Water-Air-Soil for Sustainable Agriculture and People Well-being

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WATER-AIR-SOIL FOR SUSTAINABLE AGRICULTURE AND PEOPLE WELL-BEING

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PREFACE

In the grand tapestry of life, three elements stand out as fundamental to our existence and prosperity: water, air, and soil. These elements, in their purest forms, are the lifeblood of sustainable agriculture and, by extension, the well-being of all people.

Water, the universal solvent, is the medium through which nutrients are transported, crops are irrigated, and life is sustained. Air, the invisible life force, provides the oxygen we breathe and the carbon dioxide needed for plant growth. Soil, the skin of the earth, is a complex ecosystem teeming with life, providing the foundation for all terrestrial life forms. This book is a journey into the intricate interplay between these three elements in the context of sustainable agriculture. It explores how the careful management of water, air, and soil can lead to productive agricultural systems that not only feed the world but also contribute to a balanced and healthy environment.

We delve into the science behind these elements, the challenges facing our current agricultural practices, and the innovative solutions that aim to make agriculture more sustainable. We explore how these solutions can improve not just crop yields, but also the health of the environment and the well-being of people. The goal of this book is not just to inform, but also to inspire. To inspire farmers, policymakers, scientists, and consumers alike to consider how their actions affect these three vital elements. To inspire a movement towards sustainable agriculture that respects the water, air, and soil upon which we all depend.

As you turn these pages, we hope you gain a deeper appreciation for the role of water, air, and soil in sustainable agriculture. More importantly, we hope you are inspired to become a part of the solution, contributing to a future where agriculture and well-being coexist harmoniously.

Welcome to a journey of discovery, understanding, and inspiration. Welcome to “Water-Air-Soil: For Sustainable Agriculture and People’s Well-being” in all aspects.

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TABLE OF CONTENTS

CHAPTER 1

MARKETING MIX OF TEMPEH CRIPS, THE INDIGENOUS FERMENTED SOYBEAN

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ABSTRACT

Tempeh is a traditional Indonesian food known for centuries, especially in the food culture of society, especially in Tasikmalaya. Subsequently, the technique of making tempeh spread throughout Indonesia in line with the Javanese people who migrated throughout the archipelago. The purpose of the study was to determine how the marketing mix influences the sales volume of tempeh crips so that during the Covid-19 Pandemic the business can survive and experience an increase in the sales volume of tempe crips. The study used a quantitative approach with interview and documentation methods. The sample was 80 respondents and consumers of tempeh crips by using sampling technique of random sampling and used the analysis model using multiple linear regression. The results of this study indicate that the marketing mix consisting of products, prices, promotions, distribution channels, people, processes and physical means affect the sales volume of tempe crips in the Craftsmen of tempeh crips and the marketing mix that most affects the sales volume of tempe crips in the Craftsmen of tempe crips was the price

1.1. Introduction

Tempeh is a traditional Indonesian food known for centuries, especially in the food culture of society, especially in Java Island. Subsequently, the technique of making tempeh spread throughout Indonesia in line with the Javanese people who migrated throughout the archipelago.

Tempeh is the result of fermenting grains using the fungus Rhizopus oligosporus. It can increase and maintain the nutritional values and soften the raw material's texture to make it easier to consume. In Indonesia, tempeh, which is very popular among people, comes from soybeans. Apart from soybean tempeh, other types of tempeh are not made from soybeans.

Figure 1.1. Soybean

Other ingredients used to make tempeh apart from soybeans, which can be processed into tempeh, are kara beans, begun, winged beans, black soybeans, lamtoro, green beans, red beans, pigeon peas (album), komatik beans. Still, the quality could be better than those made from soybeans. Tempeh also contains lots of vitamin B12 and minerals such as Ca and Fe, does not contain cholesterol, and is relatively free from chemical toxins.

Tempeh is perfect for consumption by all age groups because the compounds contained in tempeh are short peptides, free amino acids, fatty acids, and more straightforward carbohydrates easily absorbed by the body. The mold that grows on tempeh produces protease, lipase, and amylase enzymes, which break down proteins, fats, and complex carbohydrates into simpler compounds.

The amino acid content in tempeh is 24 times higher than in soy milk. Fermentation can also increase folic acid and form vitamin B12 from bacteria, which is not found in other vegetable products. Overcoming anemia requires adequate nutritional intake to meet the body's protein, iron, vitamin B12, and folic acid needs. Tempe is a functional food that contains all the nutrients needed to overcome anemia.

The nutritional content of tempeh is better than soybeans and other derivative products. These contents include Vitamin B2, Vitamin B12, Niacin, and also pantothenic acid; even the results of the nutritional analysis of tempeh show that the niacin content is 1.13 mg/100 grams of weight of tempeh eaten. The vitamins found in tempeh consist of two types: water-soluble (Vitamin B complex) and fat-soluble (Vitamins A, D, E, and K). Tempeh is a potential source of vitamin B. These types of vitamins are Vitamin B1 (Thiamine), Vitamin B2 (Riboflavin), pantothenic acid, nicotinic acid (Niacin), Vitamin B6 (Pyridoxine), and Vitamin B12 (Cyanocobalamin).

Tabel 1.1. Nutrien Composition of Soybean, Tempeh and Tempeh Crips

Nutrient	**Soybean**	**Tempeh**	**Tempeh Crips**
Ash (g)	6,1	3,6	-
Energy (kkal)	-	-	542
Protein (g)	46,2	46,5	40,3
Fat (g)	19,1	19,7	42,4
Carbohydrate (g)	28,2	30,2	11,5
Calcium (mg)	254	347	175
Ferum (mg)	11,0	9,0	5,2
Vitamin B1(mg)	0,48	1.5 – 6.3	0,1
Riboflavin (mg)	0,15	0,65	-
Niacin (mg)	0,67	2,52	-
Pantotenic Acid (mcg	430	520	-
Piridoxin (mcg)	180	100	-
Vitamin B12 (mcg)	0,2	3,9	-
Biotin (ug)	35	53	-
Esensial amino acid (g)	17,7	18,9	-

Resources: Astawan (2013) & Godam (2017)

Tempeh is the only vegetable source that contains B12, which is only found in animal products, so tempeh has better potential than other vegetable products. During the fermentation process in making tempeh, there is an increase in Vitamin B12, which is estimated to reach around 6.45 kg; Riboflavin (Vitamin B6) increases 4-14 times; Niacin increases 2-5 times, biotin increases by 2-3, folic acid 4-5 times, and pentatonic acid only increased two times compared to the soybean content before fermentation. Rhizopus mold does not produce this vitamin but from contamination with Klebsiella pneumoniae and Citrobacter freundii. The content of Vitamin B12 in tempeh ranges from 1.5 to 6.3 micrograms/100 grams of dried tempeh consumed; this amount is more than enough to meet a person's Vitamin B12 needs per day. By consuming tempeh daily, a vegetarian's vitamin B12 content does not need to be worried about because it is already fulfilled.

1.2. Tempeh

Tempe is one of the original Indonesian foods that is not foreign to the eyes of the Indonesian people. The nutritional value of tempeh is very high, especially its protein, and tempeh is a cheaper food when compared to animal protein sources. Tempeh is very popular among people because it tastes delicious, and besides being often used as a side dish, tempeh is also often used as a snack (Alvina & Hamdani, 2019).

Figure 1.2. Tempeh (Fermented Soybean)

The community is increasingly developing innovations in tempeh to create more public interest in tempeh. Tempeh processing varies from conventional to modern, including traditional tempeh processing, namely fried tempeh, bacon tempeh, half-done fried tempeh (*mendoan*), tempeh, tempeh crips, and others. Meanwhile, modern processing of tempeh includes tempeh nuggets, tempeh steak, tempeh brownies, pie tempeh (*bakpia)*, and others (Fitriah et al., 2017).

Some tempeh products that have a long shelf life and are widely traded are tempeh crips, but currently, many tempeh chip products are sold in many flavors and unique packaging (Sari et al., 2019). Tempeh crips are thinly fried tempeh with a dry texture and produce a crunchy texture. If packaged in plastic bags, cans, or jars, they are not airtight and can last for several weeks (Feriyana, 2021). Many tempeh artisans focus more on processing into tempeh crips because the tempeh crips industry has high product competitiveness, and the tempeh crips crafts industry is also environmentally friendly (Elisabeth et al., 2018). The industry needs to market products by adapting to current conditions, which are adjusted to economic conditions, pandemics, and developments in digital technology. Marketing has experienced disruption in line with the changes that have occurred (Darwin, 2020).

Figure 1.3. Fried Tempeh

Marketing decisions are closely related to seven main issues: product, price, promotion, distribution channels, processes, people, and physical facilities, which are variables in the marketing mix (Dunan et al., 2020). The aim of marketing tempeh crips is to expedite the sales process of tempeh crips products so that knowing and understanding the product can be accepted by consumers so that tempeh crips can be sold without having to do excessive marketing. Marketing should make consumers ready to buy. So consistent tempeh chip products are needed, which must always be available.

Figure 1.4. Tempeh Crips

One of the tempeh crips industries located in Tasikmalaya, the only tempeh crips producer in the Cihideung area of Tasikmalaya City, is the MsMEs tempeh crips. This business conducts marketing with consumers going directly to the tempeh crips shop and through online platforms, namely Shope and Grabfood. Tempeh crips products from the tempeh crips manufacturer have three flavors: original, sweet, and salty. This product is sold for 50/kg; this product is sold directly and indirectly. The distribution channel carried out by the MsMEs tempe crips is direct distribution, which is carried out between producers and consumers directly. At the same time, indirect distribution channels are also carried out through product delivery services, which then reach the hands of consumers.

This business experienced an increase in sales volume, but in 2002, the COVID-19 pandemic occurred, which caused some businesses to experience a decline in sales. This increase was due to demand for tempe crips products from regular consumers. So, there has been an increase in sales in the business selling tempeh puja flavored crips amid the Covid-19 pandemic. The following is a sales volume data table, which can be seen in Table 1:

Table 1.2. Tempeh Crips Sales Capacity in 2022

2021	Capacities (kg)	Price	Sales
Januari	210	50,000	10,500,000
Februari	214	50,000	10,700,000
Maret	200	55,000	11,000,000
April	180.5	50,000	9,025,000
Mei	155	55,000	8,525,000
Juni	180	50,000	9,000,000
Juli	185.5	50,000	9,275,000
Agustus	211	50,000	10,550,000
September	215	50,000	10,750,000
Oktober	200	50,000	10,000,000
November	215	50,000	10,750,000
Desember	228	55,000	12,540,000

1.3. Marketing Mix

The marketing mix is a collection of tools in strategic marketing that can be controlled and combined by the company so that it is efficient to get the desired response results to the target markets (Zulfa & Hariyani, 2022). The marketing mix includes products, prices, promotion, distribution channels, processes, people, and physical evidence.

1. Product

The seller offers products as goods or services to be asked, sought, purchased, used, or consumed to meet buyers' needs or desires (Wangarry et al., 2018). Products can be measured from the product's quality, product variations, sanitation hygiene, and packaging (Rompis et al., 2017), (Irawan, 2016).

2. Price

   Prices are money that has the exchange rate used to get a profit by owning or using goods and services. A price can be measured by price competitiveness, price, and price suitability with the product's quality (Zulfa & Hariyani, 2022).

3. Promotion

   Promotion is an essential variable in the marketing mix because it is an element in a company that is used to introduce and inform consumers about a product (Tinungki et al., 2018). Promotion can be measured by making attractive advertising, causing consumer attention, causing the desire to buy products, and producing action by buying products (Sinollah et al., 2020).

4. Distribution Channel

   A distribution channel is an interconnected organization that delivers products or services from products consumed or used by final consumers (Nazmi, 2021). Distribution channels can be measured from the location of a strategic, comfortable business site, the extent of the parking lot, and the supply of a product (Wangarry et al., 2018).

5. Process

   The process is an activity that shows the services provided to the buyer at the time of the election until the buyer decides to buy a product or goods (Dwinanda & Nur, 2020). A process can be measured by linking methods, activities, procedures, schedules, and routines to distributing goods and services to consumers (Zulfa & Hariyani, 2022).

6. People

   People play an essential role in providing quality service to consumers. The service quality dimension is divided into five parts: skills, physical evidence, empathy, responsiveness, and guarantee. The process of selecting, training, and motivating employees can make a difference in fulfilling consumer satisfaction. The dimensions of a service, quality can be measured from responsiveness, grade, and reliability (Zulfa & Hariyani, 2022).

7. Physical Evidence

   Physical means is a company's ability to show its existence to outsiders. The physical facility of the company is clear evidence of the services provided by the company (Wijayanti & Andriyanto, 2016). Physical facilities can be measured from sufficient parking lots, good room arrangement, and adequate facilities (Tobing et al., 2021)

1.4. Selling

Sales are transactions to purchase company products through promotions that generate buyer interest because sales are a source of life for the company. With sales, profits are generated, and efforts are made to attract buyers' interest in product results (Tinungki et al., 2018). Meanwhile, sales volume is a measure that shows the number of products or services sold. The size of a sales volume is indicated by the offer value, which has the impression that it is the same as the level of ability of the buyer to own and purchase goods or services and is expressed at financial or nominal value (Zulfa & Hariyani, 2022). The community is increasingly developing food innovations. For example, the processing of tempeh into tempeh crips is widely used as a business opportunity, where research conducted by (Elisabeth et al., 2018) stated that the tempeh crips industry has high competitiveness (Niken et.al., 2023).

In economic activities, marketing has a very important role (Sundari, et.al., 2019). Marketing itself is the function of a company, which ensures target buyers and determines the best strategy to fulfill needs and the hope of competitive cooperation (Nasution et al., 2017). Marketing of tempeh crips is currently carried out both directly and indirectly, where the aim of marketing tempeh crips is to expedite the sales process of tempeh crips products so that knowing and understanding consumers the product can be accepted by consumers so that tempeh crips can be sold without having to do excessive marketing.

1.5. The Influence of Marketing Mix on Sales

Based on the results of data processing carried out in this research, the significance value was 0.016 (attachment 3). This value explains that $0.016 < 0.05$ so it can be concluded that the independent variables, namely product, price, promotion, distribution channels, people, processes and physical facilities together have a significant effect on the dependent variable sales volume. In research conducted by (Nasution et al., 2017; Wangarry et al., 2018) a significance value of 0.000 was produced.

Table.1.3. ANOVA

	Model	Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.310	7	.044	2.675	,016[b]
	Residual	1.193	72	.017		
	Total	1.504	79			

a. Dependent Variable: Volume Penjualan
b. Predictors: (Constant), Sarana Fisik, Promosi, Saluran Distribusi, Harga , Proses, Produk , Orang

So, in this way the research problem formulation can be answered that a marketing mix consisting of product, price, promotion, distribution channels, people, processes and physical facilities influence the sales volume of tempeh crips in tempeh crips MSMEs.

1.6. Marketing Mix Variables that Have the Most Influence on Sales

Based on the results, the product variable 1) According to consumers, the quality of tempeh chip products is good in terms of taste, color, and texture. These tempeh crips use our recipe, so they taste delicious, but in terms of shape, the tempeh crips are not unique because the tempeh sold has the same shape as other tempeh crips. According to consumers, other indicators of the quality of tempeh crips are that tempeh crips have a crunchy texture and the same brownish color as regular tempeh crips.

