FUNDAMENTALS IN AGRICULTURE AND FOOD

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PREFACE

Fundamentals of agriculture focuses with the fundamental physical, chemical, biological, and economic principles that underlie agricultural practise rather than the methods for producing plants and animals. Information about the soil, the weather, soil water, the mechanical and structural characteristics of soil, and chemical reactions in soils may be found by readers. The topics covered in articles on plant biology and crop production include plant cells and their metabolism, plant structure, growth, development, and yield in crop production, as well as pasture production and use. Selected articles discuss the biology of animals, including their environment, growth and development, nutrition, reproduction, lactation, and animal behaviour. The ecology of microorganisms, the biology of diseases, and the microbiology of food are all related to the development of microbiology. The chapters also include agricultural economics.

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CHAPTER 1

UTILIZATION OF WASTE PRODUCTS FROM PLANT BASED FOOD INDUSTRIES: INDUSTRIAL AND HEALTH PROSPECTS

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1. Introduction

Losses in food occur in pre-harvest and post-harvest farms, in the transportation process, in the supply chain stages, and in the storage and consumption stages. A total of 40% of the food produced is not consumed, and 45%-70% of organic solid waste in the world consists of food waste (Goldstein, 2007). In addition, approximately 60% of food waste consists of edible and healthy foods (WRAP, 2010; 2011). This situation leads to food waste, loss of components and resources that are beneficial to health, and economic losses, as well as negative ecological effects. Fruits and vegetables are the product group with the highest loss rate among foods, with 60% loss (FAOSTAT 2021). Some actions have been taken to reduce food waste, and long-term projects and programs have been undertaken. A few of these are the food rescue program and the creation of the Food Loss and Waste Protocol. Thanks to these studies, the amount of food lost and the stages where it suffered the most loss have been recorded. Thus, priority steps to be taken for action have been determined, and corrective activities have been initiated.

Food industry waste consists of mostly leaves, sprouts, stems, pomace, seeds, kernels, bark, peels, and pulp. These materials contain bioactive ingredients such as polyphenols, carotenoids, minerals, enzymes, dietary fibers, prebiotics and probiotics, and fatty acids. The loss of bioactive components that give functional properties to food is a serious problem in the undernourished world. In addition, the disposal of food industry waste is an industrial and ecological problem. A limited amount (5%) is used as animal feed, and the rest of the food waste is handled with conventional methods: composting, burial, anaerobic fermentation, incineration, and in agricultural applications such as animal feed or manure. In the long run, these methods increases the acidity of the soil and reduces its productivity. For this reason, it is critical to evaluate wastes in terms of environmental, economic, and nutrient recovery rather than in terms of disposal.

The main factors affecting sustainable waste management and evaluation of food waste are: (1) environmental regulations, which constantly grow more rigid due to environmental impact concerns; (2) high waste disposal costs; and (3) possible sustainable use of resources with technological development (Murugan et al., 2013). However, evaluating food waste is difficult for many reasons. The fact that these wastes are not biologically stable at high moistness range and therefore suitable for increased microbial activity make it difficult to cope with these products. As examples, wastes with high fat content are sensitive to oxidation, and enzymatic activity increases spoilage, which reinforce difficulties in this regard (Russ and Meyer-Pittroff, 2004).

It has become possible to evaluate the efficiency of food wastes with the development of various high-efficiency food processing techniques. Furthermore, with the application of these technologies, it is possible to either extract valuable bioactive components from wastes or increase their functionality. Phytochemicals or micronutrients are thus obtained; these could be utilized in the food, health, and wellness industry for developing the formulation of functional foods or fortified products and nutritional supplements (F. Ahmad et al., 2020; Pattnaik et al., 2021). In addition, because food waste is a carbon source, it can be used in energy production by subjection to anaerobic or aerobic decomposition.

Reducing the disposal cost of food wastes and obtaining high-value-added products can increase nutrition industry profitability. This review presents strategies for recycling food processing waste that have been reported in the last ten years and contribute to the sustainability of the food industry by recovering valuable waste, contributing to the circular economy, and using existing resources effectively to minimize damage to human nutrition and the environment.

2. Use of Waste Components in Food and Health Industry

Food processing byproducts contain lignocellulosic substances: cellulose, hemicellulose, and lignin. As mentioned above, food waste biomass also contains many valuable bioactive phytochemicals. Isolating these health and food industry ingredients helps constitute the food industry’s circular economy.

2.1 Dietary Fibers

Dietary fiber is the cell wall and storage polysaccharide of plant cells, including lignin, cellulose, oligosaccharides, pectin, and hemicelluloses. Dietary fiber cannot be hydrolyzed by human digestive enzymes, and it plays major roles in colon health by enhancing gut microflora growth, assisting in transit of fecal bulk, improving laxation, and controlling blood glucose and lipid levels. A meta-analysis also reported that dietary fiber reduced the risk of developing colorectal cancer by 10%—its results indicate a protective effect of high dietary fiber intake against colorectal cancer in Asia. The odds ratio (OR) between high and low fiber intake was 0.63 (0.50–0.79), suggesting that individuals with high dietary fiber intake had a 37% lower risk of developing colorectal cancer than those with low fiber intake. Additionally, the OR between the highest and lowest fiber intake was 0.48 (0.34–0.67), indicating that individuals with the highest fiber intake had a 52% lower risk of developing colorectal cancer than those with the lowest fiber intake (Masrul and Nindrea, 2019). In addition, dietary fibers have significant effects on the function of bowel mucosa and the fermentation process in the large bowel. To protect people against colorectal cancer, fruit and vegetable wastes from various sources may be utilized as a possible basis of dietary fiber (Garcia-Amezquita et al., 2018; Hussain et al., 2020); mango peel is one viable option. The Ajila and Prasada Rao (2013) study reveals that total dietary fiber content in mango peels ranges from 40.6 to 72.5%, and mango peel dietary fiber is bound with several polyphenols, flavonoids, and carbohydrates. It is an excellent source of dietary fiber, with average fiber content of approximately 11.5%, and it is mainly composed of cellulose (approximately 70%), hemicellulose (approximately 20%), and pectin (approximately 10%). It is resistant to various enzymatic digestion processes in the human gut, which makes it a potential prebiotic fiber possibly contributing to gut health. One benefit of its consumption is that it increases satiety and promotes bowel regularity by increasing food's transit time through the digestive tract. Furthermore, due to its low energy density, mango peel fiber may also contribute to weight management. As mentioned above, mango peel is a good option due to its high fiber content, with both insoluble and soluble fiber. Total dietary fiber content in mango peel ranges depending on the variety and maturity of the fruit, and it is rich in insoluble fiber, with cellulose being the predominant component (approximately 50–60% of the total fiber content). The soluble fiber content in mango peel ranges from approximately 5–10%, with pectin as the main component (approximately 80–90% of the total soluble fiber content). In addition to its fiber content, mango peel also contains various bound phenolic compounds, which are associated with its potential health benefits. The total phenolic content in mango peel ranges from approximately 70–150 mg GAE/g DW (dry weight), with flavonoids and condensed tannins being the major phenolic classes. The antioxidant activity of mango peel, measured using various assays such as DPPH and FRAP, is also attributed to its phenolic content.

A number of studies have investigated the fiber an nutrient contents of various fruit and vegetable peels. In the Wanlapa et al. (2015) study, peels of some tropical fruits like rambutan, santol, durian, longong, longan, Chok Anan mango, and Kaeo mango were evaluated as a source of dietary fiber for food enrichment. Peels from these fruits were found to have a high content of total dietary fiber (52–84 g/100 g on dry basis) with significant difference in quality of dietary fiber. According to the obtained data, all fruit peels contain a high amount of dietary fiber. Mango peel has the highest dietary fiber content (%51.13), followed by papaya peel (%42.56), mangosteen peel (%32.38), and pineapple peel (%22.20). In addition to other chemical components, the amount of soluble and insoluble dietary fiber in the fruit peels was measured, providing an indicator of the fruits' usability as fiber sources. The study also measured the antioxidant capacity of each fruit peel, calculated using measurements of DPPH and ABTS radicals. The results showed that all fruit peels had a high antioxidant capacity. In conclusion, the article provides important evidence that selected tropical fruit peels can be used as a source of dietary fiber and antioxidants. This information may be potentially useful in the development of functional foods (Wanlapa et al., 2015).

In the Sharoba et al. (2013) study, green pea and potato peel, in addition to carrot pomace and orange wastes, were used as the raw materials for dietary fiber in a high-fiber-content cake preparation process. The cakes were prepared using by-products from fruits, vegetables, and wheat flour. Evaluation of the results obtained establish the used waste products as a good source of fiber. The use of grapefruit peel, apple peel, and carrot waste further increased the fiber content of cakes. Grapefruit peel had the highest fiber content at 13.2%, while apple peel and carrot waste had fiber contents of 8.6% and 4.8%, respectively. The rising ratio of cakes increased by 64.2%, 63.1%, and 61.8% with the use of grapefruit peel, apple peel, and carrot waste, respectively. The water-holding capacity increased by 70.3%, 72.6%, and 74.8% with the use of grapefruit peel, apple peel, and carrot waste, respectively. In terms of sensory attributes, the use of grapefruit peel, apple peel, and carrot waste increased the overall acceptability scores of cakes. The use of grapefruit peel increased the acceptability score from 70.5% to 84.5%, the use of apple peel increased it from 75.5% to 87.5%, and the use of carrot waste increased it from 68.5% to 80.5% (Sharoba et al., 2013).

Pectin is also obtained from fruit wastes and can be used to improve processed foods. Pectin is a complex, colloidal, acid polysaccharide utilized as a stabilizing agent and thickening material in the chemical, pharmaceutical, textile, and food industries. Mango peels are considered to be a good source of pectin (Nguyen et al., 2019). Watermelon rind powder is another such source, that also includes dietary fiber and other bioactive compounds. It has been reported that the glycemic indexes of those who consume cookies prepared by enriching wheat flour with watermelon peel powder are lower than those who consume conventional cookies. Cookies containing watermelon rind powder had 16% to 45% higher dietary fiber content and resulted in 8% to 37% lower glycemic index than the control cookies. The researchers stated that using watermelon rind powder in cookie making could reduce the amount of flour and sugar used in traditional cookie recipes by 25–30% (Naknaen et al., 2016). These studies have further corroborated the utility of plant-based food wastes as an important source of dietary fiber.

2.2 Phytochemicals

2.2.1 Antioxidants

Various extraction techniques, novel and conventional, are being used successfully to recover antioxidant compounds from fruit and vegetable wastes obtained from processing industries. Enzyme technology, continuous pulse electric fields extraction process, microwave-assisted extraction, and ultrasound-based techniques (Luengo et al., 2014) have been used widely for extraction of bioactive components in the recent past.

Waste generated from fruits and nuts still contain many bioactive compounds. The Gómez-García et al. (2012) study showed that phenolic compounds obtained from enzyme-assisted extraction of grape wastes had high antioxidative activities, and O-coumaric acid is the main compound showing high antioxidative activity. The results of the study showed that enzyme-assisted extraction significantly increased the extraction yield of phenolics from the grape residues compared to the control (extraction without enzymes). The highest extraction yield was obtained using pectinase at a concentration of 2%, which resulted in an extraction yield of 17.7%. The cellulase and hemicellulase treatments also increased the extraction yield, with 15.8% and 14.9%, respectively. The researchers also found that the antioxidant activity of the extracts was positively correlated with the phenolic content, a measure used in pharmacology to describe the significance of deterring a physical or biochemical function, usually an enzyme or a receptor. The extract obtained using pectinase had the highest antioxidant activity, with a half-maximal inhibitory concentration (IC50) of 5.5 μg/mL. This was followed by cellulase and hemicellulase extracts, with IC50 values of 7.5 μg/mL and 9.2 μg/mL, respectively (Gómez-García et al., 2012). Beneficial compounds of immature fruits, like polyphenols, were extracted using an environmental friendly 'pressurized hot water extraction method', and the compounds were shown to have antioxidant and cytoprotective activity against hydrogen-peroxide-induced oxidative stress (Heng et al., 2017). Another food waste valorisation study conducted by Moo-Huchin et al. (2015) showed that the phenolic and flavonoid components extracted from guava pomace and olive wastes have significant antimicrobial and antioxidant properties (Khalifa et al., 2016). A total of six phenolic antioxidative compounds (ferulic, caffeic, sinapic, gallic, ellagic acids, and myricetin) were isolated from the freeze-dried peels of three tropical fruits: red cashew, yellow cashew, and purple star apple. This study demonstrated that the peels of these tropical fruits can be utilized as a source of antioxidants for industrial and pharmaceutical purposes (Moo-Huchin et al., 2015).

Antioxidants are another critical nutrient in food wastes. Pomegranate juice is well known for its antioxidant activity. However, the Li et al. (2006) study has shown that among peel, pulp, and seeds, the peel of the pomegranate has the highest antioxidant activity. A mixture of ethanol, methanol, and acetone was used to extract phenolics, flavonoids, and proathocyanidins as antioxidants, showing the possibility for use of pomegranate peel in the health supplement industry. Use of the response surface methodology for extraction of phenolic compounds and flavonoids from pomegranate peel has been shown in the literature. According to the data, the pomegranate peel extract exhibited a DPPH radical scavenging capacity of 72.3%, an ABTS radical scavenging capacity of 92.7%, and a FRAP value of 476.2 μM Trolox equivalent/g. In contrast, the pomegranate pulp extract showed a DPPH radical scavenging capacity of 59.8%, an ABTS radical scavenging capacity of 84.5%, and a FRAP value of 293.7 μM Trolox equivalent/g. These results indicate that the pomegranate peel extract has a higher antioxidant capacity compared to the pomegranate pulp extract (Sood and Gupta, 2015). A new process of bioactive compound extraction from pomegranate peel has been conducted by Goula et al. (2017). This process utilises vegetable oil as a solvent for ultrasound-assisted extraction of carotenoids and other antioxidants from pomegranate wastes (Goula et al., 2017). The kernel of the macadamia nut is utilized for consumption, leaving behind its skin and husk as by products. Dailey and Vuong's study (2015) focused on the different types of solvents possible for extraction of different antioxidants such as phenolics, proanthocyanidines, and flavonoids from skin and husk of macadamia nuts (Dailey and Vuong, 2015). Nonedible parts of quince fruits such as seeds and leaves have been explored for free radical scavenging activity (Benzarti et al., 2015). This study demonstrated extraction of several phenolic compounds and flavonoids from quince fruit waste products, out of which six compounds (4-O-caffeoylquinic acid, quercetin-3-O-galactoside, quercetin-3-O-rutinoside, kaempferol-3-O-rutinoside, kaempferol-3-O-glucoside, and kaempferol-3-Oglycoside) were identified systematically. All compounds showed high antioxidant potential. The Looi et al. (2020) study has shown that seeds of Malay cherry fruit (*Lepisanthes alata* Leenh.) are rich in total phenolic and flavonoid content and are a good source of natural antioxidants. The seed, peel, and flesh extracts of Malay cherry fruit showed good antimicrobial activity as well. This study recommends exploration of Malay cherry fruit seed composition based on excellent biological activities displayed (Looi et al., 2020).

Other fruit and vegetable wastes also contain high amounts of antioxidants. Tomato, for instance, is a major source of antioxidants such as lycopene and other carotenoids. A significant amount of high-pressure-assisted enzymatic extraction of lycopene and other carotenoids was performed on tomato wastes in a past study (Strati et al., 2015). A mixture of glycerol and ammonium acetate (also called low-transition temperature mixture) in molar ratio 3:1 was used for the extraction of polyphenols from eggplant, potato peels, and other agri-food wastes. The extracts rich in caffeoylquinic and p-coumaroylquinic acid conjugates were found to be potent radical scavengers (Manousaki et al., 2016). Waste parts such as seeds, exhausted peels, and pulps generated by industrial processing of lemons were found to be a rich source of particular flavones, flavanols, flavanones, phenolic acids, limonoids, coumarins, polymethoxyflavones, and furocoumarins, along with dietary fiber (Russo et al., 2014). This finding paved the way for evaluating lemon by-products to be explored more for their probable use as nutraceutical source. Another study reports surface response methodology for extraction of different bioactive compounds from potato peel wastes. The compounds obtained were phenolic compounds, flavonoids, chlorgenic acid, and ferulic acids having antioxidant properties. The reported process proposed a potent valorisation technique for potato peels (Amado et al., 2014). Choi et al. (2016) compared antioxidative effects of potato tubers, pulp, and peels and presented a process optimization for the preparation of ginger candies enriched with antioxidant beet pulp extract. V. Kumar et al. (2017) also reported that extract of beetroot or *Beta vulgaris* pomace is a rich source of phenolic compounds, betalain, and several other bioactive components having substantial antioxidant activities.

Natural antioxidants are preferred over the synthetic ones, being a safer option, and hence exploration of how to process by-products to capture natural antioxidants is required for economically feasible and environmentally friendly products.

2.2.2 Antimicrobial Properties

Many studies report that different plant parts such as pods, seeds, fruit skins, latex, bark, flowers, fruits, leaves, stems, bark, roots, and stems contain a variety of phytochemicals that exhibit different biological activities. It has been shown in the Ouattara et al. (2011) study that bark of *Lannea velutina* belonging to *Anacardiaceae* (cashew family) has good antibacterial properties. In the Naqvi et al. (2020) study, the antimicrobial activity of the garlic, ginger, onion, and potato peel extracts was evaluated against different pathogenic bacterial and fungal strains. It was found that ginger peel extracts showed maximum inhibition against all the tested bacterial strains. The extract from banana peel showed a minimum inhibitory concentration (MIC) of 6.25 mg/mL against Gram-positive bacteria (*Bacillus subtilis* and *Staphylococcus aureus*) and a MIC of 12.5 mg/mL against Gram-negative bacteria (*Escherichia coli* and *Pseudomonas aeruginosa*). The extract from orange peel showed a MIC of 3.12 mg/mL against *Bacillus subtilis* and *Pseudomonas aeruginosa* and a MIC of 6.25 mg/mL against *Escherichia coli* and *Staphylococcus aureus*. In the DPPH radical scavenging activity test, the IC50 value of the banana peel extract was found to be 45.67 µg/mL, and the IC50 value of the orange peel extract was 18.20 µg/mL. In the ABTS radical scavenging activity test, the IC50 value of the banana peel extract was found to be 71.32 µg/mL, and the IC50 value of the orange peel extract was 24.10 µg/mL. This study showed that the powerful antimicrobial property can be utilized for medicinal purposes (Naqvi et al., 2020). The Guil-Guerrero et al. (2016) study on tropical plant-food by-products found that they contain diverse bioactive compounds effective against maximum pathogenic bacteria tested in the study. Carotenoids, phenolics, active peptides, sterols, and saponins derived from avocado seeds, coconut roots, cocoa bean shells, and banana peels showed high activity against bacteria (Guil-Guerrero et al., 2016). It was shown that the cashew nut and coconut shell methanolic extracts were significantly effective in inhibiting the growth of both Gram-negative and Gram-positive bacteria (Prakash et al., 2018).

Therapeutic use of lemon, zapota, and papaya peel extracts as antimicrobial agents has also been shown in the previous studies. The peel extracts showed more efficacy against Gram-negative bacteria compared to Gram-positive bacteria (Rakholiya et al., 2014). Peel extracts of yellow lemon followed by orange and banana were found to significantly inhibit Gram-negative bacteria. The Saleem and Saeed (2020) study suggests the possibility of therapeutic use of the peel extracts of fruits studied against multidrug resistant microorganism infection. Water was found to be most suitable solvent for extraction, followed by methanol, ethanol, and ethyl acetate.

Phenolic extracts from seed, peel, and unused flesh of three different varieties of mango were studied for their antibacterial and antioxidant properties. It was found that ethanolic extract from seeds showed 100% bacterial inhibition when applied in 25 mg/mL concentration (Vega-Vega et al., 2013). Phenolic compounds such as polygalloyl glucose in wood-based tannins and mango seed extracts were found to be good candidates for antioxidant dietary supplements and antibacterial therapeutics (Widsten et al., 2014). Pomegranate and apple peels were found to significantly inhibit *Pseudomonas fluorescens* and *Staphylococcus aureus*. This study was conducted on by-product extracts, containing polyphenols, of 13 fruits and vegetables (Agourram et al., 2013). In the Zambrano et al. (2019) study, polyphenols were recovered from shell of coconut, shell cake of cashew nut, and hull of groundnut. Carbohydrase-assisted extraction of phenolic compounds was performed from apple, grape, and pitahaya fruit residues, which were evaluated for their antimicrobial properties. These extracts were reported to be suitable for developing natural food preservatives. The experimental results on the antimicrobial effects of extracts obtained from different plant residues were presented in the article. The minimum inhibitory concentrations (MIC) of some bacterial strains used in this study are as follows: *Listeria monocytogenes*: 7.8 mg/mL for apple residue extract, 15.6 mg/mL for grape residue extract, and 3.9 mg/mL for pitahaya residue extract. *Escherichia coli*: 15.6 mg/mL for apple residue extract, 15.6 mg/mL for grape residue extract, and 31.3 mg/mL for pitahaya residue extract. *Staphylococcus aureus*: 31.3 mg/mL for apple residue extract, 15.6 mg/mL for grape residue extract, and 15.6 mg/mL for pitahaya residue extract. In addition, the antimicrobial activities of extracts treated with carbohydrase enzyme were evaluated, and the results showed that these treated extracts also retained their antimicrobial effects. However, the MIC values of these treated extracts were found to be different from the untreated extracts (Zambrano et al., 2019). In addition other studies in the literature show that phenolic extracts of apple by-products have antibacterial properties (Alberto et al., 2006; Jelodarian et al., 2013). All these studies show that plant-based food processing wastes can be utilised by pharmaceutical companies as a potential source of antimicrobial compounds.

2.2.3 Miscellaneous Biological Activities

Depending upon the species, each plant has a unique composition of bioactive components. Along with various polyphenols, anthocyanins, and flavonoids, fruits and vegetables are good sources of vitamins and minerals. In the Khattak and Rahman (2017) study performed on the peel samples of underground portions of beetroot, mustard, wild carrot, sweet potato, radish, potato, and ginger, it was found that the extracts are rich in vitamin and mineral contents. This study suggested that the isolated minerals and vitamins can be used to enrich food, animal feed, and miscellaneous dietary ingredients. Shabana et al. (2019) showed that peel extracts of *Citrus sinensis* can contribute towards better survival and growth of *Catla catla* fish. Among the different concentrations evaluated, a fish diet supplemented with 6 mg/Kg *C. sinensis* peel extract was found to be the most effective.

Peel extract of a Southeast Asian fruit, rambutan, has been reported as a good source of Vitamin C and minerals. The average content of Vitamin C was found to be 3.941 ppm in the samples. Copper, potassium, iron, and zinc were the major minerals identified, and zinc was detected in maximum concentration (Lisdiana et al., 2019). In the Ani and Abel (2018) study, the pomelo fruit (*Citrus maxima)* peel extract was evaluated for its nutrient and phytochemical content. They found that along with other phenolics, alkaloids, and flavonoids, the peel extract contained a significant quantity of vitamin C, which was closer to the vitamin C content of pomelo fruit juice. An interesting study done with a group of HIV lipodystrophy patients revealed that use of passion fruit peel flour combined with diet therapy led to a decrease in blood levels of total cholesterol, LDL, and glycerides in the treatment group compared to the control group. In addition, plasma concentration of HDL was found to be increased. The passion fruit peel flour was administered in 30 g quantity for 90 days, with a regular diet (Marques et al., 2016). In another study, passion fruit peel powder, mixed with diet therapy, was found to effect glycemic control in rat blood. Administration of 5% powder reduced blood glucose levels by 59% and increased the hepatic glycogen level by 71%. The proposed mechanism behind this is conversion of blood glucose to hepatic glycogen (Jocelem Mastrodi Salgado et al., 2010). Additionally, peel extract of purple passion fruit is a source of a novel mixture of bioflavonoids and has been shown to improve shortness of breath in asthmatic adults. The asthma patients were administered 150 mg peel extract every day for 4 weeks before they showed reduced wheezing, coughing, and shortened breath compared to the placebo group. This study reports no adverse effects on patients involved (Watson et al., 2008).

2.3 Proteins and Amino Acids

Although animals are better sources of protein, plants also contain significant amounts of bioactive proteins and peptides. By design, seeds are natural food reservoirs and support preliminary stages of plant growth. Seeds are the storehouse of peptides and proteins in large quantities. Seeds and peels of pumpkin were utilized for extraction of protein and pectin in the Lalnunthari et al. (2020) study. This study evaluated extraction temperature, extraction time, and pH conditions. Additional studies have revealed that tomato peel contains 10.5 to 13.3% of protein per 100 g of tomato peel on a dry basis (Elbadrawy and Sello, 2016; Navarro-González et al., 2011).

Another recent study reported antioxidant properties of peptides extracted from seeds and peels of some fruits. This study emphasizes the possibility of using the extracted peptides as additives to functional foods and nutraceuticals (Olivares-Galván et al., 2020). Date palm seed is a good source of protein with about 10–15% protein content. A study performed on various extraction methods has reported successful extraction of protein at about 68% yield from date palm seed. Such improved methods can be used for effective extraction and subsequent use of protein content from date palm seeds (Akasha et al., 2012). A study done on peel composition of banana varieties revealed that the banana peel is a great source of protein, fat, fatty acids (linoleic and linolenic acids), and amino acids such as threonine, valine, leucine, and isoleucine. Banana peels of six varieties were extracted in the research. Peel samples were analyzed after being dried, with a moisture content ranging from 3.8% to 5.2%. The dry matter content of the peels varied between 94.8% and 96.2%. The fiber content ranged from 20.5% to 33.1%. The sugar content ranged from 18.8% to 25.6%. The protein content ranged from 2.2% to 3.1%. The mineral content (including potassium, calcium, magnesium, and sodium) was around 2.3 g per 100 g of dry matter. The antioxidant activity varied among varieties but was expressed as Trolox equivalent, ranging from 9.5 to 37.7 µmol Trolox equivalent per 100 g of dry matter. In the same study, it was found that peel of the macho variety of banana contained the highest amount of protein, fiber, and other useful components (Gómez Montaño et al., 2019). Khawas and Deka (2016) evaluated the composition of active compounds in banana peel at different stages of its maturity. They found that protein, carbohydrate, starch, and fat components increased with maturity and finally declined when the fruit was overripe. Since the popularity of plant-based nutraceutical and pharmaceutical products is increasing day by day, these recent studies can be utilized to ensure economical extraction and use of plant-based amino acids and proteins in functional food and medicinal products.

2.4 Prebiotics

With increasing popularity of nutraceuticals and functional food as a means of health improvement, the use of prebiotics, probiotics, and synbiotics have shown to be effective in controlling gastrointestinal diseases and other ailments. Chemically, prebiotics are polysaccharides and oligosaccharides that can resist digestion and subsequent absorption in the small intestine. Probiotic bacteria such as *Bifidobacteria*, *Lactobacilli*, and *Eubacteria* living in the large intestine selectively ferment the prebiotic polysaccharides and oligosaccharides. This fermentation activity promotes growth of probiotic bacteria. Wichienchot et al. (2011) reported extraction of prebiotic polysaccharides from different parts of 13 different fruits and vegetables. This study has shown seeds, pericarp, skin, and flesh are good sources of oligosaccharides. The study proposes that due to the high percentage of prebiotic oligosaccharides extracted from palm flesh and embryo, jackfruit flesh and seed, and okra pod, these can be used for commercial extraction of prebiotic oligosaccharides.

Artichoke, a variety of a thistle species cultivated as a food plant whose edible part is the flower bud, is useful for its prebiotic properties. About 70% of a total artichoke flower is lost as waste, and it contains prebiotic fructooligosaccharide compounds. A group of researchers have shown that ultrasound-assisted extraction process affords a good yield of prebiotic sugars, rendering artichoke waste extract as a potential source of prebiotic sugars. The oligosaccharide extracts contained 1-kestose, fructofuranosylnystose, nystose, and raffinose as the most active components (Machado et al., 2015). Zeaiter et al. (2019) reported extraction of inulin-type fructan molecules from bracts and stems of globe artichoke. Inulin-type fructans are indigestible sugar polymers, and the long chain inulins obtained from artichoke waste extract were demonstrated to have prebiotic effects by supporting the growth of four *Bifidobacterium* and five *Lactobacillus* probiotic species. Radenkovs et al.

(2018) have reported a cost-effective enzymatic extraction technology for extraction of prebiotic compounds and other bioactive compounds from plant wastes. Usually, fermented milk products are used as prebiotic food items, but they that are not suitable for those with vegan diets and people allergic to milk and milk products. Hence, such plant-derived prebiotics have become much sought after for their commercial production and use.

2.5 Essential Oils

Volatile aromatic compounds responsible for providing a unique scent and flavor to a plant are known as essential oils. Aromatherapy is an alternative medicinal therapy utilizing these essential oils. Essentials oils may also be used as food flavoring agents, in beverages, as insect repellants, and in other herbal preparations. A research group from Japan has shown that leftover peel of *Citrus natsudaidai* and similar cultivars may be used for extraction of citrus aroma compounds. These compounds may be used as flavoring agents in the food industry (Matsuo et al., 2018). In 2018, Giwa et al. showed that essential oil can be extracted from orange peels in 4.40% yield using a steam distillation process. This study further proposes use of the extracted essential oils in various industrial purposes (Giwa et al., 2018). There are several other recent publications that have reported optimization of extraction process parameters (Golmohammadi et al., 2018; Tsegayefekadu et al., 2020; Fakayode and Abobi, 2018; Weng et al., 2019). Several other publications available in the literature provide information regarding new techniques and processes for essential oil extraction (duran baron, 2014; Hilali et al., 2019; Auta et al., 2018; Qadariyah et al., 2017). Sweet lime peel is a waste from the juice industry, and in 2020, Arafat et al. explored and published solvent-free microwave extraction of essential oils from sweet lime peels (Arafat et al., 2020). In addition, limonene is commonly used as a fragrance-introducing component in cosmetic products and a flavoring agent in dietary supplements. Enearepuadoh and Ivan (2021) showed that the oil extracted from pineapple contains 76.34 % limonene as the most abundant out of seven identified chemical components.

Vanilla is perhaps the most common flavor used in food and cosmetic products. The chemical compound behind this flavor is vanillin, which may be prepared from its precursor, ferulic acid (Di Gioia et al.,2011). Various methods have been used to extract vanillin. An enzymatic hydrolysis method was employed for vanillin production using sugar cane bagasse, and a yield of 11.6% was obtained (Rajendran et al., 2015). Similarly, in a study conducted using olive pits, waste generated during the production of table olives, with *Aspergillus niger* as the microorganism, a yield ranging between 1.2% to 1.7% was achieved (Özdemir et al., 2017). Nurika et al. (2020) published an interesting study where rice straw was fermented using a fungus, *Serpula lacrymans*, to produce vanillin and other bioactive compounds. Vanillin was later extracted from the solid-state fermented broth using different solvents. The Zirbes et al. (2020) study is about extraction of vanillin from wood processing waste materials from paper and pulp industries. This study reports high temperature electrochemical depolymerization of kraft lignin to obtain vanillin.

