209.09a	53.46b	53.26a	12.26b	12.32b	335.18b	333.25b
10	207.42a	210.54a	54.35b	53.94a	12.51ab	12.61ab	362.66a	358.49a
15	210.54a	209.77a	56.86a	53.43a	12.75a	12.85a	371.20a	367.86a
MOW composts								
C1	204.27a	208.19a	52.76b	53.87a	12.51a	12.57a	353.20ab	352.75ab
C2	207.11a	209.33a	55.46a	53.46a	12.43a	12.43a	346.59b	341.04b
C3	208.19a	210.94a	55.33a	53.55a	12.52a	12.51a	361.64a	356.09a
C4	209.42a	210.74a	56.00a	53.29a	12.82a	12.84a	363.95a	362.94a

Values in the column with identical letter(s) do not substantially differ at the 5% level of probability.
Here C1= only MOW compost (control), C2= 10 % Vermiculite added to MOW compost(w/v), C3= 10% cow manure added to MOW compost (w/w) and C4= 150 kg/ha NPK + MOW compost

Leaf Area Index (LAI) impacts canopy light movement, suggesting health or development. LAI impacts the canopy microclimate. Leaves block sunlight and light radiation, altering transpiration and latent heat (Teitel *et al.,* 2016). Table 2 demonstrates that compost dosages increase LAI. The maximum LAI was attained with C4 compost, followed by C2 for both seasons with 15 and 10 tons/ha compost, respectively. The cob fresh yield (ton/ha), cob dry yield (ton/ha) and nitrogen content % in grain were higher during the 2023 season than in 2022 and in every attribute, the values gradually increased with the increase of compost. In the case of treatment effect for these yield and yield contributing traits, the maximum influential effect was done by C4 followed by C2, respectively. In 2023, C4 compost recorded the highest cob fresh and dry yield of 22.69 tons/ha and 12.57 tons/ha, respectively. C2 compost came in second with 21.93 tons/ha and 12.38 tons/ha. 1.54% nitrogen in grain was found for C4, and 1.41% was found for C3 during the 2023 season. In the case of all maize cob and cob yield traits, the minimum values were recorded for C1 (control) compost, which was prepared by decomposing only MOW (Table 3).

recorded for the second season for compost vermiculite + MOW (C2) for 10 ton/ha level of compost followed by C4 compost (Figure 1, B).

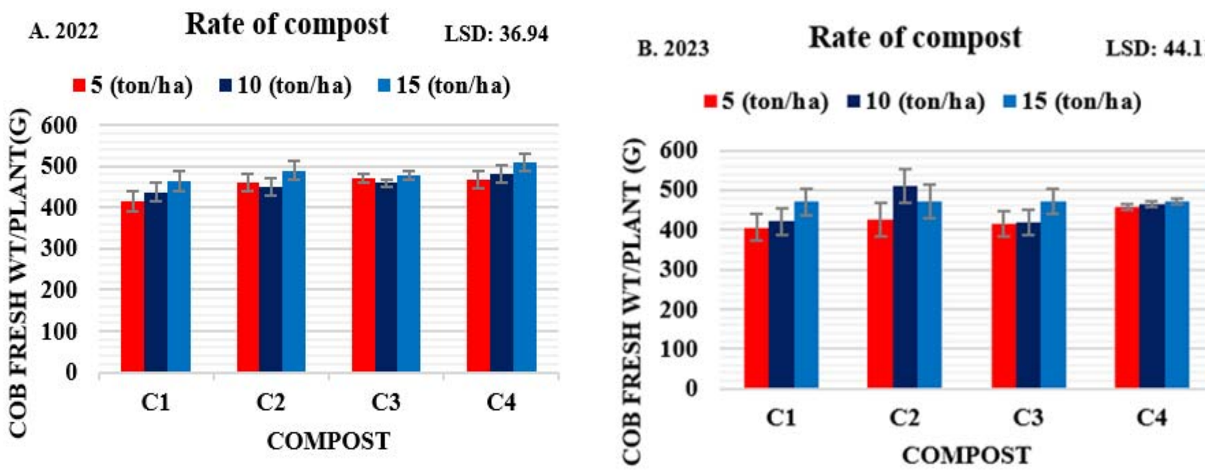


Figure 1. Effect of MOW compost on the cob fresh weight of maize during 2022 and 2023
Here C1= only MOW compost (control), C2= 10 % Vermiculite added to MOW compost(w/v), C3= 10% cow manure added to MOW compost (w/w) and C4= 150 kg/ha NPK + MOW compost

The highest cob dry weight under two seasons was obtained in the case of C4 compost compared to others, which showed a significant difference among other types of compost, especially at a level of 15 tom/ha (Figure 2). Insignificant ($p \leq 0.05$) differences were found for cob dry weight between compost C2 (vermiculite + MOW) and C3 (cow manure + MOW) during the 2023 season.

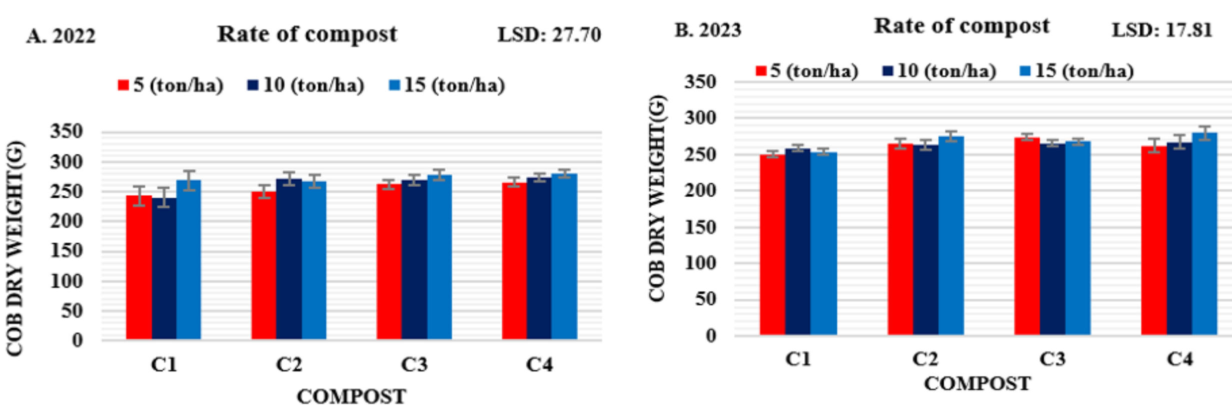


Figure 2. Effect of MOW compost on the cob dry weight of maize during 2022 and 2023
Here C1= only MOW compost (control), C2= 10 % Vermiculite added to MOW compost(w/v), C3= 10% cow manure added to MOW compost (w/w) and C4= 150 kg/ha NPK + MOW compost

2.3 Maize cob and cob yield

Table 2 and Table 3 show that 15 or 10 tons/ha of compost maximized cob length, cob girth, seed rows per cob, 1000 seeds weight, leaf area index, cob fresh yield (ton/ha), cob fresh yield (ton/ha), cob dry yield (ton/ha) and Nitrogen % in grain. The maximum values of cob length (210.54mm) and cob girth (56.86mm) and

Table 1. Fresh and dry weight plant and cob of maize under different MOW composts and compost rate in 2022-23.

Treatments	Total fresh weight (g)		Total dry weight (g)		Cob fresh weight (g)		Cob dry weight (g)	
	2022	2023	2022	2023	2022	2023	2022	2023
Compost rate(ton/ha)								
5	1081.52b	1027.78b	608.94c	606.44b	459.26a	430.08b	262.94a	255.68b
10	1108.88a	1056.51ab	638.95b	630.88b	466.90a	449.73ab	269.10a	266.60ab
15	1099.93ab	1073.27a	662.71a	671.86a	470.48a	471.46a	263.77a	270.88a
MOW composts								
C1	1073.04b	1042.61bc	616.79b	619.42b	439.28b	434.01b	261.16a	264.05a
C2	1081.45b	1007.07c	642.18a	645.08ab	466.64a	450.94a	269.50a	266.95a
C3	1101.59ab	1074.58ab	635.49ab	630.61ab	467.01ab	449.73ab	264.97a	260.08a
C4	1131.02a	1085.82a	653.01a	650.47a	470.06a	486.23a	265.46a	266.47a

Table 2. Fresh and dry weight plant and cob of maize under different MOW composts and compost rate in 2022-23.