Table 1.4. Coefficient

	Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	.279	1.175		.28	.813		
	Product	.536	.209	.291	2.56	.012	.856	1.169
	Price	-.491	.156	-.358	-3.15	.002	.849	1.178
	Promotion	.076	.110	.076	.69	.491	.925	1.081
	Place	.111	.167	.074	.66	.509	.887	1.127
	People	.290	.166	.206	1.75	.084	.796	1.257
	Process	.056	.202	.031	.28	.781	.901	1.110
	Physical Evidence	.179	.171	.119	1.05	.299	.856	1.168

a. Dependent Variable: Sales

The tempeh crips product uses the Malang tempeh type, which has good nutrition for the body and is very suitable for use as tempeh crips. 2) The packaging labeling for tempeh crips still uses ordinary plastic packaging, so there is no difference with other tempeh crips. 3) tempeh crips have three flavor variants, including original, spicy, and sweet, with three flavor variants to suit consumer interests. Based on the questionnaire results in this research, consumers prefer original flavor variants. This shows that the better a product, the more influence it will have on sales volume. In line with research according to (Intan, 2020), a significance value of 0.000 <0.05 is produced, indicating that the product variable has a significant effect. Meanwhile, other research (Syam, 2022) disagrees with this research because he obtained a significance value of 0.709, meaning that product variables do not significantly affect sales volume.

The research results show that the price variable X2 has a negative and significant effect on sales volume, where a significance value of 0.002 is obtained (attachment 3). The price variable is the variable that has the most influence on sales volume compared to other variables. Price determination is based on calculating a production factor for making tempeh crips. 1) According to respondents, the price of tempeh crips is considered affordable; the price matches the taste of the tempeh crips, and the price given is quite competitive with others, making consumers interested in buying tempeh crips. The price of tempe crips itself is sold at IDR 50,000/kg. Based on consumer answers, the price is affordable because it matches the quality of the sold tempeh crips. In line with research according to (Intan, 2020), a significance value of 0.000 <0.05 is produced, indicating that the product variable has a significant effect. Meanwhile, another study by (Syam, 2022) stated that he disagreed with this research because he obtained a significance value of 0.709, meaning that product variables do not significantly affect sales volume.

The research results show that the X3 sales promotion in the tempeh crips business does not have a positive and insignificant influence on sales volume, as evidenced by the significant value obtained of 0.491 (attachment 3). Based on the survey results, 1) Advertisements made in this business use electronic and print media advertisements, whereas print media advertisements are used at the tempeh crips shop. At the same time, consumers do not widely know electronic media advertisements, so promotions are through advertisements via electronic media. Less influence on the sales volume of tempeh crips. 2) The promotion of tempeh crips is carried out using print media and electronic media advertisements; the promotion using electronic media is carried out by the owner of the MsMEs tempeh crips through one of the social media, namely WhatsApp. 3) Marketing carried out by the tempeh crips business is through direct marketing and e-commerce, namely Shope and GrabFood. However, online sales are less significant when compared to direct sales made at the shop located on Jl. Village Wetan Market. Yudanegara District. Cihideung City. Tasikmalaya. Meanwhile, other research (Syam, 2022) is not in line with this research that the promotion variable affects sales volume because the significance value obtained is 0.002 and is also not in line with research according to (Widayanti et al., 2020) which states that the promotion variable has a significant effect on the results obtained. Significance value of 0.000.

The research results show that the X4 distribution channel has a positive but not significant effect on the sales volume of tempeh crips, where a significance value of 0.509 is obtained (attachment 3). Based on the research survey results, 1) Tempeh chip products are available in locations that are convenient for buying tempeh crips. 2) Product preparation at the right time due to the availability of tempeh crips makes consumers become customers who subscribe to the MsMEs tempeh crips. 3) This business has a strategic location because it is easily visible, making it easier for consumers to shop and has good visibility. According to (Syam, 2022), a significance value of 0.658 was obtained in line with research.

The research results show that the person variable The tempe crips manufacturing business has seven employees, including three men and four women. 1) A team member has an important role in a company in the form of service and appearance. In MSMEs tempeh crips, the service provided is quite good, such as friendly and polite service to consumers. 2) tempeh crips employees have a neat appearance, which improves the image of the shop, proven by wearing uniforms. 3) Another thing is that employees pay attention to consumer desires during the product purchasing process, but some consumers need clarification about the information asked. In research, according to (Fadillah et al., 2021), it is not in line because it obtained a value of 0.000; this shows that the person variable can influence or even not influence the volume of sales.

The results in this study show that the process variable is Based on the survey results: 1) The process of buying tempeh crips is carried out with accuracy in the purchasing and payment process to satisfy consumers. 2) The speed of purchasing and paying for tempeh crips at MSMEs is carried out well, but there needs to be more clarity in responding to consumer complaints. According to (Fadillah et al., 2021), a significance value of 0.887 was obtained in line with research. This shows that whether the transaction process is fast at the MsMEs Tempeh Crips is not a consideration for consumers in buying tempeh crips but because of a need.

The research results show that the physical facilities variable has a positive and insignificant effect, as proven by the significance value obtained at 0.299 (attachment 3). In the survey results, 1) The exterior environment of the tempeh crips shop displays a design that focuses on the products being sold so that consumers are interested in buying them. Visual graphics show the shop's name label, such as a promotional banner for tempeh crips. Parking area facilities do not support consumer needs because parking spaces are unavailable, so consumers only use the sidewalk, making them less comfortable. 2) In the interior environment of the tempeh crips shop, the layout is quite neat, and the lighting is bright enough to make it easy for consumers to shop.

The temperature, humidity, and room circulation are suitable; besides this, the cleanliness of the business location is clean enough so that consumers are comfortable when shopping. In research, according to (Fadillah et al., 2021), it is outside the line because it obtained a value of 0.265. This shows that whether the physical facilities at the shop are good does not affect the sales volume as per the data available from the tempeh crips artisans in buying tempeh crips.

The variable that has the most influence on the sales volume of tempeh crips in tempeh chip artisans is the price variable, which has a significance value of 0.002. In the sale of Tempeh crips, the price of IDR 50,000 affects sales negatively, meaning that every increase in price by one unit will reduce sales.

1.7. Conclusion

The marketing mix of product, price, promotion, distribution channels, people, processes, and physical facilities influences the sales volume of tempe crips at tempeh crips MSMEs. Meanwhile, the marketing mix variable controls the sales volume of tempeh crips at the crips MSMEs, which is a variable price.

1.8. Suggestion

In the research results, price is a variable that hurts the sales volume of tempeh crips, so the suggestion is to reduce the price of tempeh crips so that it will further increase sales volume. In addition, the quality of tempeh chip products must be maintained because this means consumers can continue to subscribe. As time progresses, it must be considered that consumers will feel bored with the various flavors of tempeh crips. So, to become superior tempe chips, innovation needs to be developed.

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CHAPTER 2

ROLE OF SPRAYERS DRONE IN SUSTAINABLE AGRICULTURE

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ABSTRACT

The population is seeing a significant surge, leading to a corresponding rise in the need for food. The conventional techniques used by farmers were inadequate in meeting these demands. Consequently, new automated techniques (utilizing Drone technology) were implemented. These novel approaches effectively addressed nutritional needs and simultaneously generated job prospects for billions of people. Drone technologies save water, reduce the need for pesticides and herbicides, preserve soil fertility, optimize labor use, enhance production, and increase quality. The purpose of this research is to examine the use of drones in agricultural applications. According to the literature, we have discovered that drones may be used for several agricultural purposes. In the technique, we used an extensive analysis of existing studies conducted worldwide. This study provides an overview of the present status of drone technology in the agricultural sector, specifically focusing on applications such as crop health monitoring, weed control, evapotranspiration measurement, and spraying. The study report finishes by advocating for increased use of drone technology among farmers to enhance agricultural yields.

Keywords: sustainable agriculture; soil health; drone technology

2.1. Introduction

The exponential growth of the population poses a significant challenge to ensuring food security. Based on data provided by the Food and Agriculture Organization (FAO) of the United Nations, it has been determined that a staggering number of over 815 million individuals suffer from chronic hunger globally. Furthermore, it has been observed that a significant proportion, specifically 64%, of these chronically hungry individuals are concentrated in the Asian continent. To sustain a projected global population of nine billion by the year 2050, it is imperative to augment food production by approximately 50%.

Conversely, the fundamental resources required for agricultural production, namely land and water, are progressively diminishing daily. According to a study conducted in 2018, Otto et al. (2018) found that a significant proportion of individuals worldwide, approximately 9.2%, experienced severe challenges in accessing an adequate food supply. Any additional reductions in the quantity of food will lead to a highly distressing state. Additionally, a notable issue of food insecurity was observed, affecting a moderate proportion of the population (specifically, up to 17.2%). This indicates that a significant portion of individuals lacked regular access to sufficient and nourishing food. According to Nasajpour et al. (2020), approximately 26.4% of the overall population is affected by the coexistence of both moderate and extreme levels of food availability challenges.

The COVID-19 pandemic had a significant impact on both crop production and food supply networks. Insufficient and untimely availability of essential resources such as labor, seeds, fertilizers, and pesticides within the agricultural sector has led to diminished productivity among numerous farmers. Several Asian countries are currently in a phase of development, and they are grappling with the challenge of a large population and relatively lower agricultural productivity compared to technologically advanced nations. India is confronted with a comparable challenge. This can be attributed to the utilization of low-level agricultural technology, limited power availability, and a lack of skilled farmers, among other factors. According to Jakob et al. (2017), a significant proportion of the Indian population, approximately 73%, relies on the agricultural sector either directly or indirectly. Conventional methods are still employed in Asian farming practices. Farmers are employing conventional methods for the processes of seed planting, compost utilization, and application of pesticides, among other practices. The conventional methods employed for the application of pesticides and fertilizers necessitate a greater amount of time and exhibit reduced efficacy. Consequently, there exists a demand for technological progress in this domain. The COVID-19 pandemic has posed significant challenges for conventional farmers in effectively monitoring crop growth, fertilizer application, and pesticide spraying. The implementation of unmanned aerial vehicles (UAVs), commonly known as drones, in the agricultural sector presents a viable solution for addressing these challenges. The utilization of accurate data obtained through the deployment of drones, in conjunction with the expertise of agronomists, rural specialists, and farmers, has the potential to enhance their agricultural practices and ultimately optimize crop yields (Gao et al., 2020).

2.2. Modern agricultural innovations

One of the most important technological advancements in Precision Agriculture (PA) and smart farming is aerial remote sensing. Unmanned aerial vehicles (UAVs) enable airborne remote sensing, which uses pictures taken at different wavelengths and quantifies vegetation indices to identify different crop situations. Over the course of recent decades, the acquisition of desired images for precision agriculture has been accomplished through the utilization of manned aircraft or satellites (Castellanos et al., 2020). The acquisition of images through manned aircraft incurs significant expenses, while satellite imagery often falls short of the desired spatial resolution in various conditions. Furthermore, the accessibility and caliber of images are contingent upon the prevailing weather conditions. The remote sensing of crops has been significantly influenced by advancements in Unmanned Aerial Vehicle (UAV) technologies and the concurrent reduction in the weight of payload devices. According to Santangeli et al. (2020), this technology offers cost-effectiveness, time efficiency, and the ability to capture high-resolution images without causing damage.

The utilization of drone monitoring systems facilitates farmers in the observation of aerial perspectives pertaining to their harvest. This provides information pertaining to the water system, diversity of soil, presence of pests, and occurrences of fungal infestations. The images of crops, obtained through the utilization of unmanned aerial vehicles (UAVs), encompass data within the infrared and visual spectrums. Various characteristics can be derived from these images, providing insights into the well-being of plants in a manner that surpasses human visual perception. An additional noteworthy characteristic of this technology is its capacity to consistently monitor the yield at regular intervals, such as on a weekly basis or even on an hourly basis. According to Ayamga et al. (2021), the regular accessibility of crop information facilitates farmers in implementing remedial measures for enhanced crop management.

Drone applications for precision farming can be examined by concentrating on the different payload devices that are employed. The weight that a drone can carry is referred to as its payload. This study's main areas of focus include pesticide application and crop health monitoring. An overview of the use of Unmanned Aerial Vehicle (UAV) technology in agriculture is given in this brief document. After that, a look at the many kinds of UAVs used for agricultural surveillance is provided. Additionally, a review is carried out about the collection of high-definition photos and the analysis that follows to track crop health. The study's authors reviewed the developments in drone technology for pesticide application as well as the creation of a drone tailored for spot spraying (Dadrass Javan et al., 2022).

The drone, originally developed for military purposes, was assigned various designations including Unmanned Aerial Vehicle (UAV), Miniature Pilotless Aircraft, or Flying Mini Robots. In contemporary times, it is being employed in various sectors such as business, infrastructure, agriculture, security, insurance claims, mining, entertainment, telecommunications, and transportation, among others. The drone possesses significant market potential, as indicated by the data presented in Table 1. (Sylvester, 2018) The extensive utilization of drones has led to rapid advancements in drone technology, resulting in its increasing user-friendliness over time (Dutta et al., 2021).

Small unmanned aerial vehicles (UAVs) are finding increasingly widespread use in the agricultural industry at the present time. Drones currently operate in a semi-automatic capacity; however, this is rapidly changing. The use of these devices in agricultural planning and associated spatial information collection holds tremendous promise. Although there are some limitations built into the system, it can be used for effective data analysis (Spalevic et al., 2018). The potential of robots to revolutionize farming has led to a surge in interest in this area in recent years. The use of drones (or unmanned aerial vehicles; UAVs) has been shown to increase agricultural output while decreasing environmental impact (Kim et al., 2021).

Among the many benefits of using drones in agriculture is the fact that they can gather data quickly and precisely. Drones equipped with cameras, sensors, and imaging technology can take detailed pictures of crops, soil, and field topography for use in crop monitoring, field evaluation, and the application of precision agriculture techniques. Improved crop yields and resource efficiency can emerge from using this information to adjust irrigation, fertilization, and pest management practices (Oliveira et al., 2018). Since they can easily maneuver over fields, drones are also useful for applying fertilizer and pesticide with pinpoint accuracy. This precise method safeguards valuable insects, reduces water pollution, and maximizes use of available resources. It helps conserve chemicals, lessens the strain on the environment, and makes the most efficient use of fertilizers and pesticides. Plus, drones allow us to reach places that are difficult or impossible to get by more conventional means. Drones allow for a more thorough field survey because they may be flown at low altitudes and capture data from a variety of angles and views. As a result, farmers can save time and effort by not having to manually audit huge agricultural areas as often. Costs can be reduced, and productivity increased by using drones to survey expansive agricultural areas (Chen et al., 2022).

Table 2.1. Role of drone in daily life

No.	Transport	Delivery of goods, Medical Logistic
1	Infrastructure	Investment monitoring, Asset inventory
2	Security	Monitoring lines and sites
3	Agriculture	Analysis of soils and drainage, Yield prediction, Crop health monitoring
4	Entertainment and media	Aerial Photography,
5	Insurance	Support in claims settlement process,
6	Mining	Planning, Exploration,
7	Telecommunication	Tower maintenance, Signal broadcasting

Drones are useful for more than simply surveillance and data collection; they may also be used to map and survey land. They can produce high-resolution maps and even 3D models, which can be utilized for agricultural planning, land management, and resource distribution. More precise analysis and judgements can be made with the help of data collected by drones equipped with cutting-edge sensors like LiDAR and hyperspectral cameras. This allows farmers to identify nutrient deficits, evaluate the efficacy of irrigation methods, and develop strategies tailored to individual locations. However, navigating the use of drones in farming can be complex. There are varying rules regarding drone use depending on where you are, so it's crucial to do your research before taking flight. Another issue with large-scale farming is that drones have limited flight periods and battery capacity. These problems are being addressed and drone applications are expanding because of technological developments such as longer battery life and larger payloads (Borikar et al., 2022).