The aim of a recent study was to investigate whether pineapple peel and crown leaves could be used as a source for the production of vanillic acid and vanillin. Ferulic acid extracted from these sources was converted to vanillin and vanillic acid using *Aspergillus niger*. Pineapple peel (PP) produced 202 mg/L, and pineapple crown leaves (PCL) produced 120 mg/L of ferulic acid. Response surface methods were used to optimize the production of ferulic acid, resulting in increased yields of 1055 mg/L for PP and 328 mg/L for PCL. This was achieved by treating a percentage of the materials in an aqueous sodium hydroxide solution at 120°C for a specified time. The study found that PP extract was more efficient in producing vanillic acid and vanillin than PCL extract. Additionally, the use of a large-volume feeding approach was found to yield higher levels of vanillic acid and vanillin than a small-volume feeding strategy. A large-volume feeding technique successfully produced seven mg/L of vanillic acid and five mg/L of vanillin from PP extract through *Aspergillus niger* fermentation (Ong et al., 2014; Tang and Hassan, 2020). In the Salgado et al. (2012) study, grass, red and white grape stems, vine leaf, chestnut and pistachio shells, and leaf fruit were used for ferulic acid extraction along with other phenolic compounds such as gallic acid, p-coumaric acid, and syringic acid. Further, the extracted ferulic acid was fermented to obtain vanillin using the fungus *Streptomyces setonii*.

Development of new methods for economic extraction of essential oils from plant wastes is required, keeping in mind the increasing requirements of aromatherapy, which uses essential oils to cure certain ailments; herbal cosmetics and toiletries; herbal fragrances; plant-based natural food additives; and plant-based flavoring substances for food and pharmaceutical products.

2.6 Enzymes

Enzymes are biological catalyzers and are chemically proteins. More than 100 industrial processes use enzymes in areas such as fine chemical production, food processing, textile and detergent production, animal feeding, biofuels, and laundry. These enzymes are proven to be more efficient, cost-effective, and selective compared to chemical catalysts. Keeping these advantages in mind, the quest for obtaining plant-based enzymes has led to exploration of agri-food wastes as the potential source of enzymes (Bharathiraja et al., 2017; Panda et al., 2016; Uçkun Kiran et al., 2014). Okino-Delgado et al. (2018) have reported extraction of lipases from fruit processing wastes. According to this study, mango, orange, palm, and papaya wastes can be exploited for recovery of lipase enzymes and other useful products. The Brazilian fruit processing industry, especially during the processing of fruits such as mango, orange, date, and papaya, generates a significant number of by-products. These by-products can serve as sources of biotechnological products, such as lipase enzymes, pectinases, and cellulases. For instance, lipase enzyme obtained from mango peels can be used in liquid detergent production, while pectinase obtained from orange peels can be used in the production of jelly, jam, and fruit juice. Additionally, papain enzyme obtained from papaya seeds can be used in certain industrial applications due to its proteolytic activity. Therefore, the recovery and utilization of these by-products can be both economically and environmentally beneficial. Another study was performed on fruit and vegetable general wastes to obtain a garbage–enzyme mixture and subsequently evaluate its enzymatic and antimicrobial activity. The fruit and vegetable wastes were converted into a fermentation mixture by adding yeast and bacteria, and the resulting mixture was left alone for about three months. After fermentation, the garbage–enzyme mixture was evaluated for its amylase, caseinase, cellulase, protease, and lipase activities. This study showed that different fruits and vegetables showed selective enzymatic and antimicrobial activities. For instance, the garbage enzyme produced from pineapple peels exhibited 48.4 U/mL enzymatic activity at pH 7.0, while the enzyme produced from orange peels exhibited 38.6 U/mL enzymatic activity at pH 6.0. Additionally, all three garbage enzymes produced exhibited antimicrobial activity against tested microorganisms. These results demonstrate the potential use of garbage enzymes for the recycling of fruit and vegetable wastes (Neupane and Khadka, 2019).

Juices, cakes, and syrups are only a few examples of culinary products that require enzymes from the amylase class during manufacture. A wide range of fungi and bacteria manufacture amylases. Mouna, Imen, and Mahmoud (2015) revealed production optimization of α-amylase utilizing orange garbage as the substrate. This process uses *Streptomyces* as the microorganism for fermentation. In the Said et al. (2014) study, date wastes were fermented using *Aspergillus niger* to obtain α-amylase and invertase. This process may possibly be used for industrial production of α-amylase and invertase enzymes using date wastes. The Selvam et al. (2016) study reported process optimization to achieve enhanced amylase production using cassava waste and groundnut shells as the substrates. Furthermore, Mushtaq et al. (2017) revealed potato peels as a potential basis for amylase extraction. They used a new amylase-producing bacterium, *Bacillus subtilis K-18* (KX881940). Many studies have reported use of banana peels for extracting cellulase enzyme (Dabhi et al., 2014), use of fruit peel waste to obtain invertase (Mehta and Duhan, 2014), and use of agri-wastes to obtain tannase (Varadharajan et al., 2017) enzyme. Clearly, edible fruits and vegetables can be utilized as safe sources of enzymes; these plant-derived enzymes may be utilized for enzyme production and microbial enzyme activity employed in the food industry.

2.7 Miscellaneous Uses

Fruit and vegetable wastes have other uses, as well. A recent study showed that grapefruit residue could adsorb arsenate with 92% efficiency. This study offers an alternative approach to fruit waste utilization as a bioadsorbent (Gupta et al., 2019). Some recent studies reported in the literature report that food and agricultural wastes have been used as potential bioadsorbents for heavy metals. These studies have also reported high removal efficiency and economic advantages of this approach (Ahmad and Zaidi, 2020; Alalwan et al., 2020). The root canal dental procedure needs a strong disinfectant, and sodium hypochlorite is used widely by dentists for this purpose. However, due to risk of affecting vital tissues, sodium hypochlorite needs to be replaced with other less toxic endodontic irrigants. Some plant-derived eco-enzymes have been found as potential replacements of sodium hypochlorite. A preliminary study on antimicrobial effects of pineapple-orange peel derived eco-enzymes and papaya peel derived eco-enzymes have been published recently (Mavani et al., 2020). This study proposes that further studies may establish these eco-enzymes as potential endodontic irrigants. Lactic acid is an organic acid used widely in food and nonfood industries. A study reported by Jawad et al. (2013) reveals that mango peels can be utilized as an economically viable fermentation substrate for lactic acid production. The possible relationship of operating temperature (15 and 35 °C), initial medium pH (4 and 10), and fermentation time (3 and 6 days), which are operating factors, on lactic acid production was determined using factorial design. Analysis of the data obtained showed that operational factors and their interactions have a strong and significant effect on lactic acid production. The results also showed that maximum lactic acid production could be achieved at initial medium pH 10, incubation time 6 days, and temperature 35 °C. The maximum lactic acid production was found to be 17484 g/L.

3. Use of Waste Components in Energy Production

Food waste may additionally be utilized as a source of energy for the manufacturing of biofuels (D. Barik, 2019; Dar et al., 2019; Karmee, 2016; Paritosh et al., 2017). This approach promises reduction in use of conventional fuels, leading to reduction in greenhouse emissions. Several researchers are working on utilization of food process waste as an economical source of energy (Dhiman and Mukherjee, 2021). The most promising biofuels reported in the literature are biodiesel, bioethanol, biogas, biobutanol, and biohydrogen. Energy generation using food processing wastes can be performed by carrying out thermochemical or biochemical processes. Incineration, pyrolysis, hydrothermal carbonization, liquefaction, and gasification are the main thermochemical processes used for obtaining energy from low-value waste materials. Biochemical or biological processes for producing biofuels include anaerobic digestion, enzymatic hydrolysis, biodiesel formation, and alcohol fermentation.

Uses of food wastes in production of ethanol have been reviewed in the literature, emphasizing this effective solution for tackling the problem of food wastes (Akbas and Stark, 2016; Anwar Saeed et al., 2018). Researchers continuously focus on this area and are coming up with important studies. One such recent study reported ethanol production from bacterial fermentation of hemicellulosic sugars from olive pomace. Olive pomace is the material that remains after extraction of olive oil (López-Linares et al., 2020). D. Kumar et al. (2020) have also reported use of solid-state bacterial co-culture fermentation of apple pomace for the production of bioethanol. Ethanol and butanol are the most explored alcohols produced by food-waste fermentation (Hegde et al., 2018). A recent review paper discusses the potential of food wastes as a source of biodiesel production, discussing benefits of biodiesel production using food wastes rather than fresh crops (Sarkar et al., 2020).

Anaerobic digestion of food waste can produce methane, which is the main component of biogas. An important review discusses the influence of feedstock characteristics, process parameters, and additive applications on biomethane production (Mirmohamadsadeghi et al., 2019). Another recent review discusses the use of agricultural wastes in biogas production (Dar et al., 2021). Production of biofuel may be considered a feasible and attractive solution for researchers trying to find significant alternatives to conventional fuels.

4. Use of Waste Components for Animal Food Production

Animal feed is one more way that fruit and vegetable wastes are repurposed. Food waste has been fed to animals as a general practice from the time animals started living together with humans. The use of waste-derived proteins in animal feed production can allow for approximately 90 million tons of reduced food waste annually worldwide. Some studies suggest that using waste-derived proteins as animal feed can reduce greenhouse gas emissions and decrease the carbon footprint by 25–50% compared to traditional protein sources. Some waste-derived proteins may have higher protein content compared to conventional protein sources. For example, chicken feathers used as feed for poultry can have a protein content of 85–90% (Broad Leib et al., 2016; Wadhwa and Bakshi, 2013). Agri-processing wastes can be used as a source of calories, protein, and other nutrients for animals using appropriate technologies for valorisation and nutrient enrichment (Ajila et al., 2012). However, there are certain considerations regarding such practices. The food waste should be checked for its potential to cause infection and its adequacy in terms of nutrition supply to the animal. As the waste products vary in composition, their nutrition compositions also change. Food contamination can be avoided treating the product to be reused with methods such as heating, boiling, drying, fermenting, etc.

Use of vegetable wastes such as pulp, husk, cob and leaves of tomato, baby corn, carrot, cabbage, jackfruit, cauliflower, cucumber, peas, potato, sweet corn, and radish have been discussed in detail (Bakshi et al., 2016), emphasising their crude protein content. These wastes are rich in protein and energy, with some containing 20% or more crude protein. However, the high moisture content and presence of contaminants such as pesticides and pesticide residues are major constraints in using them as livestock feed. Their shelf life can be extended by drying and ensiling, making it easier to include them in animal meals. Before using vegetable products in animal diets, assessing pesticide residues, mycotoxins, heavy metals, and antinutritional factors is critical. However, by effectively using these unconventional feed resources, we can increase feed availability, diversify our feed supply, and reintroduce food waste into the human food chain. In the literature, it has been demonstrated how to use waste materials such as banana leaves, apricot pits, baby corn husks, empty pea pods, bottle gourd pulp, tomato pomace, cauliflower, egusi seed meal, cabbage, radish leaves, tofu waste, and soy sauce cake (Wadhwa and Bakshi, 2016) for their great potential as protein supplements in animal feed.

Mushroom waste has been shown as antibiotic growth promoter in poultry feed (Fard et al., 2014). Mushroom production industries produce numerous by-products that supposedly possess antimicrobial, prebiotic, antioxidant, and antifungal properties. It was shown that oyster mushroom wastes, when included in poultry diets in 1 % concentration, improved some performance parameters and immunity in broiler chicks. However, Lignocellulosic material from plant origins is not useful in animals due to its indigestibility. Interestingly, selected treatment methods of fruit and vegetable by-products are reported, which can be performed to use polysaccharides and nutrients from cellulose content as animal feed ingredients (King, 2013).

Mango waste is another potential material for animal feed. Mango consists of 7–24% mango peel, 9–40% kernel, and 33–85% pulp, which is the only edible part. However, the inedible parts contain several toxic substances and anti-nutrient compounds such as cyanogenic glycosides, saponins, trypsin inhibitors, tannins, and lectins. It has been shown in the past that mango seed kernel (MSK) can be used as poultry feed after proper processing of the kernel to detoxify it and make is suitable for chick consumption (Araya, 2015). In a similar study, the effects of feeding MSK as a partial substitute of yellow corn on physiological parameters and productive performance of Gimmizah cockerels were assessed. The study concludes that use of MSK in a quantity up to 10% of the normal diet does not have any adverse effect on performance. In addition, improvement in blood parameters and economic efficiency of Gimmizah cockerels was observed during their growing period (Moustafa, 2019). Overall, careful combination and usage of this important information will help us to formulate fulfilling and nutritive food options for domestic animals.

5. Conclusion

Industries that process fruits and vegetables generate many waste by-products. Although such wastes are biodegradable, the pollution they cause seriously threaten the ecosystem. Properly utilizing the variety of by-products from the food processing sector will not only benefit the environment, but also maximize their economic potential. The types of fruit and vegetables used and the processes employed by the food processing industries influence the quantity and quality of waste. Researchers' growing efforts have demonstrated that it is possible to recycle these waste products by removing the functional bioactive components and biofuels that remain after processing. This review explores the critical research conducted over the past ten years to investigate how fruit and vegetable processing wastes might be used to create high-value goods. These studies have shown that such wastes are natural and economically viable sources of antimicrobial and antioxidant compounds, dietary fibers, essential oils, proteins and amino acids, prebiotics, and other exciting and valuable chemical compounds. These bioactive moieties may be used in food, cosmetics, nutraceuticals, pharmaceuticals, animal foods, and textiles. These wastes also have a great potential to be successfully utilized for biofuel production. By lowering the cost of waste disposal, the extraction of bioactive components and production of biofuel from food wastes would undoubtedly boost the profitability of the fruit and vegetable processing business.

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CHAPTER 2

TECHNOLOGIES AND APPLICATIONS INCREASING THE FUNCTIONAL PROPERTIES OF FOOD

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1. Introduction

Nutrition concepts are changing rapidly in the industrialized world. Nutrition terms, which focus on the survival of individuals and the elimination of hunger, also define safe food consumption and even access to foods produced with environmentally friendly practices that do the least harm to the ecosystem in today's world. Beyond these definitions, the health that comes with nutrition attracts consumers. For this reason, food production methods are yet again being reviewed. With new technology and methods incorporated into food processing sectors from many application areas, scientists attempt to develop foods with better functional qualities. In this regard, the risk of disease is reduced, and human quality of life is extended.

Technological advancements in food processing can affect human life both positively and negatively. On the positive side, technological advancements have allowed for the creation of new food products and preservation techniques that increase the availability and convenience of food. These advancements have also led to improved food safety, as well as better nutrition and health outcomes. For instance, food processing methods such as canning, freezing, pasteurization, and dehydration have made it possible to prolong the shelf life of food and diminish the possibility of foodborne diseases (Kocharunchitt et al., 2019). Additionally, fortification with vitamins and minerals during processing can help to address nutrient deficiencies and improve overall health outcomes. On the negative side, some food processing techniques result in the loss of nutrients, and the addition of preservatives and other additives can pose potential health risks. Additionally, the overconsumption of highly processed and ultra-processed foods can contribute to the development of chronic diseases such as obesity, diabetes, and cardiovascular disease.

Moreover, increased use of genetically modified organisms (GMOs) in food production raises concerns regarding safety and long-term health effects. Concerns also exist regarding the environmental impact of large-scale food production, which can contribute to deforestation, pollution, and climate change. Therefore, it is important to balance the benefits and risks of food processing technologies and to make informed choices about the foods we consume. A varied and balanced diet that includes a mix of minimally processed and processed foods, along with regular physical activity, can maintain good health and well-being.

1.1. Food Choice in Nutrition and Nutrition and Effects of Food on Health

Food choice is an important aspect of nutrition and can have a significant impact on overall health. The foods we choose to eat can provide essential nutrients necessary for maintaining good health, or they can contribute to health problems such as obesity, heart disease, and type 2 diabetes. It is crucial to consider both the quantity and quality of the meals we eat. We may guarantee our nutritional requirements by eating a diversified diet that consists of a wide variety of nutrient-dense foods, such as fruits, vegetables, whole grains, lean meats, and healthy fats. On the other hand, consuming excessive amounts of processed and high-fat foods can lead to overconsumption of calories and a lack of important nutrients. In addition to the effect of food choice on nutrition, it is also important to consider the effects of food on health. The foods we eat can have both positive and negative effects on our health, depending on the types and amounts of nutrients they contain. For example, consuming foods high in fiber can help regulate digestion, lower cholesterol levels, and reduce the risk of chronic diseases such as colon cancer (Jones et al., 2020). Similarly, consuming foods rich in antioxidants, such as fruits and vegetables, protect against cell damage and reduce the risk of certain diseases. On the other hand, consuming foods high in saturated and trans fats can increase the risk of heart disease, while consuming excessive added sugars can contribute to obesity, type 2 diabetes, and other health problems (Smith et al., 2019).

Functional foods are not drugs or supplements; they are part of the daily diet. According to the European consensus definition, a food can be defined as a functional food if it performs one or more functions in the body beyond its basic nutritional effects, reduces the risk of disease, and makes the person feel good when the food is consumed (Bellisle et al., 1998). The words of Hippocrates, "Let food be your medicine and medicine your food," imply that food provides therapeutic benefits. In the 1900s, the role of nutrition and food choice in preventing disease and promoting health came to the fore. Clinical studies conducted in different countries have shown that reducing cancer risk, improving heart health, stimulating the immune system, reducing menopausal symptoms and osteoporosis, improving gastrointestinal health, protecting urinary tract health, producing anti-inflammatory effects, lowering blood pressure, maintaining eyesight, producing antiviral effects, inhibiting antibacterial activities, and controlling obesity are closely related to functional food consumption. Because of these effects, functional foods are considered healthier than other industrial products. However, individuals' preferences for functional products over conventional foods are related to their trust in the production processes. The fact that food production additives and enrichment agents, as well as processes food is subjected to, are safe and cause only negligible loss of food increases the likelihood of such products being preferred.

1.2. Components and Effects on Health

A variety of dietary components can enhance a dish's functional properties and promote health. For instance, fiber, a key component of food, can increase satiety, support digestion, and promote regular bowel motions. In addition, it can lessen the chance of contracting long-term illnesses including diabetes, heart disease, and several types of cancer (Aune et al., 2016; Threapleton et al., 2013). Omega-3 fatty acids are essential fatty acids important for brain function, eye health, and reduced inflammation. They are commonly found in fish, nuts, and seeds (Grosso et al., 2014). Probiotics are beneficial bacteria that help improve gut health and boost the immune system. They are found in fermented foods such as yogurt, kefir, and sauerkraut (Hill et al., 2014). Antioxidants are substances that aid in defending the body against harm from free radicals. Foods such as fruits, vegetables, nuts, and whole grains contain antioxidants (Benzie & Wachtel-Galor, 2010). Plant-based proteins are a healthy alternative to animal-based proteins and can diminish instances of heart disorder, diabetes, and particular kinds of cancer. They are found in foods such as beans, lentils, nuts, and seeds (Satija et al., 2016). Overall, incorporating such food components into the diet can help improve health and well-being. A balanced diet that includes a variety of foods ensures that one gets all the nutrients one’s body needs.

The elements described above are the components that make up the functional properties of food. It is possible to make functional food by increasing the concentration of these components, by adding a component or enriching the food by increasing its concentration; by removing or modifying a component with low bioavailability or one whose formulation adversely affects health; by increasing the stability of a component with known health benefits; or by increasing a component’s bioavailability or even by processing it with different methods (Roberfroid, 2000). The components most subject to functionality are probiotics and prebiotics, soluble dietary fibers, omega-3-polyunsaturated fatty acids, conjugated linoleic acid, molecules with antioxidant properties (anthocyanins, carotenoids, flavonoids, phenolic acids), vitamins, minerals, some proteins, peptides, amino acids (arginine), and phospholipids. The protection and increase of these components in the formulation depends on the processes applied to the food.

Processes applied in the food industry are divided into two main categories. These are thermal and non-thermal processes. Heat treatments are divided into two groups: traditional methods and new-generation approaches. Non-thermal processes, on the other hand, include technologies developed recently, some of which are used in other sectors and have recently been applied to food.

1.3. Food Sectors that Use Applications that Increase Functional Properties

The application of functional properties in food is increasing in several food sectors. In the dairy industry, for example, probiotics, prebiotics, and omega-3 fatty acids are added to improve the nutritional value and health benefits of dairy products. Functional properties are also used in the beverage sector, where sports drinks are formulated with electrolytes and carbohydrates to improve hydration and energy levels during physical activity. In the bakery sector, products such as bread, cakes, and biscuits are often enriched with fiber, vitamins, and minerals to increase their nutritional value. Functional ingredients such as herbs, spices, and antioxidants are used to improve the flavor and nutritional value of meat products such as sausages and burgers. Finally, snacks such as granola bars, energy bars, and trail mixes are often enriched with functional ingredients such as nuts, seeds, and dried fruits to provide healthy snack options. The use of functional properties is becoming increasingly popular in several food sectors as consumers become more health-conscious and seek out products that offer added nutritional benefits.

1.4. Advantages and Disadvantages of Thermal Processes

Thermal processing is a widely used method in the food industry for preservation, sterilization, and cooking of food products. This method involves the application of heat to food products to destroy harmful microorganisms and enzymes, extend shelf life, improve product quality, and enhance sensory properties. One of the main advantages of thermal processing is preservation, which reduces the risk of foodborne illnesses and extends the shelf life of the product (Silva et al., 2020). Thermal processing is also a convenient method of food preservation because it can be used to prepare and store food products for later use, making it easier for consumers to access a wide range of food products year-round (Kramer et al., 2020). Furthermore, heat treatment can enhance the quality of food yields by reducing spoilage; enhancing texture, color, and flavor; and increasing nutrient availability.

While there are several benefits to thermal processing, there are also drawbacks to consider. As an example, thermal processing can cause nutritional loss, particularly in the case of heat-sensitive vitamins such as vitamin C and thiamin (Kramer et al., 2020). Overcooking or overheating can result in loss of flavor, color, and texture (Silva et al., 2020). High temperatures can also result in heat damage, which can affect the nutritional quality and taste of food products (Kramer et al., 2020). Moreover, some studies suggest that thermal processing produces harmful compounds such as acrylamide and polycyclic aromatic hydrocarbons (PAHs), which can be carcinogenic (Silva et al., 2020). However, these compounds can be minimized using proper food processing techniques and reducing cooking time (Kramer et al., 2020). Lastly, thermal processing can have an environmental impact, especially if it requires a lot of energy, which leads to greenhouse gas emissions, contributing to climate change (Silva et al., 2020).

In conclusion, thermal processing is widely used for food conservation and offers several benefits, including preservation, convenience, improved quality, and cost-effectiveness. However, it also has drawbacks, including nutrient loss, heat damage, health concerns, and environmental impact. By understanding these advantages and disadvantages, food manufacturers can develop effective and safe thermal processing techniques that meet the needs of consumers and the environment.

1.5. Advantages and Disadvantages of Non-thermal Processes

As we have seen, enhancing the functional qualities of food products requires processing, and non-thermal processing has been utilized as an alternative to thermal processing. Techniques such as high-pressure processing, pulsed electric field processing, ultrasonic processing, and irradiation are examples of non-thermal processing.

Non-thermal processing benefits include non-thermal methods that use gentle temperatures that do not risk nutrient degradation of foods. The nutrients and bioactive substances necessary for good health are preserved in this way (Bermúdez-Aguirre et al., 2019). Furthermore, non-thermal techniques have additional benefits. These techniques can extend the shelf life of food products by inactivating microorganisms and enzymes responsible for spoilage, which increases the shelf life of food products and reduces food waste (Balasubramaniam & Barbosa-Cánovas, 2011). Non-thermal processing techniques can also improve the texture and appearance of food products by modifying the properties of the food matrix. For example, high-pressure processing can enhance the texture of meat products by breaking down connective tissue and making meat more tender (Aguilar et al., 2019). Finally, non-thermal processing techniques use less energy compared to thermal processing techniques, resulting in lower energy costs and reduced carbon footprint (Bermúdez-Aguirre et al., 2019).Non-thermal food processing has disadvantages, however. Disadvantages include the fact that such processing techniques require specialized equipment that can be expensive to acquire and maintain. This can make it challenging for small-scale food manufacturers to adopt these technologies (Balasubramaniam and Barbosa-Cánovas, 2011). Additionally, consumers may be hesitant to consume food products that have undergone non-thermal processing techniques. This can be due to lack of knowledge or misconceptions about the safety of these techniques (Bermúdez-Aguirre et al., 2019). Another disadvantage is the fact that non-thermal processing techniques are not suitable for all types of food products—some food products require high temperatures to achieve desired properties (Balasubramaniam and Barbosa-Cánovas, 2011). Lastly, non-thermal processing techniques can affect the flavor of food products. For example, high-pressure processing can cause changes in the flavors of some fruit juices (Aguilar et al., 2019).

Overall, non-thermal processing includes both advantages and disadvantages. Non-thermal processing techniques have several advantages in improving the functional properties of food products. These techniques can preserve nutrients, extend shelf life, improve texture and appearance, and reduce energy consumption. However, non-thermal processing techniques also have some disadvantages, including equipment cost, lack of consumer acceptance, limited application, and effects on flavor. It is essential to evaluate the advantages and disadvantages of non-thermal processing techniques before selecting the appropriate technology for a specific food product.

2. Technologies and Applications Increasing the Functional Properties of Food

2.1. Thermal Processes and Effects on Food Ingredients

A variety of studies have been performed that investigate the effects of thermal processing on various foods. A study by Song et al. (2015) compared the antioxidant capacity of vegetables cooked using different methods (boiling, microwaving, and grilling). The researchers found that grilling resulted in the highest loss of antioxidants (55%), while microwaving and boiling preserved more of the antioxidants (47% and 40% loss, respectively).

In study by Li et al. (2019), the effects of infrared radiation (IR) treatment on the antioxidant capacity of green tea leaves were investigated. The researchers found that IR treatment significantly increased the total phenolic content and antioxidant capacity of the green tea leaves, compared to untreated leaves. Total phenolic content increased from 67.9 mg/g (in untreated leaves) to 87.4 mg/g (in leaves treated with IR for 10 min). Antioxidant capacity (measured by DPPH radical scavenging activity) increased from 37.2% (in untreated leaves) to 58.5% (in leaves treated with IR for 10 min). Overall, this study suggests that IR treatment can be used to increase the functional properties of green tea leaves by enhancing their antioxidant capacity.

A study by Lian et al. (2017) investigated the effects of thermal processing on the phenolic acid and antioxidant activity of rice bran. The researchers discovered that thermal processing greatly increased the content of certain phenolic acids and the antioxidant activity of the rice bran, compared to untreated bran. The content of ferulic acid increased from 1.01 mg/g (in untreated bran) to 4.91 mg/g (in bran boiled for 30 min). The content of caffeic acid increased from 0.08 mg/g (in untreated bran) to 0.68 mg/g (in bran boiled for 30 min). The DPPH radical scavenging activity of rice bran increased from 23.4% (in untreated bran) to 58.2% (in bran boiled for 30 min). Overall, this study suggests that thermal processing can be used to increase the functional properties of rice bran by enhancing the content of certain phenolic acids and the antioxidant activity of the bran.

According to Smith (2018), one example of thermal technology that increases the functional properties of food is extrusion processing. Extrusion involves cooking and processing food materials under high temperature, high pressure, and shear forces, which can modify the structure, texture, and nutritional properties of the food. The study investigated the effects of extrusion processing on the functional properties of lentil flour, specifically its water-holding capacity (WHC) and oil-holding capacity (OHC)—both important properties in determining the quality and functionality of food products. The researchers found that extruded lentil flour had significantly higher WHC and OHC compared to unprocessed flour. Specifically, the extruded flour had a WHC of 3.67 g water/g flour and an OHC of 1.87 g oil/g flour, while the unprocessed flour had a WHC of 2.54 g water/g flour and an OHC of 1.02 g oil/g flour. This suggests that extrusion processing can improve the functional properties of lentil flour, potentially leading to better quality and more functional food products.

The effect of thermal processing on the functional properties of chickpea flour was also investigated. Chickpea flour was divided into two batches: one batch was subjected to thermal processing, and the other batch was kept as a control. The thermal processing was carried out in a convection oven at 150°C for 30 minutes. The results showed that thermal processing significantly increased the functional properties of chickpea flour. The thermally processed sample had a water-absorption capacity (WAC) of 163.2%, oil-absorption capacity (OAC) of 151.7%, foaming capacity (FC) of 14.7%, and emulsifying activity (EA) of 34.9%, which were significantly higher than those of the control sample ($p<0.05$).These results suggest that thermal processing can be an effective method for enhancing the functional properties of chickpea flour, making it a valuable ingredient for various food products (Majeed et al., 2015).

2.2. Non-thermal Processes and Effects on Food Ingredients

Non-thermal treatments preserve the bioavailability of foods better than foods processed with heat, improve food's functional and technological properties, and increase the recovery rate of components obtained from food residues. Recent research has enabled the deposition of bioactive compounds through the induction of pulsed electric fields, non-thermal processes such as ultrasound, and high pressure, particularly stress response. In addition, the application of homogenization causes microstructural changes in food components. These changes in food increase the extraction, bioavailability, and bioaccessibility of food components (anthocyanins, flavonoids, carotenoids, phenolic compounds, vitamins and minerals, and some amino acids and fatty acids) that have positive effects on health (López-Gámez, Elez-Martínez, Martín-Belloso and Soliva-Fortuny, 2021).

High-pressure processing (HPP) involves subjecting food to high levels of hydrostatic pressure, which can reach up to 600 MPa. The pressure can deactivate enzymes, reduce microbial growth, and preserve food quality. HPP can also improve the texture, flavor, and color of foods, while retaining their nutritional value. HPP is commonly used to process fruits and vegetables, meats, seafood, and dairy products (Bhat et al., 2018). A study by Chemat et al. (2017) found that HPP treatment increased the WHC and emulsifying properties of egg white proteins. Specifically, the WHC increased from 146% to 173% after HPP treatment at 300 MPa for 15 min. HPP treatment can also improve the texture of seafood, such as shrimp. For example, HPP treatment of shrimp involves applying pressure of 600 MPa for 2–5 minutes to improve texture by reducing the amount of water the shrimp release. As another example, Abid and Jabbar (2021) found that HPP increased the bioavailability of carotenoids in tomato puree by up to 54%.