Treatments	Total fresh weight (g)		Total dry weight (g)		Cob fresh weight (g)		Cob dry weight (g)	
	2022	2023	2022	2023	2022	2023	2022	2023
Compost rate(ton/ha)								
5	1081.52b	1027.78b	608.94c	606.44b	459.26a	430.08b	262.94a	255.68b
10	1108.88a	1056.51ab	638.95b	630.88b	466.90a	449.73ab	269.10a	266.60ab
15	1099.93ab	1073.27a	662.71a	671.86a	470.48a	471.46a	263.77a	270.88a
MOW composts								
C1	1073.04b	1042.61bc	616.79b	619.42b	439.28b	434.01b	261.16a	264.05a
C2	1081.45b	1007.07c	642.18a	645.08ab	466.64a	450.94a	269.50a	266.95a
C3	1101.59ab	1074.58ab	635.49ab	630.61ab	467.01ab	449.73ab	264.97a	260.08a
C4	1131.02a	1085.82a	653.01a	650.47a	470.06a	486.23a	265.46a	266.47a

Values in the column with identical letter(s) do not substantially differ at the 5% level of probability. Here C1= only MOW compost (control), C2= 10 % Vermiculite added to MOW compost(w/v), C3= 10% cow manure added to MOW compost (w/w) and C4= 150 kg/ha NPK + MOW compost

2.2 Interaction of MOW compost types and application rates on maize fresh and dry weight

Significant changes in fresh and dry cob weight were observed among the MOW compost types and the rate of compost applied to maize cultivars. As shown in Figure 1, compost rates of 5, 10, and 15 tons/ha increased the cob fresh weight under all types of composts. Cultivar Compost 4 (C 4), made by mixing MOW compost with NPK, gave the highest cob fresh weight under 15 ton/ha dose rate compared to the two other doses. In the case of C1 compost (only MOW compost), it was found that minimum cob fresh weight for all the rates of compost was used compared to other treatments and rates. The effect of a 5 ton/ha level of compost was observed with similar results for all the treatments except the control. The maximum cob fresh weight was into 4 sub-plots. Compost types were randomly assign in four sub-plots to evaluate the effects of different types of compost. Each plot was 6m^2 in size with 3m in length and 2m in width. Line to line distance was 50 cm and plant to plant was 30 cm.

1.2 MOW composts

The experiment was conducted with four MOW-derived composts that were developed by the Agriculture Department and Centre of Excellence of Water and Environment Studies (CEES) of King Abdulaziz University, Saudi Arabia, from MOW of Jeddah landfill center. The composts were C1= Compost 1(control), C2= 10 % Vermiculite added MOW compost (w/v), C3= 10% cow manure added MOW compost (w/w) and C4= 150 kg/ha NPK added MOW compost. MOW compost without any additives was referred to as a control treatment.

1.3 Use of composts and NPK fertilizer

Prior to sowing, MOW composts were added into the top 30 centimeters of the field according to the design and rate of compost and fertilizers. 150 kg/ha of NPK was given in four equal applications (at 15, 30, 60, and 90 days after planting), along with the only MOW compost treatment in each growing season. The experimental field had a drip irrigation system, and it was irrigated every two-day intervals.

1.4 Maize agronomic traits evaluation

At harvesting, 5 plants were randomly chosen from each experimental unit to determine cob fresh and dry weight (g), total fresh and dry weight (g), cob length (mm), cob girth (mm), seed rows/cob, 1000-kernel weight (g), cob fresh yield (ton/ha), cob dry yield (ton/ha), Leaf area index and Nitrogen % content in grain.

1.5 Statistical analysis

The plant and agronomical yield data were statistically examined using analysis of variance. (ANOVA). SAS 9.4 program was used for ANOVA of group means (SAS Institute, 2011). LSD was used to compare treatment means at ($p \leq 0.05$) (van Zyl and du Preez, 2022). Three independent biological replicates were used for all observations.

2. Results

Tables (3) and (4) reveal that the different MOW-derived composts, levels, and their interaction significantly ($p \leq 0.05$) affected the plant height, yield, and its components in both 2022 and 2023.

2.1 Plant's fresh and dry weight

Results in Table 3 showed a significant increase in cob fresh and dry weights and total plant fresh and dry weight (g) during the two seasons. The maximum cob fresh weight of 471.46 g and 470.48 g were recorded in 15 ton/ha compost during 2023 and 2022, respectively, followed by 10 ton/ha compost during the two seasons. The lowest mean values of this trait during the two growing seasons for the levels of compost were obtained at 459.26g and 430.08g for the first and second seasons, respectively. Among the treatments, the highest cob fresh and dry weight were recorded for compost 4 (mixed MOW and NPK) treatment for both seasons, 486.23g and 470.06g for 2023 and 2022. In the case of cob dry weight, the maximum weight was found for 15 ton/ha for mixed treatment for two seasons. For total fresh and dry weight, the height data for compost level was obtained at 10 ton/ha for 2022 (1108.88g), but in 2023, it was obtained at the rate of 15 ton/ha compost (1073.27g). Maximum total fresh weight (1131.02g and 1085.82g) and total dry weight (653.01g and 650.47g) were found for treatment C4 (mixed MOW and NPK) during 2022 and 2023. In the case of every parameter, the lowest values were found in 5-ton/ha compost for control.

This frequently forces farmers to overuse chemical fertilizers to maximize grain yield. However, uncontrolled chemical fertilizer use harms soil health, the environment, and economic returns due to high input costs (Rodríguez-Espinosa et al., 2023). Chemical fertilizer and organic compost work well for sustainable agriculture (Jiang et al., 2022).

Amendments improved compost nutrient quality, reduced gaseous emissions and dangerous bacteria, and enhanced plant nutrition (Goldan et al., 2023). Vermiculite is a mineral often used in agriculture due to its ability to retain water and nutrients (Mazloomi and Jalali, 2019). The vermiculite helps retain moisture in the soil, ensuring that the maize plants have access to water even during dry periods. Composts with vermiculite helped dry-land maize grow and produce. These farmer-friendly composts can increase soil organic matter and cost less than basic fertilizers (Pisa et al., 2020). Cow manure, on the other hand, is a type of organic waste commonly used as a fertilizer due to its high nutrient content (Gupta et al., 2016). The cow manure compost contributes essential nutrients to the soil, promoting healthy growth and development of the maize plants (Li et al., 2022). Organic materials and plant nutrients like phosphorous (P) and nitrogen (N) are abundant in cattle manure. Cow manure-added compost prevents N leaching in any soil and runoff loses soil nutrients (Köninger et al., 2021).

Municipal organic waste (MOW) composting involves the process of converting organic waste from municipalities into compost, which can then be used as a soil amendment (Palaniveloo et al., 2020). It reduces the abuse of inorganic fertilizers, which are declining soil quality, and helps sustainable crop production (Lal, 2015).

The combined use of NPK fertilizers and MOW composts can have a positive effect on the production of hybrid maize. Synthetic fertilizers provide essential nutrients for the growth and development of maize crops (Al-suhaibani et al., 2021). NPK fertilizers and MOW composts work well together. Plants get enough nutrients for optimal growth with NPK fertilizers. Conversely, MOW composts improve soil structure, water-holding capacity, and nutrient retention (Sayara et al., 2020). MOW compost increases soil microbial biodiversity. These bacteria improve plant nutrition by cycling nutrients. Compost and NPK fertilizers increase soil microbial diversity and activity, creating a healthier soil ecology that supports maize development (Heisey et al., 2022).

Composts are effective nutrient management for crop growth and development, yet additive-amended MOW-derived composts have not yet been studied for maize cultivation. Very little information is available on the interactive effect of organic amendment and MOW in the promotion of maize growth. These knowledge gaps were addressed by adding vermiculite and cow dung to MOW composts to examine the impact of MOW composts and their amounts on hybrid maize growth and production. Thus, this research is unique in studying compost rate's effect on crop growth and clarifying the interaction between fertilizer regime, soil features, and maize growth parameters. This study has helpful suggestions for using MOW composts to increase maize growth.