2.3. Different types of drones are used in agriculture.

UAVs of many shapes and sizes are used for a wide range of tasks in the agricultural industry. These unmanned aircraft systems have specialized functions and characteristics made specifically for agricultural use. Examples of common drones used in farming include:

1. Multi-Rotor Drones

Multi-rotor drones are widely used in farming because of their versatility and reliability. Hovering in the air, flying at a low altitude, and producing high-resolution photographs are all possible because of the UAVs' numerous rotors (Lisein et al., 2015). Crop health monitoring, pest and disease identification, and the deployment of tailored therapies are only a few examples of the kinds of jobs that benefit greatly from their near and contained capture of objects. Irrigation problems, hot spots, and pest hotspots can all be located with the use of multi-rotor drones. Drones with thermal imaging can be used to improve agricultural practices through the collection of data on heat distribution and trends. (Merkert et al., 2020).

Figure 2.1. Multi-Rotor Drones

2. Fixed-Wing Drones

Unmanned aerial vehicles (UAVs) with fixed-wing configurations are distinguished by their aerodynamic wing structures and their capacity to achieve flight akin to conventional aircraft. These organisms are widely recognized for their exceptional ability to fly long distances and traverse expansive areas. Fixed wing unmanned aerial vehicles (UAVs) are commonly utilized for agricultural field mapping and surveys owing to their enhanced capabilities in terms of speed and range. Nevertheless, the presence of a runway for the purpose of take-off and landing may provide constraints in specific agricultural settings (Roslim et al., 2021; Dadi et al., 2021).

Figure 2.2. Fixed-Wing Drones

3. Hybrid Drones

Hybrid drones are a type of unmanned aerial vehicle (UAV) that combines the capabilities of both multi-rotors unmanned aerial vehicles (MORs) and fixed wing unmanned aerial vehicles (UAVs) (Verma et al., 2022; Sriram Reddy et al., 2022).


Figure 2.3. Hybrid Drones

4. Thermal Imaging Drones

Thermal imaging drones utilize thermal imaging technology, which involves the use of infrared cameras to detect the heat emitted by objects. This technology is commonly employed in the agricultural sector to monitor crop health and detect potential issues (McCarthy et al., 2023).

Figure 2.4. Thermal Imaging Drones

5. Spraying Drones

Spraying drones are specifically made to spray pesticides, fertilizers, and other agricultural components. They are also known as agricultural drones or crop-dusting drones (Lee et al., 2021). These aerial vehicles have spray systems that allow chemicals to be applied to crops precisely and effectively, minimizing chemical waste and the need for manual work. According to Zhichkin et al. (2023), spraying drones offer accurate and controlled applications that minimize environmental effect and maximize resource usage.

Figure 2.5. Spraying Drones

6. Surveillance Drones

The surveillance drone is a type of unmanned aerial vehicle (UAV) used in the agricultural sector for the purpose of monitoring and security. These unmanned aerial vehicles (UAVs) are equipped with camera systems and sensors that capture live video footage and images, enabling farmers to observe their fields, animals, and infrastructure from a distance. Surveillance drones can detect unauthorized activities, monitoring the movement of animals, and detecting potential hazards or risks in agricultural operations (Simelli et al., 2015).

7. Mapping and Surveying Drones

The use of Mapping and Surveying Drones (MDPs) to generate high-resolution aerial imagery and 3D visualizations of agricultural fields is a key component of precision agriculture. MDPs are equipped with sophisticated sensors, including LiDAR and photogrammetric cameras, which enable the capture of detailed and precise data. These drones are instrumental in the analysis of topography, the monitoring of soil health, and the development of effective land management strategies (Reinecke and Prinsloo, 2017).

8. Payload-Specific Drones

In addition to the abovementioned types of drones, there are other types of drones that are specifically designed for agricultural applications. These include drones that are equipped with sensors that can provide detailed information about crop health, nutrient content, and soil moisture levels (Satto, 2003). Additionally, these drones are equipped with specialized sensors that can be used to monitor weed infestation, assess plant growth parameters, and more. These payloads are designed to meet the specific data collection requirements of agricultural operations (Zúñiga Espinoza et al., 2017).

2.4. Advantages of drones in agriculture

There are several advantages to using drones in agriculture, including higher output, better efficiency, and more environmentally friendly practices. Some of the main advantages of using drones in agriculture are listed below:

1. **Precision Agriculture**. Drones facilitate precision agriculture practices through their ability to capture high-resolution images and data collection.

These images can be used to gain insight into crop health and soil conditions, as well as pest infestation. This data can be used to inform farmers' decisions and the application of targeted treatments (Gonzalez-Dugo et al., 2013).

2. **Cost and Time Savings**: Drones can carry out crop monitoring, mapping, and spraying operations in a much shorter period than would be possible with traditional methods. This results in cost savings due to the reduction of manual labor and the utilization of resources, such as water, fertilizer, and pesticides (Berni et al., 2009).
3. **Improved Data Collection and Analysis**: A wide range of data regarding crops, soil, and environmental conditions may be gathered by drones outfitted with several sensors, including as cameras, thermal imaging sensors, and multi-spectral sensors. Farmers may use this data to discover early symptoms of crop stress, nutritional deficits, or disease onset by using it for in-depth study and monitoring. Drone data may be subjected to advanced analytics and machine learning methods to produce insights that can be used immediately to enhance decision-making (Park et al., 2017).
4. **Enhanced Crop Management**: Drones provide farmers with timely and accurate data regarding crop health. For instance, drones can be used to identify areas that require further irrigation or fertilizer, allowing for accurate application and minimizing waste. Additionally, they can be used to monitor crop growth, estimate yield potentials, and forecast harvest times (Zarco-Tejada et al., 2012).
5. **Accessibility and Flexibility**: Drones provide access to inaccessible or difficult-to-reach areas, including steep slopes or thick vegetation. They can be flown at low altitudes, capturing data from a variety of angles and perspectives, allowing for a comprehensive overview of the field. Deployment of drones is fast and efficient, enabling farmers to react quickly to changing conditions or emergency situations (Hruska et al., 2012).

6. **Environmental Sustainability**: By lowering the usage of chemical pesticides and fertilizers and reducing the environmental impact of agricultural activities, the use of drones in agriculture has the potential to increase environmental sustainability (Ludovisi et al., 2017). To cut down on the quantity of chemicals used and their spread, drones may be used to accurately spray fertilizer and insecticides. This targeted approach to pesticides and fertilizers helps to protect beneficial insects, limit water contamination, and maintain ecological balance (Zarco-Tejada et al., 2013). The use of drones eliminates or reduces the need for physical access by farmers to areas that are hazardous or difficult to access, such as high crops, steep terrain, or areas that may present safety hazards. This enhances the farmer's safety and reduces the likelihood of accidents or injury caused by manual labor (Gonzalez-Dugo et al., 2014).

2.5. Application of drone in agriculture

1. Crop health monitoring

Throughout the agricultural season, drones may be used to monitor crop conditions and execute timely, need-based intervention. Several multispectral indices may be calculated based on the reflection pattern at various wavelengths by utilizing various types of sensors related to visible, NIR, and thermal infrared radiation (Capolupo et al., 2015). These indicators can be used to evaluate various agricultural situations, such as nutritional stress, insect pest assault, diseases, and water stress. According to Ali et al. (2017), the sensors installed on the drones can detect the prevalence of illnesses or deficiencies even before any outward signs manifest. As a result, they are useful for early illness detection.

Drones can serve as early warning systems in this way, allowing corrective actions to be applied in a timely manner according to the severity of the stress. Drones or UAVs can monitor the crop using several indices (Nauš et al., 2010). In a single trip, the UAVs can cover hectares of fields. Thermal and multispectral cameras are attached on the quadcopter's underside for this observation to measure the reflectance of the plant canopy (Balasubramaniam and Ananthi, 2016). The camera records one image per second, saves it in memory, and transmits it via telemetry to the ground station. Equation (Jia et al., 2004) represents the geographic indicator normalized difference vegetation index (NDVI), which was used to assess the data obtained from the multispectral camera via telemetry.

$$NDVI = (RNIR - RRED)/ (RNIR + RRED)$$

RNIR = Reflectance of the near infrared band. RRED = Reflectance of the red band.

Normalization disparity the health of green vegetation is indicated by the vegetation index, a straightforward statistic. The general idea is that although red and blue light are absorbed, chlorophyll significantly reflects near infrared light (NIR, or light that is approximately 750 nm). Plants seem green to humans because chlorophyll reflects heavily; however, reflection in the near infrared (NIR) is considerably larger, and this plays a very essential role in providing accurate data for analysis (Dezordi et al., 2016). The results of the computations range from -1 to +1; close to 0 (ZERO) denotes no vegetation on the crop, and close to +1 (0.8 to 0.9) denotes the maximum density of green leaves. Farmers may quickly identify crop health conditions and monitor crops based on these results (Graeff et al., 2008).

Throughout the agricultural season, drones may be used to monitor crop conditions and execute timely, need-based intervention. A prompt and suitable response can stop yield loss. Farmers won't need to physically check their crops thanks to this technology (Zarco-Tejada et al., 2009). They can keep an eye on crops grown in isolated locations, such as hilly regions, or horticulture crops. Additionally, they can effectively monitor trees and tall crops, which are difficult for farmers to physically inspect (Hoffmann et al., 2016).

2. Water stress monitoring

Since several factors may both impact and be affected by the consequences of drought, characterizing water stress on crops is a challenging undertaking. To identify stresses and other phenomena, variables obtained from thermal imaging frequently depend on minuscule temperature fluctuations (Dash et al., 2017). Because of this, regression equations and thresholds that are developed under certain conditions typically do not hold under even slightly different conditions (Dang et al., 2020). For instance, due to innate variations in stomatal conductance and transpiration rates, several genotypes of a particular crop may exhibit noticeably varying canopy temperatures under the same circumstances (Ziya et al., 2018). To identify water stressors, researchers employed a variety of sensors and models, including Spectral alterations targeted at emphasizing certain vegetation qualities result in the use of hyperspectral or multispectral pictures and the vegetation indices (NDVI, GNDVI, etc.) (Klemas, 2015).

A reflectance measurement sensitive to variations in the carotenoid pigments found in leaves is the photochemical reflectance index (PRI), which is calculated using multispectral or hyperspectral images (Wen et al., 2018). Some studies utilize the canopy temperature directly, while others employ thermal infrared images and the difference in air and canopy temperatures (Tc-Ta). The crop water stress index (CWSI), which is based on the difference between canopy temperature and air temperature (Tc - Ta) and is normalized by the vapor pressure deficit (VPD), is calculated using thermal infrared images (Maimaitijiang et al., 2017; Severtson). RGB (red, green, blue) pictures are seldom used in conjunction with thermal or multispectral photos to calculate hybrid variables like the Water Deficit Index (WDI). Water stress monitoring and detection have also occasionally been addressed using chlorophyll fluorescence, which is computed using narrow-band multispectral pictures (Gabriel et al., 2017).

3. Nutrient status and deficiency monitoring

The proper levels of nutrients are needed for plants to thrive and provide a substantial crop. According to Calderón et al. (2013), adequate quantities of phosphorus are necessary for strong root and stem growth, proper levels of nitrogen will ensure robust growth of vegetation and foliage, and appropriate levels of potassium are needed to promote disease resistance and guarantee greater crop quality. If any of these nutrients are absent from the soil, the plant will get stressed and find it difficult to develop (Sarghini and De Vivo, 2017). By using NDVI Index mosaics, it is possible to identify agricultural regions that are stressed or having problems with precision and to act quickly in these areas (Kedari et al., 2016; Niu et al., 2019).

According to Xia et al. (2016), the most popular method for determining nutritional quality at the moment is visual, using plant color guides that prevent quantitatively rigorous evaluations. Laboratorial leaf analyses are necessary for more accurate evaluations; yet, they are time-consuming and demand the use of certain techniques in order to correctly interpret the data (Malenovskþ et al., 2017). For some nutrients, there are indirect alternatives that may be used, such the chlorophyll meter (Soil-plant analyses development; SPAD) for nitrogen predictions; however, this method takes time, and the results are not always precise.

Consequently, a great deal of work has gone into creating novel techniques for identifying and quantifying nutritional issues in plants (Huang et al., 2018). Because of its relationship to yield and biomass, nitrogen has been the nutrient that has been investigated the most. Sodium and potassium have also drawn considerable interest. Although RGB and hyperspectral pictures are also commonly used, multispectral images have been the preferred option for the extraction of significant features and indices (Dutta and Goswami, 2020).

Research has also been done on data fusion, which combines two or even three different kinds of sensors (thermal, RGB, and multispectral). Most of the research published in the literature extract vegetation indices (VI) from the photos and use a regression model—typically a linear one—to connect them to the amount of nutrients present. Other variables, such as the average reflectance spectra, particular spectral bands, color attributes, and main components, have also been used to input the regression models, albeit they are less prevalent (Li et al., 2016). Except for the color characteristics, which are computed from RGB photos, all of them are derived from hyperspectral images (Calderón Madrid et al., 2013).

4. Diseases monitoring

Crop diseases are categorized as bacterial, viral, or fungal and can be quite destructive. Infrared cameras on drones allow them to investigate plants, providing a clear picture of their state (Spoorthi et al., 2014). A farmer can take preventative action, such as removing the plant, if they are able to identify an infection before it spreads to nearby plants (Vardhan et al., 2014). Thus, when human evaluation is inappropriate, incorrect, or unavailable, image-based methods can be crucial in identifying and diagnosing plant diseases, especially given the wider coverage that unmanned aerial vehicles (UAVs) provide. RGB and multispectral photos have become the go-to techniques for gathering data about the locations under study, although tests have also been done on thermal and hyperspectral images (Huang et al., 2009). The latter is primarily utilized to identify indicators of water stress that may be brought on by illness of interest (Zhu et al., 2010).

5. Weed Control

Unwanted plants called weeds may develop in agricultural crops and cause several issues. They are causing losses in agricultural yields and growth because they are competing for scarce resources like space and water (Zhu et al., 2010). In India, the following crop yields are lost to weeds: vegetables (30-40%), rice (10–100%), wheat (10–60%), maize (30–40%), sugarcane (25–50%), jute (30–70%), potatoes (20–30%), and so on (Vardhan et al., 2014). Herbicide application is the most used method of controlling weeds. According to Vardhan et al. (2014), the most popular method of managing weeds in traditional farming involves uprooting them after they have emerged and applying the same quantity of herbicide to the entire field, including the weed-free sections. But abuse of herbicides can lead to the development of weeds resistant to them, which can hinder crop growth and productivity.

Differentiating between the spectral signatures of some weeds with varying glyphosate resistances using hyperspectral pictures. classifying different weed species using RGB sensors (Zarco-Tejada et al., 2004). Drones equipped with hyperspectral sensors were utilized by researchers to track weed based on the density of leaves and the amount of chlorophyll in the plant canopy. Furthermore, it presents a significant risk of damage to the environment (Zarco-Tejada et al., 2004). Site-specific weed control is utilized to accomplish this aim and overcome the issues. To ensure accurate herbicide spraying, an accurate map of the weed cover must be created.

Drones may collect data and photos from the whole field, which can be utilized to create an accurate map of the weed cover that shows the areas that require chemical application (Zarco-Tejada et al., 2022). Applying weedicide spray with an agro-drone is beneficial for both pre- and post-emergence weeds. Spraying may be done in a variety of field conditions, including muddy, weedy, insect-filled, and sunny and rainy ones. Drone weedicide application is effective and maximizes weedicide usage.