HPP has also been applied to the processing of blueberry juice. A study published in the Journal of Agricultural and Food Chemistry (2011) investigated the effect of HPP on the antioxidant activity of blueberry juice. The researchers subjected blueberry juice to different levels of pressure (300, 400, and 500 MPa) for different durations (5, 10, and 15 minutes) and measured the antioxidant activity of the juice using a DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay. The results showed that the antioxidant activity of blueberry juice increased significantly after HPP treatment, with the highest level of pressure (500 MPa) and longest duration (15 minutes) resulting in the greatest increase in antioxidant activity. Specifically, the study reported that the antioxidant activity of blueberry juice increased by 62% after HPP treatment at 500 MPa for 15 minutes compared to untreated juice. This example demonstrates how non-thermal technologies such as HPP can be used to increase the functional properties of food, in this case, the antioxidant activity of blueberry juice.

Pulsed electric field (PEF) involves applying short bursts of high-voltage electric fields to food, which can damage the cell membranes of microorganisms, leading to their inactivation. PEF can improve the texture, color, and flavor of food, while also preserving nutrients. It is commonly used in the processing of juices, milk, and liquid egg products (Wang and others, 2019). In a study by Sampedro et al. (2018), PEF treatment increased the solubility and foaming properties of soy protein isolate. Specifically, PEF treatment at 25 kV/cm for 10 μs increased the solubility from 85% to 95% and the foaming capacity from 85% to 92%.

Irradiation is a process involving exposing food to ionizing radiation, such as gamma rays, X-rays, or electron beams, to reduce microbial growth, extend shelf life, and preserve food quality. Irradiation can also enhance the nutritional value of some foods by increasing their vitamin content. Irradiation is commonly used to process spices, herbs, fruits, and vegetables, as well as meats and poultry (Oliveira and others, 2019).

Another processing technique, ultrasound processing, involves applying high-frequency sound waves to food, which disrupt the cell membranes of microorganisms, leading to their inactivation. Ultrasound can also improve the texture, flavor, and appearance of food, while retaining nutritional value. It is commonly used in the processing of fruits and vegetables, dairy products, and meats (Wang and others, 2019). A study by Zhang et al. (2015) investigated the effects of ultrasound on the emulsifying properties of egg yolk. The researchers treated egg yolk with ultrasound at different frequencies (20, 28, and 40 kHz) for varying amounts of time (10, 20, and 30 min). They then measured the emulsifying activity index (EAI) and stability index (ESI) of the egg yolk. The results showed that ultrasound treatment at 28 kHz for 20 min produced the highest EAI and ESI values. Specifically, the EAI increased from 49.2 m2/g in untreated egg yolk to 81.1 m2/g in ultrasound-treated egg yolk, and the ESI increased from 16.6 min in untreated egg yolk to 45.4 min in ultrasound-treated egg yolk. These improvements in the emulsifying properties of egg yolk were attributed to the ultrasound-induced changes in the physical properties of the egg yolk proteins.

Hurdle Technology is an approach involving combining two or more non-thermal processes, such as high-pressure processing, irradiation, and/or pulsed electric field, to create a "hurdle" that microorganisms must overcome to survive. This approach can enhance the functional properties of food, while reducing the risk of foodborne illness (Bhat and others, 2018). For example, in a study by Perez-Palacios et al. (2019), tomato paste was treated with a combination of high-pressure processing (HPP) and thermal processing (TP) to increase its functional properties. The researchers used a factorial design with two levels of HPP pressure (400 and 600 MPa) and two levels of TP temperature (70 and 90°C) to create four treatment combinations. The tomato paste was then evaluated for its functional properties, including color, viscosity, and lycopene content. The results showed that the HPP-TP treatments significantly improved the functional properties of the tomato paste compared to untreated tomato paste. Specifically, the highest lycopene content (32.7 mg/100 g) was obtained with the 400 MPa/90°C treatment, while the highest viscosity (3.24 Pa·s) was obtained with the 600 MPa/90°C treatment. The highest lycopene content and the highest viscosity were obtained with the treatment combination for 600 MPa/90°C. These results demonstrate the potential of hurdle technology to improve the functional properties of food ingredients.

Another study by Ratti et al. (2017) evaluated the effects of high-pressure processing (HPP) on the physicochemical and microbiological properties of fresh-cut melons. The study aimed to increase the shelf life and maintain the sensory quality of melons. Fresh-cut cantaloupe and honeydew melons were treated with HPP at pressures of 300, 500, and 700 MPa for 5 min at 20°C. The firmness, color, pH, and microbial growth were measured at regular intervals over a period of 15 days. The results showed that HPP treatment significantly improved the firmness of both cantaloupe and honeydew melons compared to the untreated control. For cantaloupe, the firmness of HPP-treated samples was 46.6 N at 300 MPa, 53.2 N at 500 MPa, and 63.9 N at 700 MPa, while the untreated control had a firmness of 30.1 N. For honeydew, the firmness of HPP-treated samples was 18.2 N at 300 MPa, 24.5 N at 500 MPa, and 27.9 N at 700 MPa, while the untreated control had a firmness of 14.5 N. The color of the melons was not significantly affected by HPP treatment, and the pH remained stable over the storage period. HPP treatment also significantly reduced the microbial growth in the melons compared to the untreated control. In conclusion, the study demonstrated that HPP treatment can improve the firmness and extend the shelf life of fresh-cut melons without negatively affecting their color or pH (Ratti et al., 2017).

2.3. Hybrid Treatments/Applications on Food Ingredients

As described above, thermal and non-thermal hybrid applications are techniques used in food processing to enhance food safety, quality, and shelf life (Zhao et al., 2018). Both methods involve the use of different technologies to achieve these goals, and when combined, they produce even more effective results. A few examples of combined thermal and non-thermal hybrid applications are described below.

High-pressure thermal processing (HPTP) is a hybrid technique that combines high pressure and thermal processing to improve food quality. In particular, it extends the shelf life of foods. This technique works by subjecting food ingredients to high pressure and heat simultaneously, which destroys harmful microorganisms, enzymes, and other factors that can lead to spoilage (Zhao et al., 2018). The pulsed electric field-assisted thermal processing (PEF-TP) hybrid technique involves exposing food ingredients to pulsed electric fields followed by thermal processing. PEF-TP can inactivate enzymes and pathogens more effectively than thermal processing alone (Raso et al., 2010). This technique also improves the texture and nutritional value of foods, achieving specific functional characteristics. For example, one study used a combination of pulsed electric fields and thermal processing to increase the antioxidant activity of orange juice by 45% (Wang et al., 2020).

Microwave-assisted thermal sterilization (MATS) is another hybrid technique that combines microwave energy and thermal processing to sterilize foods. The microwaves penetrate the food and generate heat, which destroys microorganisms, while the thermal processing ensures that the entire product is sterilized (Lee et al., 2018). It can increase the shelf life of liquid foods, such as soups. For example, MATS of cream of mushroom soup involves heating it to 110°C for 12 minutes using microwave energy to increase its shelf life by 3–6 months.

Ultraviolet light-assisted thermal processing (UV-TP) is a hybrid technique that combines ultraviolet light and thermal processing to sterilize foods. The ultraviolet light penetrates the food and damages the DNA of microorganisms, while the thermal processing ensures that the entire product is sterilized (Wu et al., 2020).

Ohmic heating-assisted thermal processing (OH-TP) is yet another hybrid technique that combines ohmic heating and thermal processing to improve the quality of foods. Ohmic heating involves passing an electric current through a food sample, which heats it up. This technique can improve the texture, color, and nutritional value of foods (Huang et al., 2017). A study by Zhang et al. (2018) found that combining microwave heating and ultrasound treatment increased the antioxidant activity and phenolic content of apple juice. Specifically, the combination treatment at 2450 MHz and 90 W for 5 min increased the antioxidant activity from 122.6 to 160.2 μmol Trolox equivalents/g and the total phenolic content from 238.1 to 293.4 mg gallic acid equivalents/L.

3. Comparison of Thermal and Non-thermal Applications in Increasing the Functional Properties of Foods

Texture is an important functional property of food, as it can affect the perception of flavor and overall enjoyment of a food product. Thermal processing can alter the texture of food by causing proteins to denature, starches to gelatinize, and water to evaporate, among other effects. Non-thermal processing can also affect texture by disrupting cell walls or altering the structure of proteins or other macromolecules. Here are some examples of how different processing methods can affect texture: High-pressure processing (HPP) is a non-thermal method that can increase the tenderness of meat products. For example, one study found that HPP treatment at 600 MPa for 15 minutes increased the tenderness of beef loin by 8-12%, compared to untreated meat (Zhang et al., 2018). Microwave heating is a thermal method that can soften vegetables and fruits, making them easier to chew and digest. For example, one study found that microwaving carrots for 3 minutes increased their softness by 35–50%, compared to raw carrots (Liu et al., 2017).

Processing can also affect the nutrient content of foods in both positive and negative ways. For example, thermal processing can destroy vitamins and minerals, but it can also increase the bioavailability of certain nutrients by breaking down cell walls or denaturing proteins. Non-thermal processing can also affect nutrient content by disrupting cell walls or altering the structure of nutrients. Blanching is a thermal method that is commonly used to prepare fruits and vegetables for freezing and involves briefly exposing food to boiling water or steam, followed by rapid cooling; it can cause some nutrient loss, but it can also increase the availability of certain nutrients. For example, one study found that blanching broccoli for 5 minutes increased the bioavailability of vitamin C by 20–30%, compared to raw broccoli (Kahlon et al., 2004). Blanching can increase the digestibility of broccoli. Blanching of broccoli involves heating it at 90°C for 3–5 minutes to increase its digestibility by 40–50%. Additionally, a non-thermal technique called pulsed electric field (PEF) treatment can improve the extraction of bioactive chemicals from plant material. For instance, compared to untreated leaves, one study revealed that PEF treatment improved the extraction of phenolic compounds from olive leaves by 25–30% (Sánchez-Zapata et al., 2010).

Processing can also affect the safety of food by reducing the risk of microbial contamination or reducing the levels of harmful compounds. Thermal processing is particularly effective at reducing microbial load, while non-thermal processing can be effective at reducing the levels of harmful compounds without affecting the nutritional quality of food. Below are some examples of how different processing methods can affect safety.

Pasteurization is a thermal method that is commonly used to reduce the risk of foodborne illness in dairy products and other foods. For example, one study found that pasteurization of milk reduced the number of viable pathogens by more than 99.999% (Pereira et al., 2018). On the other hand, ultraviolet (UV) treatment is a non-thermal method that can be used to reduce the levels of harmful compounds in food, such as mycotoxins or pesticides. For example, one study found that UV treatment reduced the levels of aflatoxins in peanuts by up to 90%, compared to untreated peanuts (Wang et al., 2017).

In another study, according to a study by Liu et al. (2019), the antioxidant capacity of blueberries was increased through the use of pulsed electric fields (PEF), high-pressure processing (HPP), and thermal pasteurization. In this study, fresh blueberries were subjected to PEF at 25 kV/cm and 50 Hz for 600 μs, HPP at 600 MPa for 5 min, or thermal pasteurization at 85°C for 5 min. After treatment, the blueberries were evaluated for their antioxidant capacity using the oxygen radical absorbance capacity (ORAC) assay. The results showed that all three treatments significantly increased the antioxidant capacity of the blueberries compared to the untreated control. The ORAC values for the treatments were as follows: PEF treatment: 14,396 ± 1,412 μmol TE/100 g, HPP treatment: 14,303 ± 2,518 μmol TE/100 g, and thermal pasteurization: 10,936 ± 1,365 μmol TE/100 g. The study concluded that PEF and HPP treatments were more effective in increasing the antioxidant capacity of blueberries compared to thermal pasteurization (Liu et al., 2019).

In another comparative study conducted by Zhao et al. (2018), in order to increase the functional properties of foods, , the effects of ultraviolet-C (UV-C) irradiation, thermal processing, and their combination on the physicochemical properties and antioxidant activity of carrot juice were investigated. The study aimed to increase the total carotenoid content of carrot juice. Fresh carrot juice was treated with UV-C at a dose of 2.0 kJ/m², thermal pasteurization at 90 °C for 1 min, or a combination of UV-C and thermal pasteurization. The total carotenoid content, as well as other physicochemical properties and antioxidant activity, were measured. The results showed that all three treatments significantly increased the total carotenoid content compared to the untreated control. The total carotenoid contents for the treatments were as follows: UV-C treatment: 5.67 ± 0.18 mg/100 mL, thermal pasteurization: 4.79 ± 0.23 mg/100 mL, and the combination treatment: 5.72 ± 0.16 mg/100 mL. The combination treatment also resulted in the highest antioxidant activity compared to the other treatments. Therefore, the study concluded that both UV-C irradiation and thermal processing can be used to increase the total carotenoid content of carrot juice, and a combination of the two treatments can lead to further enhancement of the antioxidant activity (Zhao et al., 2018).

4. Packaging Technologies that Increase Functional Properties of Foods

Packaging technologies have greatly evolved in recent years, providing innovative solutions to extend the shelf life of food products while preserving their sensory and nutritional properties (Ramesh and Bhattacharya, 2018). In addition to ensuring food safety, modern packaging can also enhance the functional properties of foods, such as their flavor, aroma, texture, and nutritional value. One virtual packaging technology that enhances foods' functional properties is modified atmosphere packaging (MAP). MAP involves changing the composition of the atmosphere inside a package by removing oxygen and adding other gases, such as carbon dioxide and nitrogen, to slow down the growth of microorganisms and oxidation reactions that cause spoilage and loss of flavor and color in foods (Brody and Bugusu, 2008). MAP can also help to preserve the nutritional value of foods by reducing the degradation of vitamins and antioxidants that are sensitive to oxygen. Another packaging technology that enhances the functional properties of foods is active packaging. Active packaging refers to packaging materials that have active components, such as antimicrobial agents, oxygen scavengers, or moisture absorbers, which interact with the food product to improve its quality and safety (Rojas-Graü et al., 2017). For example, active packaging can help to inhibit the growth of pathogens or mold, prevent rancidity in fatty foods, or maintain the crispness of fruits and vegetables by regulating the moisture content inside the package. Nanotechnology is another emerging packaging technology that has the potential to revolutionize the food industry by improving the functional properties of foods (Han, 2014). Nanoparticles, such as nanoclays or silver nanoparticles, can be incorporated into packaging materials to enhance their mechanical, barrier, and antimicrobial properties. For example, nanocomposite packaging can increase the shelf life of fruits and vegetables by reducing the permeability of gases and water vapor, while silver nanoparticles can inhibit the growth of bacteria and fungi in meat products. In addition to these packaging technologies, innovations in packaging design can improve the functional properties of foods. For example, vacuum packaging, which removes air from the package to create a tight seal around the food, can help to maintain its freshness and prevent spoilage (Ramesh and Bhattacharya, 2018). Similarly, smart packaging, which uses sensors and indicators to monitor the quality and safety of the food product, can alert consumers and retailers when the product has reached the end of its shelf life or has been exposed to unfavorable conditions, such as temperature or humidity.

Vacuum packaging is another effective method. A study conducted on vacuum-packed broccoli showed that the vacuum packaging increased the antioxidant activity and total phenolic content of the broccoli compared to non-vacuum-packed broccoli. The vacuum packaging also helped to maintain the green color of the broccoli during storage, indicating better preservation of its nutritional quality. Specifically, the antioxidant activity of the vacuum-packed broccoli was found to be 16.4 μmol Trolox equivalent per gram (TE/g) of fresh weight, while the non-vacuum-packed broccoli had an antioxidant activity of only 5.5 μmol TE/g of fresh weight (Seo et al., 2014). Another study investigated the effect of vacuum packaging on the quality of fresh-cut mango slices during storage. The study found that the vacuum packaging helped to maintain the sensory quality, firmness, and vitamin C content of the mango slices during storage at 4°C for up to 12 days. Specifically, the vitamin C content of the vacuum-packed mango slices was found to be 27.4 mg/100g at day 12 of storage, while the non-vacuum-packed mango slices had a vitamin C content of only 7.1 mg/100g at the same storage time (Prakash et al., 2017).

Overall, packaging technologies play a crucial role in improving the functional properties of foods by extending their shelf life, maintaining their quality and safety, and enhancing their sensory and nutritional properties. As the food industry continues to evolve, new packaging technologies and materials will emerge, providing more sustainable and innovative solutions to meet the changing needs of consumers and the environment.

5. Conclusion

This review article has highlighted how advancements in food technology have sparked the development of creative processing methods that improve the functional qualities of food. Thermal and non-thermal processing are the two basic methods, and each has its benefits. Thermal processes, including pasteurization, sterilization, and cooking, improve the safety and shelf-life of food items while transforming their flavor, texture, and nutritional content. The sensory and nutritional quality effects of non-thermal technologies, including high-pressure processing, pulsed electric fields, and UV irradiation, are negligible. Hybrid processing combines thermal and non-thermal techniques to produce beneficial synergies that raise food items' general quality and safety.

Moreover, functional meals with improved nutritional value may be created using these technologies. In addition, innovations such as active and intelligent packaging can improve food goods' sensory qualities and shelf life. Ultimately, these developments in food technology have the potential to completely transform the food sector and provide customers with safer and better food alternatives.

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CHAPTER 3

CHICKPEA (*Cicer arietinum* L.): AN OVERVIEW

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1. Introduction

The nutritional content of chickpeas is among the greatest of any dry edible grain legumes, and chickpeas don't contain significant quantities of any major anti-nutrients. Due to their nutritional significance, there is an increasing demand for chickpeas. The farmed chickpea comes as two different types; Kabuli and Desi. The Desi type varieties have thick, colourful seed coats and pink blooms with anthocyanin on the stems. White flowers, stems devoid of anthocyanin coloration, white or beige seeds with a ram's head form, a thin seed coat, and a smooth seed surface are all characteristics of Kabuli type varieties.

Consumer dietary habits have a significant impact on both individual and environmental sustainability. Replacing meat consumption with other protein sources as just one of the many solutions to health and environmental issues (Onwezen et al., 2021). In particular, protein insufficiency needs to be treated as rapidly as feasible. Food manufacturers are also showing an increased interest in plant-based proteins. Pulse crops could therefore be employed as a sustainable and climate change-resistant source of high-quality protein (Bessada et al., 2019).

Since they provide the human diet containing protein, minerals, vitamins, and fibre as well as nitrogen for the soil and biodiversity maintenance, pulses are smart crops for both humans and the cropping system. Pulses, commonly referred to as grain legumes, supply 33% of the world's population's daily requirements for protein. Some of the most important opportunities to improve pulses are crop improvement (development of high-yielding, climate-resilient, short-duration, and disease-resistant varieties), strengthening the system of certified seed distribution, intercropping and growing pulses as a catch crop, implementing conservation agriculture to conserve resources, development and dissemination of site-specific production technologies, provision of crop-specific farm equipment, and seed encapsulation (Ullah et al., 2020).

2. Chickpea crop

44 annual and perennial species constitute to the genus *Cicer*, which is split into primary, secondary, and tertiary gene pools based on how easily they can be crossed with farmed chickpea (*Cicer arietinum* L.). The Fertile Crescent, which includes South Eastern Turkey and Syria, is the native home of these domesticated/wild annual and perennial *Cicer* species (Berger et al., 2005). One

of the earliest cultivars of legumes is the chickpea, which has a 7500-year-old history (Kumar et al., 2021). The chickpea is an annual, diploid (2n = 2x = 16), self-pollinated species that is primarily grown in arid and semi-arid regions of the world (Madrid et al., 2014). Chickpea is an important grain legumes of the Fabaceae family (Tran et al., 2018).

According to Abdel Latef et al., (2017), the chickpea seeds contain 6% fat, 17-22% protein, and 61% carbohydrates. Chickpea is an important ingredient in hummus. Additionally, it is used in salads, soups, stews, curries, and other meals that are roasted or baked (Kumar et al., 2021). The pulse chickpea is an excellent source of fat, fibre, and other carbohydrates in addition to protein and is consumed across the world. The growing population of the world is increasing the need for this pulse's protein component (Grasso et al., 2022).

Since it is a legume, it can also enhance soil fertility by fixing atmospheric nitrogen, which supports sustainable agriculture (Abdel Latef et al., 2017). Due to its high nutritional content, market value, versatility, and ability to fix nitrogen, chickpea is often regarded as a crop that will become a staple food worldwide in the future. Major producers are India, Australia, Turkey and Myanmar who collectively contribute greater than 75% of the global chickpea production (Kaashyap et al., 2018). Chickpea has a cultivation area of approximately 0.5 million ha acreage with a production of 0.6 million tons with a grain yield of 1.2 t/ha in Turkey (FAO, 2022). Chickpea is a cost-effective protein crop that can mitigate protein deficiency and improve food security and is an essential component of the diet in many Asian, European, African, and American countries (Ramani et al., 2021). It is farmed on 10–11 million hectares of land in 45 nations and five continents, with an annual production of 8–9 million tonnes. India produces 2/3 of the global production (Vandana et al., 2020).

Chickpea breeding studies aims to determine genotypes with diverse genome background to use in crossing to produce progenies with favorable traits (Seyedimoradi et al., 2020).

3. Agronomy in relation to biotic and abiotic stress

The chickpea needs temperatures of 18–26°C at night and 21–29°C during the day, as well as 560-660 mm of precipitation each year, for optimum growth and development (Vandana et al., 2020). The chickpea is among the most important food crops for food sustainability in the age of climate change (Kaur et al., 2022). It is usually grown under rain-fed conditions, yielding an average of just 1 t/ha, far less than its maximal potential of 6 t/ha. The combined effects of heat, cold, and drought have an effect on this species' productivity (Arriagada et al., 2022). The yield of chickpeas is 0.9 t/ha on average worldwide, but under optimal conditions, it can reach 6 t/ha. Low genetic variety, erratic yields, and weak resilience to biotic and abiotic stressors are the key drawbacks. As a self-pollinated plant, chickpea has a low genetic diversity (Raina et al., 2019).

Chickpea is an indeterminate dicotyledonous crop that flowers over a long period of time, with leaf and branch formation continuing during flowering and pod filling. Chickpea plants that are subjected to unfavorable conditions throughout the reproductive phase can lose their flowers, young pods, or developing seeds, and then begin flowering when the conditions improve (Peake et al. 2020). The early stages of plant inflorescence growth are just as important as the later stages of floral development. During those early phases, certain properties, such as inflorescence architecture and flower developmental timings, are defined. Various inflorescence designs in terms of meristem determinacy and the number of flowers per node have been identified in chickpea germplasm (Basu et al., 2022). In rainfed areas characterized by terminal drought and heat stress, days to first flowering are a significant component of chickpea adaptability and yield (Lakmes et al., 2022).

A variety of climatic and environmental conditions influence chickpea growth, development, and grain yield (Richards et al., 2022). Chickpea production gets hampered by climatic extremes (unpredictable rainfall, very hot and low temperatures). To handle climate differences and achieve optimal yield, the best sowing timing is a critical aspect (Irshad et al., 2022). Environmental factors like as salinity and nutrient deprivation have a significant impact on global chickpea productivity. Drought is thought to be one of the most serious abiotic stresses, accounting for 40-45% of chickpea yield losses (La et al., 2022).

Chickpea growth and productivity are affected by drought and high temperatures. In the field, these pressures frequently occur at the same time, resulting in a wide spectrum of molecular and metabolic adaptations (Yadav et al., 2022). Heat stress reduces grain Fe and Zn levels as well as protein content (Samineni et al., 2022).

For the most important yet innately salt-sensitive grain legume, chickpea, salinity is becoming an important problem. During the reproductive period, chickpea is very susceptible to salinity (Kaashyap et al., 2022). While salinity slows emergence and lengthens flowering time, differences in saline yields between genotypes were linked to aboveground biomass, filled pod number, and seed number at maturity, but not to the number of emerging plants that lived until maturity or the flowering delays. Dryland salt tolerance is associated with increased biomass and reproductive success (Turner et al., 2022).

Chickpeas, like most legumes, have specialized structures called root nodules. The symbiotic connection with rhizobium bacteria is enabled by these nodules. *Mesorhizobium* species cause chickpeas to nodulate. The rhizobia give the plant with useable fixed atmospheric nitrogen. Because of their symbiotic association with nitrogen-fixing rhizobium bacteria, which increases soil nitrogen and improves soil fertility, they are frequently employed as rotation crops (Frailey et al., 2022).

This crop is impacted by severe foliar diseases at various phases of development. The production of chickpea crops is impacted by fungi, bacteria, viruses, and mycoplasma, although fungi are the main pathogens that damage the roots, leaves, stems, flowers, and pods. Serious fungi-related diseases include rust (*Uromyces ciceris-arietini*), Botrytis grey mould (*Botrytis cinerea*), Ascochyta blight disease (*Ascochyta rabiei*), and Sclerotinia blight (*Sclerotinia sclerotiorum*). Among these, Ascochyta blight and Botrytis grey mould are the most detrimental (Vandana et al., 2020).

Every year, *Fusarium oxysporum* f.sp. *ciceris* causes massive yield losses in chickpeas (Fatima et al., 2022). Chickpea disease *Fusarium oxysporum* f. sp. *ciceris* reduces chickpea productivity and quality, and can reduce yield by up to 15%. The growth of *Fusarium oxysporum* f. sp. *ciceris* was strongly inhibited by a newly identified, *Pseudomonas aeruginosa* strain A7 (Mozumder et al., 2022).

In warm and dry areas, the chickpea disease known as dry root rot (*Rhizoctonia bataticola*) can be highly hazardous (Karadi et al., 2021). Another significant soil-borne disease of chickpeas is Phytophthora root rot (*Phytophthora medicaginis*). Both domesticated and wild chickpea species have sources of resistance (Amalraj et al., 2019). 50% to 70% yield losses are possible under this diseases existance (Miranda, 2019).

4. Breeding and genetics

The chickpea is primarily represented by its desi and kabuli types cultivars, whose genomes have just been sequenced and exhibit a clear differential in both agro-morphological and architectural traits (Jain et al., 2013). The Desi variety can be identified by its typically small, angular seeds, which are occasionally noticeable and appear in a variety of colours. Larger, smoother, more light-colored seeds with larger seed diameters are characteristics of the Kabuli variety. 80% of the world's production of chickpeas is of the Desi type, with 20% coming from Kabuli types (Mahmood-ul-Hassan & Hayat, 2020).

Given the growing global population and more challenging environmental conditions, it is crucial for plant scientists to uncover and better understand distinctive plant traits that could be used to improve agricultural productivity. However, architecturally sophisticated crop species like the chickpea remain a mystery because of their small leaves, high levels of branching, and indeterminate characters (Salter et al., 2021). The global germplasm collections for chickpea today consist of tens of thousands of accessions stored in dozens of genebanks. With these large collections, breeders have a unique opportunity to develop new varieties that will ensure global food security during times of climatic change and increased demand for high-quality proteins. It is imperative to follow rules, follow protocols, and exchange data in order to manage this germplasm effectively (Piergiovanni, 2022).

In order to preserve global food security, high-yielding cultivars that are resilient to biotic and abiotic stress, as well as climate-ready, must be developed. Quantitative trait loci (QTL) mapping, fine-mapping/map-based cloning, association analysis, and other genomics-assisted breeding techniques have all been used to understand the inheritance pattern and quantitatively dissect complex yield and stress tolerance traits for genetic improvement of chickpeas in order to achieve these goals (Basu et al., 2018).

The combined impacts of heat, cold, and drought reduce chickpea productivity. The Mediterranean region is known for its wide range of temperatures and precipitation levels, as well as for various toxic or deficient soil mineral conditions. Breeders must recognise and comprehend special plant characteristics that might be used for increasing crop productivity in context of challenging environmental conditions. Most often, a limited number of important genes regulate qualitative traits. It is easier to distinguish between and identify genotypes since these traits are easily observable. On the other hand, a large number of small genes with a convoluted inheritance pattern control quantitative traits. These characteristics are more influenced by environmental conditions and the crop's maturation stage (Karim et al., 2020). Numerous legume species have adapted to survive in the Mediterranean region despite the region's vast variation of temperature and moisture supply, as well as some toxic or deficient soil mineral conditions (Porqueddu et al., 2016).

The productivity of chickpeas may be significantly impacted by climate change, which may lead to an increase in climate variability and extreme weather. The average global temperature and climate variability, both of which are expected to rise, both increase the frequency of extreme temperature events. Both the amount and rate of change of precipitation and temperature vary greatly from region to region (Mahmood-ul-Hassan & Hayat, 2020).

For grains and legumes, seed size/weight is a key characteristic for crop yields. Identifcation of genetic variations governing seed size/weight ofers excellent opportunity to select candidate genes to manipulate seed size/weight (Rajkumar et al., 2018). The plant height of the chickpea, as an annual herbaceous crop with many branches, typically ranges from 30 to 70 cm. A crucial yield-component characteristic is plant height. It has an impact on crop performance, especially lodging, which then has an impact on grain yield and grain quality. Crop plants with an erect habit and a very tall habit tend to lodge as they mature, but erect accessions with lower height can prevent wind and rain damage, and are considered to be more lodging resistant (Kujur et al., 2016). Matching crop phenology to environment is critical for stress adaptation and crop yield, hence accurate prediction of fowering time is important. According to crop simulation models, temperature and photoperiod influence the phenology of chickpeas (Chauhan et al., 2019).

In contrast to other food crop plants, the chickpea has a limited genetic base and low intra-specific marker variation among desi and kabuli accessions (Toker, 2009). Although the chickpea's genetic base is relatively limited, the germplasm exhibits a sizable degree of genetic variety (Kaashyap et al., 2018). Stressors like salinity and drought are two of the key variables that lower its production (Khandal et al., 2017). A number of biotic (such Ascochyta blight, Fusarium wilt, and pod borer) and abiotic (like drought, salinity, heat, etc.) problems have significantly hampered chickpea production during the past few decades. Reducing the losses due to these pressures is primarily crucial for improving the crop production. Chickpeas are infected by *Fusarium oxysporum* f.sp. ciceri (Foc), which produces the severely devastating and widespread vascular wilt disease (Upasani et al., 2017).

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CHAPTER 4

LAND COVER CHANGE MONITORING IN ERBIL CITY USING REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM

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1- INTRODUCTION

The important of land use land cover (LULC) cannot be overstated, as it is a significant factor in global environmental change due to factors such as rapid population growth, urbanization and industrialization. Throughout human history, land has been closely tied to economic growth and improper land use can lead to environmental degradation. To confirm that the land ecosystem is being used sustainably, it is essential to comprehend its natural characteristics, extent, location, quality, productivity, suitability, and limitations for different land uses.