1. Materials and methods

1.1 Design of field experiment

A split-plot design with three replications was followed. In split plot design usually treatment which wants to evaluate is applied in sub-plots. The amount of 5, 10 and 15 tons/ha compost were used in main plots to evaluate the effects of compost rate. Each main plot was divided

JKAU: Met., Env. & Arid Land Agric. Sci., Vol. **33** No. 1, pp: 15 - 27 (2024 A.D.)
DOI:10.4197/Met.33-1.2

Effect of municipal organic waste compost for sustainable maize production in arid land agriculture

Shahadat Hossain[1]*, Samir G. M. Al-Solaimani[1], Fahad Alghabari[1], Khurram Shahzad[2] Mohammed Reda Kabli[3], Chen Qing[4] and Muhammad I. Rashid[2]

[1]Department of Agriculture, Faculty of Environmental Sciences, King Abdulaziz University, Jeddah, Saudi Arabia, salsolaimani@hotmail.com, falghabari@gmail.com,
[2]Centre of Excellence in Environmental Studies (CEES), King Abdulaziz University, Jeddah, Saudi Arabia, kramzan@kau.edu.sa, irmaliks@gmail.com,
[3]Industrial Engineering Department, King Abdulaziz University, Jeddah, Saudi Arabia, mkabli@kau.edu.sa
[4]College of Resources and Environmental Sciences, China Agricultural University, Beijing, China, qchen@cau.edu.cn
*Corresponding author: shossain0001@stu.kau.edu.sa
PhD. Fellow, Department of Agriculture, Faculty of Environmental Science, King Abdulaziz University, Jeddah, Saudi Arabia. Email: shossain0001@stu.kau.edu.sa,

Abstract. effective use of municipal organic waste (MOW) derived composts for soil nutrient management is crucial for sustainable crop production and environmental protection. Maize cultivation using MOW compost is economical and environmentally beneficial around the world. Adding MOW compost to the soil improves maize yield. A field study was conducted in 2022 and 2023 to determine the effects of two composts made from MOW mixed with Vermiculite, Cow dung, and NPK fertilizer at three levels (5, 10, and 15 ton/ha) on maize yield and yield components. Three replications split plot statistical design. Main plots had compost levels, while subplots had four MOW waste composts: MOW, Vermiculite + MOW, Cow manure +MOW, and 125 kg/ha NPK fertilizer with MOW. Each 6 m^2 plot had a 50 cm line-to-line and 30 cm plant-to-plant distance. MOW compost with NPK fertilizer had the greatest impact on yield and yield-related characteristics, followed by Vermiculite and Cow manure compost at 15 ton/ha. Finally, MOW mixes with NPK at 15 ton/ha performed best for all maize characteristics. This qualitative and quantitative analysis will not only shed fresh light on converting MOW to compost in the context of arid land agriculture but will also pave the way for a substantial and worthwhile expansion of maize production.
Key word: Municipal Organic Waste, Maize, Additives, compost rate, and Arid Land

INTRODUCTION:

Population is one of the primary contributors to food insecurity (Kousar et al., 2021). A growing population creates demand in the agriculture sector, making it challenging to feed a growing population (Giller et al., 2021). Food insecurity rises when urbanization expands and people use the land for urban expansion instead of agriculture (Abu Hatab et al., 2019). Modern agriculture's biggest challenge is economically and environmentally sustainable sustenance for a growing population. To feed the expanding population by 2050, food output must rise by 70% (Fróna et al., 2019).

Maize (*Zea mays* L.) is cultivated worldwide for food and fodder production (Revilla et al., 2022). Many sectors employ maize, including human meals, poultry feed, and animal fodder (Chang'a et al., 2020). However, maize consumes more nutrients and mineral fertilizers than other cereal crops during growth (Aziiba et al., 2019). When grain maize production exceeds 16 tons per hectare, it can use 250–300 kg of nitrogen (Liu et al., 2019).

نظرة عامة عن تأثير تحضير بذور في الطماطم تحت تأثير الظروف الطبيعية والملوحة: من انبات البذور إلى الحصاد

رنين جوهر سويلم محمد, مجدي علي احمد موسي، عمر حسني ابراهيم و هشام فيصل الحربي

مستخلص. تعتبر الطماطم أحد أهم محاصيل الخضار في جميع أنحاء العالم وفي المملكة العربية السعودية، نظرًا لقيمتها الغذائية العالية وكفاءتها للزراعة في ظل مجموعة واسعة من الظروف البيئية. الطماطم هي واحدة من محاصيل الخضار النقدية التي تولد دخلاً جيدًا ومستمرًا للمزارعين لمدة شهرين إلى ثلاثة أشهر. على الصعيد العالمي، تعتبر الطماطم المصدر الرئيسي للدخل والمساهم الرئيسي في الأمن الغذائي لصغر حجم المجين في الطماطم، فإنه يعتبر نموذجًا للدراسات الفسيولوجية والوراثية والجزيئية والتربية لتحسين الصفات والمحصول وتحمله للضغوط الأحيائية وغير الأحيائية. إن إنتاج الطماطم وتوسيع نطاق زراعتها يواجهان تحديات كثيرة، لا سيما مع التغيرات البيئية العالمية فيما يتعلق بالتغيرات المناخية، وتوافر المياه العذبة وجودتها، والآفات والأمراض، وجودة التربة. تم إجراء العديد من الدراسات لإيجاد حلول فعالة وقابلة للتطبيق للتغلب على المشاكل البيئية التي تواجه التوسع في زراعة الطماطم وزيادة الإنتاجية، بما في ذلك اتباع الممارسات الزراعية الجيدة، وتحسين وتربية أصناف جديدة ذات إنتاجية وجودة عالية في ظل ظروف بيئية قاسية واستخدام المحفزات الحيوية للنمو التي تساعد النباتات على النمو والإنتاج في ظل ظروف صعبة. يعد تحضير البذور أحد الحلول الموصى بها للمساعدة في إنبات الطماطم ونموها وإنتاجيتها في ظل الضغوط الأحيائية وغير الأحيائية. وتهدف دراسة المراجعة المقدمة إلى تقديم الدراسات الحديثة التي تم إجراؤها حول استخدام تحضير البذور لتحسين إنبات الطماطم ونموها وإنتاجيتها في ظل ظروف الإجهاد البيئي. تنقسم المراجعة المقدمة إلى ثلاثة أقسام: (١) تحضير البذور لتحسين إنبات بذور الطماطم؛ (٢) تحضير البذور لتحسين نمو الطماطم وإنتاجها؛ (٣) تحضير البذور لتحسين قدرة الطماطم على تحمل الإجهاد الملحي.

الكلمات الرئيسية: الطماطم، الاجهاد الملحي، تحضير البذور، تحضير الهالة، الملوحة، المقاومة المستحثة.

Coastal Salt-Affected Soils. Water. 14(18): 2804. https://doi.org/10.3390/w14182804

50. Patel, Y.K. and Rai, P.K.2018. Effect of Seed Priming on Seed Quality of Tomato (Solanum lycoperscium L.). 7(2): 264-267

51. Galviz,Y.C., Bortolin, G.S., Guidorizi,K.A., Deuner, S., Reolon, F. & Moraes, D.M.D. 2021. Effectiveness of Seed Priming and Soil Drench with Salicylic Acid on Tomato Growth Physiological and Biochemical Responses to Severe Water Deficit. Journal of Soil Science and Plant Nutrition. 21: 2364–2377

52. Fajardo , Y. C. G., Bortolin , G.S., Deuner ,S., Amarante ,L.D., Reolon , F., Moraes, D.M., 2020. Seed priming with salicylic acid potentiates water restriction induced effects in tomato seed germination and early seedling growth. Journal of Seed Science. 42: 1-12.