It is easy to transport, maintain, and operate (Torres-Rua et al., 2015). Utilize remote work, which is extremely health safe. Drone for measuring evapotranspiration (ET) Water is moved from the land to the atmosphere by evaporation from the soil and transpiration from live plants, a process known as evapotranspiration (ET) (Nguyen and Symmons, 1984). Professionals in the domains of hydrology, agriculture, and water management employ estimates of potential ET. Due to water constraint, population growth, and climate change, estimating evapotranspiration has become one of the most significant agricultural research initiatives in recent years (Al-Arab et al., 2013).

Various unmanned aerial vehicle types are employed for various scientific objectives related to extraterrestrial estimates. There are three main types of UAVs: fixed-wing aircraft, quad copters, and aircraft. Although aircraft are often costly, they can carry large sensors and fly for longer (Barnhart et al., 2021). Fixed-wing planes and quadcopters are more affordable than aircraft. Fixed-wing aircraft can often fly for two hours, making them appropriate for big fields.

Quadcopters are utilized for short flying missions on small fields because of their approximately 30-minute flight time. In addition to providing a platform for remote sensing, UAVs also raise new research issues related to flight path planning and drone image processing. Using two source energy balance models, a fixed-wing UAV will gather thermal data to estimate ET (Qin et al., 2018). Using very-high-resolution footage from a UAV platform (S1000, DJI, Shenzhen, China), evapotranspiration in a peach orchard was measured (Yanliang et al., 2017). The drone is also equipped with a multispectral camera RedEdge (MicaSense, Seattle, WA, USA) and a TIR camera (A65, FLIR Systems Inc.).

An aerial digital system designed by Utah State University for evapotranspiration estimation was used to gather multispectral and thermal photos (Me et al., 2016). These cameras have the following spectral bands: Near-infrared (NIR) (0.780 µm – 0.820 µm), Blue (0.465 µm – 0.475 µm), Green (0.545 µm – 0.555 µm), and Red (0.645 µm – 0.655 µm). The airplane is equipped with a Thermal CAM SC640 (FLIR Systems Inc.) for the purpose of capturing thermal infrared (TIR) pictures, which have a wavelength range of 7.5µm–13µm. UAV platforms with lightweight sensors can produce greater quality, higher spatial and temporal resolution pictures as compared to other satellite-based remote sensing techniques (Yallappa et al., 2017).

6. Spraying

For agriculture to reach high productivity levels, production and protection materials were required. Fertilizer and chemicals for agriculture are often required to eradicate insects and promote crop development. Depending on how differently the crops and field are positioned in space, drones may be used to spray chemicals such as insecticides, fertilizers, etc. Depending on the crop conditions or the intensity of the insect-pest assault, the quantity of chemicals to be sprayed might be changed. The possibility for a platform for vector control and pest management arises from the combination of UAV with sprayer system. For a sizable agricultural field, this is an accurate site-specific application. Heavy lift UAVs are needed for this function to spray a big area.

The lightweight and inexpensive quadcopter (QC) technology, commonly referred to as an unmanned aerial vehicle (UAV), was proposed by researchers. Due to its compact design, this quadcopter system is suitable for both indoor and outdoor farming. Using an Android device, Quadcopter is an autonomous flying tool for applying fertilizer and insecticides. Real-time Bluetooth connectivity is used to operate the quadcopter and an Android device. This technology is used to boost agricultural productivity and lessen issues associated to the agricultural sector. When applying pesticides, the PWM controller on the spraying system attached to the UAV improves its efficiency (Yallappa et al., 2017).

Based on GPS coordinates in a lower altitude setting, an aerial automated pesticide sprayer (AAPS) known as a blimp integrated quad copter was created. To get around this, the user-friendly, low-cost pesticide spraying drone known as "Freyr" was created. It is operated using an Android smartphone. The development of a hexa copter mounted sprayer is examined in terms of droplet density, sizes, spray uniformity, liquid loss, and pressure rate of the liquid in both laboratory and field settings. An electrostatic sprayer with a hexarotor UAV was invented and constructed based on electrostatic spray technology to minimize pesticide waste.

2.6. Conclusion

Drone technology in agriculture has the potential to completely transform farming methods and increase production, sustainability, and efficiency. Drones may be used for a variety of agricultural tasks, such as precise spraying, mapping, surveying, and crop monitoring and evaluation. Drones collect data in real-time and with high resolution, which helps farmers use resources wisely and maximize crop management techniques. Because they consume less resources and require less physical effort, they save money and time. Drones' utility and efficiency in large-scale farming operations are improved by their capacity to visit difficult-to-reach locations and offer full views of the fields. Drones also lessen the environmental effect of agricultural methods, allow targeted spraying, and cut down on chemical waste, all of which help to environmental sustainability. Given that drones minimize or completely remove the need for farmers to physically enter dangerous locations, the safety component of drone use must be considered. Notwithstanding obstacles like laws and flying duration restrictions, drone technology is always improving to overcome these constraints. Drones provide several benefits to agriculture overall and incorporating them into farming operations has the potential to revolutionize the sector by maximizing resource use, increasing crop yields, and promoting sustainable agricultural methods.

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CHAPTER 3

PRODUCT AND MANAGEMENT EXCELLENCE AS MAJOaR DETERMINANTS OF PRODUCTION: IMPLICATIONS FOR RICE FARMING INCOME OF MENTIK SUSU VARIETY

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ABSTRACT

This study used a combined qualitative and quantitative method to measure the business scale of farming corporations, with a focus on rice farming of the Mentik Susu variety. The main variables involved Business Scale, Human Resources, Technology, Cultivation Techniques, Capital, Institutionalization, Management, Local Wisdom, and Product Excellence. Data were collected through a survey of 100 farmers in four districts of Majalengka Regency. The results of the analysis using PLS modeling (Partial Least Squares Structural Equation Modeling) show that Farm Scale, Management, and Product Excellence have a significant positive influence on the production of Mentik Susu variety rice farms. On the other hand, Institutionalization and Local Wisdom have a negative influence on production. In the context of farm income, Institutionalization has a significant positive impact, while Farm Scale, Management, Local Wisdom, and Product Merit have a negative impact. Regression analysis also shows that production has a positive impact on farm income. Overall, the study concludes that factors such as farm scale, management, and product excellence play an important role in increasing farm production, while institutional factors have a positive impact on farm income. With this understanding, this research provides valuable insights for the development and improvement of the corporate farming system in Majalengka Regency.

Keywords: Corporate farming, farming; system, institutional.

3.1. Introduction

Agriculture is crucial in providing food and plays a central role in a country's economic development, especially in Indonesia where a large proportion of the population relies on the agricultural sector. Nonetheless, the agricultural sector, especially in rice, faces significant challenges, such as small economies of scale, limited cultivation technology, and often limited land tenure. To overcome these problems, the government through the Ministry of Agriculture has initiated a program to incorporate farmers into agricultural corporations (Widodo & Kaswanto, 2020).

The incorporation of farmers into corporations is a vital strategy in facing the complex challenges facing the agricultural sector, especially in Indonesia. Farmer corporations, as a forum for farmer consolidation, aim to improve farmers' competitiveness and welfare through collective management of agricultural businesses. In 2019, the Ministry of Agriculture launched a program that focuses on encouraging collective management of agricultural businesses, viewing agricultural corporations as an important pillar in the development of a professional and competitive agricultural sector. The concept of agricultural corporations is in accordance with the principle of mutual cooperation, where farmers unite to achieve common goals, utilize resources more efficiently, and overcome various obstacles faced at the individual level (FAO, 2019).

The farmer corporation development program involves various parties, including SOEs, non-SOEs, and communities, with the aim of building farmer-focused economic institutions. The importance of developing farmer corporations is reflected in several regulations, such as the Farmer Empowerment and Protection Law, the Agriculture, Fisheries, and Forestry Extension System Law, the Cooperatives Law, and the Microfinance Institutions Law. Farmer corporations are instruments that are in accordance with the values of Pancasila, especially in realizing a gotong royong economy and a dynamic family system (Iskandar & Wiratna, 2020).

In the context of democratization, there is a strong drive to improve the welfare of farmers, who are considered a pillar of development that has been neglected. Agriculture, particularly the rice subsector, plays a significant role in the Indonesian economy, contributing around 12.72% to the Gross Domestic Product (GDP) in 2019. However, this sector is faced with various problems, such as increasingly widespread industrial land tenure and lack of access and market information for small-scale farmers (Sudaryanto & Yulianto, 2020).

Marketing of agricultural products, especially price fluctuations that reach 60% - 80%, is a serious challenge for farmers. The development of farmer corporations is expected to provide a solution to this problem by creating market stability, reducing post-harvest costs, and providing price certainty. Although the government has initiated the program, its implementation is still faced with obstacles, such as the low quality of human resources and the lack of commitment in carrying out business partnership mechanisms, both by farmers and partner companies.

The importance of developing farmer corporations becomes more apparent when looking at changes in people's consumption patterns that tend to be consumptive (Hidayah et al., 2022). In a situation where food-related supply and demand are still in a relatively normal balance, the challenges faced by the agricultural sector in Indonesia can still be overcome (Thornton & Herrero, 2015). However, climate change, extreme cycles such as more frequent floods and droughts, and the development of resistant pests are increasingly threatening food security and the carrying capacity of society.

Therefore, this research emerged as a response to the complexity of the challenges of the agricultural sector, particularly on the development of farmer corporations in Lumbung Bumi Majalengka Cooperative. The research focuses on the role of product excellence and management as the main determinants of production, with the hope of providing an in-depth understanding of the positive impacts that can be generated by the farmer corporation model in increasing production and income of the mentik susu rice variety. The implications of this research are expected to provide concrete contributions in formulating policies and strategies for developing more effective farmer corporations in the future, creating a sustainable agricultural model and prospering the farming community.

3.2. Methods

This research uses a combined qualitative and quantitative method to measure the business scale of farmer corporations. The main variables include Business Scale, Human Resources, Technology, Cultivation Techniques, Capital, Institutionalization, Management, Local Wisdom, and Product Excellence. Each variable has dimensions and indicators that are operationalized to collect data, such as Farm Business Frequency, Productivity, Efficiency, Job Satisfaction, Local Customs and Culture, and Comparative and Competitive Advantage (Smith & Brown, 2020). This method details the measures, criteria, and scores for each indicator, ensuring a comprehensive analysis of the farming corporation's business scale, institutions, and factors affecting product excellence.

1. Sources, Methods and Techniques of Data Collection

The number of respondents who will be sampled for this research is 100 people in four (4) sub-districts, namely; Sindangwangi sub-district, Kadipaten sub-district, Kertajti sub-district and Jatitujuh sub-district with each respondent as many as 25 farmers. The way of determining data is by conducting surveys to farmers who do Mentik Susu Rice Farming Business. data collection is done by giving questions or written statements to respondents to be answered.

2. Design of Analysis

The analysis technique used is using PLS 4 modeling: Based on the research hypothesis and the design of the hypothesis testing tool used, the research hypothesis can be described in Figure 1.

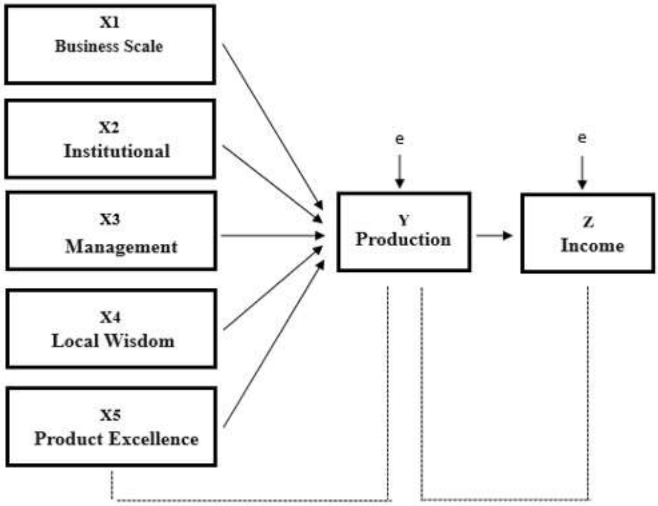

Figure 3.1. Diagram of the Relationship between Research Variables and Hypothesis Test

Corporate Agriculture System in Rice Farming Business (Oryza sativa L) Mentik Susu Variety in Lumbung Bumi Majalengka Cooperative with dimensions; Business Scale, Institutionalization, Management, Local Wisdom, and Product Excellence have a positive effect on production. In this case, the dependent variable is the effect of the Farmer Corporation System on the Rice Farming Business (Oryza sativa L) Mentik Susu Variety in Majalengka Earth Barn Cooperative, while the independent variables are Business Scale (X1); Farming Business Frequency, Human Resources, Technology, Cultivation Techniques, and Capital. Institutional (X2); Legality Aspects, Institutional Roles, Organizational Structure, Policies/Procedures and Involvement of Policy Makers. Management (X3); Management Principles, Human Resource Management, Financial Management, and Production Management. Local Wisdom (X4); Local Customs and Culture, Adaptability. Product Excellence (X5); Comparative Advantage, Competitive Advantage, Price, Sustainability, Marketing. Each hypothesis is solved using SMART-PLS (Partial Least Squares Structural Equation Modeling) is one of the statistical analysis methods used to test and model the relationship between variables in structural models (Kotler & Armstrong, 2018).

3.3. Result and Discussion

3.3.1 Description of Factors Associated with the Farming System Rice (Oryza sativa L.) Variety Mentik Susu Farming Corporation

1. Scale of Business

From the results of the questionnaire given to 100 farmer respondents, it shows that the scale of the corporate farming system is categorized as good, For more details, the results of respondents' assessment of farmers' knowledge in the corporate farming system can be seen in Table 3.1.

Table 3.1. Scale of Farming towards the Corporate Farming System

No.	Farm Scale Indicator	Score		Percent (%)	Category
		Hope	Reality		
1.	Frequency of Farming Business	1600	1107	69,18	Good
2.	Human Resources	1600	1269	79,31	Good
3.	Technology	2000	1401	70,00	Good
4.	Cultivation Techniques	3200	2560	80,00	Good
5.	Capital	1200	300	60,08	Good
	Business Scale	9600	7058	73,52	Good

Source: Data Analysis (2023)

From Table 3.1 above, it can be explained that the frequency of farming is the initial factor that reflects the extent of farmer involvement in agricultural activities. In this case, the data shows that most farmers have been involved in farming, which can facilitate the implementation of corporate farming systems. Adequate human resources also play an important role in running a corporate farming system. The data results show that a fairly high percentage score on the human resources indicator illustrates the readiness of farmers in running a corporately managed farming process.

Cultivation technology and techniques scored relatively well, indicating that farmers have the ability to adopt modern agricultural technology that may be required in a corporate farming system. Strong cultivation technology and techniques can help improve production efficiency (Marina et al., 2022). However, the capital aspect shows a lower score. This indicates that in the implementation of corp

orate farming systems, there are still challenges related to access to adequate capital for farmers. Higher capital availability will help farmers to maximize production potential.

2. Institutionalization

The results of the questionnaire given to 100 farmer respondents show that the institutionalization of the corporate farming system is categorized as good, with an institutional score of 1,595 or 79.25% of the expected score of 2,000. For more details on the results of respondents' assessment of institutions in the corporate farming system can be seen in Table 3. 2.