Remote sensing (RS) and geographic information systems (GIS) were also new tools that can help improve ecosystem management. Remote sensing collects data from a distance, which allows for analyzing the function, patterns and changes of the earth; s systems at different scales over time. These tools also allow localized ecological research to be linked to regional, national, and worldwide conservation efforts to manage biological diversity (Wilkie and Finn, 1996). Extracting information about land use land cover (LULC) is a critical exercise for agricultural land as it can used for decision-making, planning and development in agriculture (Varoon and Kumar, 2011). Lot of natural resources are critical for successful management and planning.in the study of LULC pattern analysis, among other things, soil survey manuals, topographic maps, aerial photographs, vegetation surveys, flood maps, hydrology maps, and property surveys (Amber, 2000). Urban green spaces (UGSs) are crucial for maintaining ecological balance and promoting the health of individuals. They have a significant impact the adverse effects of urbanization and encouraging physical activity among people (Khalil, 2014; Liu et al., 2021). Precise measurement of the change in land use and land cover (LULCC) is required for a better grasp of its effects on the environment and climate systems, as well as the adoption of successful environmental management practices (Camilleri, S., De Giglio, 2017). Population growth can lead to land degradation as it puts pressure on the land without proper management practices. This often leads to people moving towards sensitive area, such as agricultural lands, and using them without regard for the soil's fertility and chemical lushness. Remotely sensed data and geographical information systems (GIS) are important tools for detecting and monitoring changes in urban land use as well as land cover. However, it is significant to mention, that data and information are not equated in digital image analysis because information from remote sensors symbolizes pixel values or digital numbers (Satiprasad, 2013). Monitoring land use land cover (LULC) in Erbil especially and Iraq generally is not easy because of a shortage of data. In recent times, the GIS technique, which is regarded an advanced tool, has been used in large numbers of pixels in Iraq and the Erbil region. The Geoinformatic: system or 3S system (R.S, GIS and GPS) is combining acquisitor modeling, and analysis management of spatially referenced data. the Erbil city is growing in the size and complexity. In the recent years, increasing of population is one of the main reasons the urbanization in Erbil.

The aim of the research is to look into LULC monitoring in Erbil using Geographic information systems (GIS) technologies and remote sensing techniques. To accomplish this goal, the following specific objectives are pursued.

i. Using satellite image from 2010, 2016 and 2022 identify the urban, vegetation, soil and water changes in Erbil city usin remote sensing and GIS software.
ii. In order to analyze the matrix of LULC changes in Erbil city for the years 2010, 2016, and 2022, GIS will be used.
iii. A discussion of the factors contributing to the LULC change in Erbil.
iv. Produce the point interpolation maps of the soil chemical and physical properties for the selected area.

2- MATERIALS and METHODS

2.1. Study Area

This research area spans 194411.86 hectares in the governorate of Erbil, Iraq, and is bounded to the north by Turkey and to the east by Iran. The latitudinal position is 36°419' to 35° 748' N and longitude 43° 854' to 44° 291' E. Erbil is one of Iraq's most important cities. Erbil is one of the oldest cities in the world. The governorate is situated in a flat area and has a climate that transitions between Mediterranean and desert climates. The climate is known for its extreme cold temperatures and low levels of humidity (Fig 3.1). However, the region is greener than of Iraq. In the spring and winter, vegetation thrives, giving the region a green appearance. The vegetation dries up during the summertime, and the climate is dry and hot.

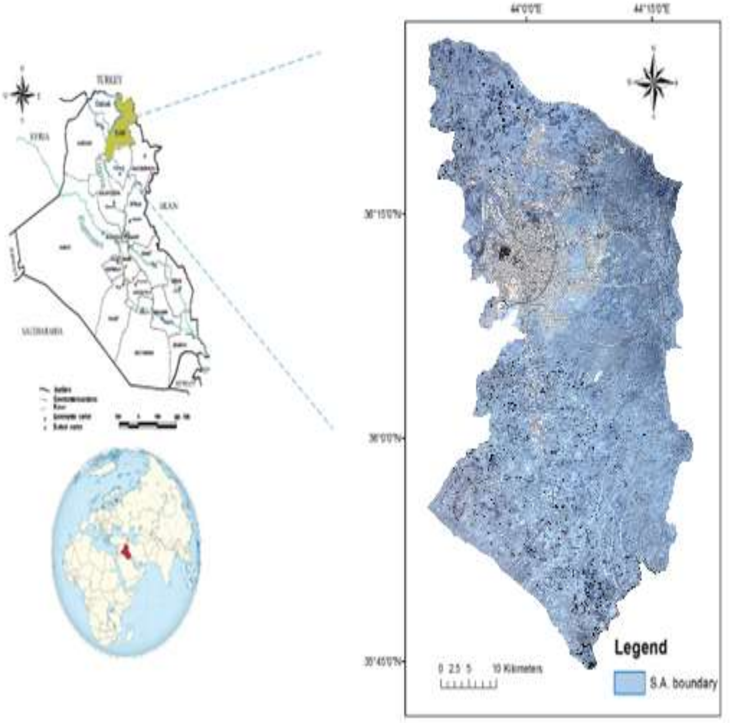

Figure 1. depicts the location of the research area in Erbil.

2.2. Data Acquisition

The majority of the monitoring data for this study came from the US Geological survey's website (USGS). Landsat satellite data from 2010, 2016 and 2022 was obtained. Landsat-5 TM acquired the data from 2010 on May 22nd, while landsat-8 OIL acquired the data from 2016 on June 7th. Meanwhile the study year. It was decided to use an image with a spotless appearance and minimal interference. The WGS 1984 UTM Zone had been projected onto all existing satellite images.

2.3. Image Classification

The image classification technique was used by the researcher to assign each pixel in the image to one of several categories (Chipman and Jonathan, 2004)

Using supervised classification, an image classification technique was applied to the image data in ER Mapper 7.0. The supervised classification process involved selecting different pixels from a picture as a training sample that represented multiple land use types. Using supervised classification, the satellite images were divided into four major land use categories: urban, vegetation, soil, and water.

2.4. Land cover / Land use Change Monitoring (LCLUCM)

From the moment the first earth observation satellite was launched, land use change monitoring has been one of the most famous applications of remote sensing. Monitoring urban growth means observing the state of an object over time and comparing it with previous observations. Land use change monitoring involves monitoring the changes in land uses and purposes, which includes changes in land cover as well as intensity and monitoring.

Understanding the patterns of LULC in a region is important as it is the result of Both natural and socioeconomic factors, along with human activities, are considered over space and time. Accurate and up-to-date information about land use changes is crucial for updating land-cover maps, as well as effective resource management and planning to encourage sustainable growth. (Anil et al.,2012).

The arrangement of LULC within a region is generally regarded as the consequence of both natural and socioeconomic factors, and how they are utilized by humans over time and space. This data is crucial in updating land cover maps and for managing resources effectively to promote sustainable development. (Haleform et al. 2018).

2.5. post-Classification

A comparison of post-classification was used to identify changes between the three Images produced by each technique. The results were compared on a from-to basis. Classified images of 2010, 2016 and 2022 were overlaid in order to produce change images. The land cover change between the

TM and ETM+ images was monitored using two methods. One was post-classification, the other image differencing. In addition to showing the complete matrix of change, thematic change maps also allow observers to focus on specific compartments of change. Classification comparison minimizes the problem of normalizing sensor differences (TM and ETM) between the three dates. Using analysis of different and available spectral signatures, ancillary data, as well as field visits, a classification scheme with 4 classes was decided upon, for which training areas were delineated, Table (2.1).

Table 2.1 The land cover classes names and codes

Class Code	Class Name
1	Urban
2	Vegetation
3	Soil
4	Water

2.6. Accuracy Assessment

The accuracy assessment was conducted to validate the classification process and to determine that the classified images were accurate according to the truth in order to improve knowledge of classified image interpretation (Nur Hakimah & Lam, 2016). To determine accuracy a value was assigned to each class the classification process, which was then compared with ground truth values. The kappa co0ffcient, which is calculated from the error matrix, is an important component of accuracy assessment (Campbell & McGee, 2010). A Kappa statistic indicates the difference between actual agreement and what would have been expected by chance based on the following formula:

$$K = (N\Sigma C_{ii} - \Sigma r_i \Sigma c_i) / (N^2 - \Sigma r_i \Sigma c_i)$$

K: Kappa Coefficient

N: Total number of observations

C_{ii}: Number of observations that were classified correctly for

Σr_i: Total number of observations in row i

Σc_i: Total number of observations in column i

3. RESULTS and DISCUSSION

3.1. Land Use Land Cover Change Monitoring (LULCCM)

The results of land use land cover monitoring (LULCM) thematic maps in Erbil for the years 2010, 2016 and 2022 the results of Landsat image supervised classification in 2010, 2016, and 2022 revealed that a specific land use type dominated Erbil city during those years. The supervised classification results (table 3.1., and figures 3.1., 3.2. and 3.3.) a different change in land use changes in the study region during the period of study.

Changes occurred in every land use classification in Erbil, providing useful information on the development trend. According to table 2, the land use land cover change monitoring distribution of Erbil city was still dominated by soil land, covering more than 71% of the total area for each study year, despite a significant decrease of more than 10% within those 12 years. In 2010, the total area of soil land was 159915.76 hectares, and in 2022, the total area of soil land will be 140567.83 hectares.

Erbil city recorded a significant increase in its urban cover between 2010 and 2022, which increased by more than 17%. In 2010, the total area of urban land was equal 12493.57 hectares and the urban land in 2022 equal 46300.03 hectares.

Despite the fact that vegetation was the second most common land cover in 2010, Its coverage shrank dramatically by more than 6% in 2022, with the total vegetation covering 21644.39 hectares in 2010 and 8323.19hectares in 2022. Even so, the situation deteriorated in twelve years when vegetated land was drastically reduced.

While water was a minor land use distribution category in Erbil city, representing less than 1% of the city’s total area. The water category includes reservoirs such as rivers, lakes, and ponds. Every study area recorded a different total area, which first decreased to 358.14 hectares in 2010 from 310.29 hectares in 2016 and 220.81hectares in 2022. In general, it has few changed in the last 12 years. Since 2010, the urban area has experienced significant growth until 2022, while vegetation has declined significantly in the last 12 years.

Table 3.1 Statistics on total land use and land cover in Erbil city in 2010, 2016, and 2022 based on Landsat imagery interpretation.

Year/land use type	2010		2016		2022		Percentage of change (12years)
	Area Hectares	Area Percentage	Area Hectares	Area Percentage	Area Hectares	Area Percentage	
Urban	12493.57	6.43%	33099.82	17.03%	46300.03	23.82%	17.39%
Vegetation	21644.39	11.13%	10786.49	5.55%	7823.19	4.02%	-7.11%
Soil	159915.76	82.26%	150215.27	77.27%	140067.83	72.05%	-10.21%
Water	358.14	0.18%	310.29	0.16%	220.81	0.11%	-0.07%
Total	194411.86	100%	194411.86	100%	194411.86	100%	

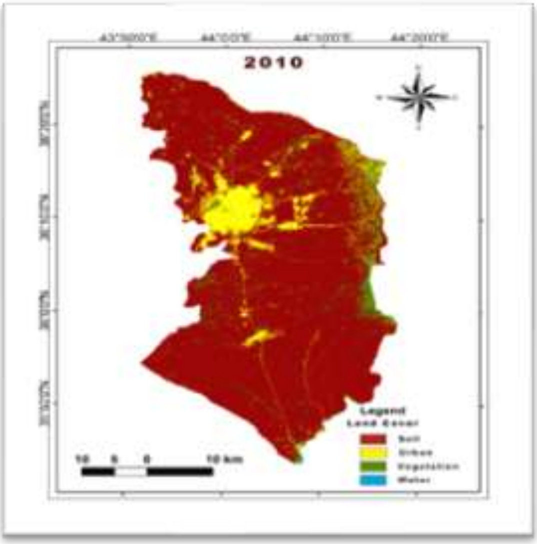

Figure 3.1. Land cover classification 2010.

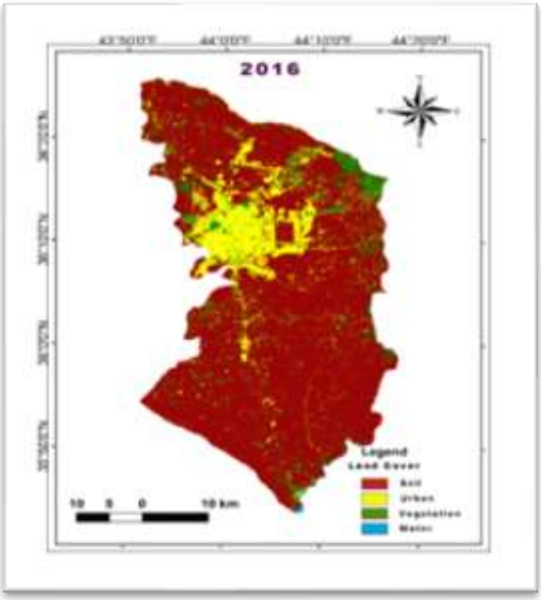

Figure 3.2. Land cover classification 2016.

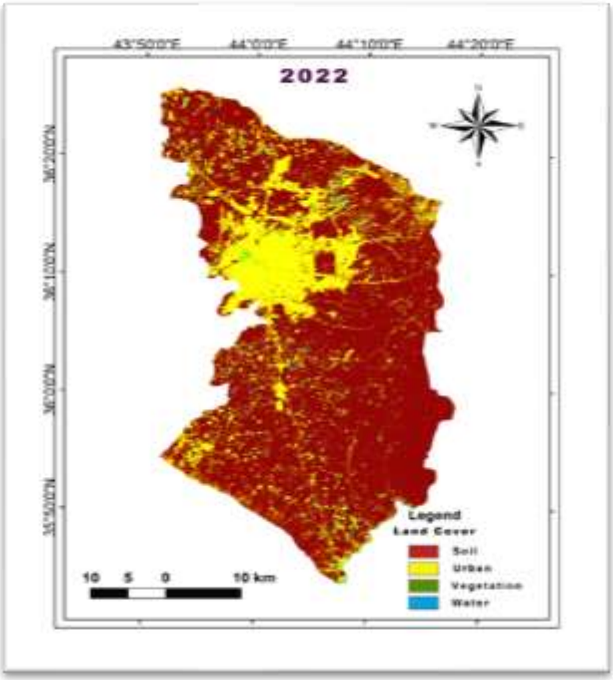

Figure 3.3. Land cover classification 2022.

3.2. Monitoring LULC Changes in Erbil City Between Years 2010 And 2016

Table 3.2. depicts the LULCC matrix between 2010 and 2016, with 19% changes recorded. According to the statistical table, vegetation was the most affected by modifications 63%, followed by water 41%, soil area 14% and urban area only 8%. The results showed that vegetation coverage had changed significantly between 2010 and 2016, with 63% of it converted to other land uses. The majority of the vegetation coverage had converted to soil area, with 8636 hectares, 4279 hectares to urban area and only 30 hectares to water areas. By 2016 Erbil is green area had decreased dramatically due to the dramatic shift of vegetation to soil and urban areas.

Since the majority of the vegetation areas have been converted to urban coverage, the urban area has increased dramatically since 2016, increasing from 11542 hectares to 331339 hectares. This scenario had an impact on Erbil city, which was covered by urban land more than 17% of total urban coverage in 2016.according to the statistics, Land ownership of soil and vegetation made a contribution the most to the rise of urban areas over a six-year period.

The results for water showed a steady decrease from 358.14 hectares in 2010 to 310.29 hectares in 2016. It appeared that some water areas had become vegetation, soil and urban. As according Figure 3.4. it appeared that land transformations had occurred in every part of Erbil city, especially in the city center, where significant changes had occurred. Within six years, it appeared that most of the vegetated land in those areas had been converted to urban areas on a large scale. Overall, vegetation coverage land had changed significantly between 2010 and 2016, contributing to an increase in urban area by 2016.

Table 3.2. Matrix LULC of Erbil between years 2010 and 2016

	Year/land use type	2010 (Hectares)				Total
		Urban	Vegetation	Soil	Water	
2016 (Hectares)	Urban	11541	306	633	8	12488
	Vegetation	4279	7689	8636	30	20634
	Soil	17258	4716	136901	61	158936
	Water	60	67	18	208	354
	Total	**33139**	**8778**	**150187**	**306**	**192411**
	Unchanged (Hectares)	11541	7689	136901	208	156338.54
	Unchanged %	92%	37%	86%	59%	81%
	changed (Hectares)	947	12945	22035	146	36072
	changed %	8%	63%	14%	41%	19%

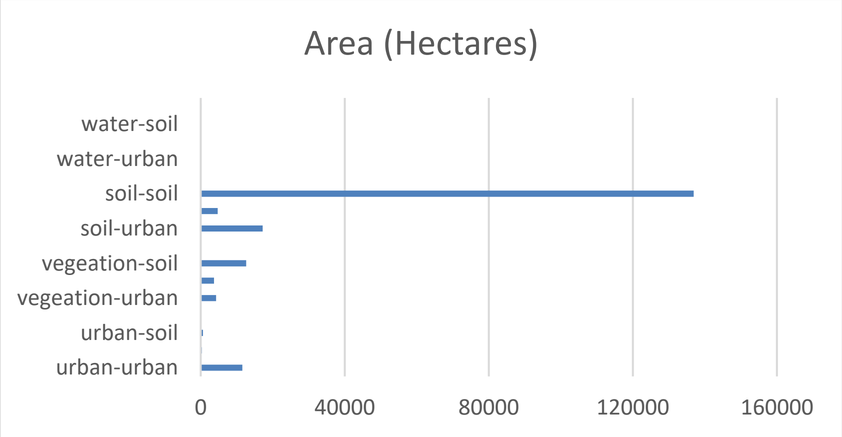

Figure 3.4. Shows how the land use and land cover in Erbil changed between the years 2010 and 2016.

3.5. Monitoring LULC Changes in Erbil City Between Years 2016And 2022

According to table 3.3. between the years 2016 and 2022, only 12% of the region's total area had changed. Among these changes, vegetation was affected the most with a significant impact of 58%, followed by water (38%), soil area (15%), and urban area (10%). The majority of urban area remained unchanged, accounting for more than 88% of the urban area. The majority of land-use conversions were from vegetation to urban areas., with 3516 hectares of vegetation being converted to urban areas, and 19567 hectares of soil and 83 hectares of water area also being converted. Only a small amount of land (40 hectares) had been converted from urban areas to vegetation within six years. As a result, water levels in 2022 decreased.

The percentage of changes in vegetation coverage was the highest, with 58% converted to other type of land. Specifically, 3516 hectares of vegetation was converted to urban land, 1574 hectares to soil, and a small amount (28 hectares) was converted to water. Due to this significant land conversion, the vegetation area in Erbil city has decreased, and only 2.77% of it remains in the year 2022. In contrast, the urban land area has steadily increased from 2016 to 2022 by 6.86%. the expansion of the urban areas was primarily due to the conversion of vegetated and soil land, with only a minor contribution from water. In terms of the urban category, only 12% of a urban area had changed, with the rest remaining unchanged.

Table 3.3. matrix of LULC change of Erbil between years 2016and 2022

Year/land use type		2016 (Hectares)				Total
		Urban	Vegetation	Soil	Water	
2022 (Hectares)	Urban	23962	433	2659	27	27081
	Vegetation	3516	3660	1574	28	8778
	Soil	19567	3233	133313	70	156183
	Water	83	40	17	229	369
	Total	**47129**	**7365**	**137562**	**355**	**192411**
	Unchanged (Hectares)	23962	3660	133313	229	161163
	Unchanged %	88%	42%	85%	62%	84%
	Changed (Hectares)	3119	5118	22870	140	31247
	Changed %	12%	58%	15%	38%	16%

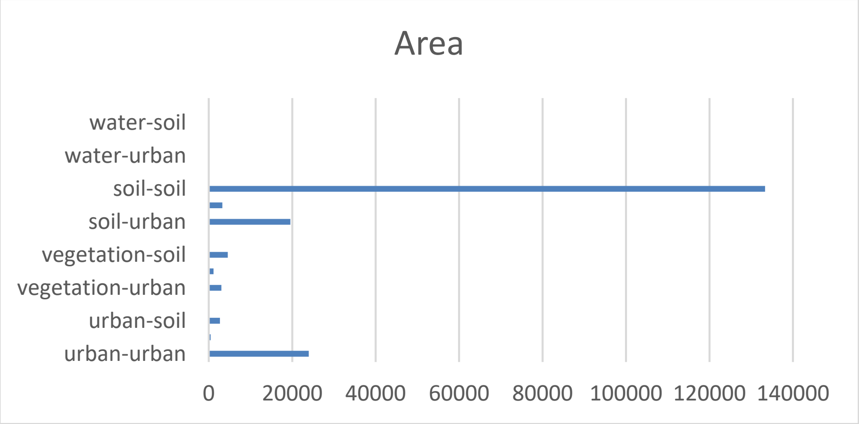

Figure 3.5. Shows how the land use and land cover in Erbil changed the between years 2016 and 2022.

3.4. Monitoring LULC Changes in Erbil City Between Years 2010 And 2022

According to Table 3.4. land use change in Erbil city involved 23% of the total area within the 12 years from 2010 to 2022. Within 12 years, the vegetation category experienced the most dramatic changes, whin more than 65% of it undergoing rapid change. The majority of vegetative cover land was already taken over by urban activities and had become an urban area.

Meanwhile, the soil land had changed by 18%, with 82% of the soil area remaining unchanged. soil area had changed to urban by 25141 hectares, 3834 hectares had changed into vegetation and only 96 hectares had changed into water area. While water had changed significantly 62%, with 121 hectares changed into vegetation area, 89 hectares changed into urban area and only 40 hectares changed into soil area. Despite the fact that water had decreased significantly, the majority of its parts remained unchanged, with more than 75% coverage within 12 years of development growth. In terms of urban land, it had changed by 8%, with 92% of the urban remaining unchanged. By 2022, 1034 hectares of urban area will have been converted in to soil, vegetation and water. Despite the fact that the urban area had a large area that remained unchanged. This category of land use had grown a lot and was still the most prominent one.

Table 3.4. Matrix of LULC change of Erbil between years 2010 and 2022

	Year/land use type	2010 (Hectares)				Total
		Urban	Vegetation	Soil	Water	
2022 (Hectares)	Urban	11455	127	903	4	12489
	Vegetation	8545	7249	4815	26	20635
	Soil	25141	3834	129816	96	158887
	Water	89	121	40	150	400
	Total	**45230**	**11331**	**135574**	**275**	**192411**
	Unchanged (Hectares)	11455	7249	129816	150	148670
	Unchanged %	92%	35%	82%	38%	77%
	Changed (Hectares)	1034	13386	29071	250	43741
	Changed %	8%	65%	18%	62%	23%

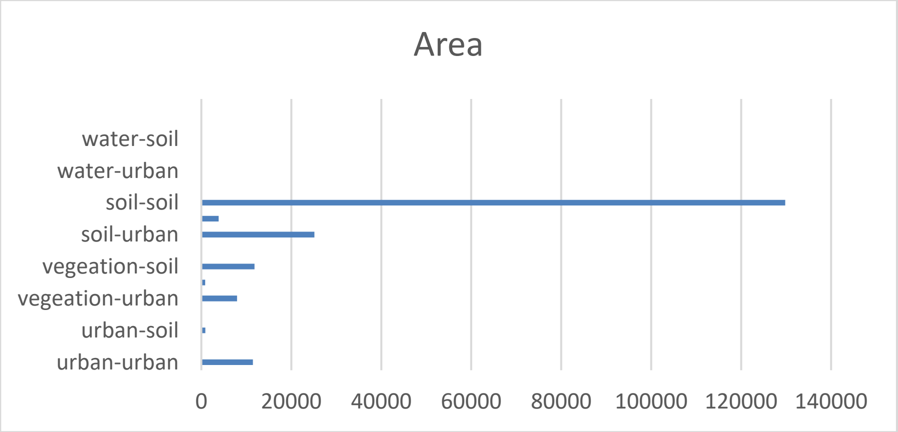

Figure 3.6. Shows how the land use and land cover in Erbil changed between the years 2010 and 2022.

Accuracy Summary of LULC

Making sure the classification is correct is very important, and it's one of the last things you need to do in the process. The purpose of accuracy assessment is to measure how accurately the different types of land were identified in the pixels. To do this, they chose pixels from areas that were easy to recognize on both Landsat high-resolution images and Google Maps. 360 points (locations) were created in the classified image of the study region. The best guess for each reference point was entered into the accuracy cell array source column. To classify the selected point, google maps was used as a reference source.

The table 3.5. shows that out of 360 randomly selected points in the 2022 classification image, 334 were correctly identified as matching the authorized land use map for 2022.

Table 3.5. shows the totals for error matrix accuracy for the 2022 classified image

Class Value	urban	vegetation	soil	water	Total	U.A.	P.A.
urban	104	5	3	0	112	93%	93%
vegetation	2	48	3	1	54	89%	81%
soil	6	5	157	0	168	93%	96%
water	0	1	0	25	26	96%	96%
Total	112	59	163	26	360		
Overall Accuracy			**93%**				
Kappa Coefficient			**89%**				

This overall accuracy result interpreted as that image classification was 93% and the kappa coefficient final outcome translated since classification of images had been 89%, improved agreement than by likelihood on its own. Because the kappa coefficient was considered important, which means that the classified image was appropriate for more research, and the study could continue with other significant Landsat images.

5- CONCLUSION

The three-stage period investigation clearly showed the rate of change for LULC in Erbil city varied. The findings which urban areas had changed more than any other, with a massive rise in overall area from 2010 to 2022. Meanwhile, soil areas have shown a significant decile over the last 12 years, with nearly 8.26% of the area lost due to the large-scale transformation of soil into urban areas, with most soil coverage completely lost in some areas. Water and vegetation, on the other hand, experienced only minor changes, with less than 1% declining from 2010 to 2022Overall, the development in Erbil has had a big effect on changes to how the land is used, and it has led to the city's urban areas getting bigger. Whenever urbanization spreads throughout the city, every aspect of it experienced rapid changes that impacted its original land function. The development’s goal is unquestionably to benefit people. Uncontrolled and unplanned development, on the other hand, has the potential to reverse the benefits and have a negative impact. As a result, To reduce the possibility of negative consequences, it is critical to prioritize development planning.

Researchers demonstrated the effectiveness of remote sensing methods in analyzing intricate land surface patterns. This technique makes it possible to monitor land cover modifications resulting from shifting urban environments. A supervised classification scheme was applied to the classification of land covers. By analyzing the land and developed surfaces, surface patterns could be determined, as well as areas where vegetation, urbanization, and water had increased and decreased. We were able to determine patterns of change over time by using image differentiation. Statistics could be used to illustrate how Erbil city has evolved over time. These techniques could support the environmental characterization of a city.

The Erbil city is expected to continue with this pattern urbanization. This analysis indicates there may have been significant urban space expansion over the last 12 plus years. The techniques used in this study could potentially be used in other changing urban environments. These techniques could prove useful in classifying and quantifying land cover changes in urban areas over time. Further research would include a broader scope of the changes that have occurred in the surrounding center of Erbil city and how this area compares to that of Erbil. These data could assist in assessing regional landscape patterns that may be occurring. Others considerations would be the use of different indices and band ratios to assess the changing landscape. Also, utilizing a satellite sensor with a higher spatial resolution may enable the detection of more subtle landscape features such as smaller urban lots. However, these data are not widely available and the catalog does not encompass many anniversary images.

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CHAPTER 5

BREEDING FOR BROOMRAPE (*Orobanche cumana*) RESISTANCE IN SUNFLOWER (*Helianthus annuus* L.)

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1. Introduction

"*Sunflower broomrape*" is still one of the biggest obstacles to sunflower cultivation in Europe, Asia, and more lately, in some regions of Africa, even after more than a century of coexistence. It is a reality that infestations of sunflower broomrape are constantly moving to new locations, and at the same time, populations are becoming more virulent. The genetics, genomics, and breeding of sunflower cultivars for enhanced broomrape resistance are the main topics of this paper. According to archaeological researches, the earliest people grown sunflowers were American Indians in 4625 B.C. Sunflower (*Helianthus annuus* L.) is utilised as a food source, an oil source, a source of colour, a medicine, and a decorative plant. It is primarily used for making oil from its seeds, but is also grown for its protein content and utilised for both food and animal feed. There are three basic types of sunflowers: oilseed, confectionary, and ornamental sunflower, depending on the breeding objectives and intended purpose. Depending on the main breeding technique, the process of breeding sunflowers run through three directions. These are mass selection, individual selection for development of varieties, and development of hybrids. The genotypes for all three directions of breeding must meet certain common criteria in terms of flower appearance (Jocic et al., 2015).

In marker-assisted breeding programmes for sunflower, molecular markers for simple traits like fertility restoration, high oleic acid content, herbicide tolerance, or resistances to Plasmopara halstedii, Puccinia helianthi, or Orobanche cumana have been employed successfully for many years. Although difficult to select, genome-wide techniques are needed for agronomically significant complicated quantitative traits including yield, heterosis, drought tolerance, oil content, or selection for disease resistance, such as against *Sclerotinia sclerotiorum*. In order to study complex characteristics, plant genetic resources for sunflower are being collected and conserved globally. To overcome the drawbacks of biparental populations, sunflower association panels serve as the foundation for genome-wide association research. Novel techniques at the whole genome level are now possible because of technological advancements and the availability of the sunflower genome sequence. Based on next-generation sequencing technologies, genotype-by-sequencing and whole genome sequencing allowed for the development of a large number of SNP markers for high density maps and SNP arrays, as well as for genome-wide association studies and genomic selection in sunflower. Branching, flowering period, and resistance to Sclerotinia head and stalk rot are just a few traits for which genome-wide or candidate gene-based association studies have been carried out. The first steps in genomic selection for hybrid performance and hybrid oil content have demonstrated that complicated quantitative traits in sunflowers can be successfully addressed, and this will accelerate sunflower breeding programmes in the future. Higher levels of disease resistance and improved production performance are needed to make sunflower more competitive against other oil crops. Additionally, modifying plant design to promote a more complicated growth type for denser plant populations has the potential to significantly increase yields per hectare. The discovery of target genes and markers for complex traits will be facilitated by integrative approaches combining omic technologies (genomics, transcriptomics, proteomics, metabolomics, and phenomics), employing bioinformatic tools, and will provide a better understanding of the mechanisms underlying the traits (Dimitrijevic & Horn, 2018).