53. Zhang, M., Wang, Z., Yuan, L., Yin, C., Cheng, J., Wang, L., Huang, J., Zhang, H. 2012. Osmopriming Improves Tomato Seed Vigor Under Aging And Salinity Stress. African Journal Of Biotechnolog.11(23):6305-6311

irrigation water salinity. JFAE Vol 11. (2) – 132-138.
33. Maiti.R., Dasari,R., Mangalarapu, J., Pramanik K., Vidyasagar, P.2013. Effect of Seed Priming on Seedling Vigour and Yield of Tomato and Chilli. International journal of Bio-resource and Stress Management.4(2):119-125
34. Rengasamy, P. 2010. Soil Processes Affecting Crop Production in Salt-Affected Soils. Functional Plant Biology, 37, 613-620. https://doi.org/10.1071/FP09249
35. Bewley, M., Friedman, A., Ferrari, R., Hill, N., Hovey, R.,Barrett, N., Marzinelli,E.E., Pizarro, O., Figueira, W., Meyer, L., Babcock, B., Bellchambers, L., Byrne,M.& Stefan, B. (2015).Scientific Data. 2(24): 150057.
36. Elouaer,M. A., Hannachi, C. 2012. Seed priming to improve germination and seedling growth of safflower (Carthamus tinctorius) under salt stress. EurAsian Journal of BioSciences. 6:76-84. DOI:10.5053/ejobios.2012.6.0.9
37. Ali,M.M., Javed, T., Mauro, R.P., Shabbir,R., Afzal, I. and Yousef, A.F.2020. Effect of Seed Priming with Potassium Nitrate on the Performance of Tomato. 10(11):498
38. Munns, R. 2002. Comparative physiology of salt and water stress. Plant, Cell and Environment, 25(2), 239–250. https://doi.org/10.1046/j.0016-8025.2001.00808.x
39. Munns, R., & Tester, M. (2008). Mechanisms of salinity tolerance. Annual Review of Plant Biology, 59, 651–681. https://doi.org/10.1146/annurev.arplant.59.032607.092911
40. Nafees, K., Kumar, M. & Bose, B.2019. Effect of Different Temperatures on Germination and Seedling Growth of Primed Seeds of Tomato. Russian Journal of Plant Physiology, 66, 778–784
41. Ogbaji, P.O., Shahrajabian, M.H. and Xue. X. 2013. Changes in germination and primarily growth of three cultivars of tomato under diatomite and soil materials in auto-irrigation system. Int. J. Biol., 5: 80.
42. Paparella ,S., Araújo, S. S., Rossi G., Wijayasinghe , M., Carbonera, D., and Balestrazzi, A. 2015. Seed priming: state of the art and new perspectives. Plant Cell Rep. 34:1281–1293. doi: 10.1007/s00299-015-1784-y
43. Al-Amri, S.M.2013. Improved growth, productivity and quality of tomato (Solanum lycopersicum L.) plants through application of shikimic acid. Saudi Journal of Biological .20 (4):339-345
44. Biswas,S., Rasal-Monir,M.D., Islam, M., Modak, S., Kabir, M.H.2019. Induction of Salt Tolerance in Tomato Through Seed Priming, Plant. 7 (3):47-53. doi: 10.11648/j.plant.20190703.14'
45. Sattar, F.A.,Hamooh, B.T., Wellman, G.,Ali, M..A.; Shah, S.H., Anwar, Y., Mousa, M.A.A.2021. Growth and Biochemical Responses of Potato Cultivars under In Vitro Lithium Chloride and Mannitol Simulated Salinity and Drought Stress. Plants, 10: 1-12. https://doi.org/10.3390/plants10050924
46. Singh,V., Upadhyay, R.S., Sarma, B.K., Singh, H.B.2016. Seed bio-priming with Trichoderma asperellum effectively modulate plant growth promotion in pea. nternational Journal of Agriculture, Environment and Biotechnology. 9(3).
47. Sivachandiran, L. and Khacef , A. 2017. Enhanced seed germination and plant growth by atmospheric pressure cold air plasma: combined effect of seed and water treatment. RSCAdvances.7,18221832. doi.org/10.1039/C6RA24762H
48. Weitbrecht K., Müller K., Leubner-Metzger G. 2011. First off the mark: early seed germination. J. Exp. Bot. 62: 3289–3309. 10.1093/jxb/err030
49. Xie, W., Yang, J., Yao, S.G.R. and Wang, X. 2022. The Effect and Influence Mechanism of Soil Salinity on Phosphorus Availability in

In Vitro Osmotic and Salt Stresses. Plants, 10: 1-14. https://doi.org/ 10.3390/plants10010098

18. El-Beltagi,H.S., Ahmad, I., Basit,A., Shehata, W.F., Hassan, U., Shah, S.T., Haleema, B., Jalal, A., Amin,R., Khalid, M.A., Noor, F. & Heba I. Mohamed .A.I. 2022. Ascorbic Acid Enhances Growth and Yield of Sweet Peppers (Capsicum annum) by Mitigating Salinity Stress. Gesunde Pflanzen.74(14) :423–433

19. https://dx.doi.org/10.1590/2317-1545v42n1221062

20. Horii, A., McCue, P., Shetty, K.2007. Enhancement of seed vigour following insecticide and phenolic elicitor treatment. Bioresource Technology. 98 (3) : 623-632

21. Ibrahim, E.A. 2016. Seed priming to alleviate salinity stress in germinating seeds. Journal of Plant, Physiology, 15(192):38-46. doi: 10.1016/j.jplph.2015.12.011.

22. Jisha, K. C., Vijayakumari, K., and Puthur, J. T. 2013. Seed priming for abiotic stress tolerance: an overview. Acta Physiol. Plant. 35: 1381–1396. doi: 10.1007/s11738-012-1186-5

23. Ling, J., Wang, H., Wu, P. and Zh, J. 2016. Plant nodulation inducers enhance horizontal gene transfer of Azorhizobium caulinodans symbiosis island. Pnas.113 (48): 13875-13880. https://doi.org/10.1073/pnas.1615121113

24. Taïbi ,K., Abderrahim , L. A., Boussaid, M., Bissoli, G., Taïbi ,F., Achir , M., Kada Souana , Mulet, J.M.2021. Salt-tolerance of Phaseolus vulgaris L. is a function of the potentiation extent of antioxidant enzymes and the expression profiles of polyamine encoding genes. South African Journal of Botany.140:114-122. https://doi.org/10.1016/j.sajb.2021.03.045

25. Khan, M.S.A., Chowdhury, J.A., Razzaque, M.A., Ali, M.Z., Paul, S.K.,and Aziz, M.A. 2016. Dry matter production and seed yield of soybean as affected by post-flowering salinity and water stress. Bangladesh Agron. J. 19(2): 21-27

26. Lara, T.S., Lira,J.M.S., , Rodrigues ,A.C., Rakocevic.M. & Alvarenga.A.A.2014. Potassium Nitrate Priming Affects the Activity of Nitrate Reductase and Antioxidant Enzymes in Tomato Germination. Journal of Agricultural Science.6(2): 72-80

27. Lopes, C.A., Carvalho, M.L.M., Guimarães, R.M.,Oliveira, A.M.S., Andrade, D.B.2019. Sodium Hypochlorite in the priming Of Tobacco seeds. Journal Of Seed Science, 41(1): 108-111

Feizi,F., Sahabi,H., Moghaddam1, P.R., Costa,M., Heuvelink, E.2007. Today's Worldwide Tomato Production. International Suppliers Guide 2007 - Www.Hortiworld.Nl, Published As Part Of The Fruit&Vegtech Magazine.