Table 3.2. Institutionalization in the corporate farming system

No	Indicator Institutional	Skor		Persen (%)	Category
		Hope	Reality		
1.	Aspek Legalitas	400	300	75,00	Good
2.	Institutional Role	400	320	80,00	Good
3.	Organization Structure	400	300	75,00	Good
4.	Procedure Policy	400	358	89,50	Very Good
5	Engagement Stakeholder Interests	400	317	79,25	Good
	Institutional	2.000	1.595	79,75	Good

Source: Data Analysis (2023)

From Table 3.2 above, it can be explained that institutions in the utilization of corporate farming systems in Majalengka Regency obtained, the institutional score is 1,595 or equivalent to 79.75% of the maximum expected score of 2,000. This data reflects respondents' perceptions of the various institutional aspects that exist in the corporate farming system.

Further analysis of the institutional indicators in the table shows that several aspects received good ratings. These aspects are legality, institutional role, organizational structure, and stakeholder involvement, where the percentage score of each aspect ranges from 75% to 80%. This indicates that in these aspects, the corporate farming system has met or exceeded the expectations of the respondents.

In addition, the policies and procedures aspect was rated as excellent, with a percentage score of 89.50%. This indicates that the policies and procedures applied in the corporate farming system have a high level of institutionalization and are positively recognized (Marina et al., 2021).

3. Management

From the results of the questionnaire given to 100 farmer respondents, it shows that the management of the corporate farming system is categorized as very good, with a perception score of 1,286 or 80.36% of the expected score of 2,925. For more details on the results of respondents' assessment of the management of the corporate farming system can be seen in Table 3.3.

Tabel 3.3. Management of the corporate farming system

No.	Management Indicator	Skor		Persen (%)	Category
		Hope	Reality		
1.	Management Principles	400	332	83,00	Very Good
2.	HR Management	400	331	82,75	Very Good
3.	Financial Management	400	323	80,75	Very Good
4.	Product Management	400	300	75,00	Good
	Management	1.600	1.286	80,36	Very Good

Source: Data Analysis (2023)

From Table 3.3 above, it can be explained that almost all aspects received a very good assessment from respondents. The principle of management received a percentage score of 83.00%, which indicates that respondents see the principles applied in the management of corporate farming systems as having very good quality. Furthermore, the management of human resources (HR) was rated very well with a percentage score of 82.75%. This shows that respondents feel that labor management in the corporate farming system has been running well and efficiently. Financial management also received a positive assessment with a percentage score of 80.75%. This illustrates that financial management in corporate farming systems is considered effective in managing financial aspects, which in turn can support the continuity of farming. However, product management received a "good" assessment with a percentage score of 75.00%. This indicates that there are some aspects related to product management in the corporate farming system that may require further improvement.

The relationship between the results of this assessment and farm production and income is very significant. Good management in corporate farming systems has the potential to increase efficiency, productivity and quality of agricultural products. Strong management principles can lead to better Local Wisdom, optimization of resource use and improved competitiveness. Effective management of human and financial resources can help manage costs, optimize labor use, and improve efficiency. All of these can contribute to increased quality production and ultimately, increased farm income for farmers in corporate farming systems. Nevertheless, attention needs to be paid to aspects of product management that still need improvement to ensure optimal and maximum production results (Nursalam et al., 2022).

4. Local Wisdom

From the results of the questionnaire given to 100 farmer respondents, it shows that farmers' Local Wisdom towards corporate farming systems is categorized as good, with a Local Wisdom score of 539 or 67.36% of the expected score of 800. For more details on the results of respondents' assessment of farmers' Local Wisdom towards corporate farming systems can be seen in Table 3.4.

Tabel 3.4. Farmers' Local Wisdom in Corporate Farming System

No.	Indicator Local Wisdom	Score		Percent (%)	Category
		Hope	Reality		
1.	Local Cultural Customs	400	290	72,50	Good
2.	Adaptability	400	249	62,25	Good
	Local Wisdom	800	539	67,36	Good

Source: Data Analysis (2023)

From Table 3.4 above, it can be explained that in the Local Cultural Customs indicator, respondents gave a score of 290 or 72.50% of the maximum expectation of 400. This indicates that farmers see that the corporate farming system is sufficient to accommodate local customs and culture in its implementation. On the other hand, the Adaptability indicator received a score of 249 or 62.25% of the maximum expectation of 400. This reflects the respondents' positive view of the ability of corporate farming systems to adapt to local needs and conditions, thus supporting more effective implementation.

Its relationship to farm production and income can be understood from the following perspective: When farmers perceive that Local Wisdom has been respected and integrated in the corporate farming system, they may be better able to implement farming practices that are appropriate to the local environment and culture. This has the potential to impact productivity and production efficiency. In addition, if farmers feel that the corporate farming system is able to adapt well to changes in the environment, weather and local conditions, the chances of overcoming challenges and optimizing yields may increase. In the long run, increased productivity and production efficiency can have a positive impact on farmers' farm income, as they can produce more with lower costs (Andayani et al., 2022). Therefore, the positive results of farmers' Local Wisdom assessment of the corporate farming system may reflect the potential for increased production and farm income in the context of the corporate farming system.

5. Product Excellence

From the results of the questionnaire given to 100 farmer respondents, it shows that farmers' Product Excellence towards corporate farming systems is categorized as good, with a Product Excellence score of 1,475 or 73.75% of the expected score of 2,000. For more details on the results of respondents' assessment of the Product Excellence of farmers towards the corporate farming system can be seen in Table 3.5.

Tabel 3.5. Farmer Product Excellence in the Corporate Farming System

No.	Product Excellence Indicator	Score		Percent (%)	Category
		Hope	Reality		
1.	Comparative Advantage	400	283	70,75	Good
2.	Competitive Advantage	400	325	81,25	Very Good
3.	Price	400	327	81,75	Very Good
4.	Sustainable Agriculture	400	290	72,50	Good
5.	Marketing	400	250	62,50	Good
	Product Advantages	2.000	1.475	73,75	Good

Source: Data Analysis (2023)

From Table 5 above, it can be explained that several indicators of Product Advantage get a good assessment from the respondents. First, the Comparative Advantage aspect has a percentage score of 70.75%, indicating that the superiority of farmers' products in terms of comparison with similar or competing products is considered quite good by respondents. Furthermore, the Competitive Advantage indicator was rated very well with a percentage score of 81.25%. This indicates that farmers' products in the corporate farming system have high competitiveness in the market, gaining positive appreciation from respondents.

The Price indicator was also rated very well with a percentage score of 81.75%. This indicates that the price of farmers' products in the corporate farming system is considered appropriate or better than respondents' expectations. However, there are several indicators that received lower ratings. Sustainable Agriculture has a percentage score of 72.50%, while Marketing has a percentage score of 62.50%. While these scores remain in the "Good" category, there is potential to improve and enhance these aspects to support the growth of farmers' farm production and income in corporate farming systems.

In relation to farm production and income, a positive assessment of farmers' Product Excellence can have a positive impact on increasing production and income (Sukmawati et al., 2022). Product excellence, particularly aspects of competitive advantage and appropriate pricing, can help farmers' products become better known and in demand in the market. This can lead to increased product demand and sales, which in turn has the potential to increase farmers' farm income (Marina, 2017). In addition, a focus on sustainable agriculture and better marketing can also support increased sustainable production and improve access of farmers' products to a wider market, ultimately contributing to the growth of farmers' income in the corporate farming system.

3.3.2 Effect of the Corporate Farming System on Farm Business Production Rice (oryza sativa l.) Mentik Susu Variety in Cooperatives

Based on the analysis of the corporate farming system (X) on the production (Y) of rice farming varieties of Mentik Susu can be modeled in Figure 2. Based on the analysis, it can be explained that the coefficient value of each variable farming scale (X1) -0.057, Institutional (X2) 0.034, Management (X3) 0.185, Local Wisdom (X4) -0.070, Product Excellence (X5) 0.602, meaning that the regression coefficient values provide an overview of the direction and strength of the relationship between each independent variable with the dependent variable as follows:

- Farm Scale (X1) with Coefficient -0.057:
  The negative coefficient indicates that an increase in the Scale of Farming variable will be associated with a decrease in the Production of Rice Farming Business of Mentik Susu Variety. Although this relationship is negative, it should be noted that this interpretation does not indicate a cause-and-effect relationship. The coefficient value of -0.057 indicates that a one unit change in the Farm Scale variable is followed by a 0.057 unit decrease in Production.

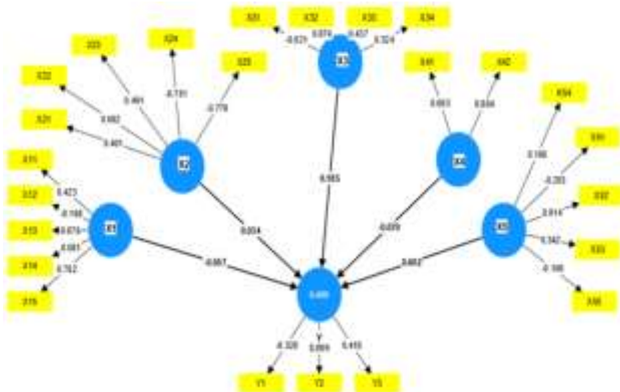

Figure 3.2. Model of Corporation System on Rice Crop Production

- Institutional (X2) with a coefficient of 0.034
  The positive coefficient indicates that an increase in the institutional variable will be associated with an increase in the production of the Mentik Susu Variety Rice Farming Business. However, the level of influence is relatively small, with a one-unit change in the Institutional variable followed by an increase of 0.034 units in Production.
- Management (X3) with a coefficient of 0.185:
  A larger positive coefficient indicates that an increase in the Management variable will be associated with a more significant increase in the Production of Rice Farming Business of Mentik Susu Variety. A one-unit change in the management variable is followed by an increase of 0.185 units in production.
- Local Wisdom (X4) with a Coefficient of -0.070:
  The negative coefficient indicates that an increase in the Local Wisdom variable will be associated with a decrease in the Production of Rice Farming Business of Mentik Susu Variety. Like X1, this coefficient is also

negative, but with a lower value. A one-unit change in the Local Wisdom variable is followed by a 0.070-unit decrease in Production.

- Product Advantage (X5) with a Coefficient of 0.602:
  The highly positive coefficient indicates that an increase in the Product Superiority variable will be associated with a significant increase in the Production of Rice Farming Business of Mentik Susu Variety. A one-unit change in the Product Excellence variable is followed by an increase of 0.602 units in Production.

In the overall analysis, the Product Excellence variable (X5) has the strongest positive influence on the Production of Mentik Susu Variety Rice Farming Business, followed by the Management (X3) and Institutional (X2) variables. The variables of Farm Scale (X1) and Local Wisdom (X4) have a negative influence, but keep in mind that all of these interpretations are based on statistical relationships and can be influenced by context and other factors not modeled in this analysis at 0.501.

3.3.3 Effect of Corporate Farming System on Business Income Rice Farming (Oryza sativa L.) Mentik Susu Variety in Cooperatives

Based on the analysis (Figure 3), it can be explained that the coefficient value of each variable farming scale (X1) -0.029, Institutional (X2) 0.292, Management (X3) -0.277, Local Wisdom (X4) -0.062, Product Excellence (X5) -0.203, meaning that, each variable farming scale, institutional, management, local wisdom, and product excellence (corporate farming system indicators) contribute to the variable income of rice farming.

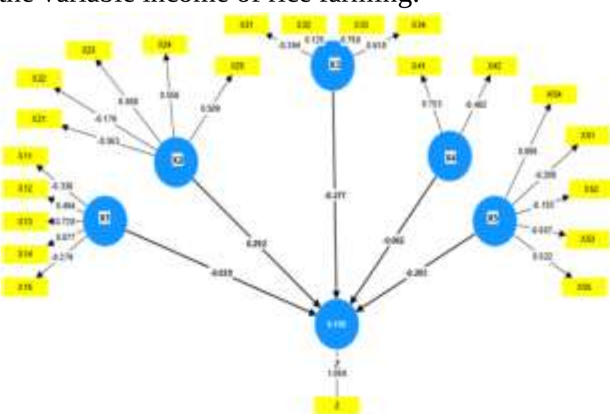

Figure 3.3. Model of Agricultural System on Rice Crops Production Income

The following is the interpretation of the coefficient for each variable:

- Farm Scale Variable (X1): -0.029

The negative coefficient indicates that an increase in farm scale will result in a decrease in rice farming income. Although the impact is relatively small (based on the magnitude value), it indicates that the larger the scale of farming, the income tends to decrease.

- Institutional Variable (X2): 0.292

  The positive coefficient indicates that institutions have a significant positive influence on rice farming income. An increase in institutional aspects can increase farm income.
- Management Variable (X3): -0.277

  The negative coefficient indicates that an increase in management will result in a decrease in rice farming income. This suggests that an increase in management, in the context measured, may reduce income.
- Local Wisdom Variable (X4): -0.062

  The negative coefficient indicates that an increase in the level of local wisdom is associated with a decrease in rice farming income. However, the impact appears to be lower compared to the other variables.
- Product Excellence Variable (X5): -0.203

  The negative coefficient indicates that an increase in product excellence has a negative impact on rice farming income. This is an indication that increasing product excellence in the context of the corporate farming system might reduce income.

  Overall, the results of the regression analysis show that factors contributing to rice farming income in the context of corporate farming systems have complex variability. Some factors such as institutions can have a significant positive impact, while other factors such as farm scale, management, local wisdom, and product excellence have a negative impact on income, which is understandable as these factors have an indirect influence on income. However, it should be noted that this interpretation is based solely on the coefficient values and it is important to consider the broader context and the interrelationships between the variables in actual farming practices i.e. the other unmodeled factors of 0.802.

3.3.4 Effect of Production on Income of Rice Farming Business (*Oryza sativa* L.) Mentik Susu variety in the Cooperative

Based on the analysis of the effect of production on the income of rice farming (Oryza sativa L.) variety mentik susu in the Cooperative can be modeled in Figure 4. Based on the analysis can be explained that the coefficient value of each variable farming scale (X1) -0.052, Institutional (X2) 0.049, Management

(X3) -0.163, Local Wisdom (X4) -0.053, Product Excellence (X5) 0. 619, on Production (Y) means that, each variable of farm scale, institutional, management, local wisdom, and product excellence (indicator of corporate farming system) contributes to the variable income of rice farming and indicates the influence of certain variables on Production (Y) and also the impact of Production on Income.

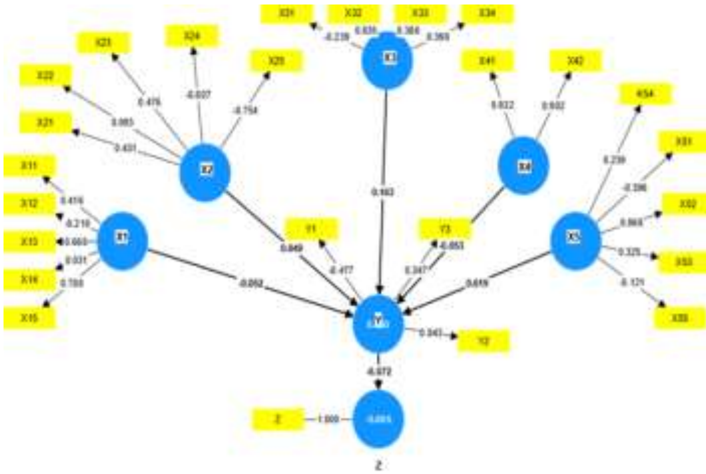

Figure 3.4. Model of Production Factors on Ricr Crops Production Income

The following is the interpretation of the coefficient for each variable:

- Farm Scale (X1): Coefficient -0.052
  Indicates that every one unit increase in Farm Scale will be followed by a decrease of about 0.052 units in Production (Y), assuming other variables remain constant. This indicates that as farm scale increases, production tends to decrease.
- Institutionalization (X2): Coefficient 0.049
  Indicates that every one unit increase in Institutionalization will be followed by an increase of about 0.049 units in Production (Y). This indicates that the presence of institutions can contribute positively to production.
- Management (X3): Coefficient -0.163
  Indicates that every one unit increase in Management will be followed by a decrease of about 0.163 units in Production (Y). This indicates that poorer management can have a negative impact on production.
- Local Wisdom (X4): Coefficient -0.053
  Indicates that every one unit increase in Local Wisdom will be followed by a decrease of approximately 0.053 units in Production (Y). This indicates

that a lack of implementation of local wisdom may negatively impact production.