Development of hybrids with altered oil properties, confectionary hybrids, herbicide resistant hybrids, ornamental hybrids, and high seed and oil yielding hybrids resistant to dominant diseases and tolerance of drought are some basic directions in sunflower hybrid breeding (Jocic et al., 2015). Additionally, certain markets have specific requirements, such as 1) achene and kernel characteristics, high protein content, and a low oil content (less than 40%) in the production of confectionary sunflowers, 2) a particular fatty acid and tocopherol composition in the food and non-food industry, or 3) plant height, ray and disc flower colour, and flowering time in the hybrid breeding of ornamental sunflowers. The common needs for resistance against abiotic and biotic stress as well as the special needs of the various breeding purposes require the development of markers to facilitate the introduction of different traits (Dimitrijevic & Horn, 2018).

Botanically, sunflower (*Helianthus annuus* L.) is a member of the *Asteraceae* family, one of the most diverse and largest families of flowering plants. Because of the cultivated sunflower's economic significance and the ecophysiological diversity found within the genus *Helianthus*, the sunflower has served as a model plant species for genome research in this family (Bachlava et al., 2012). According to Badouin et al. (2017), the 3.6 Gb sunflower genome is quite huge, being three times bigger than the rapeseed genome or more than eight times bigger than the rice genome. Sunflower may replace other oil crops in the future as the preferred oil crop due to its adaptability to various agroecological environments and moderate drought tolerance, particularly in light of upcoming environmental changes on a global scale. Consequently, more attention should be paid on breeding for better adaptation with regard to climate changes. Along with increased drought tolerance, these traits should also include insect resistance, salt tolerance, and modifications to plant architecture for improved adaption. Sunflower could be greatly improved by making use of the available plant genetic resources, as well as modern molecular technologies for genome-wide association studies (GWAS) and the use of genomic selection (GS). However, sunflower plant and genetic resources have only recently become comparable to other crops (Dimitrijevic & Horn, 2018).

2. Plant genetic resources of sunflower

2.1. Biparental and wild populations

For gene mapping, marker detection, QTL analyses, and gene cloning in sunflower, biparental populations based on crosses between elite breeding, conventional, or introgressed lines, as well as landraces and wild species, have been used (Kane et al., 2013; Livaja et al., 2016; Brouillette et al., 2007; Ma et al., 2017). Recombinant inbred lines (RILs) have also been developed, which can self-replicate indefinitely and are immortal (Tang et al., 2006; Talukder et al., 2016). However, biparental populations have three significant drawbacks: 1) they must be established separately for each research project, which takes time and resources; 2) only two alleles per locus can be evaluated; and 3) due to missing recombination events, populations show low mapping resolution (Patrick and Alfonso, 2013). These issues are solved through the usage of association panels. Comparing the genetic diversity of wild populations to the genetic diversity fixed in association panels allowed researchers to confirm the utility of association panels (Filippi et al., 2015). Even though alleles present only in the wild populations were detected, the majority of the alleles were present in the investigated association panels (Dimitrijevic & Horn, 2018).

2.2. Sunflower collections

The greatest sunflower collection is housed at the Institute of Field and Vegetable Crops in Novi Sad, Serbia, and includes over 7,000 inbred lines (447 accessions in total) of sunflowers derived from 21 perennial and 7 annual species (www.nsseme.com/about/inc/oilcrops/wild.php) (Atlagic and Terzic, 2014). The USDA-ARS NPGS in Ames is home to the second-largest collection of more than 5000 domesticated and wild *Helianthus* accessions (Marek, 2016). The majority of these, 2,519 accessions, make up the collection of 53 species of wild relatives of sunflowers, including 39 perennial and 14 annual species (Seiler et al., 2017). Another sizable collection of both domesticated and wild sunflowers is kept at the Vavilov Institute of Plant Industry. It has a total of 2,780 accessions, of which 2,230 are domesticated and 550 are wild, with 24 species (19 perennials and 5 annuals) represented (Gavrilova et al., 2014). To highlight the global diversity of sunflower, INRA has put together a well-defined collection of 400 open-pollinated varieties, landraces, and breeding pools (Mangin et al., 2017). However, due to the self-incompatibility of wild sunflowers and the potential for genetic drifts occurring during the propagation of seed stocks, the conservation of population diversity of sunflower populations poses a problem in the maintenance process (Gandhi et al., 2005). To reduce the loss of genetic diversity in cultivated genetic resources, it is advised to utilise cages or to multiply in isolation fields (Dimitrijevic & Horn, 2018).

2.3. Association panels

In order to research complex features, plant genetic resources of sunflowers are being gathered and conserved globally. To overcome the drawbacks of biparental populations, sunflower association panels serve as the foundation for genome-wide association research. Novel techniques at the whole genome level are now possible due to technological advancements and the availability of the sunflower genome sequence. Based on next-generation sequencing technologies, genotype-by-sequencing and whole genome sequencing enabled the production of a large number of SNP markers for high density maps and SNP arrays as well as genome-wide association studies and genomic selection in sunflower (Dimitrijevic & Horn, 2018). An effective method for QTL mapping and pre-breeding is association panels. To prevent false associations caused by population structure and family relationships, association panels must be defined via molecular markers like SSRs or SNPs. In order to take advantage of increased recombination frequencies and better mapping resolution, the multi-parent advanced generation intercross (MAGIC) technique is interesting for investigations of multiple alleles (Cavanagh et al., 2008). Development of MAGIC populations is in progress for numerous plant species and would be interesting for sunflower as well (Dimitrijevic & Horn, 2018).

Due to Argentina's extensive history of breeding sunflowers, Argentinean germplasm also serves as an important genetic resource (Moreno et al., 2013). The Active Germplasm Bank of INTA (National Institute of Agricultural Technology, Argentina) Manfredi (AGB-IM) (Filippi et al., 2015) is responsible for maintaining the plant material. The National Institute for Agricultural and Food Research and Technology's Centre of Plant Genetic Resources (CRF-INIA) maintains a germplasm collection of 196 Spanish confectionery sunflower accessions. In terms of hundred-seed weight, kernel %, seed oil content, fatty acid and tocopherol composition, phytosterol composition, and other characters, it was found that there is significant genetic diversity (Perez Vich et al., 2018).

2.4. Mutagenized populations

With regard to flowering period, dwarf habit, oil content, high oleic trait, herbicide resistance, and branching, mutant populations have been effectively produced and utilised to screen for mutant phenotypes useful for breeding objectives. In addition to naturally occurring mutations in wild sunflower populations, induced mutagenized populations have also had a substantial impact on sunflower hybrid breeding, particularly in the field of herbicide resistance. The excessive use of herbicides in recent years has caused populations of wild sunflowers to become resistant. Commercial sunflower hybrids were successfully modified to introduce resistance from populations. Clearfield® technology refers to sunflower production based on the use of this imidazolinone (IMI) resistance, which offers an effective and simple control of post-emergence broadleaf weeds in Europe. Along with the detection of IMI-resistant sunflowers, Kansas (United States) experienced the discovery of another population of sulfonylurea-tolerant wild sunflowers known as ANN-

KAN. By using EMS mutagenesis, the same tolerance was obtained as well (Dimitrijevic & Horn, 2018). Later, more AHAS herbicide-resistant populations of wild sunflowers were discovered (Jacob et al., 2017). In addition, a new tolerance for imidazoline called Clearfield Plus® was selected from an M2 population of 600,000 plants treated with EMS (Sala et al., 2008). Natural genetic diversity and naturally occurring or chemically/gamma-ray induced genetic variability represent a perquisite for selection in breeding. Successful breeding programmes in sunflower are greatly aided by the broad variety of accessions that germplasm banks maintain and make available to the research community. These accessions allow for association studies and the introduction of new traits into current commercial breeding material. However, where natural diversity is insufficient, mutagenesis may generate additional new genetic variability (Dimitrijevic & Horn, 2018).

3. Broomrape resistance

A non-photosynthetic plant called broomrape (*Orobanche cumana* Wallr.) parasitizes the roots of sunflowers, severely reduces the production. Sunflower broomrape is believed to have evolved in Russia from *O. cernua*, which parasitizes wild species in the sunflower family *Asteraceae*. Later, it spread to other sunflower-growing countries in Asia, Central and Western Europe, and Tunisia (Amri et al. 2012). Yield decreases can range from 5 to 100%, depending on the severity and timing of the infestation (Fernandez-Aparicio et al., 2009). When a broomrape plant reaches physiological maturity, it can generate and disseminate up to 100,000 seeds, each of which has a 20-year viability period (Parker, 2013). Despite being frequently brought into new locations via contamination of sunflower seeds, the small seeds are easily transported by wind and water (Imerovski et al., 2019). In sunflower, dominant monogenic genetic resistance to broomrape predominates. Massive use of vertical resistance has led to the progressive extension of increasingly virulent races of the parasite. For the development of longer-lasting resistance, more horizontal resistance gene introduction is essential (Akhtouch et al., 2016).

Utilising realistic screening approaches to generate enough selection pressure and readily accessible and effective sources of resistance are both essential components of breeding for broomrape resistant cultivars. However, it necessitates ongoing effort since broomrape responds by evolving a more virulent race as soon as resistance to the most recent race is discovered. Sunflower has been found to have both qualitative and quantitatively inherited resistances to *O. cumana*. Major genes regulate qualitative resistance to broomrape, which are race-specific (Pérez-Vich et al., 2013). Considering that resistance genes are rapidly overcome, it is necessary to search for new resistance sources and combine available genes (Imerovski et al., 2016).

Because sunflower broomrape is mostly self-pollinated, it is expected that there would be significant genetic variation among populations. *O. cumana* populations are frequently divided into races based on their level of pathogenicity. Eight races, denoted by the letters A to H, have so far been reported (Kaya, 2014). Molinero-Ruiz et al., (2014) were the first to report the presence of broomrape race F in Hungary and confirm existence of races F in Spain and Turkey, as well as race G in Turkey. Virulence changes are frequently caused by *O. cumana* and its host coexisting in various environments (Cvejić et al., 2020).

The most significant source of broomrape resistance originates from wild *Helianthus* species, but other sources, such as open pollinated varieties and various gene pools of cultivated sunflower developed in research facilities all over the world, have also been used. In the first part of the 20th century, Soviet breeders developed the first sunflower varieties that were resistant to broomrape. These were regional varieties resistant to race A, including Saratovsky 169, Zelenka, and Fuksinka. Especially important varieties resistant to broomrape, like Zhdanovsky 6432, Zhdanovsky 8281, and Stepnyak, were developed by academician Zhdanov and developed at the Saratov experimental station when the occurrence of broomrape race B threatened sunflower production (Gorbachenko et al., 2011). Given that they are produced under various conditions, the current gene pools of farmed sunflower are also a key source of broomrape resistance. These gene pools are made up of many inbred lines and synthetic populations developed over many generations of breeding. After the introduction of inbred lines and hybrids in the 1960s and 1970s, resistance to broomrape in cultivated sunflower has begun to be extensively investigated. Numerous reports of inbred lines resistant to race G of broomrape that came from various farmed sunflower germplasm collections have already been documented (Cvejić et al., 2020).

Wild sunflower species are adapted to various conditions and exhibit a wide range of biotic and abiotic resistance characteristics because they grow in a variety of environments, including plains, deserts, salt marshes, woodlands, and mountains. One of the first uses of wild sunflower species is linked to the beginnings of sunflower breeding, when the Russian scientist Sazyperow tried to incorporate resistance to rust from *H. argophyllus*, while academician Zhdanov successfully used *H. tuberosus* for the development of cultivars resistant to broomrape. Since that time, the main genetic source of resistance to significant diseases limiting sunflower productivity is derived from wild species of sunflower. The USDA-ARS National Plant Germplasm System (NPGS) is kept at the North Central Regional Plant Introduction Station (NCRPIS) in Ames, Iowa, and is the largest and most significant collection of wild species of the genus *Helianthus* as well as an important collection of exceptional sunflower germplasm. In other countries, such as Serbia (IFVCNS), Bulgaria (Dobroudja Agricultural Institute, General Toshevo), France (INRA), Argentina (Instituto Nacional de Tecnologia Agropecuaria, Pergamino), Spain (Institudo de Agricultura Sostenible, Cordoba), Ukraine (Institute of Oilseed Crops, Zaporozhie), and Russia (Vavil), there are now significant collections (Cvejić et al., 2020).

For race F, resistance was found in germplasm of both cultivated and wild sunflower (Velasco et al. 2012), and depending on the source has been reported to be controlled by a single dominant gene named Or6 (Pérez-Vich et al. 2002), two recessive genes (Akhtouch et al., 2016), two partially dominant genes (Velasco et al., 2007) or multiple quantitative trait loci (QTLs) (Pérez-Vich et al., 2004; Louarn et al. 2016). With respect to race G, preliminary results imply that resistance is conferred by a single dominant gene (Velasco et al., 2012). In contrast, Imerovski et al. (2016) reported that resistance to races higher that F can be controlled by a single recessive gene.

Fig. 1. Selfing individual plants from segregating sunflower broomrape populations for genetic study of avirulence genes (Velasco Varo et al., 2016).

There are 2,519 accessions of 53 species in the USDA-ARS National Plant Germplasm System crop wild relatives (CWR) collection, including 1641 accessions each of 14 annual and 878 accessions each of 39 perennial species. Particularly in Europe and the Middle East, this CWR collection offers a significant genetic resource for novel BR resistance genes (Velasco Varo et al., 2016).

In several accessions of *H. tuberosus*, *H. grosseserratus*, *H. mollis*, *H. nuttalii*, *H. debilis*, *H. neglectus*, *H. niveus*, *H. argophyllus*, *H. petiolaris*, and *H. praecox*, varying degrees of broomrape resistance have been found (Terzi et al., 2010). Interspecific hybridization was used by Jan et al. (2002) to introduce resistance genes from several wild species into cultivated sunflower, generating four resistant populations (BR1–BR4) in response to the occurrence of the more virulent broomrape race F. Later, it was discovered that the *H. debilis* population of wild sunflowers contained a dominant gene for resistance to the new race G (Höniges et al., 2008). Sunflower inbred line LIV-17 derived from the interspecific cross with *H. tuberosus* was found to carry recessive resistance to broomrape populations present in Turkey and Spain. INRA owns genotypes named LR1, resistant to race G (Turkey) and race F (Spain) (Louarn et al., 2016). Also HA267 named genotype selected from the Novi Sad gene-pool is resistant to race G (Spain, Romania, Turkey) (Imerovski et al., 2014; Imerovski et al., 2019). Genotype named AB-VL-8 obtained by interspecific hybridization with *Helianthus divarticatus* is resistant to race G (Spain, Romania, Turkey) Imerovski et al., 2019). Genotypes named LIV-10 and LIV-17 obtained by interspecific hybridization with *Helianthus tuberosus* is resistant to race G (Spain, Turkey) (Imerovski et al., 2019).

Breeding for resistance is a continuous and extensive work, which includes discovering resistance gene(s) and development of resistant sunflower genotypes. Broomrape resistance genes are denoted as Or genes (Cvejić et al., 2020). Production of commercial sunflower hybrids resistant to the predominant broomrape races has been near exclusively based on resistance determined by single, race-specific dominant genes, which has led to a rapid evolution of new virulent races (Fernandez-Martinez et al. 2012). New breeding strategies such as pyramiding of major genes or combining vertical and horizontal resistance mechanisms are required to develop more durable resistant cultivars (Akhtouch et al., 2016).

The *O. cumana*-sunflower parasite system distinguishes out for being primarily controlled by a gene-for-gene interaction. This establishes total resistance in the host that is governed by dominant alleles at a single locus, making it easier to manage resistance for the production of hybrid seeds. On the other hand, dominant alleles at a single gene also regulate avirulence in the parasite. Monogenic, dominant resistance exerts a strong selection pressure on the parasite that maximizes the probability of overcoming resistance mechanisms in a short period of time. In fact, this has led to a number of physiological races that occasionally surpass all the sources of resistance. Another factor supposed responsible for the genetic diversity in sunflower broomrape and the recombination of avirulence genes is, the expansion of populations into new locations and the subsequent hybridization between populations. After more than a century of coexistence, genetic resistance to broomrape in sunflower must be addressed under an integrated strategy that takes into account both the genetic and physiological bases of the parasite's avirulence as well as the characterization of host resistance mechanisms. The most important factor in genetic resistance in sunflowers is to follow pyramiding tactics rather than depending solely on single dominant genes.

Priority should be placed on combining complementing resistance mechanisms that are subject to both qualitative (vertical) and quantitative (horizontal) genetic regulation (Velasco Varo et al., 2016).

Sunflower breeding proved challenging due to the limited and difficult-to-assess resistance to parasitic broomrape (Rubiales et al., 2006). By locating closely related markers and using marker-assisted selection, the process could be accelerated significantly. An SSR marker was used to locate the earliest broomrape resistance gene (Or5) on the region of linkage group 3 (LG 3); subsequently, Or6 and Or4 were discovered on the same linkage group (Imerovski et al., 2013). Five QTLs with resistance to broomrape of race E were located on LG 1, 3, 7, and 13 and other QTLs with minor effects to race F were on LG 1, 4, 5, 13, and 16 (Pérez-Vich et al., 2004). Five QTLs associated with broomrape resistance to race F have been fixed on LG 2, 3, 4, 5, and 6 (Akhtouch et al., 2016). For broomrape race E, preliminary results implied that resistance was conferred by several QTLs (Liu et al., 2020).

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CHAPTER 6

IN VITRO-BASED DOUBLE HAPLOID PLANTS PRODUCTION

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1. Introduction

Haploid is a term used for plants containing one of the gametic chromosome set. In sexual reproduction, the chromosome number, which is halved as a result of meiosis, is doubled as a result of fertilization and the resulting embryo has a chromosome similar to the number of chromosomes carried by the parent plant. If meiosis occurs in a diploid plant, the gametes have half of the number of chromosomes of the main plant and this plant is called a "monohaploid plant". The new plant that is formed without fertilization from the gametes of a tetraploid plant is called a "double haploid plant".

Biotechnological methods, which have been used in plants since the middle of the 20th century and can be applied to plants with economic importance, especially in the third quarter of the 20th century, have great potential in terms of accelerating the breeding process as auxiliary methods to traditional plant breeding methods. It has been revealed that the development of new varieties can be shortened by means of the developments in agricultural technologies in recent years. One of the most important points in traditional plant breeding methods, which are widely used today, is that the breeding period takes a long time. Shortening the breeding period by utilizing different sources and methods has been an important development in plant breeding.

Different biotechnological methods are used to shorten the traditional plant breeding period. One of these techniques is to obtain haploid plants using different techniques and to obtain double haploid plants by doubling the chromosomes of these haploid plants. Androgenesis, gynogenesis, polyembryo, semigami, chromosome elimination are seen in nature in plants. Among these techniques, especially androgenesis, gynogenesis and chromosome elimination techniques are widely used. Besides, the use of inducer technique has started to become widespread successfully in obtaining haploid plants in some plant species.

Haploid technique is becoming increasingly important in obtaining homozygote plants of diploid and allopolyploid species and new variety and pure line breeding. Thus, the selection of genotypes that are resistant to diseases and superior in terms of agronomic and quality characteristics is made faster in the F_2 generation (Kasha et al., 2003). Nowadays, haploid plants can be obtained in a short time under in vitro and in vivo conditions. Doubling of chromosome sets of haploid plants and rapid development of 100% homozygous pure lines is the basis of haploid technique. In practice, chromosome doubling is mostly carried out by chemical applications. With these methods, homozygote lines can be obtained in a short period of 1-2 years (Geiger, 2009). It is known that double haploid technique is widely used in wheat, barley, rice, maize, pepper, rapeseed, eggplant, *Brassica* species, gerbera, watermelon, melon and squash.

Genetic variation in populations directly affects the success of traditional plant breeding and is of great importance in terms of increasing the existing variation. Since the narrowing in the genetic base causes the intra-species genetic variation to remain limited, it also limits the increase in biological yield that can be achieved by traditional breeding methods. Since the 1980s, it has been revealed that this process can be shortened by using biotechnological techniques or in integration with traditional breeding methods. Anther culture, one of the various biotechnological methods used in plant breeding, is the most widely used technique for obtaining homozygous lines in a short time. 100% homozygous lines can be obtained in a short time by means of the doubling of the chromosomes of haploid plants, the purification process, which requires many years, is carried out in a short time and thus, significant time saving can be achieved in F_1 hybrid variety development studies (Ellialtıoğlu et al., 2001). Although they have all the organs found in a normal plant, compared to diploid plants, haploid plants have narrower and smaller leaves, shorter height and smaller flowers. Since they show the structure of gametes with reduced chromosome number, they are sterile and do not set seed. For haploid plants, the number of chromosomes must be doubled for seed attachment and the continuation of their progeniture. Haploid plants are used for different purposes in breeding. The most common use of haploids is the double haploid technique, which offers the opportunity to achieve complete homozygosis in a very short time. With the use of double haploid lines, genetic and breeding studies become easier and results can be achieved more quickly. Since the heterozygote rate is very high in foreign pollinated species, it is necessary to perform inbreeding for 8-10 generations in order to obtain homozygous lines in them; even in self-pollinated species, 6-7 generations of inbreeding are needed for the same purpose.

With the double haploid method, homozygous lines can be reached in one generation. Anther culture studies started with the discovery of the first natural haploid plants in *Datura stramonium L.* by Blakeslee et al. (1922). Since then, studies increased to generate haploid plants spontaneously in many plants. Today, anther culture is the most widely used technique to obtain haploid plants. The advantage of this technique over other techniques is the presence of a large number of pollens in the anther and the production of a large number of haploid plants from anthers when a suitable in vitro culture system is introduced. The basic principle of anther culture is to stop the development of the pollen cell, which would normally form the male gamete, and to force the pollen cell to form a plant directly, as in somatic cells. Anther culture is the name given to the process of transferring anthers containing immature pollen to artificial growth culture in vitro and obtaining haploid embryos from immature pollen. Anther culture studies give successful results especially in most of the *Solanaceae* family species.

The ways of formation of haploid plants in nature are given below:

1. *Gynogenesis:* It is called “gynogenesis” when the egg cell begins to divide like a zygote without fertilization and forms a haploid embryo. Although the female germ cell and the male germ cell do not combine, the secondary nucleus of the embryonic sac and the pollen generative nucleus combine to form the endosperm that the embryo will need in order to develop and germinate (Sauton, 1987).

2. *Androgenesis:* Before the fertilization of the egg cell, the nucleus of the female germ cell disappears or becomes inactive. Since haploids formed in this way contain only the chromosome set of the male gamete in their cells, this event is called "androgenesis".

3. *Chromosome elimination:* The egg cell and the pollen generative nucleus combine and fertilization occurs. However, in the first stage of embryo development, chromosomes belonging to one of the parents are eliminated and the developing embryo contains “n” number of chromosomes.

4. *Semigamy:* In the case of semigamy, in which male and female germ cells combine in the formation of embryos, but nuclear fusion does not occur, chimera haploid plants with maternal and paternal sectors are formed (Turcotte and Feaster, 1969).

5. *Polyembryony:* As a result of normal fertilization, the zygote begins to divide. However, one of the synergid cells next to the fertilized egg cell also divides and develops into a haploid embryo. Thus, there are two embryos, one diploid and the other haploid, in the newly formed seed (Lacadena, 1974). This is called "polyembryony". Haploid plants can be formed by polyembryo in pepper and peach.

2. Obtaining Haploid Plants By In Vitro Techniques

2.1. Embryo Rescue

Haploid embryos are formed as a result of the loss of one of the parents chromosomes in the embryo formed as a result of interspecies hybridization. If these embryos are enabled to develop under in vitro conditions, haploid plants are obtained. This technique is successfully applied especially in wheat and barley. This method was first introduced by Kasha and Kao (1970) in barley. Another technique within the scope of obtaining active haploid plants from female gametes is based on the loss of chromosomes belonging to one of the parents in the embryo formed as a result of interspecies hybridization in the *Hordeum* genus in chromosome elimination. In this method, the cultivated barley *Hordeum vulgare* (2n =14) was crossed with the tuberous barley *H. bulbosum* (2n=14). As a result of this cross, the zygote is formed normally and the embryo continues its normal development for 14-16 days after pollination. However, then the chromosomes of tuberous barley start to be eliminated in the embryo and in about two weeks only a haploid embryo with the chromosomes of *Hordeum vulgare* remains. In this case, the development of the endosperm stops completely and the embryo develops very slowly. If this slow-developing embryo is grown in in vitro culture in the appropriate period under sterile conditions, this haploid embryo, which will not survive under normal conditions, germinates to form haploid plants. These plants are then treated with colchicine and their chromosome numbers are doubled. When this technique is applied to F_1 plants in any breeding program, the homozygosis level that can be obtained in a long time with traditional methods can be reached in 1 year.

The most important factor preventing the widespread use of this technique is genotype. In the studies carried out on wheat, when tetraploid tuberous barley was used as paternal, 54 haploid embryos were obtained from 100 crossed wheat flowers, whereas this rate descended to 28.2% when diploid barley was used as maternal (Barclay, 1975). Studies with hexaploid wheat varieties showed that some wheat genes prevented fertilization with tuberous barley (Sitch and Snape, 1987). Laurie and Reymondie (1991) reported that in their studies conducted with 19 hexaploid wheat varieties, they obtained 3-4 times more haploid plants from hybrids made with maize compared to hybrids made with tuberous barley.

2.2. Ginogenesis

The production of haploid plants from unfertilized egg cells or ovaries by in vitro culture is called "ovary or ovule culture". This type of plant formation is called "parthenogenesis". In many plant species, the possibility of obtaining haploid plants by in vitro culture of unfertilized egg cells and ovaries has been investigated. However, the most important problem in this technique is that after the callus is formed from the egg cell, growth stops and plant regeneration does not occur. In addition, haploid plants could be obtained by ovule culture technique in barley, wheat, rice, maize, sugar beet and onion plants. One of the most important points to be considered in order to obtain successful results from ovule or ovary cultures is the size of the flower from which the ovary is taken, that is, the developmental period in which the ovary is physiologically present. The most effective method to determine the development period of the ovary practically is to observe the microspore development periods in the anthers of the same flower. In a study conducted in barley, the ovaries in the same flower were cultured at the stages before anthesis, in which the pollen was uninucleate, dichotomous and tri-nucleated. It was stated that the most convenient period for the haploid embryo was the bi-nucleate or trinucleate period (San Noeum, 1976). However, in some studies, it was determined that the eggs taken in wheat and tobacco when the pollen of the same flower was uninucleate formed haploid plants (Zhu and Wu, 1979). In addition, the ovule culture technique is not widely used to obtain haploid plants because the frequency of obtaining haploid plants from ovules is very low in many plants.

2.3. Androgenesis

Androgenesis is the production of haploid plants by culturing anthers and pollen isolated from anthers in vitro. This technique has given successful results especially in cereals. Pollen culture has some advantages over anther culture. Since the anther walls are removed in pollen culture, the chance of obtaining diploid regenerates from cells other than pollen decreases. Since pollen directly contacts the culture media, they make better use of the culture media. In anther culture, the problem of inhibitory and toxic substances originating from anthers is eliminated. As a result of the prevention of callus formation from anthers, much less chimera plants are formed.

Today, anther culture is the most widely used technique to obtain haploid plants. The advantage of this technique over other techniques is the presence of a large number of pollen in the anther and the production of a large number of haploid plants from anthers when a suitable in vitro culture system is introduced. The basic principle of anther culture is to stop the development of the pollen cell, which would normally form the male gamete, and to force the pollen cell to form a plant directly, as in somatic cells. Anther culture is the name given to the process of transferring anthers containing immature pollen to artificial growth culture in vitro and obtaining haploid embryos from immature pollen. By means of anther culture, the gametic development direction of the pollen grain, which would normally turn into a binucleate structure under normal conditions, is turned towards the direction of somatic development while it is still in the uninucleate period, and thus the formation called androgenesis occurs. The use of new biotechnological methods that complement and support classical plant breeding programs for the development of plants with higher yields, higher quality, and resistance to abiotic and biotic stress factors is gaining importance and their use is increasing day by day. Transformation, production of haploid plants and in vitro selection come to the fore among biotechnological methods that complement and support plant breeding programs in the selection of plants with variation and desired characteristics, which form the basis of classical plant breeding (Simmonds 1983; Philips and Eberhart, 1993).

Today, although the response rate is different, haploid plant production has been achieved by androgenesis in many species. The factors described below affect the androgenesis response.

1. *Genotype*: The response in anther culture largely depends on the genotypic structure of the plant from which the anthers are taken. For example, it has been known that the genotype effect is important since the beginning of in vitro anther culture studies in wheat. In wheat, the androgenesis response is predominantly determined by additive gene effects (Agache et al., 1989), but non-additive effects and cytoplasmic effects have also been observed in anther culture (Orlov et al., 1999). In some studies, the effect of heterosis and additive genes in anther culture in wheat was reported (Lantos et al., 2019). The use of genotypes with high response to anther culture in fertilization can increase the number of double haploid lines produced in breeding programs (Tuvesson et al., 2003). However, detailed information retrieval on parental characteristics should be done before fertilization, which may prolong the double haploid breeding process.

In general, anther culture implementation in segregation generation breeding materials can increase the number of double haploid lines produced. For this reason, the first method to be applied in order to obtain a high level of adrogenetic response from the genotype desired to produce haploid plants in anther culture is to optimize the culture conditions for each genotype (Dunwell, 1981), and the other method is to crossbreed genotypes with high embryo formation capacity with genotypes with low embryo formation capacity in anther culture and to use the progeny with high response from the hybrid progeny in anther culture. Henry and Buyser (1985) reported that haploid production in wheat was controlled by at least three different and independent factors and listed them as embryo stimulation, regeneration ability and the ratio of green plants to albino plants.

2. *Pollen Development Period in Anthers:* One of the most important factors affecting androgenesis in vitro is the development period of the pollen when the anthers are isolated from the donor plant. The development stage of microspores is one of the most critical factors in androgenetic diffusion in vitro. In anther and isolated microspore culture of wheat, the microspore embryogenesis process was initiated to examine the development of microspores, initial cell divisions and embryo formation (Dwivedi et al., 2015; Seldimirova et al., 2017; Niazian and Shariatpanahi, 2020).

In the studies on anther culture in wheat, androgenesis of microspores (uninucleate vacuum microspores) can be induced in a narrow range of developmental stages in vitro. When considered from this point of view, possible differences between published methods and protocols can be observed. Some researchers revealed that it was appropriate to remove anthers when microspores were in the middle to late uninucleate stage in donor plants (Soriano et al., 2007, Castillo et al., 2015; Weigt et al., 2019; Lazaridou et al., 2017; Broughton et al., 2020; Orlowska et al., 2020), some researchers revealed that it was more appropriate to remove anthers in the early and middle uninucleate stage (Lantos et al., 2013). When the results obtained from the studies are evaluated, it can be said that the early and middle uninucleate period is more effective for anther culture studies in wheat (Barnabas, 2003; Lantos and Pauk, 2016; Kanbar et al., 2020).