28. Vargas,L., Rubisela,E., Ortega-Ortíz ,H., Cadenas-Pliego,G ., Romenus ,K.D.A., Fuente, M.C.D.L., Benavides-Mendoza.A. and Juárez-Maldonado,A. 2020. Foliar Application of Copper Nanoparticles Increases the Fruit Quality and the Content of Bioactive Compounds in Tomatoes. Appl. Sci. 8: 1020. doi:10.3390/app8071020

29. Nakaune , M., Hanada ,A., Yin , Y.G., Matsukura , C., Yamaguchi , S.,Hiroshi Ezura. 2012. Molecular and physiological dissection of enhanced seed germination using short-term low-concentration salt seed priming in tomato. Plant Physiology and Biochemistry. 52: 28-37

30. Haghighi ,M., Abolghasemi ,R., Silva, J.A.T.D.2014. Low and high temperature stress affect the growth characteristics of tomato in hydroponic culture with Se and nano-Se amendment. Scientia Horticulturae. 178:231-240

31. Irfan ,M., Hayat , S., Ahmad ,A., Alyemeni,M.N.2013. Soil cadmium enrichment: Allocation and plant physiological manifestations. Saudi Journal of Biological Sciences. 20(1) :1-10

32. Mousa, A.A. M., Al-Qurashi, A.A. and Bakhashwain A. A. S. 2013. Response of tomato genotypes at early growing stages to

References

1. Alam, M.S., Tester, M., Fiene, G., Mousa, M.A.A.2021. Early Growth Stage Characterization and the Biochemical Responses for Salinity Stress in Tomato. Plants, 10: 1-20. https://doi.org/10.3390/plants10040712

2. Ashraf, M. and Harris, P.J.C. 2013. Photosynthesis under Stressful Environments: An Overview. Photosynthetica, 51, 163-190 . https://doi.org/10.1007/s11099-013-0021-6

3. Bacha, H., Tekaya, M. Drine, S. Guasmi, F.Touil, L. Enneb,H., Triki, T. Cheour, F. Ferchichi, A. 2017. Impact of salt stress on morpho-physiological and biochemical parameters of *Solanum lycopersicum* cv. Microtom leaves. South African Journal of Botany 108: 364–369

4. Badek, B., van Duijn B., Grzesik M. 2006. Effects of water supply methods and seed moisture content on germination of China aster (Callistephus chinensis) and tomato (Lycopersicon esculentum Mill.) seeds. Eur. J. Agron. 24:45-51. DOI: 10.1016/j.eja.2005.04.004

5. Adhikari, B., Adhikari, M. and Park.G.2020. The effects of plasma on plant growth development and sustainability. Appl. Sci. 10(17):6045. https://doi.org/10.3390/app10176045

6. Gebreegziabher,B.G. and Qufa, C, A.2017. Plant physiological stimulation by seeds salt priming in maize (Zea mays) Prospect for salt tolerance. Academic Journals.16(5): 209-223. https://doi.org/10.5897/AJB2016.15819

7. Bewley J. D., Bradford K. J., Hilhorst H. M. W., Nonogaki H. 2013. Seeds Physiology of Development Germination and Dormancy. New York, NY: Springer.

8. Cano, E. A., Bolarín,M. C., Pérez-Alfocea,F & Caro, M.1991. Effect of NaCl priming on increased salt tolerance in tomato. Journal of Horticultural Science. 66(5):621-628. https://doi.org/10.1080/00221589.1991.11516192

9. Tan, D.X., Hardeland, R., Manchester, Lucien. C., Korkmaz, A., Ma,S., Corral, R.S., Reiter, R. J.2012. Functional roles of melatonin in plants, and perspectives in nutritional and agricultural science. Journal of Experimental Botany. 63(20):577–597. https://doi.org/10.1093/jxb/err256

10. Sayed, E. G., Mahmoud, A.W.M., Wahab, A.A., El-bahbohy,R.M.and Azoz, S.N.2022. Rootstock Priming with Shikimic Acid and Streptomyces griseus for Growth, Productivity Physio-Biochemical and Anatomical Characterisation of Tomato Grown under Cold Stress. Plants. 11(21): 2822

11. Stasio,E.D., Cirillo ,V., Raimondi,G., Giordano, M., Esposito, M. and Maggio, A.(2020). Osmo-Priming with Seaweed Extracts Enhances Yield of Salt-Stressed Tomato Plants. Agronomy article. 10(10):1559

12. FAOSTATE. 2020. https://www.fao.org/faostat/en/#data.

13. FAOSTATE. 2021. https://www.fao.org/faostat/en/#data.

14. FAOSTATE. 2021. https://www.fao.org/faostat/en/#data.

15. Grande, G.P., N. Suárez, N. & Marín, O.2020. Effect of salinity and seed salt priming on the physiology of adult plants of Solanum lycopersicum cv. ‘Río Grande. Brazilian Journal of Botany. 43: 775–787

16. Gupta, P., Sreelakshmi ,Y., Sharma, R. A. 2015. rapid and sensitive method for determination of carotenoids in plant tissues by high performance liquid chromatography. Plant Methods.11(5). doi: 10.1186/s13007-015-0051-0. PMID: 25688283; PMCID: PMC4329677.

17. Hamooh, B.T., Sattar, F.A., Wellman, G., Mousa, M.A.A. (2020) Metabolomic and Biochemical Analysis of Two Potato (Solanum tuberosum L.) Cultivars Exposed to

growth stages (vegetative, flowering and maturity) based on physiological, biochemical and genetic aspects. It was reported that seed priming with NaCl enhanced seed germination and seedlings vigor of tomatoes under salt conditions by alleviating the adverse effects of salt (Elouaer and Hannachi 2012; Ibrahim 2016; Gebreegziabher and Qufa 2017). In a recent research, González-Grande et al., (2020) demonstrated the positive impact of seed priming using NaCl on the growth and yield of the tomato variety 'Río Grande'. The seeds were treated with NaCl at concentrations of 0, 85, 171 and 257 mM until germination, then transferred to a hydroponic system, where the salt concentration in the system was 85 mM NaCl. The water salinity reduced the leaf water potential, photosynthetic pigments, stomatal conductance and photothensitic rate. Seed priming with NaCl improved salt tolerance in tomato plants by enhancing the antioxidant enzyme system, osmotic adjustment and water use efficiency. Priming with 0.5 and 1.0 M NaCl mitigated the adverse effects of salt stress of two tomato varieties and enhanced the growth and yield as compared to non-primed seeds (Cano et al., 1991). The authors observed a significant decrease in shoot contents of Cl and Na, while the K/Na ratio was significantly increased, which may explain the yield increase of the tomato variety 'GC-72'. Soaking the tomato seeds in Ascorbic acid (AsA) at 100mM alleviated the negative effects of salt stress during different growth stages (Alex et al., 2021). According to the authors, AsA treatment increased water potential and water use efficiency, leaf photosynthetic pigments, and antioxidant enzymes SOD, CAT, POX, GAX, GA, and GSH. Contrarily, the authors observed a significant decrease in Na, lipid peroxidation, and H2O2. Finally, the authors attributed the improved yield of tomatoes under salt stress to the positive effects of AsA as a promising seed-priming agent.

4. Conclusion

Pre-treatments of tomato seeds using different seed priming materials/techniques significantly improved seed germination, seedling vigor, plant growth, and yield under normal conditions and or diverse environmental stresses. Seed priming, physiological and metabolic operations that caused the DNA repair pathway will be activated, the pathway for synthesis of de novo protein, inhibit or reduce cell metabolite leakage, gene expression for defense pathway and synthesis of an antioxidant enzyme system. This prevents oxidative damage in the plant cells, and lipid peroxidation, and helps the plant grow and yield under different diverse conditions. Most of the research during the past decades was directed to study the impact of seed priming on tomato seed germination and seedling vigor under normal and stressful conditions. Additional physiological, biochemical and molecular studies are required, especially with the great progress in analytical technologies, protocols and types of equipment, to illuminate the positive impact of seed priming on metabolism and secondary metabolite, antioxidant enzyme system and molecular processes. Also, additional research is required to study the impact of seed priming of tomato seeds and or/seedlings on the growth and yield of tomato plants at the greenhouse and field levels, to achieve the sustainable production of tomatoes.

environments. Al-Amir and Attia, (2022) tested the efficiency of seed priming using UV-C at a dosage of 0.85 and 3.42 $kJ.m^{-2}$, on growth and yield under water salinity (NaCl, 100 mM). A significant increase in the growth parameters of tomato plants was observed due to the priming treatment with UV-C. The authors attributed the positive impact of UV-C treatments, as a seed priming approach, on tomato plant growth, to the possible increase in essential micronutrients and the stimulation of the plant defense system due to the radiation treatment of the seeds (Al-Amir and Attia, 2022). Cold plasma is usually used in medicinal fields, it is an environmentally safe/friendly technique/procedure, and it has a great impact on the generation of various reactive oxygen/nitrogen species, however, it is rarely used in agriculture. The reactive oxygen/nitrogen species are essential for the regulation of plants' physiological, biochemical, and cellular processes (Sivachandiran and Khacef, 2017; Ling et.al, 2016). Recently, experiments were conducted to test the efficiency of treating the crops seed with Cold Atmospheric Plasma (CAP) for 1 min, 5 min and 10 min, on the seed germination and plants growth and yield (Adhikari et al., 2020). According to the authors, tomato seeds that were treated with Cold plasma seed priming (CAP) showed the highest germination percentage and germination time and germination uniformity as compared to untreated seeds. In Addition, CAP seed priming enhanced the plant's growth, antioxidants capacity system, phytohormone, and expression of defend genes under drought stress. The authors attributed the positive impact of CAP on tomato plants' growth and development to the generation of reactive oxygen/nitrogen species, which control many of the biochemistry and physiological parameters of plants.