- Product Excellence (X5): Coefficient 0.619
  Indicates that every one unit increase in Product Merit will be followed by an increase of approximately 0.619 units in Production (Y). This indicates that product excellence has a significant positive impact on production.

Meanwhile, the effect of production on the income of rice farming (Oryza sativa L.) variety mentik susu in the Cooperative can be modeled in Figure 3.5.

Figure 3.5. Model of Production on Rice Crops Farming Income

The Production variable (Y1) has a regression coefficient of 0.987. This means that each unit increase in the Production variable will be followed by an increase of 0.987 units in the income variable (Z) of the milk variety rice farming in Majalengka Lumbung Bumi Cooperative. This indicates that each unit increase in the Quality variable will be followed by an increase of 0.117 units in the income variable (Z) of the milk variety rice farming business at the Majalengka Earth Barn Cooperative. The Efficiency variable (Y3) has a regression coefficient of 0.265. This indicates that each unit increase in the Efficiency variable will be followed by an increase of 0.265 units in the income variable (Z) of the milk variety rice farming business at the Majalengka Earth Barn Cooperative.

3.4. Conclusion

Based on the analysis of the factors associated with the corporate farming system in Mentik Susu rice farming, it can be concluded that in general, farm scale, institutions, management, local wisdom, and product excellence have a significant role in influencing key aspects of the corporate farming system in Majalengka Regency. In particular, farm scale reflects the level of farmer involvement in corporate farming activities, with results showing that most farmers have been actively involved in farming, which can facilitate the implementation of corporate farming systems. Adequate human resources, technology, and cultivation techniques also received good ratings, indicating farmers' readiness to adopt modern agricultural.

Institutionalization in corporate farming systems is rated well, with aspects such as legality, institutional roles, organizational structure, policy procedures, and stakeholder involvement receiving positive ratings. This indicates that the corporate farming system in Majalengka Regency has met or exceeded respondents' expectations in terms of institutions. Management in corporate farming systems is rated very well, with management principles, human resource management, and financial management receiving positive ratings. However, the product management aspect still needs improvement.

Farmers' local wisdom towards the corporate farming system is also considered good, with local cultural customs and adaptability receiving positive assessments from respondents. This indicates that the implementation of corporate farming systems has sufficiently accommodated farmers' local values. The advantages of farmers' products in the corporate farming system were well assessed, especially in the aspects of competitive advantage, price, and sustainable agriculture. However, there is potential to improve aspects of sustainable agriculture and marketing to support production growth and farm income.

Furthermore, the regression analysis results show that farm scale, management, and product excellence have a positive influence on the production of Mentik Susu rice farming, while institutions and local wisdom have a negative influence. In the context of farm income, institutions have a significant positive impact, while farm scale, management, local wisdom, and product excellence have a negative impact.

1.4. Implication

Based on the analysis of the corporate farming system in Mentik Susu rice farming in Majalengka Regency, there are several implications and recommendations that can be taken to improve sustainability and productivity in this system.

First, it is necessary to increase the capacity of farmers through training and mentoring programs. Focusing on improving farmers' skills and knowledge will contribute significantly to production efficiency and effectiveness. In addition, optimizing product management is key in improving competitiveness.

Improvements in the supply chain, marketing, and distribution of agricultural products need to be implemented, possibly through collaboration with third parties such as marketing companies.

Second, it is important to strengthen farmers' local wisdom. This can be achieved by involving them more in decision-making and supporting traditional agricultural practices that are proven to be sustainable. Institutional strengthening is also needed, including improved regulatory clarity, transparency and stakeholder participation. Strong institutions will provide a solid foundation for system growth and sustainability.

Furthermore, encouraging diversification of agricultural products and more innovative marketing strategies can help improve the competitiveness of local products. Value-added product development and effective promotion need to be addressed. Improving infrastructure and market access is also a focus, with roads and storage systems built to support the distribution of products to marke.

Finally, the implementation of a continuous monitoring and evaluation system is necessary to monitor the progress of the corporate farming system. This will help detect potential problems or emerging opportunities and ensure rapid adaptation. These recommendations are expected to serve as a guide for relevant parties, including the government, agricultural institutions, and business actors, in improving the effectiveness and sustainability of the corporate farming system in Majalengka Regency.

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Brief Curriculum Vitae

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CHAPTER 4

CIRCULAR ECONOMY APPLICATION TO IMPROVE THE QUALITY OF LIFE

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ABSTRACT

There are a challenge to achieve a "Golden Indonesia" 2045, which are depression of natural resources and degradation of environmental quality, high vulnerability, risk of disaster, and increased potential impacts with the effect of climate change. It is necessary to make various efforts to be able to face the challenge. The application of circular economy can be one of the best alternatives to improve the environment quality. The circular economy model is design using an approaching systems to production and consumption activities, focus on minimizing resource use and waste generation with the aim of maintaining availability and renewable materials. This concept is made more than just waste management and the environment, but also focusing on reducing the consumption of resource and materials in the production chain.

4.1. Introduction

The goverment lauched the vision of “Golden Indonesia” in 2045, with the 8 missions of the development agenda, which are : 1) social transformation, 2) economic trasformation, 3) governance transformation, 4) rule of law, 5) stability and leadership of Indonesia, 6) social, cultural, and ecological resilience, 7) equitable regional development, and 8) high quality and sustainable infrastructure.

To achieve a “Golden Indonesia” in 2045, the challenges faced are related to strategic issue: depression of natural resources and degradation of environmental quality, high vulnerable abd risk of disaster as well as increased potential impacts and dangers of climate change. Based on that, varius efforts should be made to face the challenge and supported by clear policy directions in improving the quality of life and increasing disaster and climate recilience. This is important to do in order to maintain a balance of the use of natural resources and the environment, sustainability and their existence and usefulness so that their carrying capacity in the future is maintained.

Environmental issues is being the special concern to every segment, including Indonesia. Environmental issues that occurs right now is, global warming, climate change, high pollution, and deforestation caused legally and illegally. This problem certainly wont happens itself, but because the involvement of parties on the basis of various interests. To achieve the natural sustainability for the environmental issues is needed. Public awareness of the impact of economic activities that cause excessive negative ectanalities is predicted to lead to goverment policy determination (Rany et al., 2020).

The Circular Economic model is offered as an effort to improve the quality of the environment. In contrast to the linear economic model which is better known as the "take-use-waste" model (the linear production and consumption model is not sustainable), the circular economy model is an alternative that reflects the natural life cycle, both in economic, social and environmental factors (Guarango, 2022). Generally, environmental management can be done with the 3R method, namely reduce, reuse and recycle, but in the application of the circular economy method, a more complex method has been known again called the 5R reduce, reuse, recycle, replace, and replant methods (Yuliwati & Yusmartini, 2022) and then develop again into 9R, namely: R0 (refuse), R1 (rethink), R2 (reduce), R3 (reuse), R4 (repair), R5 (refurbish), R6 (remanufacture), R7 (repurpose), R8 (recycle) and R9 (recover).

4.2. Develompent Challenges

The purpose of a circular economy is to generate economic growth by paying attention to and maintaining the value of products, raw materials, nd resources in the economy in a sustainable manner. So that damage to social and environmental aspects can be minimized. The circular economy is not only in the form of waste management with the concept of recycling more, but the circular economy is the scope of a broad set of interventions in all economic sectors (Karimah et al., 2023). The application of a circular economy as a sustainable development effort in improving the quality of life certainly cannot be separated from challenges, including:

a) Global Demography and World Urbanization
By 2045, the world's population is expected to be 9.45 billion. Africa accounts for more than half of the world's population growth, but Asia still accounts for the largest population at around 55%. These global demographic trends can drive urbanization, migration flows and the elderly population. The world's urban population is expected to increase by 65% by 2045 and 95% of this growth will occur in developing countries including Indonesia. (Bappenas, 2019).

b) The Role of Emerging Economies
In 2050, the output of developing countries is estimated to reach 71% of total world output, with Asia as the main driver reaching 54%, one of which is Indonesia. Infrastructure, human resource investment, structural reforms and business climate are drivers of high, competitive and sustainable economic growth (Bappenas, 2019).

c) Trade-offs between Economic Growth and Environmental Sustainability
Based on the results of research using the Environmentak Kuznet Curve (EKC) by Rany et al., (2020), it shows that GDP growth will have an impact on increasing environmental damage caused by people choosing to improve the quality of life rather than consuming without paying attention to externality. This illustrates the trade-offs between economic growth and environmental sustainability.

d) International Trade and International Finance
Global trade until 2045 is estimated to grow at around 3.4% per year. The axis of world trade and investment in developing countries experiencing growth of 6% annually dominated by world currencies has shifted from the

US dollar to multi currencies. The financial assets of emerging economies are expected to exceed developed countries by 2050 and China is one of the sources of finance for future development (Bappenas, 2019).

e) Investment with Conventional Patterns
Generally, Indonesia still uses conventional investment patterns that are only concerned with profits compared to environmental impacts. In its application, it is hoped that there will be public awareness of negative externalities where companies and individuals can make investments that are based on the environment and profit-oriented and responsible for the implementation of environmental mitigation (Rany et al., 2020).

f) Middle Class
According to Bappenas, the number of middle and upper income classes in 2050 is estimated to exceed 84% or around 8.1 billion people. Where it is estimated that Asia and Latin America occupy the number of middle and upper income classes with the largest population.

g) Natural Resources Competition
The increasing economy and population will encourage competition for natural resources. The availability of natural resources that do not increase but the increasing needs make it a challenge for sustainable development even though technological developments will increase the efficiency of natural resources (Bappenas, 2019).

h) Technology
The advancement of digital technology has affected aspects of life. Information and communication technology, biotechnology and genetic engineering, health and medicine, renewable energy, wearable devices, automation and robotics, and artificial intelligence will be the trend of technological change in the future (Bappenas, 2019). To increase awareness and understanding of environmental issues, communication technology plays a role in it through the presentation of accurate information and effective and sustainable environmental communication strategies in the future (Anindya & Lokita, 2023).

i) Climate Change and Geopolitical Change
The issue of global warming is getting bigger, it is a challenge in the process of sustainable development. If not addressed by reducing emissions, it is estimated that average global temperatures will increase by 3-3.5 degrees

Celsius by the end of the current century. Geopolitical changes are also predicted to continue (Bappenas, 2019).

4.3. Stages of Sustainable Develompment

Sustainable development has basically become a strategic issue worldwide according to SDG's by 2030 adopted by all UN countries. According to Suparmoko (2020), there are two definitions of sustainable development. First, sustainable development refers to the value of all development capital such as the value of human capital, the value of ecosystems (natural capital and artificial capital) which as a whole the value remains unchanged. Second, sustainable development is defined as the substitution between three types of development capital, especially the value of natural can be balanced with the value of human capital and artificial capital in the event of a decline.

Based on the challenges that have been outlined, efforts to achieve a golden Indonesia in 2045 are arranged into 4 stages in sustainable development (Figure 4.1).

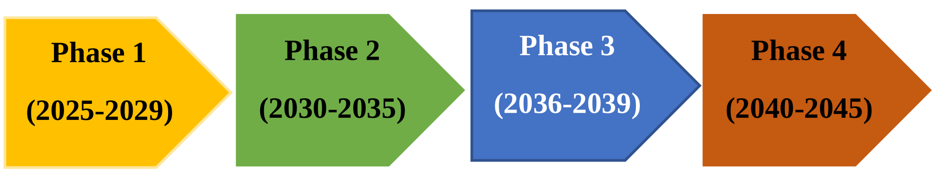

Figure 4.1. Stages of Sustainable Development

Based on Figure 1, the stages of sustainable development are described as follows:

Phase 1 (2025-2029) : Fondation of Transformation

- Economic Transformation, including downstream natural resources, research and innovation, green economy, urban development and growth centers, digitalization, transition to new renewable energy (EBT), carbon credits, electric vehicles (EV) which are very likely to be an alternative for sustainable energy management, energy efficiency and smart grids.
- Socio-Cultural and Eclogical, including resilience to change and disaster, research and technology for the carrying capacity of natural resources and environmental capacity, institutions and policies for environmental natural resource management, acceleration of the achievement of the Theory of Planned Behavior (SDGs) and reduction of greenhouse gas emissions.

Phase 2 (2030-2035) : Acceleration of Transformation

- Economic Transformation, including productivity improvement, growth centers, optimization of the blue economy, green economy and bioeconomy, retirement of coal-fired power plants, expansion of new and renewable energy (EBT), smart grids, electric vehicles (EV), risnov energy efficiency and digital producers.
- Socio-Cultural and Eclogical, including the acquisition of risnov-based technology (innovation research) for food, water and energy security, consistency of supervision and law enforcement, Resilient and adaptive to face change and disasters.

Phase 3 (2036-2039) : Global Expansion

- Economic Transformation, through economic power houses to take advantage of the productivity advantages of each country, the role of global value chains (GVC), mastery of medium and high technology, Asian maritime relations, retirement of coal-fired power plants, expansion of new renewable energy (EBT), energy efficient and smart grids.
- Socio-Cultural and Ecological Affairs, through resilient and adaptive to change and disaster, comprehensive green and blue economy policies, productivity and efficiency technologies, environmental pollution reduction, clean energy and waste management and food system integration.

Phase 4 (2040-2045) : Golden Indonesia

- Economic Transformation, through the world's maritime axis, global competitive innovation, retirement of coal-fired power plants, expansion of new and renewable energy (EBT) and smart grids.
- Socio-Cultural and Ecological Affairs, through resilience to change and disaster, green and blue economy References, good quality environment, clean energy, food products and pharmacology based on biological resources and towards net zero emission (NZE).

4.4. Application of Circular Economy to Improve Environmental Quality

A circular economy is one approach to a closed circular economy system by reducing the amount of waste that is not reused and ends up in landfills by maximizing the use and value of raw materials, components, and products. The circular economy is an economic model that is used as a driving tool to achieve Indonesia's economic transformation, especially to support the green economy with low-carbon development strategies and climate resilience as its pillars (Norman, 2022).

Quoted from the release of the Indonesian Forum for the Environment, the earth's temperature is currently increasing by 1.1 degrees Celsius, the impact of these environmental issues is increasingly felt. The rate of increase of 1.1 degrees celcus seems very small, but when associated with the temperature of the earth the effects that arise are very large and destructive. Climate change that occurs will cause changes in erratic weather patterns, such as frequent heat waves and droughts and long-term rain intensity (Walhi Indonesia, 2021).

Environmental problems are one of the anomalous events that generally involve natural components and have a negative impact on the survival of living things on earth. According to Syilvianisa & Rahmanto specifically, (2021), Indonesia has entered an environmental emergency that must be followed up immediately. The main thing to do is awareness from various parties. One of the actions in saving the sustainability of nature to improve the quality of the environment is by applying the concept of circular economy.