In many plant species, anthers in the early-middle uninucleate period gave the highest response, whereas in maize, it was reported that the highest response was obtained from anthers in the late uninucleate period (Hosseini et al., 2014). During this period in maize plants, the tassels did not emerge from the leaves and were found in the leaves at the top.

3. *Pre-Cold Application:* Some pre-treatments applied to flower buds have a positive effect on the development of pollen in the culture medium. Researchers reported the successful effects of many pretreatments such as cold, heat, colchicine, osmotic shock, 2-HNA, DMSO, etc. on anther culture applied for androgenesis in wheat (Echávarri and Cistué, 2016).

The most frequently applied pretreatments in plants are cold and hot applications, separately or in combination. While the application of pretreatments (cold and hot application) in optimal dose and combination promotes androgenesis, their application in low and high doses may reduce the efficiency of androgenesis. Increasing doses of pretreatment may reduce plant regeneration or increase the ratio of albino plantlets (Niazian and Shariatpanahi, 2020).

Cold application to donor spikes as a pre-treatment is the easiest way to increase the response of microspores. In the in vitro androgenesis of microspores in anthers, cold pretreatment of donor plants is applied at 2-5 °C for 7-14 days (Wang et al., 2019). Some researchers successfully used short-term cold application (3-8 days, 4-6 °C) as a pretreatment to initiate androgenesis in anther culture (Weigt et al., 2019; Lazaridou et al., 2017). However, first applications to anthers can be time-consuming steps in in vitro plant production that may necessitate further work. It was determined that the application of heat (3 days, 32 °C) as a pretreatment to isolated anthers in anther culture also increased the response in androgenesis (Lantos and Pauk, 2016).

4. *Culture Media:* It is very difficult to find a culture media that can respond to all plant species in anther culture applications. Response to anther culture may differ even between different genotypes of the same species. Therefore, it seems quite difficult to reproduce all species in a common culture media. In anther culture, while auxins are required to stimulate gametophytic tissues to transform into sporophytic development in the first stage, the presence of cytokinins is required at the stage of transformation into plantlets. Generally, 2,4 D, IAA (indole acetic acid) and NAA (naphthalene acetic acid) are added to the culture media as auxin source in anther culture. Kinetin, benzyl adenine (BA) and zeatin are mostly used as cytokinin sources. Today, there are different culture media recommended for each species and even on the basis of variety. Good androgenesis results were obtained in studies in which N6, YPI and P II medium were used as initial environment in the studies on cereals. 190-II and MS culture media supplemented with different auxins and stokinins are widely used as regeneration media. While sucrose can be used as a carbon source in the environment, successful results were also obtained in the studies in which the maltose was used in cereals. Responses were obtained in solid culture media obtained by adding agar in anther culture and in liquid culture media without agar. Generally, 0.6-0.7% of agar is used in solid culture media.

There are many initial culture media (MS, N6, AM, C17, P2, P4, LIM, W14, MS3M) successfully applied in anther culture in wheat. These media were supplemented with maltose as a carbon source (Hunter, 1987) and Ficoll as an osmotic agent.

Table 1. Composition of Some Culture Media

Compound	**Concentration (mg/l)**			
Macro Elements	**MS**	**LS**	**B5**	**N6**
$MgSO_4.7H_2O$	370	370	250	185
KH_2PO_4	170	170	-	400
$NaH_2PO_4.H_2O$	-	-	-	150
KNO_3	1900	1900	2500	2830
NH_4NO_3	1650	1650	-	-
$CaCI_2.2H_2O$	440	440	150	166
$(NH_4)2SO_4$	-	-	134	463
Micro Elements				
H_3BO_3	6.2	6.2	3.0	1.6
$MnSO_4.H_2O$	15.6	16.9	10.0	3.3
$ZnSO_4.7H_2O$	8.6	8.6	2.0	1.5
$Na_2MoO_4.2H_2O$	0.25	0.25	0.25	-
$CuSO_4.5H_2O$	0.025	0.025	0.025	-
$CoCI_2.6H_2O$	0.025	0.025	0.025	-
KI	0.83	0.83	0.75	0.80
$FeSO_4.7H_2O$	27.8	27.8	-	27.8
Na_2EDTA	37.3	37.3	-	37.3
EDTA NA ferric salt	-	-	43.0	-
Organic Matters				
Saccharose	30	30	20	50
Thiamin.HCI	0.1	0.4	10.0	1.0
Pyridoxine.HCI	0.5	-	1.0	0.5
Nikotianic acid	0.5	-	1.0	0.5
Myo-inositol	100.0	100.0	100.0	-
pH	5.8	5.8	5.8	5.8

Gamborg, 1984.

Different growth regulators (2,4-D, benzyl adenine, centrophenoxine, dicamba, indole-3-acetic acid, kinetin etc.) and their combinations were successfully applied in the initial culture media (Zhao et al., 2017; Orlowska et al., 2020). In recent years, W14 (Lazaridou et al., 2017) and MS3M culture media (Castillo et al., 2015; Echávarri and Cistué, 2016) are frequently used in haploid studies and wheat breeding programs. The modified W14 culture media, which is the W14MF synthetic media, was successfully applied in studies on wheat (Kanbar et al., 2020; Pauk et al., 2020). Some organic components (potato essence, wheat ovaries) were also reported to increase the efficiency of in vitro anther culture (Castillo et al., 2015; Broughton et al., 2020). Depending on research groups, the most commonly applied plant regeneration media were 190-2 (Çay, 2012; Lantos and Pauk, 2016; Lazaridou et al., 2017; Orlowska et al., 2020), J25-8 (Castillo et al., 2015; Echávarri and Cistué, 2016), and MS (Zhao et al., 2017; Weigt et al., 2019) culture media.

5. ***Growing Conditions:*** Even if the genotypic structure of the donor plant is extremely suitable for anther culture, it is also very effective to grow these plants under suitable conditions in order to achieve haploid induction of microspores in in vitro conditions. Donor plants are one of the most critical factors affecting the efficiency of in vitro androgenesis in anther culture. Healthy (grown under ideal growing conditions) donor plants, tillers and spikes that grow well on these plants are the first important factors in the implementation of double haploid plant production. Two different media (greenhouse or phytotron chamber/field conditions) are commonly used for growing donor plants. Controlled light and temperature conditions (greenhouse, phytotron chamber) offer a good opportunity to grow donor plants all year round (Nielsen et al., 2015; Seifert et al., 2016; Barakat et al., 2017; Coelho et al., 2018; Wang et al., 2019).

Winter type genotypes need vernalization for a certain period of time (6-8 weeks at 3-4 °C) after germination. Donor plants successfully grow at 18-21/12-15 °C (day/night) under the conditions with a photoperiod of 12-18 hours and humidity of 70-80% (Wang et al., 2019; Broughton et al., 2020). It is also very important to regularly feed the plants with a fertilizing solution for their healthy development.

Some researchers prefer plants grown under field conditions instead of those grown in a greenhouse or phytotron chamber (Weigt et al., 2019; Lazaridou et al., 2017). Plants grown in field conditions have larger spikes, more tillers, more and stronger anthers and microspores in anthers. For large-scale production of double haploid lines, more efficient studies can be done using field-grown plants. All environmental factors, especially temperature, light intensity and daily light time, CO_2 concentration in the air, nutritional conditions of the plant, during the growing period of the plants can be effective on the response of anthers taken from those plants. In field crops such as wheat, barley, rice and rye, the growing conditions of the donor plant are highly effective on the response in anther culture. When suitable growing conditions are not provided, albino plantlets were produced even in the Igri barley variety, which has a high response level to anther culture (Foroughi-Wehr and Wenzel, 1993). In general, in many plant species, plants grown in the normal growing season and field condition respond better to anther culture than plants grown in greenhouse and phytotron chamber during normal growing season.

6. *Incubation conditions:* In anther culture application, anthers are initially cultured at temperatures between 20-30 ^{o}C (28 ^{o}C) for 5-6 weeks. In some species, incubation of anthers at different temperatures in the first days of culture positively affects the response of anthers. In anther culture made on cereals, anthers are initially incubated in dark environments. In some plant species, in the later stages of culture, anthers kept at low light intensity (2000 lux) and different daily light exposure period, are transferred to the conditions with higher light intensity (3000-10000 lux) during the regeneration of plantlets after embryo formation.

3. Process of Anther Culture Technique

It takes a long time for the lines to be purified (homozygosization) after fertilization in traditional plant breeding studies. 100% homozygote plants can be obtained as a result of doubling the chromosomes of cells or regenerants obtained by tissue culture from cells with haploid number of chromosomes (pollen/microspore or megaspore) or plant parts containing these cells (anther or ovary). This technique is called “in vitro haploid technique”. Anther culture, on the other hand, is the technique of growing new plants by taking isolated anthers from a plant into a suitable culture media. This technique, which is used to produce haploid (n chromosome) plants, is of great importance especially in terms of plant breeding. It is possible to select the desired mutant types and develop new varieties with anther culture, which will provide a large amount of haploid plant production. In order to better understand the subject, the stages of anther culture application in wheat are explained in order below.

3.1. Growing of Donor Plants

Good growth of donor plants is one of the most critical factors affecting the effectiveness of the response in in vitro androgenesis in anther culture. Healthy (grown under ideal growing conditions) donor plants are the first important factors for large-scale double haploid production. These plants can be grown in field or greenhouse conditions. Light and temperature controlled greenhouses and phytotron chambers allow donor plants to be grown all year round. Donor plants grown healthily under controlled conditions can be used to provide material for research programs throughout the year. On the other hand, field-grown donor plants are more preferred by researchers because they generally have larger spikes, more anthers, and microspores in the anthers. High rates of double haploid production in conventional breeding can be synchronized using field-grown materials.

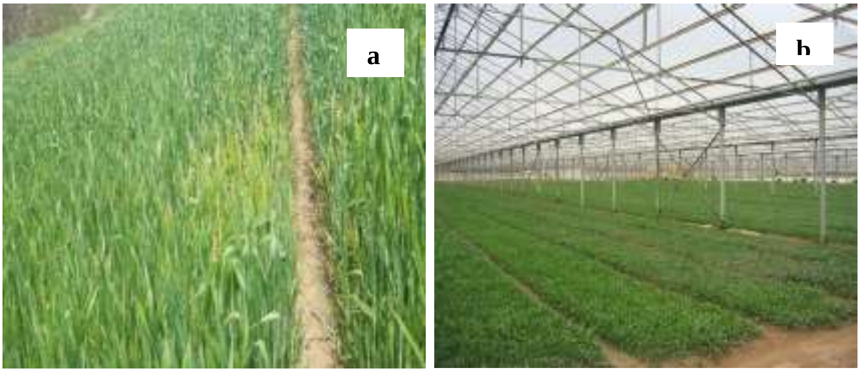

Figure 1. Donor Plants Grown in Field (a) and Greenhouse (b) Conditions

Since the development of spikes in plants grown in field conditions is almost synchronized with the development of plants, the period when anthers will be taken from the spikes can be determined by examining the pollen development, as well as by visually examining the developmental period of the plant. In plants grown in greenhouses or phytotron chambers, the plants can be individually controlled and the appropriate plants can be determined by reviewing the pollen development periods. It is important that the donor plants develop strongly and be free from diseases and pests. While the main spikes with sufficient anther can be used alone in plants, in cases where the main spikes is not sufficient, it is important to prefer the spikes of the most developed tillers in order to get a higher response.

3.2. Determination of Pollen Development in Anthers

Plant samples are taken according to the developmental status of pollen on the spikes of plants grown in field or greenhouse conditions. Pollen found in the anthers of these plants is crushed on a cover glass in the laboratory, a drop of acetocarmine is dripped onto it, and the development of pollen is examined under a light microscope. The development stage of microspores in the anthers of wheat spikes is one of the most critical factors for determining the androgenetic response in vitro. In anther and microspore culture, microspore embryogenesis process, development of microspores, first cell divisions and embryoid formation are examined in detail. In studies conducted by different researchers, different results were obtained for androgenetic response in vitro. Some researchers indicate early and middle uninucleate microspore period for a good androgenetic response in anther culture in wheat, while others indicate middle to late uninucleate microspore period. However, in general, it can be said that the early-middle uninucleate microspore period is more successful in wheat.

Figure 2. Plant Samples Taken at the Appropriate Period for Microspore Development

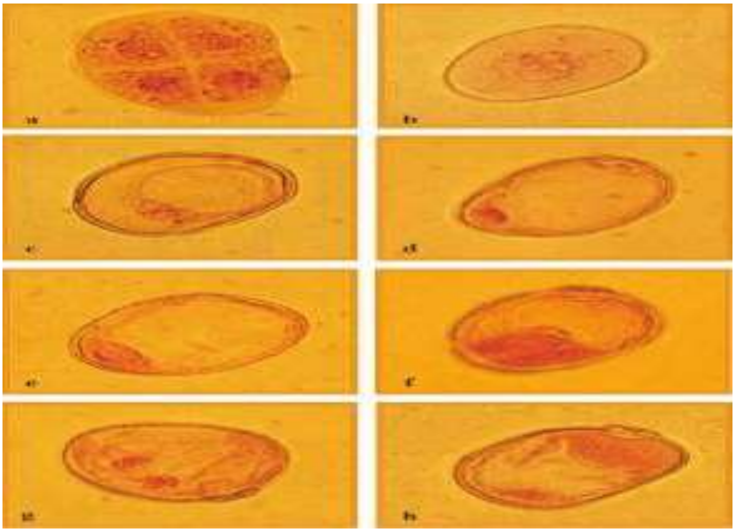

Figure 3. Microspore Development Periods. a) Tetrad Period, b) Early Uninucleate Period, c) Early-Middle Uninucleate Period, d) Middle Uninucleate Period, e) Middle-Late Uninucleate Period, f) Late Uninucleate Period, g) Anaphase Period of The First Microspore Division, h) Two Nucleate Period, (Szarejko, 2003).

Spikes taken from the growing area (field or greenhouse) by cutting under the third node from the top in the appropriate period are put in a container with water. Information such as genotype name and date of receipt are written on the container. A protective plastic bag is put on the spikes and the containers with the spikes are kept in a cold room or environment at +4 ^{o}C for 7-14 days.

3.3. Surface Sterilization

One of the most important sources of contamination in in vitro studies is the plant material used in cultivation. Material grown in field conditions hosts more microorganisms than material grown in greenhouse or phytotron. When explants carrying these microorganisms are not sterilized or sufficiently sterilized, the culture media is contaminated with microorganisms and this causes the explant to die in a short time. The material studied in vitro must be sterilized before being cultured. Before the sterilization process, residues such as soil and dead plant parts on the plant are removed to increase the efficiency of sterilization.

Various chemicals listed below are used for sterilization of plant materials.

- ... 1% sodium hypochlorite solution
- ... 7% saturated calcium hypochlorite solution

- ... 70% alcohol
- ... 0.2% mercury chloride solution
- ... 10% hydrogen peroxide solution

While the spikes samples taken from the plants are kept in a cold environment for the pre-cold application, before starting the surface sterilization of the spikes, equipment such as forceps and petri dishes must also be sterilized.

Figure 4. Sterilization of Spikes

In plant samples brought to the laboratory, all plant parts such as stems and leaves are removed, except for the spikes. If the spikes have awns, removing them will be beneficial to increase the efficiency of sterilization. The prepared spikes are shaken for 30 minutes in a solution of 2% sodium hypochlorite (3 units of water and 2 units of sodium hypochlorite are added when we have 5% sodium hypochlorite) in which a few drops of Tween-20 are added, and then surface sterilization is completed by washing 3-4 times with sterile water (Figure 4).

3.4. Inoculation of Anthers

For the inoculation of the anthers, the anthers in the spikelet on the surface sterilized spikes are transferred to the appropriate initial culture media by using sterile equipment under a sterile cabinet. Different types of media can be used as initial culture media. The initial culture media may differ depending on the plant species studied and the preferences of the researchers. Initial culture media can be liquid or solid, even sometimes, semi-solid culture media are used.

W14 (Quyang et al., 1984) culture media can be prepared for inoculation of anthers (Table 2). The prepared W14 liquid initial culture media is autoclaved under 90 kPa pressure at 120 °C for 20 minutes. After autoclaving, if temperature sensitive hormone or colchicine is to be added, filter sterilization (40 mg/l) is performed and added to the culture media. Colchicine Mille X-GS is sterilized by filtering through a 0.22 micrometer filter and added to the culture media. Then, the initial culture media is poured into petri dishes with a diameter of 90 mm (different sizes of petri dishes can be used depending on the characteristics of the study) under a sterile cabinet as 25 ml. Under sterile conditions, anthers taken from spikes using sterile forceps are transferred onto culture media in petri dishes (Figure 5).

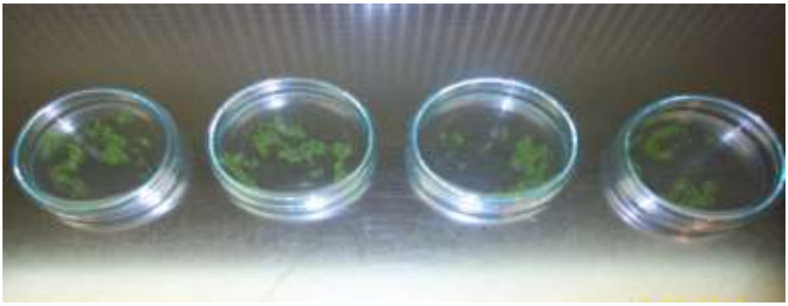

Figure 5. Transfer of Anthers to the Induction Culture Media

Different culture media can be used as induction media in the production of double haploid plants. Some of the culture media commonly used in cereals are given in Table 2.

Table 2. Induction Culture Media

Compounds	**Concentration (mg/L)**		
	W14F	**C17F**	**190-2**
$CuKNO_3$	2.000	1.400	1.000
KCI	-	-	40.0
$NH_4H_2PO_4$	380.0	-	-
$(NH_4)_2SO_4$	-	-	200.0
NH_4NO_3	-	300.0	-
KH_2PO_4	-	400.0	300.0
$Ca(NO_3)_2$ x $4H_2O$	-	-	100.0
$CoCl_2$ x $6H_2O$	0.025	0.025	-
$MgSO_4$ x $7H_2O$	200.0	150.0	200.0
Na_2MoO_4 x $2H_2O$	0.005	-	-
NA_2EDTA	-	37.25	37.30
NA_2EDTA x $2H_2O$	37.300	-	-
$FeSO_4$ x $7H_2O$	27.800	27.850	27.800
$MnSO_4$ x $4H_2O$	8.0	11.200	8.0
$ZnSO_4$ x $7H_2O$	3.0	8.600	3.0
H_3BO_3	3.0	6.200	3.0
KI	0.500	0.830	0.500
$CuSO_4$ x $5H_2O$	0.025	0.025	0.500
$CaCl_2$ x $2H_2O$	140.0	150.0	-
K_2SO_4	700.0	-	-
myo-Inositol	-	100.0	100.0
Thiamine HCI	2.000	1.000	1.0
Pyridoxine HCI	0.500	0.500	0.500
Nicotinic acid	-	0.500	0.500
Nicotionic acid	0.500	-	-
D-Biotin	-	1.500	-
2,4-D	2.0	2.0	-
Glycine	-	2.0	2.0
Sucrose	-	90.000	30.000
Maltose	80.000	-	-
Kinetin	0.500	0.500	0.500
Folic acid	-	0.500	-
NAA	-	-	0.500
Agar	-	-	6.000
pH	5.8	5.8	5.8

Depending on the size of the petri dishes used, the number of anthers placed in the induction culture media may change. In general, an average of 100 anthers are transferred to each petri dish in 4 repetitions. If possible, all three anthers in the spikelet on the wheat spike are taken at once with sterile forceps and transferred onto the culture media. After a sufficient number of anther transfer to the petri dishes is completed, the lids of the petri dishes are closed and surrounded with stretch film or lesco film. Petri dishes with anthers for early chromosome doubling are kept in incubators in dark conditions for 3 days at 28 ^{o}C until the first microspore mitosis division is observed.

However, there are also applications where a transfer to 28 ^{o}C is done after a short-term high temperature application (3 days at 33 ^{o}C). Here, the anthers are kept for 4-6 days (Figure 6). During this period, petri dishes are examined and any contaminated ones are removed.

Figure 6. Keeping the Anthers in the Incubator

At the end of the incubation period, callus and embryo-like structures developing from the anthers are examined, the ones in the appropriate period are opened under a sterile cabinet and transferred onto the previously prepared regeneration medium. For this purpose, a solid regeneration medium is prepared a few days ago. Transfer is made to petri dishes in different numbers according to the number of developing callus. Transfer can be done once or more than once depending on the callus development. Many researchers successfully use 190-2 culture media as a regeneration medium in their wheat studies. The prepared 190-2 culture media is sterilized under 90 kPa pressure at 120 °C for 20 minutes. The sterilized culture media is poured into petri dishes and sterile glass containers at 25 ml each.

Calluses or embryos developing in petri dishes in the incubator are transferred to this regeneration medium with sterile forceps under a sterile cabinet (Figure 7). The lids of the dishes in which the calluses are transferred are closed and surrounded with para film. These dishes are then transferred to climate chambers containing 70% humidity, with a temperature of 24 °C and a photoperiod of 16 hours light/8 hours of darkness (50 minimole s^{-1} m^{-2}). Here, plantlet development from calluses is observed.

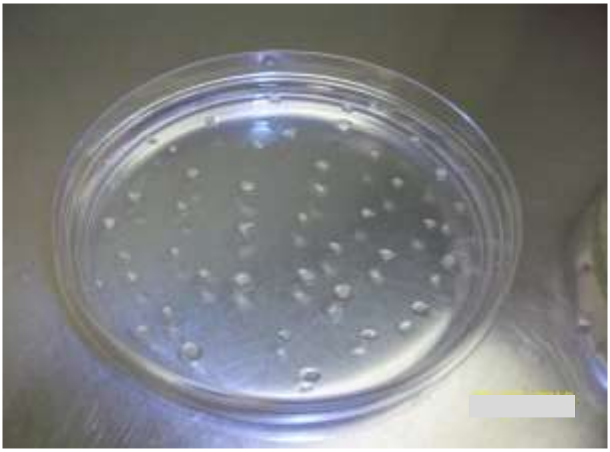

Figure 7. Calluses Transferred to Regeneration Medium

Green plantlets with suitable growth (Figure 8) are transferred to test tubes with fresh regeneration medium (Figure 9).

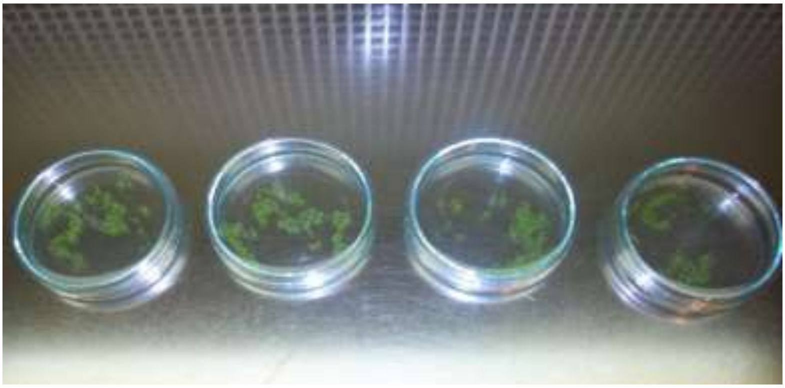

Figure 8. Green Plantlets Developing From Calluses

The content of the regeneration medium in which the green plantlets developed from the calluses are transferred is the same as the regeneration medium in which the calluses are transferred, except for the plant growth regulators, and the rate of sucrose has been reduced by 1.5%. Albino plantlets developing from calluses are counted and removed from the environment.

Figure 9. Transfer of Green Plantlets Developing From Calluses to Test Tubes

Plants showing sufficient shoot and root development in test tubes are transferred to small plastic pots containing special compost soil (Figure 10). In order for the plants to acclimate to the outside environment, plastic bags are placed over the pots and left in this way for 3-4 days in the acclimatization environment (Figure 10). If the plants being studied need vernalization, the plants are left in the cold room for 5-6 weeks (at 2-4 ^{o}C, 16 hours at 62.5 micromole m^{-2} s^{-1} light intensity). During this period, the ploidy level is determined in the plants. Before the plants are transferred to the greenhouse, acclimatization is done again.

Figure 10. Acclimatization of the Obtained Plants (a) and Vernalization (b)

4. Determination of Ploidy Level

Ploidy level in plants can be determined using different methods described below.

***Phenotypically**:* Haploid plants have many small panicles and small spikelet with sterile, short and narrow leaves. In this way, it can be distinguished from other plants (Figure 11).

***According to stomatal cells**:* Significant relationships were determined between the size of stomata and ploidy level in different plant species. It was determined that the stomata of haploid plants were smaller than the diploids, so there were more stomata per unit area. In normal diploid plants, stomata cells are larger, while in haploid plants they are smaller.

By Chromosome Counting: Counting the chromosomes isolated from the fresh root tips of plants, which generally show healthy growth, is the most reliable method for determining the ploidy level.

By Flow Cytometry: Flow cytometry, which is used when other methods do not work effectively, is a device and technique in which the physical or chemical characteristics of cells or other biological particles are measured quickly and reliably in a liquid flow. Determination of ploidy level by flow cytometry is based on analyzing the absorbed laser beam while individual cells pass through a fluorescence detector.

5. Chromosome Doubling

Chromosome doubling in haploid plants obtained in vitro can be performed with colchicine added to the initial culture media or after haploid plants are obtained.

Figure 11. Haploid (a) and Double Haploid Plants (b) Obtained In Vitro

Plants developed in vitro are taken to a suitable environment in the greenhouse. These plants are removed from the pots, their soils are washed, and the roots (2 cm) and leaves of the plants are cut to a certain extent (Figure 12).

Figure 12. Plants Prepared for Chromosome Doubling

The roots of these plants are immersed in a solution containing 0.1% colchicine + 2% DMSO + water and left for 4-5 hours. Then the plants are removed from the solution and washed under running tap water for 24 hours. The plants whose roots are washed are transferred back to pots with soil in the greenhouse. The roots of the plants should be kept in a humid environment for a few days in order to better hold on to the soil. Thus, it is provided that the plants become more adaptable to the outer environment conditions. Plants in the pots are transferred to greenhouse conditions until harvest. Necessary maintenance and observation procedures are performed here. Spontaneous double haploid plants are transferred to larger pots without any chromosome doubling and transferred to greenhouse conditions to complete their development.

Figure 13. Double Haploid Plants

Haploid and double haploid plants grown in the greenhouse are examined (Figure 13). Double haploid plants transferred to pots are kept in greenhouses with 80% humidity, a constant temperature of 17 °C and a photoperiod of 16 hours of daylight/8 hours of darkness until they mature.

Figure 14. Spike Samples of Double Haploid (a) and Haploid (b) Plants

Double haploid (a) and haploid (b) plants that have reached harvest maturity are harvested and threshing separately. Thus, in order to continue breeding work on fully homozygous genotypes, they are sown in breeding experimental fields next year.

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CHAPTER 7

AUTOMATED SYSTEMS IN AGRICULTURE

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INTRODUCTION

Over the years, agricultural productivity has increased significantly due to intensification, mechanization and automation. This has led to the development of automated agricultural equipment for field operations, animal husbandry systems, and cropping systems such as greenhouse climate control and irrigation systems. The implementation of mechanization in farming has not just decreased the expenses of production and alleviated the physical strain of human work, but has also enhanced the caliber of newly harvested crops and ecological management.

On the contrary, while various automation systems utilized in industry are designed for basic and repetitive tasks, the implementation of automation in agriculture demands sophisticated technologies capable of managing intricate and greatly diverse environmental factors and produce. The farming environment is intricate and lacks a strict structure, exhibiting substantial differences not only between fields but also within the same field. This complexity, coupled with environmental and genetic factors, results in a significant degree of variation in agricultural products. To meet the challenges of automation in agriculture, fundamental technologies need to be developed to meet the ever-changing conditions, variability of products and environment, sensitive products, and adverse environmental conditions.

Dynamic real-time interpretation of the environment and objects necessitates the utilization of intelligent control systems. The precision requirements for automation systems in agriculture can be lower than in industry because the cost of agricultural products is relatively low, and the cost of the automated system must also be low for it to be economically viable. In addition, it is difficult to achieve as high a utilization rate in agriculture as in the manufacturing industry because of seasonality.

Automation in agriculture has become an increasingly important part of modern farming practices. From seeding and harvesting to irrigation and fertilization, there are a variety of automated systems designed to help farmers increase efficiency and productivity. In this article, we will examine the different types of automated systems used in agriculture and how they help farmers achieve better results (Fouda, 2021).

Advancements in Field Machinery

Significant advancements in field machinery have been made in the 20th century with the introduction of tractors and an increasingly wide range of farm implements to mechanize crop production. The accomplishment has established a sturdy groundwork for mechanization, augmenting the efficiency, dependability, and accuracy of farming equipment while diminishing the requirement for human involvement, hence boosting productivity.

Examples of automation and control can be found in many agricultural operations, but the variation in agricultural systems worldwide poses a challenge for making generalizations (Schueller, 2006; Singh, 2002).

Automatic guidance, autonomous vehicle and robots

Automatic guidance systems have been developed to release operators from constantly making steering changes during agricultural operations (Keicher and Seufert,2000; Torii ,2000; Reid et al.,2000 and Wilson,2000). Furnish exemplary citations on automated vehicle control studies conducted in diverse nations. An auto-guidance system typically includes hardware components such as a steering angle sensor, a position sensor, a path planner, and a steering actuator, as well as software components such as a steering controller and a navigation controller. The position sensor provides the measured position of the vehicle, which is then compared to the desired position provided by the path planner. Based on the difference between the measured and desired positions, the navigation controller estimates the necessary steering control angle. Subsequently, the steering controller calculates an appropriate steering control signal by considering the difference between the measured and desired steering angles and sends it to the steering actuator for execution. E/H (electrohydraulic) steering systems are frequently used in modern agricultural vehicles, and improvements in each of the system parts are continuously being made (Grewal et al.,2020).

Autonomous vehicles take this technology even further, allowing machines to operate with minimal human intervention. Equipped with sensors such as GPS, LIDAR, and cameras, these vehicles can navigate through fields, plant seeds, spray crops, and harvest produce (Slaughter et al.,2008). The use of robots in agriculture is also gaining popularity, as they can perform tasks such as pruning, weeding, and fruit picking with high precision and speed.