3. Impact of seed priming on tomato tolerance to Salinity stresses

Seeds pretreatment not only improved seed germination time, percentage and rates, but the effects of seed pretreatments can help the plants' performance at vegetative, flowering and fruit/seeds setting and maturity stages. The explanation for the long-term efficient effects of seed priming during the plant life cycle may be attributed to the positive impact of priming materials on different metabolites and secondary metabolic processes including, 1) activating the physiological and metabolic operations that caused the DNA repair pathway, 2) activating the pathway for synthesis of de novo protein, 3) inhibiting or reducing cell metabolite leakage, 4) enhancing gene expression for defense pathway and 4) enhancing the synthesis of an antioxidant enzyme system (Ibrahim, 2016; Rahman et al., 2020). During the past decades, several research reports demonstrated the positive impact of pretreatments of crops seed (seed priming) on the enhancement of plant growth and yield under soil and/or water salinity (Taïbi et al., 2021; El-Beltagi et al., 2022; Xie et al., 2022). Most of the researchers focused on the study of the effect of seed preparation on the development of plants' tolerance to salinity at early growth stages (seed germination and seedlings stage). There is limited information available about the impact of seed priming treatments/agents on enhancing the salt tolerance of tomatoes at late protein, inhibit or reduce cell metabolite leakage, gene expression for defense pathway and synthesis of an antioxidant enzyme system (Ibrahim, 2016). This prevents oxidative damage in the plant cells, and lipid peroxidation, and helps the plant grow and yield under different biotic and abiotic stresses (Rahman et al., 2020). Halopriming of tomato and chili seeds in 3% KNO_3 significantly enhanced seedlings' vigor at the laboratory level and plant growth and yield at the field as compared to hydropriming and nonprime seeds of both crops (Maiti et al., 2013). According to the author's findings, soaking the seeds in 3% of KNO3 for 30 hours (tomato) and 40 hours (chili) enhanced early flowering, plant height and total fruit yield as compared to non-primed and hydro-primed seeds at the field level. Under Saudi conditions, Al-Amri (2013) conducted a field experiment to investigate the response of tomato varieties to seed priming with shikimic acid at 30, 60 and 120 ppm. The author observed a significant increase in plant biomass, fresh fruits number and weight per plant, and total yield of fresh and dry fruits as compared to nonprime and hydro-primed seeds (Al-Amri,2013). Moreover, soaking the tomato seeds in shikimic acid improved fruit quality by enhancing vitamin C, lycopene, carotenoid contents, total acidity and fruit total soluble sugars (TSS%). The impact of halopriming using 60 ppm of shikimic acid and biopriming using *Streptomyces griseus* (MT210913) (*S. griseus*) for seeds of two tomato rootstocks (*Solanum cheesmaniae* L. (line LA 524) and GS hybrid) on growth and yield of the tomato scion 'Peto 86' under cold stress in the field were investigated (Sayed et al., 2022). The results revealed that biopriming the seed of tomato rootstock 'GS-hybrid' with *S. griseus* helped the tomato scion 'Peto-86' mitigate the negative effects of cold stress as compared to the primed seeds with shikimic acid, non-primed and hydro-primed seeds. The yield of fresh fruits was increased by 10.5% and 5.7% in the first and second seasons when the tomato scion 'Peto-86' was grafted on seedlings of GS hybrid produced using bio-primed seeds with *S. griseus* (Sayed et al., 2022). The leaves of bio-primed grafted combination Pet0-86/GS hybrid contained higher concentrations of GA3 and macro- and micro-elements. salicylic acid was used as seed priming at concentrations of 0.25mM, 0.5mM and 0.75mM to enhance the growth and yield of tomatoes under heat stress (Singh et al., 2016). The authors' findings indicated that seeds germination, plant vegetative growth and yield were significantly reduced under high temperatures. However, soaking the seeds in 0.5mM salicylic acid extremely improved the percentage of germinated seeds and germination time under heat stress. but also reduced germination time under stress conditions. Also, the quality of the fruit including TSS, TA, vitamin C and lycopene content was significantly improved by priming using Salicylic acid. They recorded a significant increase in the fruit yield of tomatoes as compared to no-primed seeds (Singh et al., 2016). In recent research, many researchers directed their attention to the radiation priming of crops seed using Infrared Radiation (IR), Ultraviolet radiation (UV), Ultraviolet C-band radiation (UV-C) and Cold Atmospheric Plasma (CAP) to improve crop growth and productivity under different

2015). Soaking the tomato seeds in salicylic acid (SA) at 250, 500 and 1000 µM enhanced germination rate, germination time and seedlings' growth and development as compared to control (seeds soaked in water) and lower concentrations of SA (5, 50 and 100 µM) (Galviz-Fajardo, et al., 2020). The effects of chemo-priming using $Mg(NO_3)_2$ at 5, 7.5 and 10 mM on tomato seeds germination and seedlings' vigor under different temperatures (10, 25 and 40°C) was investigated (Nafees et al., 2019). The authors found that soaking the tomato seed in 7.5 mM of $Mg(NO_3)_2$ recorded the highest germination rate at all tested temperature degrees (10, 25 and 40°C). Moreover, they reported that seed priming with 7.5 mM of $Mg(NO_3)_2$ increased plant height, number of branches and green leaves, leaf area/plant, plant fresh and dry weights, root number/plant, root length, root fresh and dry weight, superoxide dismutase activity (SOD) and protein content at all tested temperature degrees (10, 25 and 40°C). Yogesh and Prashant (2018) studied the effects of treated tomato seeds of two varieties (Navodya and S-22) with NaCl and KNO3 at 1% on germination and seedlings growth after 12, 24 and 24 hours. They found that the primed seed of the variety 'S-22' recorded the highest germination percentage (91.75%), Vigour index length (1957.52), Vigour index mass (9.083), Seed metabolic efficiency (0.188), Electrical conductivity of seed leachates (dSm^{-1})(91.59) as compared to the control (hydro-primed seeds of the variety S-22). Seed priming using nano-size titanium dioxide (N-TiO2) at 0, 100, 200, and 400 mg L^{-1} to improve germination and seedlings vigor of tomato (*Lycopersicum esculentum* L.), onion (*Allium cepa* L.), and radish (*Raphanus sativus* L.) seeds were investigated (Haghighi Maryam and da Silva, 2014). The highest germination percentage of tomato (100%) and onion (30%) was observed at 100 mg L^{-1} of N-TiO2, while a 100% germination of radish seeds was observed at 400 mg L^{-1} N-TiO2. Regarding seedlings growth, the tallest seedlings of tomato, onion and radish were observed with 400, 200 and 100 mg L^{-1} N-TiO2, which indicated that N-TiO2 can be used as a seed-priming agent for horticultural crops (Haghighi Maryam and da Silva, 2014). Priming with low levels (2 and 4%) of ethanol improved seed germination, seedling vigor and enhanced antioxidative activity that results in better performance of tomato seeds in both tomato cultivars. Priming the tomato seeds with ethanol at 2 and 4% for 24 hours improved seed germination percentage and the seedlings vigor and antioxidant capacity system of the plants (Irfan, et al., 2013). Gupta et al., (2015) investigated the responses of cherry tomato seedlings to seed priming with the pulsed magnetic field (PMF) and fish protein hydrolysate (FHP). They obtained an increased seedling vigor of 23% for the treated seeds as compared to the control. According to Horri et al., (2007) the seed priming using fish proline hydrolysate (FPH) at 2.5 mL/L significantly increased plant height as compared to the control. Osmopriming with PEG caused a remarkable increase in the radicle length, shoot length and total fresh weight of tomato seedlings under saline conditions (Zhang et al., 2012).