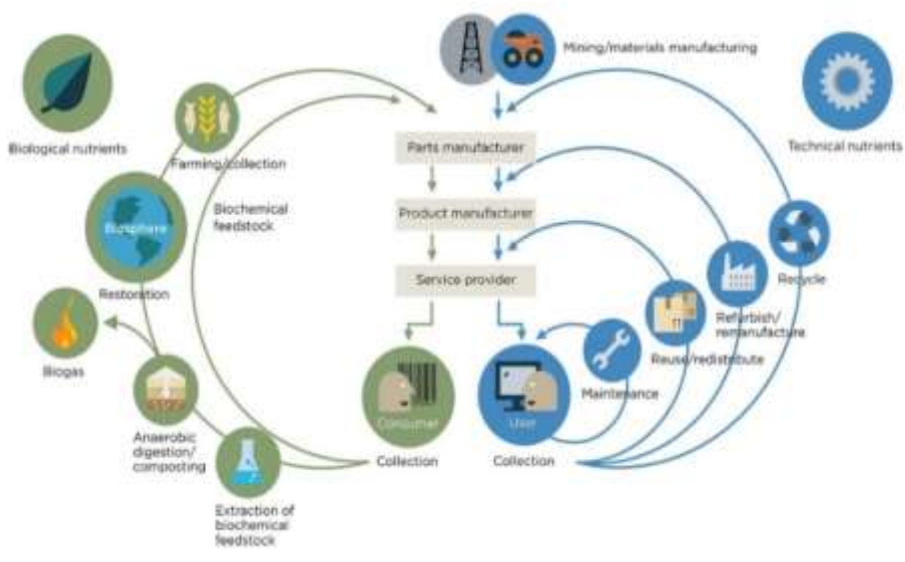

Figure 4.2. Economic Circular Ilustration. *Source: (Dwi Anugrah, 2023)*

The circular economy model is designed using a systems approach to production and consumption activities with a focus on minimizing resource use and waste generation with the aim of maintaining availability and renewable materials. The concept of a circular economy is made more than just waste management and the environment, but the circular economy focuses on reducing the consumption of resources and materials in the production chain. Norman, (2022) summarizes the circular economy model in The Future is Circular into a 9R framework consisting of 10 economic principles sorted from 0 to 9 as shown below:

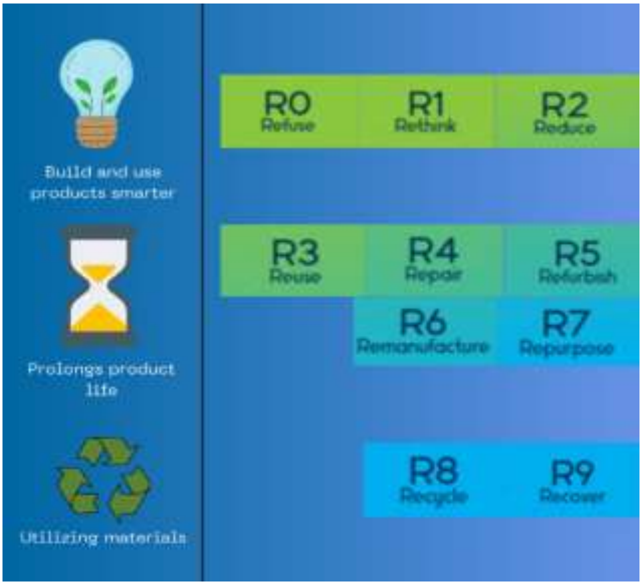

Figure 4.3. 9R Framework. *Resource : The Future is Circular*

Based on Figure 4.3, the circular economy model is divided into 3 important parts including:

1) Using and manufacturing products intelligently which includes:
   a. R0 (refuse), meaning that if the product provides the same function, then there is no need to make/manufacture other products because it provides the same benefits.
   b. R1 (rethink), meaning maximizing the use of the product more intensively.
   c. R2 (reduce), meaning that it increases production efficiency by minimizing material use.

2) Extend product life which includes:
   a. R3 (reuse), meaning reusing products that are still suitable for use

b. R4 (repair), meaning repairing products that have been damaged for reuse
c. R5 (refurbish), meaning restoring an unused product to have use and function again
d. R6 (remanufacture), meaning reusing part of a defunct product for reuse in a new product with the same function
e. R7 (repurpose), meaning reusing part of a defunct product for reuse in a new product with different functions

3) Take advantage of materials that include:
a. R8 (recycle), meaning processing material to produce new material
b. R9 (recover), meaning the process of burning materials to extract useful energy.

According to Potting et al., (2017) in Norman, (2022), the 9R framework describes the recycling rate that supports a circular economy, where the smaller the R number, the higher the recycling value, but conversely the greater the R number, the smaller the recycling value which is almost close to the linear economy. This circular economy concept is expected to be able to produce systematic solutions to overcome global challenges such as climate change, reduced biodiversity, availability of natural resources, waste management and pollution.

The application of the circular economy is a solution for the sustainability of quality of life, where in principle the circular economy focuses on sustainable product design by considering raw materials that can be recycled and used continuously, extending product life, and the use of environmentally friendly materials, efficient use of natural resources and material recovery through product recycling (Dwi Anugrah, 2023). According to Dwiningsih & Harahap (2022), the circular economy can be applied starting from a small scale, such as at the household level which is closely related to daily life with the aim of preventing and slowing down the occurrence of environmental problems that interfere with achieving sustainable living.

4.5. Conclusion

The circular economy was created into one of the environmentally oriented business models and as an effort to fulfill the achievements of sustainable development. The concept of a circular economy is a circular economic system by paying attention to environmental aspects, in contrast to the linear economy which has the concept of "take-use-waste" so that it produces waste continuously, but in the application of the circular economy products are redesigned to have uses both with the same and different functions so as to extend the economic value of the product and have a positive impact on the environment.

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CHAPTER 5

CHRONICLES OF WHEAT: ANALYZING THE TRANSFORMATIVE JOURNEY OF VARIETIES

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ABSTRACT

Grain yield and harvest index of various varieties of wheat were observed in different thesis of the researchers. It was found that higher grain yield was observed in Atta Habib, Bakhtawar-92, Pirsabak-2013, Siran-2010, Saleem-2000 and Tatara. Increased harvest index was noted in Khyber-87, Bakhtawar-92, Pirsabak-85, Pirsabak-2005, Atta Habib, Siran-2010, Tatara and Suleman-96. From the observation of all the thesis, it was concluded that Atta Habib, Saleem-2000, Siran-2010, Tatara and Pirsabak-2013 performed better in yield as compared to other varieties. With time due to a reduction in yield, certain varieties like Khyber-87, Inqilab-91, Pak-81 and Uqab are not recommended for further cultivation by the researchers while Pirsabak-2005, Atta Habib, Siran-2010, Saleem-2000 and Pirsabak 2013 are high yielding varieties and is recommended for better performance in terms of yield in the future.

Keywords; Wheat, Chronicle, Yield transformation, Historical analysis

5.1. Introduction

Triticum aestivum L., or wheat, is a member of the Triticum genus, tribe Hordie, and family Poaceae (Granzineae). This long-day winter cereal is self-pollinated every year and is photographed occasionally. Numerous civilizations have benefited greatly from the use of wheat in their growth. In terms of both area and productivity, it is the most significant food grain crop worldwide. One of the most valued crops in ancient Persia, Greece, and Egypt, wheat was grown throughout prehistoric Europe. The top 10 nations that produce wheat are Australia, Argentina, Canada, China, France, India, Russia, Germany, and the United States of America. After rice and maize in terms of global production, wheat ranks first in Pakistan in terms of total cultivated area annually. Almost every province, including AJK, cultivates it. It is grown on 37% of the country's cropped land, with 77% coming from Punjab, 11% from Sindh, 9% from the NWFP, and 4% from Balochistan (MINFAL, 2007).

In Pakistan, wheat holds the top spot among cereal crops. Proper wheat husbandry has a direct and indirect impact on Pakistan's prosperity. While 8358 thousand hectares of wheat were cultivated in 2006–07, with a total production of 2586 thousand tons, 748.6 thousand ha of wheat were cultivated in the NWFP in the same year, yielding 2161.23 thousand tonnes of wheat (MINFAL,2007).

It is the staple food for humans, particularly in Pakistan and India. It is significant to the country's economy. Reduced wheat production harms Pakistan's economy and exacerbates the country's citizens' suffering. According to Sarwar and Nawaz (1985), the average wheat yield in Pakistan has never exceeded 30–35% of its maximum yield potential, which is generated by optimal experimental conditions. It is commonly known that certain inputs, like balanced fertilizer, ideal planting density, and ideal sowing timing, can significantly raise the yield of a variety of crops, including wheat. An integrated management system is crucial to provide plants with a balanced diet, which is necessary for them to grow healthily. Farmers may apply excessive amounts of nitrogen fertilizer or none at all, which could lead to an imbalance in the availability of nutrients.

Pakistan will eventually need more wheat, day by day. It will be necessary to either increase the yield per unit area or put more area under cultivation in order to meet the new requirements. In the case of the first option, the country has almost exhausted the horizontal frontiers. However, encouraging results were found by many researchers in vertical development in wheat. About 50-97% of variation in yield plant' is due to yield components, were observed by Barriga and Funtealba (1986). Utilising recently created high-yielding, disease-resistant varieties along with suitable production techniques like irrigation, fertiliser, and assimilate partitioning understanding might boost wheat output. It is possible to boost productivity and wheat production by adjusting the yield components.

The wheat yield has been stagnating for the past few years despite the use of an acceptable amount of chemical fertiliser and management (Khan et al., 2001). It is still 30-80% lower than the potential yield of the wheat crop. Though wheat is a commodity that is widely farmed all over the world, different types thrive better in different environments. A cultivar with a good yield in one area could cause issues in another environmental zone. Different kinds, such as Pak-81, Khyber-70, and WL-71, have varying yield production (Khan et al., 1990). Chia (1982) noted a considerable variation in yield and yield components between cultivars. The way that various genotypes perform is greatly influenced by the relationship between genotype and environment. To generate comparatively stable cultivars, extensive genotype testing of wheat has been conducted under various environmental conditions (Gebeyuhu, 1987).

5.2. Methods

The observations were carried out in the thesis to check the performance of wheat varieties from year 1992 to 2016 at the Department of Agronomy, Library, The University of Agriculture Peshawar.

Wheat Varieties: Atta Habib; Bakhtawar; Inqalab-91; Khyber-79; Pak-81; Pirsabak; Saleem-2000; Siran-2010; Suleman; Tatara; Uqab
Recommended agronomic practices were collected from the findings of the study conducted by the previous researchers in the Department of Agronomy:
The following parameters were recorded during the study:

1. Grains yield (kg ha^{-1})
2. Harvest index (%)

Procedure for data collection:
The nature of the data in the current study was purely secondary. No experimental treatments or practices have been adopted during study. The study was based on research previously done in the Department of Agronomy and was then discussed.

5.3. Result and Discussion

1. Atta Habib

Harvest Index: Information on the harvest index is provided in Table 1. Data analysis revealed that the Atta Habib variety was sown by many researchers at the University of Agriculture Peshawar's Department of Agronomy in various years. The findings of the study showed that the maximum harvest index (42%) was recorded from Atta Habib in the year 2016 while the minimum harvest index (27%) was noted from Atta Habib in 2015. Grain yield kg ha^{-1}: The table also indicated the grain yield (kg ha^{-1}) in Atta Habib. The results showed that the maximum grain yield (4462kg ha^{-1}) was in 2014 while the lowest grain yield of wheat (3197 kg ha^{-1}) for the Atta Habib was in 2016.

2. Inqalab

Harvest Index (%): Table 1 provides information regarding the Inqalab-91 harvest index. Data analysis revealed the harvest index of Inqalab-91 for several researchers in various years at the University of Agriculture Peshawar's Department of Agronomy. The findings of this researcher showed that the maximum harvest index (35.69%) was recorded in Inqalab-91 in the year 2000 while the minimum harvest index (16.96%) was noted in Inqalab-91 in 2000. Grain yield (kg ha^{-1}): The table also pointed out the grain yield kg ha^{-1} in Iqalab. The result showed higher grains yield in 2000 i.e. (3597 kg ha^{-1}) for Inqalab-91 while the lowest grain yield for the Inqalab-91 was in 2000 i.e. (2353 kg ha^{-1}).

3. Bakhtawar

Harvest Index (%): Information on the harvest index is provided in Table 1. Data analysis revealed the harvest index of the Bakhtawar-92 wheat variety based on findings from several researchers in various years at the University of Agriculture Peshawar's Department of Agronomy. According to the data, the Bakhtawar-92 variety had the lowest harvest index (27%) in 2004 and the maximum harvest index (50%) in 2001. Grain yield (kg ha^{-1}): The table also highlighted the grain yield kg ha^{-1} in Bakhtawar. The results showed that the maximum grain yield of (4469 kg ha^{-1}) was in 2001 while the lowest grain yield for the Bakhtawar-92 was in 2000 i.e. (1965 kg ha^{-1}).

4. Khyber

Harvest Index (%): Table 1 contains information about the harvest index. Data observations made by many scholars in various years at the University of Agriculture Peshawar's Department of Agronomy revealed the harvest index of

Khyber-87. The results of the data revealed that Khyber-87 had the highest harvest index (42.84%) in 1995 and the lowest harvest index (29.95%) the following year, 1997. Grain yield (kg ha^{-1}): The table also conveyed the grain yield kg ha^{-1} in Khyber 87. The results showed that the maximum grain yield (3510 kg ha^{-1}) was in 1995 for Khyber- 87, while the lowest grain yield (2406 kg ha^{-1}) for Khyber- 87 in 1993.

5. Pak

Harvest Index (%): Table 1 provides information regarding the Pak-81 harvest index. Agronomy department experts at the University of Agriculture Peshawar determined the harvest index of Pak-81 in different years, according to an analysis of the data. The findings of the researchers showed that the maximum harvest index (39.54%) was recorded with wheat variety Pak-81 in the year 1993, while the minimum harvest index (23.43%) was noted with Pak-81 in 1995. Grain yield (kg ha^{-1}): The table also indicated the grain yield in pak-81. The results showed that maximum grains yield (3780 kg ha-^{1}) was in 1995 for Pak-81, while the lower grain yield (2437 kg ha-^{1}) for the Pak-81 in 1993.

6. Pirsabak

Harvest Index (%): Data concerning harvest index of Pirsabak varieties are given in Table 1. Observation of the data indicated the varieties of Pirsabak grown by different researchers in different years in the department of agronomy, the University of Agriculture Peshawar. The findings of the researcher showed that maximum harvest index (47.19%) was recorded in Pirsabak-2004 in the year 2005 while minimum harvest index (21.16%) was noted in Pirsabak-85 in 1995. Grain yield (kg ha^{-1}): The table also showcased the grain yield kg ha^{-1} of wheat. The results showed maximum grains yield (3905 kg ha^{-1}) of Pirsabak-2013 was in 2015 while the lowest grain yield for the Pirsabak-85 was in 1995 i.e. (1913 kg ha^{-1}).