These robots use advanced sensing technologies like machine vision to detect crops and make precise movements (Sorensen et al.,2006). Together, these technologies have the potential to increase efficiency, reduce labor costs, and improve yield quality in agriculture.

Advancements in Automated irrigation systems

Irrigation is the supply of water to crops to replace a lack of rainfall or to support crops grown in controlled environments (Sorensen et al., 2006). There are different types of irrigation methods, such as surface irrigation systems that rely on gravity to move water across the terrain and into the earth, and localized irrigation systems that distribute water through piped networks under pressure and deliver it directly to the crop and the environment. Automated irrigation systems have evolved significantly in recent years. These include irrigation timers such as electromechanical and mechanical timers, and sensors that measure soil properties and plant stress (Zazueta and Smajstrla,1992; Wanjura et al., 2004; Lailhacar et al., 2005; Evett et al., 2006; Haley and Dukes, 2007) (Figure 1).

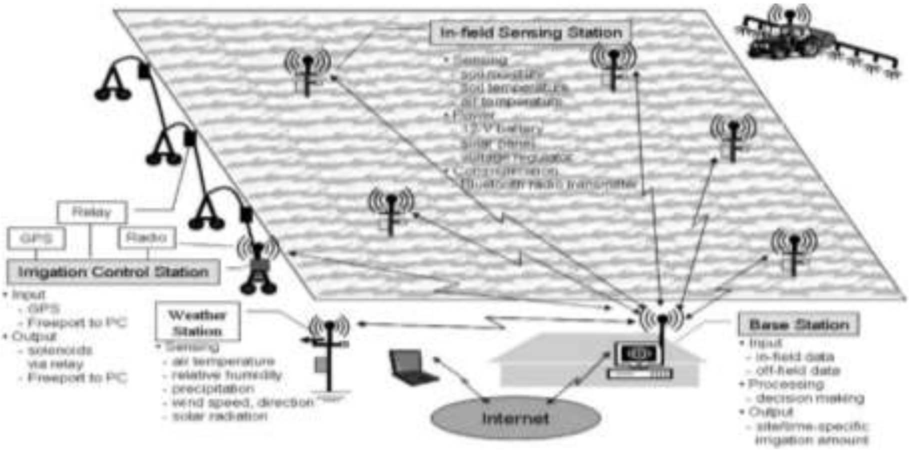

Figure1: Wireless irrigation structure conceptual layout (Edan et al., 2009)

High-resolution information on water and soil dynamics is obtained from weight-based soil lysimeters and volumetric lysimeter structures (Poss et al.,2004; Raut and Shere,2014). The development of scheduling programs that use weather data to recommend and control the timing of irrigation, crop growth stage, and the amount of water and nutrients required in real time, has resulted in a significant advance in automated irrigation systems (Upcraft et al.,1989; Hess,1996). Commercial produce monitors and remote sensors are also used to accurately map crop production.

In addition, wireless sensor-based irrigate on management structures have been developed to provide variable rate irrigation. Real-time control signals are sent by a computer to irrigation controllers through wireless communication based on GPS sprinkler locations and field information, thus controlling the irrigation (Peters and Evett,2005). These advances in irrigation management allow efficient control of labor and water use across all techniques by controlling the amount, duration, and frequency of water application precisely at the point of application.

Advances in automated seedling production

Automated seedling production is a critical technology for ensuring high-quality yields in vegetable and fruit production. Over the years, various seedling production operations, such as seed selection, transplanting, seeding, grafting, irrigation, staking and pruning, have undergone mechanization or automation. (Kittas et al.,2001; Edan et al.,2009).

There are even reports of fully automated factories for seedling production, including specialized seeders that can seed in a similar orientation (Edan et al., 2009).

In addition, commercial transplanting and grafting robots have been developed for transferring seedlings from one cellular provider to another or to a cellular tower(pot) (Van Henten,1994; Weiss and Biber,2011).

These advances in automated seedling production are revolutionizing the agricultural industry and ensuring that high-quality products are always available.

Advances in automated spray technology

Automation of chemical sprays is necessary to enable precise crop production while reducing chemical exposure. In recent years, the commercialization of robotic sprayers has been reported (Gavric et al.,2011; Bac et al.,2014). A key feature of these robots is their ability to control the vehicle independently, which allows for more precise application of chemicals.

To achieve this, the front axle of machines with self-steering can be easily rotated about an axis A-B that is diagonal to the body, resulting in a change in the direction of the vehicle's motion (Morimoto and Hashimoto, 2000). To achieve a higher accuracy in the steering angle, a decrease of 35 millimeters in the rear tread is implemented compared to the front tread.

Another automatic spray technique is electromagnetic induction. Induction wires are laid under headland and/or ridge cuts, and a vehicle with an induction sensor can automatically move along the wires, ensuring more precise application of chemicals. Various techniques have been devised for vehicles journeying towards the next ridge to cut thin headlands in greenhouses, such as four-wheel steering, a pivot shaft protruding for rotation, an added rail system transporting the vehicle to the subsequent cut, and a manual approach.

In 1993-1994, automatic sprayers utilizing induction tubes and wires were created and used in orchards, respectively (Arima et al., 1994a, b). The use of remote-controlled helicopters for spraying has also been reported in the fields. These advances in automated spraying technologies are revolutionizing the agricultural industry and making precision farming more efficient and effective.

Development and challenges of fruit harvesting robots

Robotic fruit harvesters have been created to collect a range of crops, such as tomatoes, cucumbers, eggplants, strawberries, and cherry tomatoes. As mentioned by (Kawamura et al.,1984), the history of agricultural robots began with the development of a tomato harvesting robot, first studied at Kyoto College in 1982.

Over the years, various types of tomato harvesting robots have been developed, the main components of which are an end effector, an image processing system, a manipulator, and a driving device, as shown in Figure 2 (Kondo et al.,1993; Subrata et al.,1997). The robot is designed to automatically move between ridges and breaks in front of a plant and determine its position in the greenhouse using reflective plates and photosensors on the ridges.

After the moving device comes to a halt, the image recognition system analyses the color and position of the fruit, following which the manipulator advances towards the cluster and the end effector plucks a fruit. Upon completion of the task at hand, the robot moves on to the next site on the reflective plate (Kondo et al.,1994; Subrata et al.,1997). Despite the slow operating speeds, fluctuating crop features, and seasonal expenses posing limitations on the commercialization of harvesting robots, it is highly probable that they will be put to practical use in the future (Kondo et al.,1998).

Figure 2: A tomato Harvesting robot (Liu et al, 2021)

Automation in greenhouses

Greenhouse automation is a relatively simple process due to the structured nature of the environment. The variability of agricultural products is the main reason for automation. Climate regulation, spraying, seedling cultivation, and harvesting are all aspects addressed by the advancement of automated systems for greenhouse operations (Simonton, 1990).

One of the most important areas of automation in greenhouses is climate control, which involves retaining solar radiation energy and protecting plants from harmful natural influences and insects. Microcomputers and sensors have led to the latest greenhouse operations that include irrigation, plant nutrient management, and climate control to provide the best growing conditions for plants throughout the year. Climate control in greenhouses involves monitoring various parameters, including CO2 concentration, airflow, light, temperature, and humidity (Monta,1997a, b).

Control models for greenhouse climate control should consider weather forecast models, greenhouse models, and plant growth models, due to the need to account for multiple non-linear and interconnected factors, regulating the climate in a greenhouse necessitates careful attention. Control methods include soft computing methods with artificial intelligence, classical methods, and advanced control methods. Control is achieved with microcomputers or programmable logic controllers (PLCs) (Albright, 2001; Bailey, 2004).

In the future, climate controls will be developed that use on-line measurements of plant temperature, fruit growth, and fruit quality to approximate photosynthesis and actual transpiration. This will enable the development of closed-loop systems that use plant response as feedback to the control system, leading to more efficient greenhouse climate regulation. Effective greenhouse climate regulation must also include long-term management strategies to improve quality and profitability (Daskalov et al, 2006; Serodio et al.,2001).

In addition, the Arduino platform can also be used to control greenhouses for experimental purposes (Kraiem, et al.,2022). The Arduino platform provides an open-source and flexible environment that enables the development of customized and low-cost greenhouse control systems.

Automation systems in animal husbandry

Advances in animal husbandry have also been made in sheep and pig farming. For example, Advanced shearing automatons have been created and are presently in commercial utilization within Australia. The actual shearing of wool is controlled by hydraulically positioned shearing machines with force feedback, while trajectory calculations are continuously updated during the shearing process (Perez et al.,1998).

In addition, various feeding systems are used in sow management, including electronic catering services for commercial purposes structures that feed one at a time and computer-controlled structures that allow sows to eat from 1/2 feed formulations to meet their nutritional needs (Lopes et al.,2002; Wang et al.,2006).

Furthermore, weighing systems based on imaging systems and mechanical scales have been developed (Schofield et al.,2002), and physiological variables are measured using image analysis and ultrasound probes to determine back fat to monitor feeding and growth of animals (Tillett et al.,2002; Xin and Shao,2005). These advances have greatly improved efficiency, productivity, and animal welfare in the industry.

Continued research and development are expected to drive further technological advances in the future (Harrell et al., 1990; Hoyt et al., 2007; De Villiers, 2008).

Conclusion

This chapter has provided an overview of the major advances in automation systems in various areas of agriculture. In this regard, field machinery, automatic steering, autonomous vehicles, and robots have shown promising results in terms of precision, efficiency, and cost-effectiveness. Automated irrigation systems, seedling production and spraying technologies have also been extensively researched and have led to significant improvements in crop yield and quality. The development of robots for fruit harvesting has brought both opportunities and challenges, particularly in the areas of fruit detection, manipulation, and transportation. In addition, automation systems in livestock, including feeding, shearing, weighing, and monitoring, have contributed to livestock welfare and productivity. Overall, the automated technology in farming has significant promise for enhancing sustainable agriculture and tackling the issue of global food security. However, additional investigations are necessary to refine their effectiveness and guarantee their economic feasibility.

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CHAPTER 8

ADVANCEMENTS IN AGRICULTURAL SENSOR TECHNOLOGY

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INTRODUCTION

In recent years, the demand for more effective and sustainable agricultural practices has driven the growing momentum in the field of precision agriculture Utilizing sensors to gather information on soil conditions, weather patterns, and crop vitality is a crucial component of precision agriculture. These sensors can be integrated into automated systems to enable real-time decision making, resulting in improved efficiency, less waste, and reduced environmental impact.

In this chapter, we will explain the different sensors used in agriculture and their applications, as well as how these sensors can be integrated into automated systems to develop smart solutions for agriculture. The integration of these sensors into automated systems requires the use of different types of networks, which are essential to fully integrate the sensors into automated systems.

Research has demonstrated that implementing automated systems and sensors in agriculture can enhance crop yields, reduce resource consumption, and minimize the negative effect of agriculture on the climate. This has led to significant advances in agricultural sensor technologies, with recent developments focusing on the use of artificial intelligence and machine learning in information analysis and decision making. However, the use of these technologies also presents some challenges.

Some of the challenges are the exorbitant expenses associated with the adoption of these technologies and the requirement for particularized education to operate and uphold them. In addition, there is a need for continued research and development to overcome the limitations of these systems, such as the need for better standardization of data collection and analysis.

By providing a comprehensive overview of the various sensor categories and networks utilized in agriculture, we hope to contribute to ongoing efforts to improve agricultural practices. We will also highlight recent advances in agricultural sensor technologies and identify potential areas for future research and development, encouraging further innovation in the field.

Employing sensors for agricultural purposes

Sensors play a critical role in agriculture by collecting information about physical and environmental characteristics. These data are used to identify people, objects, places, and their conditions, which is called context. The collection of contexts is particularly valuable in modelling situations with a variety of time-varying attributes, which are common in agriculture.

However, parallel and distributed applications and processing, as well as wireless sensors and actuators, are required to meet agricultural needs such as collecting weather, crop, and soil information, monitoring distributed areas, managing multiple crops on a single piece of land, and accommodating different crop needs depending on weather and soil conditions.

Therefore, wireless sensors, actuators, and their networks are a promising tool for developing systems that sense context, relay sensed data to remote systems for decision support, and provide a controlled environment based on decisions. Table 1 (Rehman et al.,2014) shows the different types of sensors used in agriculture to capture different attributes, depending on the type of sensor.

These sensors include those that measure temperature, humidity, moisture, light, gas, and various other parameters. Agricultural sensors, utilizing wireless connectivity, can be installed and repaired in drones, weather stations, and agricultural robots. Mobile applications, tailored for this purpose, provide precise control. The sensors can be managed through Wi-Fi or cell phone applications that interface with cell towers (Vangala et al., 2020). There are many uses for sensors in agriculture that can take away much of the privilege of farmers.

The invention of agricultural sensors was driven by the need to meet the increasing demand for food production while minimizing the use of scarce resources like water, fertilizer, and seeds (Patricio et al., 2018). Their user-friendliness, easy installation, and low maintenance costs make them a desirable option. Moreover, these sensors are reasonably priced, yet offer superior quality. Additionally, they have the capability to gauge pollution levels and monitor global warming trends within crops and fields. To top it all off, they come with a wireless chip, enabling remote control functionality.

Table1: Some popular sensors used in agricultural applications (Rehman A et al.,2014)

Domain	**Sensor Name**	**Temperature**	**Moisture**	**Dielectric Permittivity**	**Rain/Water Flow**	**Water Level**	**Conductivity**	**Salinity**	**References**
Soil	Hydra Probe II soil sensor	✓	✓	✓	✓✓	✓			www.stevenswater.com
Soil	Pogo portable soil sensor	✓	✓✓		✓				www.stevenswater.com
Soil	MP406 Soil moisture sensor	✓	✓✓						www.ictinternational.com.au
Soil	ECH2O soil moisture sensor	✓	✓✓		✓				www.ictinternational.com.au
Soil	EC sensor (EC250)	✓		✓		✓	✓		www.stevenswater.com/catalog/products/water_quality_sensors/manual
Soil	ECRN-50 low-REC rain gauge				✓				www.decagon.com
Soil	ECRN-100 high-REC rain gauge				✓				www.decagon.com
Soil	Tipping bucket rain gage				✓				www.stevenswater.com
Soil	107-L temperature Sensor (BetaTherm100 K6A1BThermistor)	✓							www.campbellsci.com/107-l
Leaf Plant	237 leaf wetness sensor		✓						www.campbellsci.com
Leaf Plant	LW100, leaf wetness sensor		✓						www.globalw.com/lw100b.pdf
Leaf Plant	SenseH2™ hydrogen sensor		✓✓						www.ntmsensors.com
Leaf Plant	Leaf wetness sensor		✓						www.decagon.com
Leaf Plant	YSI 6025 chlorophyll sensor							✓	www.ysi.com/ysi_6025.pdf
Leaf Plant	Field scout CM1000TM								www.specmeters.com/pdf/2950fs.pdf

✓ : Indicates that the sensor measures the corresponding parameter
✓✓: Indicates that the sensor has high sensitivity for the corresponding parameter
– : Indicates that the sensor does not measure the corresponding parameter or no data is available

- Acoustic sensor technology is useful in agriculture for detecting differences in noise levels to which different tools are exposed, such as during tillage, harvesting and fruit picking. This low-cost sensor offers a fast response time, making it suitable for portable equipment (Roy et al.,2020). Figure.3(a) displays a visual representation of this sensor.
- FPGA-based sensor technology is used in agriculture to measure transpiration, irrigation, and plant moisture in real time (Roy et al.,2020). However, its use is limited due to size, cost, and power consumption. The FPGA-based sensor can overcome these limitations and provide an acceptable solution for certain applications. Figure.3(b) displays a visual representation of this sensor.
- Light reflectance is utilized by optical sensors to gauge soil moisture, soil organic matter, mineral composition, clay concentration, color, and other parameters. The fluorescence-enabled optical sensor is an effective tool for tracking fruit maturation, whereas the optical microwave sensor can ascertain the coverage of trees and similar crops. Figure.3(c) displays a visual representation of this sensor.
- The cost-effective Ultrasonic Ranging Detector is adaptable, user-friendly, and suitable for diverse uses, including sample collection, tank supervision, and spray distance measurement. In combination with a camera, this detector is capable of weed identification and plant height estimation. Figure.3(d) displays a visual representation of this sensor.
- Moisture gauges are used to measure moisture, which helps farmers regulate their crops by allowing them to dry the grain to the desired moisture level. Figure.3(e) displays a visual representation of this sensor.
- Airflow sensors detect the composition, breathing behavior, and water level of the ground to differentiate among various types of soil. This device generates a distinct pattern by identifying numerous characteristics of the soil, including density, consistency, and hydration level. Figure.3(f) displays a visual representation of this sensor.
- Electrochemical detectors gauge the levels of nitrogen, macro- and micronutrients, and soil salinity in the soil, and have the potential to supplant conventional soil analysis that is frequently costly and takes up a lot of time. Figure.3(g) displays a visual representation of this sensor.
- By utilizing electrical circuits, electromagnetic sensors identify the ability of soil particles to carry or transmit electric charges. These

sensors have the capability to quickly evaluate the remaining nitrates in soil that consists of organic materials. Figure.3(h) displays a visual representation of this sensor.

- Mass flow sensors quantify the volume of particulate flow and furnish valuable data on yield, thus facilitating yield monitoring. They find extensive application in harvesters, with the crop management system encompassing additional constituents like a seed moisture sensor, a digital memory device, and an inbuilt program for data analysis. Figure.3(i) displays a visual representation of this sensor.
- Stand-alone devices with optics and electronics are used to identify and treat weeds, known as weed detection sensors (Castellanos et al.2020). These sensors can greatly decrease the need for herbicides, resulting in consistent savings on application costs due to minimal chemical use. Figure.3(j) displays a visual representation of this sensor.
- Wind speed sensors measure wind speed using physical devices that rotate wind cups and stimulate the internal sensors to generate a signal that is utilizable in computing the velocity of the wind. Figure.3(k) displays a visual representation of this sensor.
- The exchange of water vapor, carbon dioxide, and energy between the Earth's surface and the atmosphere can be measured using Eddy covariance technology (Nawandar et al.,2019). This technology is valuable in comprehending the impact of climate change on agriculture and ecosystems.Fig.3(l) displays a visual representation of this sensor.
- The Soft Water Level-Based (SWLB) sensor is employed in agricultural catchments for evaluating hydrogeological properties, including water level and flow rate, utilizing personalized sampling periods (Matilla et al., 2021). This device functions by gauging precipitation, stream flow, and indicators of water presence. Figure.3(m) displays this sensor.
- The utilization of Light Detection and Ranging (LIDAR) sensors is extensive in multiple agricultural applications, including but not limited to, segmenting and mapping, 3D modeling of farms, soil classification, erosion assessment, and yield prognosis. Furthermore, LIDAR is frequently implemented to acquire additional measurements of fruit tree leaf area and can be integrated with GPS technology to produce a comprehensive 3D map. Additionally, the estimation of biomass for various plant species and trees is another common usage of this technique (Cisternas et al., 2020). Figure.3(n) displays a visual representation of this sensor.
- The use of telemetry sensors facilitates the exchange of information

between two distant sites. These sensors are capable of gathering data from various remote locations, providing insights into the performance of different machines and recording their locations to avoid unnecessary revisits (Pathak et al., 2019). By leveraging these services, agricultural managers can effortlessly track and maintain a comprehensive record of their operations, thus optimizing their environmental impact and maximizing benefits (Akhter et al., 2021). Figure.3(o) displays a visual representation of this sensor.

- The sensor for soil water content has the ability to determine the water content present in the crop field and provide an estimation of the water stored in the soil horizon (Chlingaryan et al., 2018). It is important to note that the sensor does not measure moisture directly in the soil (Shafi, et al., 2020), but rather detects changes in other soil properties that are indicative of water content. Figure.3(p) displays a visual representation of this sensor.
- According to Daskalakis et al. (2017), GPS satellites are relied upon by the location sensor to determine the latitude, longitude, and elevation of any location within the area of interest. The measurement range indicates the distance range from the sensor at which measurements can be acquired, while the resolution specifies the smallest possible position increment that the sensor can measure. Figure.3(q) displays a visual representation of this sensor.
- The surface or soil moisture presence can be detected by the leaf wetness sensor, primarily utilized in environmental applications (Tsouros et al., 2019). Additionally, the leaf moisture sensor can monitor factors that promote the emergence and expansion of fungi on plant surfaces. To measure the electrical resistance of the water film on the leaf surface, the sensor features a surface contact (Pallottino, et al., 2019) Figure.3(r) displays a visual representation of this sensor.
- An apparatus that is used for the purpose of measuring temperature is called a temperature sensor, as defined by Daskalakis et al. (2018). The temperature measured can be that of air, liquids, or solids. Various techniques and principles are employed by different types of temperature sensors to take temperature readings Figure.3(s) displays a visual representation of this sensor.
- Farmers can respond to field conditions, such as low water levels, by using moisture sensors that trigger a stress response (Jiang, et al., 2021). These sensors estimate soil moisture content by analysing the dielectric frequency of the soil, which refers to its ability to conduct electricity. Figure.3(t) displays a visual representation of this sensor.
- The utilization of PH sensors is crucial in detecting nutrient deficiencies and undesirable chemical properties in the soil (Khanna

et al., 2019; Thenmozhi et al., 2018). By employing these sensors in smart agriculture, the agricultural sector can gain valuable insights into the soil's pH and nutrient levels, which are continually monitored for any fluctuations. Figure.3(u) displays a visual representation of this sensor.

- Using an optoelectronic device that aids in the differentiation of different plant species, thereby aiding in the detection of undesirable plants such as weeds and herbicides in widely cultivated crops Figure.3(v) displays a visual representation this sensor.

Figure 1: Various Types of IoT Sensors in Smart Agriculture (M.Pyingkodi et al.,2020)

Applied networks in agriculture

Sensor networks are becoming increasingly popular in agriculture because of their ability to collect data in real time, providing insights into crop growth, soil moisture content, weather conditions, and more. These networks can be either wired or wireless, with each option offering its own advantages and disadvantages.

Wired sensor networks tend to be more reliable and secure than their wireless counterparts, but they can be more expensive to install and maintain. In agriculture, wired sensor networks are often used to monitor soil moisture and nutrient levels, as well as weather conditions such as temperature, humidity and precipitation. Data collected by these sensors can be transmitted to a central server for analysis, allowing farmers to make informed decisions about irrigation, fertilization and other agricultural practices.

Wireless sensor networks, on the other hand, are often less expensive and easier to install than wired networks. They can be deployed in remote or hard-to-reach areas and allow farmers to monitor crop growth and weather conditions across their operations. Wireless sensor networks are commonly used to monitor crop growth and development, as well as soil moisture and weather conditions. The data collected by these sensors can be transmitted to a central server via wireless communication technologies such as Wi-Fi, Bluetooth, ZigBee, LoRaWAN, NB -IoT or cellular networks (Rehman et al,.2008).

To compare the different communication technologies used in agriculture (Akyildiz, et al,.2002 ; Yick. J et al,.2008 ; Vlajic et al,.2010), the following table shows the main features and capabilities of wired, Wi-Fi, Bluetooth and Zigbee networks.

Table 2: Comparison of Wireless Communication Technologies for Sensor Networks

Communication Technology	Classification	Data Speed	Power Consumption	Charge
Wired	Short	High	Low	High
Wi-Fi	Medium	High	Medium	Medium
Bluetooth	Short	Low	Low	Low
Cellular	Long	High	High	High
ZigBee	Medium	Medium	Low	Low
LoRaWAN	Long	Low	Low	Low
NB-IoT	Long	Low	Low	High

In summary, both wired and wireless sensor networks have their place in agriculture, with each option offering its own advantages and disadvantages. Farmers should consider factors such as cost, reliability and data transmission requirements when selecting a sensor network for their operation.

Conclusion

In conclusion, the integration of sensors in agriculture has ushered in a new era of data-driven farming practices. By collecting and analysing information about soil, weather, and crop conditions, sensors have enabled real-time monitoring and decision-making in various agricultural areas. Both wired and wireless sensor networks have played a pivotal role in providing valuable insights to farmers, empowering them to optimize resource management and enhance sustainable agricultural practices.

The benefits of sensor technology in agriculture are manifold. Farmers can now implement targeted irrigation and fertilization strategies, resulting in improved resource efficiency and higher crop yields. Real-time monitoring of soil moisture, nutrient levels, and weather conditions enables proactive pest and disease management, minimizing losses and maximizing productivity. Moreover, the ability to deploy sensors in remote or hard-to-reach areas expands the scope of agricultural monitoring, ensuring comprehensive coverage of farming operations.

While the integration of sensors has shown tremendous potential, further research and development are crucial. Refining the effectiveness of sensors, addressing technical challenges, and optimizing economic feasibility are essential for widespread adoption and long-term viability. Collaboration between researchers, technology developers, and farmers will be vital in advancing sensor technology and tailoring it to meet the diverse needs of agricultural contexts.

In summary, the integration of sensors in agriculture holds great promise for enhancing sustainable farming practices and addressing global food security challenges. By leveraging real-time data and advanced analytics, farmers can make informed decisions, optimize resource management, and increase productivity. The ongoing advancements in sensor technology will drive the future of agriculture, ensuring a more efficient, resilient, and environmentally conscious farming sector.

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CHAPTER 9

GENOME-WIDE ASSOCIATION IN PEANUT

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1. Introduction

Crop improvement programs in general are focused on enhancing productivity, improving quality and resilience to biotic and abiotic stress by generating and/or harnessing genetic diversity. Genomics-assisted breeding has accelerated crop improvement programs for development of improved cultivars in several crops. Availability of high density genotyping platform with uniformly distributed genome-wide genetic markers must have genomic resource in a crop for high resolution genetic dissection of complex traits and tracking the favorable alleles in a breeding population.

It has been shown that methods like genome-wide association study and genomic selection can effectively find molecular markers linked to characteristics of interest in agriculture. Since they are affordable and can be processed in a high-throughput way, single-nucleotide polymorphisms (SNPs) have become the preferred molecular marker. Genome-wide association studies can efficiently identify SNP markers associated with traits of interest.

Biology can only be fully understood by understanding the genetic architecture of complex traits. According to Mackay et al. (2009), the majority of traits with agronomic and evolutionary significance are complex traits that are impacted by a variety of genetic loci, environmental factors, and how those factors interact. Simple sequence repeat (SSR) and amplified fragment length polymorphism (AFLP), which are mostly gel-based markers and have a limited capacity to perform rapid analysis on a large number of marker loci, are the fundamental DNA-based marker systems used in mapping the most complex traits in various crop species. The most modern and effective mapping tools are Single Nucleotide Polymorphism (SNP) and the Diversity Arrays Technology (DArT) marker system, and they become more reliable when combined (Odesola et al., 2023).

The next-generation sequencing (NGS) platform includes a revolutionary platform called Diversity Array Technology sequencing (DarTseq), which was developed for simultaneously finding single nucleotide polymorphisms (SNPs) in populations, particularly non-model germplasm sets (Raman et al., 2014). Reducing complexity by using restriction enzymes that target gene-rich regions is the core of this approach to understanding genetic variation. It uses DarTseqTM technology to completely cover the genome, resulting in a high-density genetic map that increase the chance of discovering

QTL (Thudi et al., 2011). The combination of SNPs and the NGS reported for other crops of interest had been identified to bring uniqueness to the identification of genetic variants (SNPs), phylogenetics, germplasm assessment, and population structure (Odesola et al., 2023).

2. Genome-wide association studies

By comparing the allele frequencies of genetic variants in individuals with similar ancestry but different characteristics, genome-wide association studies (GWAS) seek to find relationships between genotypes and phenotypes. Genome-wide association studies examine thousands of genomes and analyse hundreds of thousands of genetic variants to identify those statistically linked to a particular characteristic or disease. With the expansion of GWAS sample sizes, it is expected that this methodology will continue to produce an increasing number of robust associations for a variety of traits and disorders. The results of GWAS can be used for a variety of purposes, including understanding the underlying biology of a phenotype, calculating its heritability and calculating genetic correlations (Uffelmann et al., 2021). The most frequent DNA sequence variations in genomes that can be utilised to link genotypic variation to phenotype are SNPs. Because of this, having a high-density SNP array with consistent genome coverage can enhance genetic research and breeding applications (Pandey et al., 2017).

Modern computational genetics has presented challenges with regard to the efficient management, storage, and analysis of GWA data. Numerous SNPs are genotyped in tens of thousands of individuals and controls as part of GWA research, which provide enormous volumes of data. Each SNP's data is subjected to many sorts of research, including frequency distribution characterisation, testing for Hardy-Weinberg equilibrium, investigation of associations between certain SNPs and haplotypes and particular phenotypes, and more (Aulchenko et al., 2007).

In several key crop species, genome-wide association studies have examined features that are crucial for agriculture and have found genomic areas linked to a variety of agronomic, physiological, and fitness factors, including as flowering time, plant height, kernel quantity, stress tolerance, and grain production. Additionally, researchers have investigated in geographic divergence, adaptations during domestication, and biochemical and molecular characteristics including flavonoid, fatty acid, amino acid, and nucleic acid metabolites. GWAS can be carried out for a variety of purposes, including marker-assisted selection, gene cloning research, stand-alone investigations, and more. Utilising this knowledge consequently speeds up crop breeding. Genome-wide association studies have also been used to enable genetic engineering, as in the case of transgenic drought-tolerant maize developed after detection of ZmVPP1 by GWAS (Tibbs Cortes et al., 2021).

3. GWAS in peanuts (*Arachis hypogaea* L.)

Arachis duranensis (AA, 2n = 20) and *Arachis ipaensis* (BB, 2n = 20) are two wild diploid species, while the domesticated peanut (*Arachis hypogaea* L.) is an allotetraploid (AABB, 2n = 40) with homoeologous A and B genomes (Moretzsohn et al., 2012). The two subspecies of cultivated peanut, *hypogaea* and *fastigiata*, are distinguished by the presence or lack of floral axes on the main stem. In subspecies *fastigiata*, flowers appear on leaf axils on branches in addition to the main stem, but subspecies *hypogaea* is often described as having a prostrate growth style with no floral axes on the main stem (Zhang et al., 2017).