2. Impact of seed priming on growth and yield of tomato plants

An important question is frequently asked, how is seed priming still effective during the plant life cycle and can help the plants at their late growth stages (i.e. vegetative, fruit, and seed setting and maturity) to perform well under biotic and abiotic stresses?. And we can easily answer, as a result of seed priming, physiological and metabolic operations that caused the DNA repair pathway will be activated, the pathway for synthesis of de novo their attention to studying the effect of different seed priming substances (Hydropriming, chemo-priming, biopriming, natural substances, …etc) on the speed and uniformity of germination, seedlings' vigor and development for a large number of crops, including tomatoes (Biswas, et al. 2019; Galviz-Fajardo, et al., 2020; López-Vargas, et al.2020). It is agreed that having fast and uniform germination and strong seedlings are the major premise of plant growth, yield and quality. The seeds germination processes is evaluated by measuring physiological (antioxidant activity, chemical and biochemical indicators …etc) and morphological (seeds imbibition, radical emergency, shoot sprouting …etc) indicators that can be used to explain the obtained results. Seed germination requires the critical germination factor of water of good quality and in limited cases light and temperatures and specific pretreatments for hard/dormant seeds. In hydropriming, the seeds will be germinated at imbibition range from 35%-100%, however, the seed will be faster germinated at imbibition for a range of 35% followed by incubation for 1 hour (Badek et al. 2006). Seeds of cherry tomato were treated using static magnetic (magneto-priming method) at a dosage of 50–150 milli Tesla (mT) for 30 min and 1 hour, the results showed that maximum germination is ensured by using 100 mT for 30 min (Gupta et al., 2015). Treating the seeds of tomato with potassium nitrate (KNO3) (50 mM), as a chemo-priming method, lead to a significant increase in germination speed % and germination rate compared to other chemo-priming treatments (i.e. polyethylene glycol (PEG 6000) -1.1MPa and PEG+KNO3) (Lara et al., 2014). The authors explained the increased germination time and rate to activation of the nitrate reductase enzyme pathway, because of the absorbance of nitrate, which enhance seed embryo metabolism and promoted seed germination without any negative effects on germination percentages and seedlings uniformity. Seed priming with KNO3 at 0.75 mM led to significantly improved seeds viability of tomatoes which was reflected in the increase of final emergence (%), mean emergence time, and physiological attributes (Ali et al., 2020). The tomato germination rates and time were also promoted by treating the seeds with natrium chloride (NaCl) and gibberellic acid (GA) (Nakaune et al., 2012). According to the Authors, the rate of germination was higher by 4.9 and 4.6 times at 36 hours after sowing for treated seeds as compared to hydro-primed seeds (treated with water), while the levels of endogenous abscisic acid was similar for both chemo-primed (seeds treated with NaCl and GA4) and hydro-primed (seeds treated with only water) seeds. Osmopriming is the treatment of seeds in aerated osmotic solutions containing KNO_3, K_3PO_4 or KCl salts or polyethylene glycol (PEG), which help to enhance seed germination through the activation of many pre-germination metabolites processes and enhance the antioxidant enzymes system. Osmopriming of tomato seeds with PEG at 10% (w/v) (PEG) solution for 48 hours in the dark at 20±1°C in the dark improved germination percentages under normal and saline water (100 mM NaCl) treatments (Zhang et al., 2012).

1.2. Seedlings vigor of tomato

Recent work focused on seed priming using melatonin, which is known as a molecule with many benefits for human health. Also, melatonin in plants works as one of the important components for defense systems in plant, and melatonin works as an internal sensor for oxidative stress in the plant (Tan et al., 2012). It was reported that treating the tom,ato seeds with melatonin at 0.1 mM improved the seedling health index of tomatoes by 44.11% and root dry weight by 24.6% as compared to the control (Liu et al.,

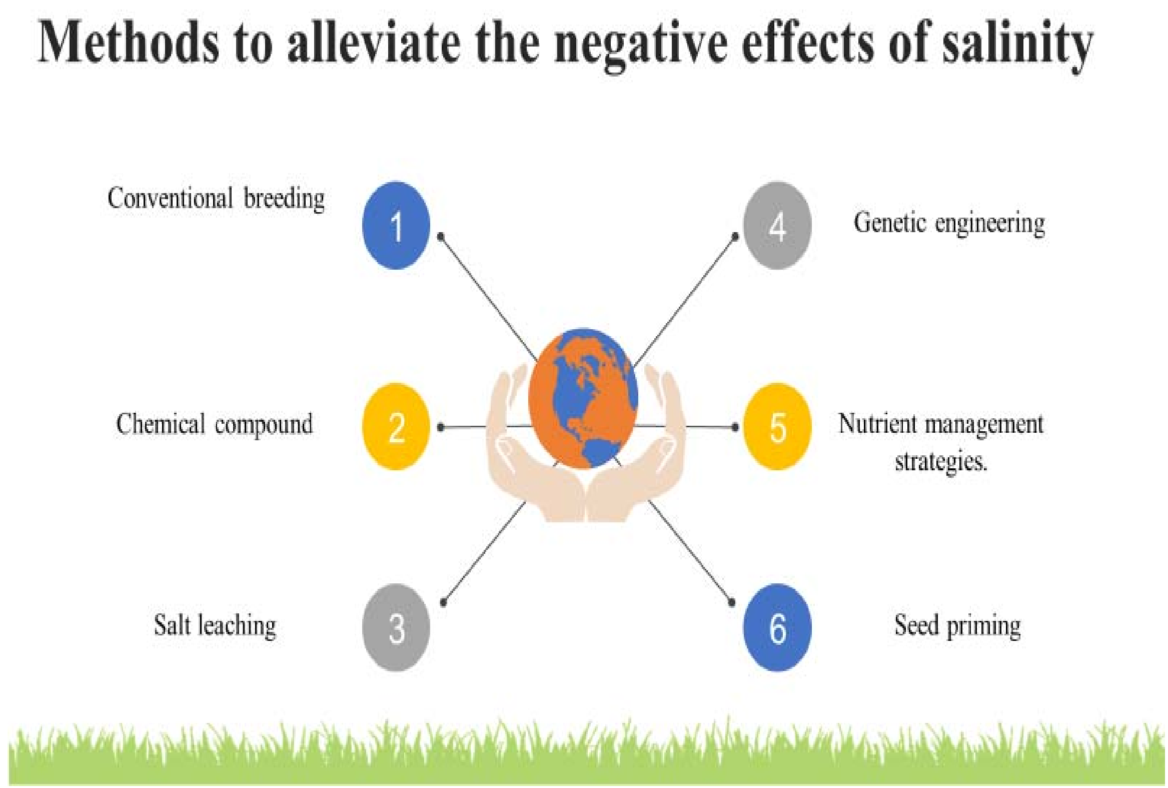


Figure 2. Alleviating negative effects of salt stress on plant growth and productivity