Given that the polyploidization process very recently happened, there is extremely low genetic diversity in cultivated peanuts (Kim et al., 2017). Peanut subgenomes are very closely related (Moretzsohn et al., 2013) and have an estimated repetition rate of 64%, which makes the assembly of peanut genome sequences extremely difficult. *A. duranensis* and *A. ipaensis*, the diploid ancestors of cultivated peanut, had their genome sequences published in 2016, which served as the foundation for comprehending the cultivated peanut genome (Bertioli et al., 2016). The biology, evolution, and genome alterations of the cultivated peanut were better understood thanks to the sequencing results of *A. duranensis* (A genomic progenitor) and *A. ipaensis* (B genome progenitor), which also accelerated up the molecular breeding of peanut variants (Chen et al., 2016). The genomes of the related diploid *A. duranensis* and *A. ipaensis* and the cultivated peanut allotetraploid *A. hypogaea* were recently sequenced and compared. The allotetraploid subgenome has been determined to contain a total of 39,888 A subgenome genes and 41,526 B subgenome genes (Chen et al., 2019). The re-sequencing of two Korean peanut germplasms, K-Ol and Pungan, resulted in the development of numerous SNP and cleaved amplified polymorphic sequence (CAPS) markers, demonstrating the value of molecular marker information for peanut breeding programmes (Kim et al., 2017). Development of SNP array chips for high-throughput genotyping is required due to the cultivated peanut's comparatively large genome size and minimal genetic diversity. SNPs, which are the most prevalent type of DNA sequence variation in the genome, can be used to link genotypic changes to specific phenotypes. Highdensity SNP arrays have been developed for high-resolution mapping of crops and are widely used in many applications that require a large number of molecular markers, such as high-density genetic profiling, GWAS, and genomic selection (Pandey et al., 2012). The whole-genome association study, or GWAS, is an observational study of a genome-wide set of genetic variants in various individuals to determine whether any variant is connected to the desired attributes (Tam et al., 2019). Quantitative trait loci (QTL) mapping is one of the mapping techniques that could be used to link any phenotypic differences back to the underlying causal loci. Numerous research teams have employed GWAS to find relationships between genotypes and phenotypes and to learn about unique biological pathways (Zou et al., 2020). According to Allen et al. (2017), the majority of GWAS have been conducted utilising high-throughput SNP data acquired from SNP arrays with a wide range of allele frequencies and a higher density of variations. GWAS can be carried out with a variety of tools and software, and the format is simple to exchange and generate (Zou et al., 2020).

For peanut breeders looking to expand the genetic foundation of breeding materials and incorporate significant alleles linked to desirable qualities, a variety of germplasms with high genetic diversity are ideal resources (Zhao et al., 2018). Through ongoing breeding programmes, several germplasms of peanuts have been exploited to improve yield potential, introduce disease and insect resistance, and enrich genetic resources (Zou et al., 2020).

A core collection is a subset of all accessible germplasm resources that preserves the majority of a species' genetic diversity while allowing for the effective use of genetic resources and the identification of germplasms with desirable traits (Jeong et al., 2019). To overcome the size issue, core collections have been constructed for important crop species. A core collection was originally described as "a limited set of accessions" showing genetic diversity with a low level of repetition in the entire collection. Currently, core collections have been built for over 30 species, including peanut (*Arachis hypogea* L.). Numerous studies have assessed different methods for building core collections of many crop species. These strategies include random, proportion, constant, logarithmic, and genetic diversity-based methods. Among them, genetic diversity-based method has been considered the simplest and the most efficient (Odong et al., 2013).

In peanuts, GWAS studies have been conducted for leaf spot resistance (Zhang et al. 2020), root-knot nematode resistance (Kumral, 2019), yield and yield components (Wang et al. 2019; Zhou et al. 2021), and amino acid profiling (Martino et al. 2017). Genomic selection models have also been built for yield and yield-related traits in peanuts (Ravelombola et al., 2023). Yu et al., (2020) identified 60 associated SNPs through GWAS in the Chinese peanut mini-mini core collection.

The use of GWAS to investigate the genetic basis of significant features in peanut has increased (Pandey et al., 2017), although the majority of these research are constrained by the finite number of markers that can be employed. In the past decade, the fast developing next-generation sequencing (NGS)-related technologies, such as reduced-representation sequencing including genotyping-by-sequencing (GBS), restriction-site-associated DNA sequencing (RAD-seq), specific-locus amplified fragment sequencing (SLAF-seq), and single nucleotide polymorphisms (SNP) array, have generated a large amount of SNPs that provide us a great opportunity to use GWAS for studying the genetic base of crop traits (Wang et al., 2019). Now, NGS-based GWAS has been proved to be a cost-effective tool with great resolution for detecting important QTLs in crops. In peanut, a high-density SNP array ‘Axiom_Arachis’ with 58K SNPs that has a genome-wide coverage has been developed from 41 peanut accessions and some wild peanut relatives (Pandey et al., 2017); this SNP array has the potential to be used for peanut genotyping, which can further help carry out GWAS analyses for dissecting important agronomic traits in peanut. (Zhang et al., 2017) identified 17,338 high-quality SNPs using the SLAF-seq method, and based on these high-quality SNPs, they have also implemented GWAS analyses to dissect the molecular basis of domestication-related agronomic traits within 158 peanut accessions. Further exploration of the genetic resources embedded within the cultivated peanut is possible by the recent release of peanut whole genome sequence data (https://www.peanutbase.org/) (Bertioli et al., 2019)

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CHAPTER 10

THE IMPORTANCE OF DROUGHT AND SOIL-WATER MANAGEMENT IN AGRICULTURAL PRODUCTION UNDER CLIMATE CHANGE

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Introduction

It is possible to consider the impact of climate change on agricultural production as drought and erosion on soil and water resources conservation.

With climate change, there will be a decrease in water resources, changes in agricultural productivity, increase in forest fires, drought, erosion, desertification, and ecological deterioration (Broadleaf Capital International. (2006).

The effective and efficient use of water should be made in agricultural irrigation, where 80% of our natural resources, especially water saving, clean water resources are used.In order to save water, first of all, it is necessary to know the water and the soil well (Pamir, 2003;Aküzüm et al.,2010). When the soil is rehabilitated with organic matter, it is ensured that both the water holding capacity of the soils increase and their porosity, that is, aeration, and thus a healthy microbial activity occurs.

Irrigation is defined as the completion of the part of the plant that cannot meet the water needed for growth and development from precipitation and soil moisture. Soil properties are not taken into account sufficiently in irrigation applications and the irrigation program is calculated according to the plant pattern. Determining and completing the missing water in the plant growth medium will only be possible with soil management. At this point, soil management emerges as a necessity that should not be separated from water management.

Today, the understanding of deficient water in both rural and urban irrigation manifests itself as excessive and misuse of water with the approach of irrigating the soil to the saturation point.

Irrigation of the soil to the saturation point or more in each irrigation will stop the development of the plant, as well as the excessive water washing the soil, resulting in barrenness and infertility in the soils.

In agricultural irrigation, the water holding capacity of the soil should be known and accordingly irrigation should be provided according to the useful water capacity.

In general, agricultural and urban irrigation in Turkey is carried out above this capacity according to the saturation point. This situation causes the soils to become barren due to the waste and excessive use of water, and to decrease the yield and quality of the product. Agricultural water management plays a key role in controlling drought.

It has been demonstrated by scientific studies that increasing soil organic matter reduces agricultural water use.It has also shown that it has an effect on product quality and yield. Irrigation was made with the addition of organic matter and by monitoring the soil moisture, and it was determined that the yield, which was 650 kilograms, reached 750 kilograms under optimum conditions. Application made by utilizing the ability of organic matter to increase the water holding capacity of the soil. This increase in yield was achieved by maintaining the water and soil-moisture balance in the soil. Although the amount of water gradually decreased in the study, a significant increase in yield was observed (Karagöz, 2015).

As can be seen from here, it is understood that the understanding of excess yield is an understanding that puts the future of natural resources in danger. As a result of the study, it was seen that the genetic potential of the product could be increased by giving measured water.. However, monitoring of soil moisture is not sufficient for water management. In addition, another important factor, the climate, should be monitored. Climate organizes the components of ecology and causes different needs in different conditions.

For example, it has been revealed that sugar beet (beta vulgaris), one of the most important industrial plants, has different soil and water needs in different climatic zones (Özaydin, et al.,2015,).

With climate change, different soil and water conditions emerge, changing climatic conditions cause floods, storms and other natural disasters in some regions, while water shortages and droughts occur in other regions.Drought is the most insidious natural disaster and its effects are the most dangerous in the long run (Bayraç and Doğan, 2016;Kahriman, 2020).

Drought plans should be made in the long term in order to be affected by the damage of this disaster in the least possible way.

Climate Change and Drought

Drought, which is one of the important events caused by climate change, is defined as a natural disaster that affects all natural resources. Among the 28 types of meteorological disasters observed in the world, one of the most important is drought. Drought, which is seen as one of the natural disasters brought by climate change and the most dangerous, has increased by more than 100% in the last 40 years all over the world. Drought severity and duration are increasing in many parts of the world, triggering a series of disasters **(FAO, 2022).** Drought is defined as the decrease in the amount of falling precipitation, but the form, severity and season of the falling precipitation are also very important for human life. Drought has been classified as meteorological, hydraulic, agricultural and socio-economic in the literature. Many studies include definitions of drought varieties. In general, agricultural drought is defined as the lack of sufficient water in the root zone of the plant and is taken into account in soil water management in agriculture (Mukherjee et al.,2018; Cook et al., 2018; Li, et al., 2009).

Global climate change, drought affects not only the living habitat but also the product quality and decreases the market value.The negative effects of global climate changes seen during phenological events including flower, maturity and seed periods also affect the existence of vegetation. It is adversely affected on vegetation, flowering and fruit formation. This causes the harvest time to change and the quality to decrease.

As a result of climate change, high temperatures have started to be seen with the change of climate zones and low yield and quality of vegetables grown at low temperatures have begun to be seen in the ongoing agricultural production in these regions. In some regions in Korea, it has been observed that the locations of orchards have changed by shifting to the north.In the researches, it has been observed that as the temperature increases, the yield of agricultural products specific to the region decreases (IPCC, 2014). The resulting economic loss is an unpredictable development even in climate change scenarios

The structure, composition, productivity and geographical distribution of many ecosystems will also change, especially for endemic species, as they will react at different levels in different temperature, humidity, evaporation and subsequently biological activity conditions with the deteriorated precipitation regime (Uzunoğlu et al., 2015). Thus, it is inevitable that plant and animal habitats will change in the future, and the emergence of new species or the adaptation of known species.

At the United Nations (UN) meeting held on September 25-27, 2015, a new global development roadmap was drawn with the “Agenda 2030 UN Sustainable Development Goals” and environmental issues such as sustainable cities, climate change, combating drought, and conservating biodiversity were brought to the agenda. Climate change affects all countries without borders, regardless of their level of development. In 2017, climate and weather-related disasters around the world cost thousands of lives and caused US$320 billion in damage (Pamir, 2003; Anonymous, 2023).

However, due to climate change, excessively increasing temperature and decreasingprecipitation in the world increase the continuity and possible negative effects of drought. The process of combating drought is much more difficult than other natural disasters, as this disaster starts very slowly, affecting very large areas cumulatively for months or even years.

Drought and Combat Ways In Terms of Soil and Water Management

Agriculture; Based on natural resources such as soil, water, vegetation, its economic value, social impact, and product yield and quality depend entirely on climatic conditions and ecology.

Drought is a disaster that develops slowly in the long term and its severity is felt the most. For this reason, it is necessary to take precautions in the long term, monitor the symptoms and evaluate them in a short time.It is possible to say that the effects of this type of disaster, which firstly affected agricultural areas, are very different from other sectors.

Misuse of agricultural lands as a result of farmers' inability to obtain sufficient yield from the soil, insufficient protection of water basins and the pressure of cities on rural areas listed among the reasons underlying this situation (Kadıoğlu M., 2001).

Changing precipitation and temperature regimes directly affect the ecological water cycle, causing drought and subsequent soil degradation and erosion of soils with fragile soil structure and will be (Australian Greenhouse Office, 2006).

In the assessment made on the basis of social impact, financial impact, number of people affected, duration of impact, area and severity in the world, drought ranked first, followed by tropical cyclones and floods and floods (Bryant, 1993).

It should be foreseen that the emergence of drought and its long duration will have immediate economic effects such as yield and supply chain, as well as the deterioration of soil structure in the long term, the transformation of agricultural areas into marginal areas, and the decrease in soil resistance in both rural and urban areas, leading to other disasters.

Therefore, the combating against drought requires a planning not only in terms of agricultural production and industry, but also in terms of urbanization and urbanization.

Drought prevention, direct interaction of the public-private sector and other stakeholders with the producer to minimize damage and in terms of the urgency of the measures to be taken in communication; It will prevent the loss of time, product and money.

For this, planning can be handled under three main headings, taking into account climate change.These main topics should be addressed in terms of both agricultural production and urbanization.

a) Determination of agricultural areas and microclimate zones of provinces and districts
b) Production and dissemination of drought-resistant varieties suitable for the region
c) Water management
d) Soil management

a) Determination of Agricultural Areas and Microclimate Zones of Provinces and Districts

Soil, water and climate are part of an ecological cycle that complements each other. Economic benefit will arise if they are interdependent and the other is not neglected when it comes to the management of one.

It has been demonstrated by many studies that climate change will have different effects according to regions in the world. In particular, the determination of micro-effects for regions, cities and smaller areas in all countries will make a great contribution to revealing realistic solutions for a future projection and planning. In this context, all the elements that make up the climate should be taken into consideration.

b) Production and Dissemination of Drought Resistant Varieties Suitable for the Region

Vegetation and biodiversity are essential for the sustainability of human life under healthy conditions.

Determination of the economic value of cultivated crops and pasture plants, which have great contributions to biodiversity in terms of human and animal welfare, are vital issues that will guide the projection and planning studies suitable for the region by determining their habitat requirements.

c) **Water management**:

Water, which has an important place among our natural assets, has a great value for all living things. However, due to mismanagement, excessive use, lack of legislation, climate change and pollution, our water resources are under vital threat. More than 40% of the world's population is currently affected by water scarcity. By 2025, it is predicted that 1.8 billion people will live in water-scarce areas (Anonymous, 2022).

Although the rate of industry in water use is low, the use of unsustainable, untreated water causes water pollution in many watersheds. This situation threatens agriculture and industrial production as well as human and ecosystem health.

Water resources need to be managed with an ecosystem-sensitive approach. Drinking water, geothermal water, rain water, sea water and all underground and surface water resources should be used effectively with a holistic approach that includes the development of water resources, the management of water services and the use of water.

In water management, the basic principles should be to protect the water from its source, not to be polluted, to be in harmony with the environment of the dams, to protect the dam lakes from the effects of erosion and urban wastes, and to provide healthy drinking and utility water in appropriate standards.

The planning, management, development and operation of all water resources according to the priorities of the region and the monitoring, evaluation and coordination of national policies and international agreements on water should be ensured (TBMM. 2021).

It is necessary to evaluate the water used in agriculture under a separate heading as Agricultural Irrigation and Water Used in Processing Agricultural

Products. It is known that clean water resources are 70-75% of water used in agriculture.

Approximately 80% of this water is used in agricultural irrigation. Therefore, planning in the part of clean water resources used in agriculture and industry rather than the urban area in water management is an urgent and imperative for the continuation of human life and quality of life.

Conventional irrigation methods in the planning of water resources used in agriculture and the coefficients of previous years' climate data and standard water consumption calculations have lost their validity within the scope of the knowledge gained today.

The common deficiency in the commonly used pressurized or flood irrigation methods is the neglect of soil properties and soil moisture monitoring. Thus, the damage of excess or missing water is one of the problems observed in the field. It has been observed that the dissemination of pressure systems in irrigation methods does not prevent this damage.

d) Soil Management:

In the studies conducted in recent years, it has been noted that the climate zones have shifted, the humid regions have turned into semi-arid regions, the precipitation seasons have shifted forward one or two months, and the precipitation form has changed in Turkey as in many parts of the world.

It is understood that the harvest season of the region is getting longer and shorter and the periods of falling precipitation have changed. This situation affects the vegetation period for natural pastures together with the plants with economic value. Therefore, it affects not only the grazing time but also the nutritional values of forage crops in pastures.For dry agricultural areas, it means re-planning the product pattern. There was an increase in semi-dry and dry humid regions, and a decrease in semi-dry-less humid, semi-humid and humid regions.

In this context, it has been determined that semi-arid regions have increased significantly (about 14%) between two 30-year periods across Turkey. It is to form the basis for the adaptation of water resources management policies to climate change in the Seyhan River basin.

Water resources management scenarios have been developed to evaluate adaptation alternatives to climate change scenarios at the basin level. Although there was no water shortage in the Seyhan basin in 2010, it was determined that serious famines are expected in many parts of the basin in the coming years (Selek and Selek, 2020).

Soil management cannot be separated from water management. The structure of the soil, its microbial content and activity, and accordingly its physical and chemical structure are largely dependent on the presence of water in the soil. For sustainability in agricultural production, the evaluation of soil and water management as a chain should not be separated. In drought conditions, the plant cannot meet its water needs, as well as disruption of the vitality activities of the soil and deterioration in its structure.

The change of seasons, forms and intensities of precipitation regimes due to climate change is one of the most important factors triggering soil erosion.In the coming years, clean water resources, food production and food safety will be among the most important problems of human life.

Erosion is one of the most important factors in the emergence of these risks. Erosion areas are also a problem that threatens fresh water resources. Drought, erosion, floods and weather events are natural disasters that are directly caused by climate.

The climate is not waiting for us and the most urgent issue for human life is the determination of food and clean water needs.On determining an effective strategy for the conservation of fresh water; Planning climate, soil and water management as successive steps under the same title will form the basis of sustainable agricultural production.

In order to respond to the needs of the society in the current conditions and due diligence of natural resources, small pilot areas should be selected in the first step and a demonstration function should be performed in order to disseminate the obtained results on a national scale in a short time.Soil plays an important role in the global carbon cycle as a source of storing organic carbon.

Changes in land use have various positive or negative effects on carbon emissions or storage (Ferré, 2014).

When land use is planned correctly, it reduces the amount of carbon stored in natural terrestrial ecosystems, but this decrease is estimated to be more than in previous periods in the time period from the 1850s to the present. this may be due to the fact that natural vegetation dominated more land in earlier times. The carbon storage of terrestrial ecosystems is closely related to global climate change. Therefore, assessing the impact of land use changes on carbon storage is indicative for reducing global carbon emissions (Zhu et al.,202; Houghton, et al.,2012).

The decrease in organic carbon in the soil generally affects the physical, chemical and biological properties of the soil, and causes cumulative effects such as decreased productivity, biodiversity and ecosystem resistance. Changes in land use, such as increased farmland, intensive tillage in agriculture, and increased water and wind erosion, significantly reduce soil carbon stocks (Polat, et al.,201; Nieder and Benbi, 2008).

Conclusion and Recommendations

Some recommendations on the issues discussed are given under the relevant subject headings.

The adoption of ecosystem-based adaptation practices for adaptation to climate change in Turkey by integrating them into activities that sustainably support biodiversity, livelihoods and ecosystem services is seen as an opportunity for regional and local organizations, civil society and the private sector (FAO, 2018; Aydın, 2023).

As a result, in the light of all this information and perspective; Today, climate change projections are mostly focused only on weather events. Many studies on climate change focus only on precipitation and temperature parameters. It is largely overlooked that ecology and climate are a chain that influences each other.

When dealing with weather events, the focus is generally on the negative aspects of urbanization. The planning made as a result of this lack of vision brings along other problems and problems in other areas affected by these problems.

The issue of sustainability in both agricultural production, agriculture-based industries and industrialization; It is a priority that overlaps with issues such as the conservation and preservation of ecosystems, the development of biodiversity, and the preservation of water and soil quality in ecosystems intertwined with agriculture.

Looking at climate change from a wider perspective in the future will be the most important step in putting forward more realistic solutions.

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CHAPTER 11

EFFECT OF PREHARVEST AND POSTHARVEST METHYL JASMONATE TREATMENTS IN FRUIT AND VEGETABLES

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1. Introduction

Plants defend itself against environmental stress by enhancing defense reactions that both occur in locally damaged areas, and in distant regions. In common, plants can display a number of defense responses: (1) plants can deploy direct defense mechanisms like the synthesis of toxic compounds, proteinase inhibitors and phytoalexins to fight off pathogens and herbivores. (2) Plants have enhanced diverse adaptive mechanisms like hormonal regulation, redox signaling and epigenetic control of stress-related genes to deal with whimsical environmental stresses. (3) Plants are capable of triggering antioxidant defense enzymes and are able to detoxify stress-induced ROS such as hydrogen peroxide (H_2O_2), superoxide radicals (O_2) and reactive hydroxyl radicals (OH) to defend them against further damage (Ryu and Cho 2015; Yu et al., 2018).

Being involved in both local and systemic immune responses, small molecule hormones have an important role and, MeJA plays an important role in regulating various developmental processes and signaling networks in plants under different types of stresses. MeJA is a naturally derived plant hormone that operates as a key signaling molecule. It influences a number of biochemical and physiological processes and leads to diverse effects on plant tolerability to biotic and abiotic stresses (Takahashi and Hara 2014). In particular, MeJA influences seed germination, root growth, gravitropism, trichome formation, embryo development, seedling development, tuber formation, fruit ripening, leaf senescence as well as the accumulation of phenolic compounds, the most potent group of non-enzymatic antioxidants in maintaining fruit and vegetable quality after harvest (Gumerova et al., 2015; Çavuşoğlu, 2018) and induce reprogramming of gene expression, allowing plant cells to deal with insect damage, pathogens and environmental stresses such as drought, low temperature, salinity and in the protection of postharvest fruit and vegetables from chilling injury (Wolucka and Goossens, 2005). Therefore, MeJA is commonly considered as a promising phytohormone for enhancing plant tolerance to stress conditions (Wang et al. 2015). Possible mechanisms to enhance plant resistance by MeJA are as follows: (1) activation of the expression of protective genes such as pathogenesis-related genes, proteinase inhibitors and antifungal proteins (Zhu and Tian 2012); (2) effects on antioxidant defense-related enzymes (Hristova and Popova, 2002); (3) the induction of the accumulation of protecting compounds (e.g. phenolics); and (4) regulating photosynthesis such as stomatal closing (Yu et al., 2018).

2. Biosynthesis methyl jamonate in plants

Jasmonates (JAs) are derivatives of fatty acid cyclopentanones and are members of the family of oxygenated fatty acid derivatives, collectively referred to as oxylipins formed in plants as a result of the oxidative metabolism of polyunsaturated fatty acids. Currently, JAs are found in nearly all higher plants and are found at higher levels in flowers and reproductive tissues, while they are quite low in roots and mature leaves (Dar et al., 2015). JA s are first synthesized in plants through the octadecanoid pathway. Some stimulants promote linolenic acid synthesis in plants by activating phospholipase D (PLD) in chloroplast membrane lipids and defective anther dehiscence (DAD) in anther plastid membrane lipids. Linolenic acid is a predominant in the production of jasmonic acid (JA) and is then converted to 12-oxo-phytodienoic acid by oxygen oxidation utilizing lipoxygenase (LOX), alenoxido synthase (AOS) and alenoxido cyclase (AOC). JA is then produced from 12-oxo-phytodienoic acid (OPDA) by 12-oxo-phytodienoic acid reductase (OPR) and three-step b-oxidation, and is catabolized by JA carboxylmethyltransferase (JMT) to make a volatile analog of MeJA (Seo et al., 2001). As JA is derivatized from 18:3 (octadecatrienoic acid), the sequence of enzymatic interactions resulting in the biosynthesis of JA is frequently termed as the octadecanoic pathway (Sasaki et al., 2001; Yu et al., 2018).

3. Effects of preharvest methyl jasmonate treatment

MeJA inhibits root and stem growth (Staswick et al., 1992), chlorophyll breakdown, carotenoid formation (Saniewski et al., 1983), decreases respiration activity (Popova et al., 1998), and increases plant susceptibility (Yeh et al., 1995).

Research on MeJA treatments has mostly focused on tomato, radish, and cabbage species. In the studies conducted on this subject, it was reported that MeJA treatment increased the amount of caffeoylputresin, a combination of caffeic acid and putresin, which strengthens the post-signaling defense mechanism in tomato leaves (Chen at al., 2006), and increased anthocyanin synthesis in soybean and radish seedlings (Franceschi et al., 1991; Feys et al., 1994). Sun et al., (2012) found that MeJA treatment at a dose of 100 µM 6 days before harvest increased glucosinalate, total phenol and antioxidant capacity in Chinese cabbage 6 days after harvest.

In corn, tomato, radish and onion seedlings, gaseous MeJA treatment at a dose of 50 µL increased anthocyanin accumulation in all but radish hypocotyls. It was stated that this may be due to the fact that vegetable species contain different free amines. Likewise, MeJA treatment increased the amount of putrescine, one of the polyamines necessary for cell proliferation and growth in the hypocotyls. In tomato leaves, MeJA increased the level of putrescine, while in onion and radish leaves, it was not effective, but a small amount of spermine, one of the other amines that provide cell growth, was found. High levels of phenylethylamine (PEA), an aromatic amine, were detected in maize Radish seeds were treated with MeJA at a dose of 100 µM and some of them were left in the light and some in the dark. Seedling development was examined after 12 days. As a result of the study, it was reported that exposure of sprouts to MeJA and light positively affected the anthocyanin content and transport of all genes after 3 days of sowing (Park et al., 2013; Horbowicz et al., 2014).

MeJA treatment increases glucosinalate biosynthesis in some vegetable species. In studies conducted in broccoli, it was found to increase existing neoglucobrassin and gluconasturtin (Kim and Juvik, 2011), and glucoiberin, progoitrin, sinigrin, and gluconapin glucosinates in cabbage (Fritz et al., 2010). The same researchers found that this effect varied depending on the cultivar.

It has been reported that the treatment of preharvest MeJA significantly increased the total phenolic content in lettuce and basil compared to the control (Kim et al., 2006; 2007). Similarly, preharvest treatment of cherries with MeJA has been reported to make cherries resistant and healthier against the postharvest pathogen *Monilinia fructicola* (Li et al., 2004).

4. Effects of postharvest methyl jasmonate treatment

Ayala-Zavala et al., (2005), treated strawberry fruit with three different treatments as MeJa and Meja-ethanol and stored the treated fruit at 7.5ºC. At the end of storage, they reported that MeJa-treated berries had higher amounts of antioxidant capacity, total phenolics and anthocyanins than the other groups. They observed that the postharvest storage life of the fruit treated with MeJa-ethanol combination was higher.

Saavedra et al., (2016), treated strawberry fruit with methyl jasmonate (MeJa) and chitosan. After the treatment, the fruit were kept at room temperature and then analyzed at 0, 24, 48, and 72 hours. They reported that the hardness of the fruit treated with MeJa and chitosan was preserved and the decay rate decreased. As a result, it was stated that both treatments extended the shelf life of the fruit compared to the control group. Wang et al., (2021), investigated the effect of methyl jasmonate application on softening of blueberry fruit after harvest. They reported that compared to the control fruit, methyl jasmonate treatment delayed fruit softening after harvest by preventing the degradation of the structure of compounds in the cell wall and preserving energy metabolism.

Zhang et al., (2009), investigated the effect of methyl jasmonate (MeJa) and Rhodotorula glutinis treatments on blue mold, fungal decay, fruit firmness and titratable acidity of pear fruit after harvest. They reported that the combination of MeJa and Rhodotorula glutinis was more effective in protecting the quality parameters of pear than the use of the treatments alone.

Flores et al., (2015), studied the effects of methyl jasmonate (MeJa) treatment on the antioxidant capacity, total phenolic content, and anthocyanin concentration of grapes during postharvest. After the treatments, the stored grapes were analyzed on the 5th and 7th days. As a result of the analysis, they reported that MeJa-treated fruit had an increase in antioxidant capacity and total phenolic content compared to the control group. They also found that the anthocyanin concentration in the treated fruit increased from 14% to 42% in 5-day storage and from 22% to 64% in 7-day storage.

Kücüker et al., (2014), investigated the effect of MeJa treatment before harvest on ethylene production, respiration rate and bioactive compounds in plum fruit after harvest. They reported that ethylene production and respiration rate increased significantly in MeJa-treated fruit. They also found that flesh color and firmness were preserved, the amount of water soluble dry matter increased, but titratable acidity decreased.

Mustafa et al., (2018), applied salicylic acid (SA) and methyl jasmonate (MeJA) to dragon fruit after harvest to control abiotic stresses caused by cold storage. The treated fruit were stored at 6 °C for 21 days. As a result of the analysis during storage, they reported that salicylic acid treatment decreased metabolism, and MeJa treatment significantly increased antioxidant activity.

Sayyari et al., (2011), treated pomegranate fruit with methyl jasmonate and then stored them in cold storage for 84 days. They reported that pitting and browning occurred in the control fruit as the storage period progressed and the amount of pitting and browning increased as the storage period progressed further, as well as softening and electrolyte leakage began. On the other hand, MeJa-treated fruit significantly reduced the symptoms regardless of the used doses.

Meng et al., (2009), peach fruit were treated with methyl jasmonate after harvest and stored at 5 °C for 3 weeks and at 20 °C for 3 days for shelf life. As a result, they found that the proportion of fruit with chill injury was lower in the the MeJa-treated fruit than in control group. As a result, they reported that MeJa treatment may be an effective method to protect the quality of peach fruit under low temperature stress as it reduces chilling damage.

Cao et al., (2014), applied methyl jasmonate to loquat fruit and stored them at 20°C for 6 days. At the end of storage, they reported that MeJa treatment significantly reduced the decay rate in fruit. They reported that MeJa treatment may prevent decay by increasing polyamine content in loquat fruit.

MeJA treatments had positive effects on antioxidative enzymes (CAT, SOD, and APX) and lipid peroxidation in apricot fruit during storage. It was reported that MeJA triggered antioxidant enzymes such as APX, CAT, and SOD and reduced MDA content in fruit. High antioxidative enzyme activities in postharvest products are considered an indication that product quality is maintained and cold damage is prevented during storage (Cavusoglu et al., 2021a).

Çavuşoğlu et al., (2021b), examined the effect of MeJA applied to cherry fruit after harvest on the biochemical and physicochemical contents of the fruit. As a result the study, MeJA treatments showed higher levels of total phenolic content, total antioxidant capacity and quality and were also effective on superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX), malondialdehyde (MDA), ethylene production and respiration rate.

Çavuşolu et al., (2020), examined the effect of postharvest MeJA applications on apricot fruit. They reported that MeJA treatments preserved the amount of titratable acidity (TEA) in fruit, retaining changes in fruit skin color, increased total antioxidant capacity and total phenolic substance content as well as decreased respiration rate and ethylene production during storage.

4. Conclusion

There are numerous studies in the literature on the effectiveness of MeJA treatments, both postharvest and postharvest. On the other hand, it is still not actively used in commercial conditions because it is not easy to access and still costly. Addressing these challenges through ongoing research and collaboration between academia, industry, and regulatory agencies will contribute to the development and adoption of effective postharvest MeJA. With the increasing demand for sustainable and residue-free agricultural practices, the use of MeJA is expected to play a crucial role in future postharvest disease management strategies.

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