1. Seed priming for the improved seeds germination and seedlings vigor of tomato

1.1. Seeds Germination

The successful life cycle of any plant starts with seed germination and establishment/development vigor seedlings which require several physiological changes in the metabolites and secondary metabolites levels leading to healthy reproductive plants (Bewley et al., 2015; Weitbrecht et al., 2011; Ogbaji et al. 2013). The rapid and uniform germination of plant seeds is one of the most important factors that affect plant performance in the vegetative, flowering and reproductive stages of the life cycle. Rapid and uniform germination can help the plant to alleviate environmental constraints and enhance growth and yield and overcome abiotic and biotic stresses (Zhang et al. 2012, Mousa et al., 2013; Alam et al., 2021). Treating the seeds with some substances improves seeds germination (germination speed and uniformity), seedling growth and development (fasten radical and shoot emergency and development) and plant performance during vegetative, flowering, and productive stages. Seed germination comprises all morphological, physiological and biochemical changes inside the seeds at the imbibition phase (soaking the seeds with enough water) that result in the radicle emergence from the seed coat and then shoot sprouting (López-Vargas, et al.2020). During the past 20 years, researchers have directed values of tomatoes, it was reported that tomato fruits contain 95% water, 4% carbohydrates, and contains less than 1% of proteins and fats. Tomato is rich in many nutrients, a major dietary source of the antioxidant lycopene, which has been linked to many health benefits, including reduced risk of heart disease and cancer. In Saudi Arabia, the total cultivated area with tomatoes was 15030 hectares and the total production quantity was 620866 tones (FAO, 2021). The soil quality, freshwater limitation, and arid climates were the most important challenges to expanding tomato production in Saudi Arabia. There were reported that tomato cultivation challenges many problems worldwide and in Saud Arabia. These problems include climate change, abiotic stresses (salinity, drought and heat stresses), biotic stresses (pests and diseases problems) and soil quality (soil nutrition, saline-affected soils, and desertification (Alam et al., 2021; Yutecia González-Grande, et al., 2020). Abiotic stresses including salinity and drought are regarded as of the most deadly external constraints for successful and sustainable agricultural production in arid or semi-arid regions of the world (Khan et al., 2016; Rengasamy, 2010). Salt stress enhances the deposition of harmful salt ions in the soil surface as well as at the crop root zone, which gradually converts arable regions to fallow or barren (Fig 1). Globally, at this moment,

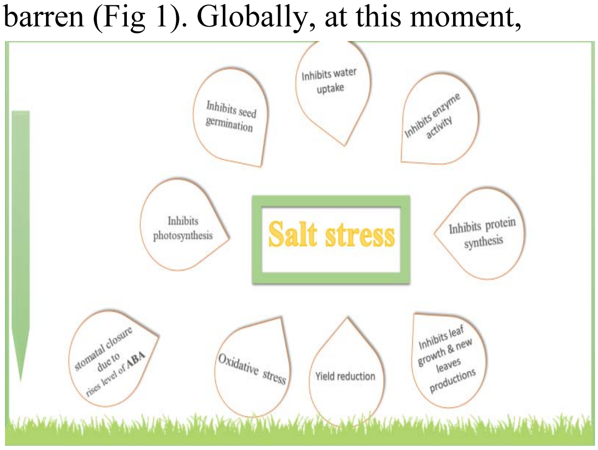


Fig 1. Effects of salt stress on plant growth, yield and quality.

more than considerable areas of arable lands (>6.0 %) and zones under irrigation (20 %) are severely suffering from salinization (Alam et al., 2021; Ashraf and Harris, 2013; Bacha et al., 2017). Soils become saline when electrical conductivity (EC) of more than 4 dS/m with NaCl (approximately 40 mM) and osmotic pressure (0.2 MPa). Salt stress decreases the water potential resulting in osmotic stress, ionic disparity, and disturbance of essential plant nutrient dynamics. Moreover, Salt stress negatively affects the chloroplast functions and renders a deleterious impact on the photosynthetic performance in crops (Munns, 2002; Munns & Tester, 2008). Seed priming (Fig 2) is considered one of the most promising methods for alleviating salt stress's negative effects on plant crops. Seeds priming is the treatment of seeds with different methods include hydropriming, osmopriming, Chemopriming, and hormonal priming (Jisha et al. 2013; Paparella et al. 2015). Priming of seeds helps the plants by stimulating the pregerminated metabolic process and activating of many enzymes that confer the metabolism of proteins, carbohydrates and lipids involved in the mobilization of stored reserves in seed and play role in the breakdown of the macromolecules for embryo growth and development that exerts a positive influence on early and better seedling emergence (Jisha et al. 2013; Paparella et al. 2015). The present review aims to summarize the recently published studies that focused on the use of seed priming to improve tomatoes germination, growth and productivity under environmental stress conditions.

JKAU: Met., Env. & Arid Land Agric. Sci., Vol. **33** No. 1, pp: 1 - 13 (2024 A.D.)
DOI:10.4197/Met.33-1.1

An Overview of the Impact of Seed Priming on Tomato (*Solanum lycopersicum*) L.) Under Normal and Salt Conditions: From Seed Germination to Harvest

Raneen J. S. Mohammad[1], Magdi A. A. Mousa[2,3*], Omer H Ibrahim, Hisham[2], F. AlHarby[1]
[1]*Department of Biological Sciences, Faculty of Science, King Abdulaziz University*
[2]*Department of Agriculture, Faculty of Environment Sciences, King Abdulaziz University, Jeddah 21589, Saudi Arabia*
[3]*Department of Vehgtables, Faculty of Agriculture, Assiut University, Assiut 71526, Egypt*
**Corresponding author: mamousa@kau.edu.sa*

Abstract: tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops worldwide and in Saudi Arabia, due to its high nutritional value and suitability for cultivation under a wide range of environmental conditions. Tomato is one of the cash vegetable crops that generate good and continuous income for farmers for two to three months. Globally, tomato is considered a major source of income and a major contributor to food security. Due to the small genome of the tomato, it is considered as a model for physiological, genetic, molecular and breeding studies to improve the morphological, yield and yield attributes and its tolerance to biotic and abiotic stresses. However, tomato production and expanding cultivation face many challenges, especially with the global environmental changes regarding climate changes, freshwater availability and quality, pests and diseases and soil quality. There were many studies conducted to find effective and applicable solutions to overcome the environmental problems facing the expansion of tomato cultivation and increase productivity, including following good agricultural practices (GAP), improving and breeding new varieties of high yield and quality under harsh environmental conditions and the use of growth biostimulants that help plants grow and produce under difficult conditions. Seed priming is one of the recommended solutions to help tomatoes germination, growth and productivity under biotic and abiotic stresses. The presented review study aims to present the recent studies that have been carried out on the use of seed priming to improve tomatoes germination, growth and productivity under environmental stress conditions. The review is divided into three sections focusing on: (1) seed priming to improve tomato seeds germination; (2) seed priming to improve the growth and yield of tomatoes; and 3) seed priming to improve tomato tolerance salt stress.
Keywords: *Solanum lycopersicum*, salt stress, seed Priming, halo Priming, Salinity, Induced resistance

INTRODUCTION:

Globally, the total area cultivated with tomatoes is 5167388 hectares, while the total production of fresh and processed tomatoes is 189133955.04 tons (FAO, 2021). Tomato is the second crop after potato and the fourth after rice regarding the cultivated area, total production and consumption worldwide (Hamoh et al., 2020; Sattar et. al., 2021). It was reported that the tomato market represents 0.059% of total world trade. The top tomato exporter countries in the world were Mexico ($2.62B), Netherlands ($1.82B), Spain ($1.11B), Morocco ($852M), and Canada ($448M) (FAO, 2020). China is the leading country in production with 61,631,581 tones followed by India with 19,377,000 tones, the USA (12,612,139 tones), Turki (12,150,000 tones), and Egypt with 6,624,733 tones (FAO, 2021). Regarding the nutritional

Contents

English Section

King Abdulaziz University Press

JKAU: Met., Env. & Arid Land Agric. Sci., Vol. **33** No. 1, 99 Pages (2024 A.D.)
ISSN: 1319- 1039

Journal of
KING ABDULAZIZ UNIVERSITY

Meteorology, Environment and Arid Land Agriculture Sciences

Volume 33 Number 1

2024 A.D.

Scientific Publishing Center
King Abdulaziz University
P.O. Box 80200, Jeddah 21589
Saudi Arabia
http://spc.kau.edu.sa

IN THE NAME OF ALLAH,
THE MOST GRACIOUS,
THE MOST MERCIFUL