7. Saleem

Harvest Index (%): Data concerning harvest index as given in Table 1. Observaton of the data indicated that harvest index of Saleem-2000 resulted by different researchers in different years in the department of agronomy, The University of Agriculture Peshawar. The findings concluded that maximum harvest index (51.1%) was recorded with Saleem-2000 in the year 2012 while the minimum harvest index (31.5%) was noted with Saleem-2000 in 2009. Grain yield (kg ha^{-1}): The table also presented the grain yield of wheat variety Saleem-

2000 studied in different years. The results showed that maximum grains yield of (4397 kg ha^{-1}) was in 2012 for Saleem-2000 while the lowest grain yield for the Saleem-2000 was in 2009 i.e. (2045 kg ha^{-1}).

8. Siran

Harvest Index (%): Data concerning harvest index is given in Table 1. Observation of the data indicated that the varieties of Siran-2010 sown by different researchers in different years at the Agronomy farm, The University of Agriculture Peshawar. The findings of the experiments showed that maximum harvest index (42.1%) was recorded with Siran-2010 in the year 2012 while the minimum harvest index (27%) was noted with Siran-2010 in 2015. Grain yield (kg ha^{-1}): The table also pointed out the grain yield kg ha^{-1}. The results show that the maximum grains yield was achieved in 2015 i.e. (4287 kg ha^{-1}) for Siran-2010 while the lowest grain yield for the Siran-2010 was in 2016 i.e. (2818 kg ha^{-1})

9. Suleman, Tatara, and Uqab

Harvest Index (%): Data concerning harvest index as given in Table 1. The data in table indicated the harvest index of different varieties of Suleman, Tatara, Tatara-96 and Uqab-2000 studied by different researchers in different years in the department of agronomy, The University of Agriculture Peshawar. The findings of the researchers showed that the maximum harvest index for Suleman-96 (41.4%), in 2000, Tatara (49%) in 2002, Uqab-2000 (41.66%) in 2009 was recorded while the minimum harvest index for Suleman (30.67%) in 2000, Tatara (29.96%) in 2001 and for Uqab-2000 (36.86) was noted in 2009. Grain yield (kg ha^{-1}): The table also highlighted the grain yield kg ha^{-1}. The results showed that the maximum grains yield for Suleman was in 2000 i.e.(3245 kg ha^{-1}), for Tatara was in 2003 i.e.(4336 kg ha^{-1}) and for Uqabl-2000 in 2009 i.e. (3829 kg ha^{-1}) while the lowest grain yield for the Suleman was in 2000 i.e. (1936 kg ha^{-1}), for Tatara in 2016 i.e. (2114 kg ha^{-1}) and for Uqab-2000 in 2009 i.e. (2471 kg ha^{-1}).

5.4. Result and Discussion

The table provides information on the harvest index. The data analysis revealed that the Atta Habib variety was sown by many researchers at the University of Agriculture Peshawar's department of agronomy in various years. As per the researcher's results, Atta Habib had the highest harvest index (42%) in 2016, while the lowest harvest index (27%) was witnessed in 2015. The results showed that the maximum grains yield kg ha^{-1} was in 2014 i.e. (4462 kg ha^{-1}) while the lowest grain yield for the Atta Habib was in 2016 i.e. (3197 kg ha^{-1}).

The findings of the table show that the maximum harvest index (50.4%) was recorded in with Bakhtawar in the year 2001 while the minimum harvest index (27%) was noted with Bakhtawar in 2004. The results show that the maximum grains yield kg ha^{-1} was in 2001 i.e. (4469 kg ha^{-1}) for Bakhtawar-92 while the lowest grain yield for the Bakhtawar-92 was in 2000 i.e. (1965 kg ha^{-1}).Observation of the data indicated that the varieties of Inqalab-91 done by different researchers in different years in the department of agronomy, University of Agriculture Peshawar. The findings of the table show that the maximum harvest index (35.69%) was recorded in with Inqalab-91 in the year 2000 while the minimum harvest index (16.96%) was noted with Inqalab-91 in 2000. The results show that the maximum grains yield kg ha^{-1} was in 2000 i.e. (3597 kg ha^{-1}) for Inqalab-91 while the lowest grain yield for the Inqalab-91 was in 2000 i.e. (2353 kg ha^{-1}).

Observation of the data indicated that the varieties of Khyber-79 and 87 done by different researchers in different years in the department of agronomy, University of Agriculture Peshawar. The findings of the table show that the maximum harvest index (42.84%) was recorded in with Khyber- 87 in the year 1995 while the minimum harvest index (19.26%) was noted with Khyber-79 in 1995. The results show that the maximum grains yield kg ha^{-1} was in 1995 i.e. (3510 kg ha^{-1}) for Khyber- 87 while the lowest grain yield for the Khyber- 87 was in 1993 i.e. (2406 kg ha^{-1}).

Observation of the data indicated that the varieties of Pak-81 done by different researchers in different years in the department of agronomy, University of Agriculture Peshawar. The findings of the table show that the maximum harvest index (39.54%) was recorded in with Pak-81 in the year 1993 while the minimum harvest index (23.43%) was noted with Pak-81 in 1995. The results show that the maximum grains yield kg ha^{-1} was in 1995 i.e. (3780 kg ha^{-1}) for Pak-81 but the lowest grain yield for the Pak-81 was in 1993 i.e. (2437 kg ha^{-1}).

Observation of the data indicated that the varieties of Pirsabak done by different researchers in different years in the department of agronomy, University of Agriculture Peshawar. The findings of the table show that the maximum harvest index (47.19%) was recorded in with Pirsabak-2004 in the year 2005 while the minimum harvest index (21.16%) was noted with Pirsabak-85 in 1995. The results show that the maximum grains yield kg ha^{-1} was in 2015 i.e. (3905 kg ha^{-1}) for Pirsabak-2013 while the lowest grain yield for the Pirsabak was in 1995 i.e. (1913 kg ha^{-1}).

Observation of the data indicated that the research work done on the performance of Saleem-2000 done by different researchers during different years in the department of Agronomy, the University of Agriculture Peshawar. The findings of the table showed that the maximum harvest index (51.1%) was recorded in with Saleem -2000 in the year 2012 while the minimum harvest index (31.5%) was noted with Saleem-2000 in 2008. Further, the results showed that the maximum grains yield kg ha^{-1} was in 2012 i.e. (4397 kg ha^{-1}) for Saleem-2000 while the lowest grain yield for the Saleem was in 2008 i.e. (2045 kg ha^{-1}). Observation of the data indicated that the variety i.e. Siran-2010 done by different researchers during different years in the department of Agronomy, the University of Agriculture Peshawar, showed that the maximum harvest index (42.1%) was recorded in Siran-2010 during 2012, while the minimum harvest index (27%) was noted with Siran-2010 in 2015. The results showed that the maximum grain yield kg ha^{-1} was produced in 2015 i.e. (4287 kg ha^{-1}) by Siran-2010, however the minimum grain yield (3416 kg ha^{-1}) was observed for Siran-2010 during year 2015.

Table 5.1**.** Grain yield (kg ha^{-1}) and harvest index (%) of different wheat variety/years studied in different thesis.

Year	**Variety**	**Grain yield kg ha^{-1}**	**Harvest index (%)**
	Atta Habib	3778	39.6
	Atta Habib	3850	42
	Atta Habib	3197	35.53
	Atta Habib	3969	41
2016	Atta Habib	3447	41.32
	Pirsabak-2005	3063	37.8
	Siran-2010	3758	31.5
	Siran-2010	2818	37.5
	Tatara	2114	44
	Atta Habib	3517	27
	Atta Habib	4066	39.21
2015	Atta Habib	4451	39.17
	Atta Habib	3697	34.8
	Pirsabak-2013	3905	36.2

Year	Variety	Grain yield kg ha^{-1}	Harvest index (%)
	Siran-2010	4287	38.42
	Siran-2010	3416	27
	Siran-2010	4239	39.35
2014	Atta Habib	3729	37.8
	Atta Habib	4462	38.3
	Siran-2010	3855	38.7
2013	Atta Habib	3522	40.17
	Pirsabak-2004	3423	39.36
	Saleem-2000	3889	48
	Siran-2010	3724	41.86
	Tatara-96	3994	49
2012	Atta Habib	3949	40.7
	Pirsabak-2004	2338	35.34
	Saleem-2000	4263	51.1
	Saleem-2000	4397	37.87
	Siran-2010	4038	42.1
	Siran-2010	4019	40.9
2011	Pirsabak-2005	3242	43.07
	Saleem-2000	3093	41.02
	Uqab-2000	3158	41.66
2010	Saleem-2000	3502	34.8
2009	Pirsabak-2005	2324	37.5
	Pirsabak-2005	3286	24.7
	Pisabak-2004	3288	42.76
2009	Saleem-2000	2045	31.5
	Saleem-2000	3000	38.99
	Uqab-2000	2470	36.86
	Uqab-2000	3829	39
2008	Pirsabak-2005	2275	34.38
	Tatara	2875	41
2007	Saleem-2000	2071	37
	Saleem-2000	2579	34
2005	Pirsabak-2004	2292	47.19
2004	Bakhtawar-92	2245	27
2003	Tatara	4336	35.47
2002	Tatara-96	4139	37.66
2001	Bakhtawar-92	2395	36.7

Year	Variety	Grain yield kg ha^{-1}	Harvest index (%)
	Bakhtawar-92	4469	50.4
	Tatara	3952	29.96
	Inqalab-91	2353	16.96
	Inqalab-91	3597	35.69
	Bakhtawar-92	3535	30.6
2000	Bakhtawar-92	3640	39.9
	Bakhtawar-92	1965	39.1
	Suleman-96	3245	30.67
	Suleman-96	1936	41.4
1999	Bakhtawar-92	2917	30.3
	Inqalab-91	2868	31.02
1998	Bakhtawar-92	3404	35.8
	Bakhtawar-92	3301	42.7
	Bakhtawar-92	3112	38.5
1997	Bakhtawar-92	3248	31.1
	Khyber-87	2642	29.95
	Pirsabak-91	2696	34.11
1996	Pirsabak-85	3299	24.87
	Khyber-87	2830	34.03
	Khyber-87	3510	42.84
	Pak-81	2708	23.43
1995	Pak-81	3780	37.69
	Pirsabak-85	3262	21.16
	Pirsabak-85	2395	27.04
	Pirsabak-85	1913	31.21
	Pirsabak-85	3480	40.69
	Pirsabak-91	1986	29.9
	Pirsabak-91	3010	31.05
	Khyber-87	2406	37.99
1993	Pak-81	2437	39.54
	Pirsabak-85	2261	25.19
	Pirsabak-85	2138	38.74
1992	Khyber-87	2533	31.5
	Pirsabak-85	2800	32.54

Observation of the data indicated that the varieties of Suleman, Tatara, Tatara-96 and Uqab-2000 done by different researchers in different years in the department of agronomy, University of Agriculture Peshawar. The findings of the table show that the maximum harvest index for Suleman-96 (41.4%) in 2000, Tatara (49%) in 2002, Uqab-2000 (41.66%) in 2009 was recorded while the minimum harvest index for Suleman (30.67%) in 2000, Tatara (29.96%) in 2001, and for Uqab-2000 (36.86) was noted in 2009. The results show that the maximum grain yield kg ha^{-1} for Suleman was in 2000 i.e.(3245 kg ha^{-1}),for Tatara was in 2003 i.e (4336 kh ha^{-1}) and for Uqabl-2000 in 2009 i.e. (3829 kg ha^{-1}) while the lowest grain yield for the Suleman was in 2000 i.e. (1936 kg ha^{-1}), for Tatara in 2001 i.e. (2114 kg ha^{-1}) and for Uqab-2000 in 2009 i.e. (2470 kg ha^{-1}).

5.5. Conclusion

The research investigated into the performance of various wheat varieties, such as Atta Habib, Inqalab-91, Bakhtawar-92, Khyber-87, Pak-81, Pirsabak, Saleem-2000, Siran-2010, and Suleman, Tatara, Tatara-96, Uqab-2000, over different years at the University of Agriculture Peshawar. Regarding Atta Habib, the study revealed a fluctuation in harvest index, with the highest (42%) in 2016 and the lowest (27%) in 2015. Similarly, grain yield peaked in 2014 at 4462 kg ha-1 and hit a low of 3197 kg ha-1 in 2016. Findings for Inqalab-91 showcased a maximum harvest index of 35.69% in 2000 and a minimum of 16.96% in the same year. The grain yield followed suit, with the highest (3597 kg ha-1) and lowest (2353 kg ha-1) recorded in 2000. The research encompassed diverse varieties, each displaying distinct harvest index and grain yield trends, emphasizing the need for specific strategies in wheat cultivation for sustainable and optimized yields.

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CHAPTER 6

RAINFALL FORECASTING IN GUNUNGKIDUL DISTRICT AS AN ENDEAVOR TO MITIGATE DROUGHT DISASTER IN 2024

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ABSTRACT

This study aims to predict the rainfall of Gunungkidul district in 2024 with the ARIMA method, the ARIMA method is used to find historical patterns to determine future probability values based on the assumption of continuity. The climate data used includes rainfall from January 2014 to December 2023. The results showed that the best ARIMA model was (4,0,4) with an AIC (Akaike information criteria) value of 1460.948. Drought adaptation and mitigation strategies in Gunungkidul District are carried out by revitalizing the functionality of the Bribin Watershed. At the same time, the community can carry out climate change adaptation through rain harvesting with simple tools such as barrels or drums and the construction of public facilities such as reservoirs, boreholes, and public wells.

Keywords: Adaptation and Mitigation, ARIMA Method, Drought Disaster, Rainfall forecasting

6.1. Introduction

Climate change is defined as a transfiguration of the physical conditions of the atmosphere related to temperature and precipitation distribution with a wide impact on creatures' survival. Furthermore, climate change has a major impact on the food supply chain and natural disasters such as forest fires, droughts, floods, and heat waves. Yanto's research shows that climate change in Indonesia is characterized by an increase in sea level of 0.8 mm/year in the 1960-2020 period, a downward trend in rainfall in various locations, and an increase in average temperature each year. Climate change is the main trigger of natural disasters, which occur due to the disruption of natural equilibrium. Drought is characterized by a slow on-set with a minimum duration of 6 months and damage to the ecological functions of watersheds.

Climate change significantly affects the water cycle, including precipitation, runoff, and evapotranspiration. the trend of changes in this cycle can reduce water quality; of course, climate variability will also affect watershed hydrology, soil erosion, and land quality degradation (Chen & Hsu, 2014; Fraker et al., 2020; Gomiero, 2016; Lamsal & Mishra, 2010; Qiu et al., 2019). Watersheds play a vital role in providing and distributing water for various purposes.

Gunungkidul District is part of the Gunung Sewu karst that developed through the cartification process of thick carbonate rocks so that the soil formed is characterized by very porous, high permeability, and fast drainage, causing water not to be stored in the soil (Ashari, 2015; Li et al., 2023; Nurzaman et al., 2020). Certainly, in the dry season, karst areas often experience groundwater deficits, exacerbated by the continuous dissolution process, and produce exokarst landscapes that form on the surface and have a distinctive phenomenon (Anam et al., 2021; Ashari, 2015). This distinctive phenomenon produces a network of vertical and horizontal passages of varying sizes and types that form a cave system or underground river system (Alwi et al., 2019; Apriyani et al., 2022).

Local people call it Luweng. As a result, water accumulates in the subsurface, and water resources are continuously depleted. Therefore, water resources management is needed for drought disaster mitigation efforts; in the long term, this is expected to help manage water resources for the surrounding community; this study aims to estimate the amount of rainfall throughout 2024 in response to climate shifts that occur throughout the year. Forecasting methods can be done using time series of past data. This analysis is based on past variables and errors. This model aims to explore past patterns into the future (Al Badri et al., 2023; Al Fitri Syawal & Meiliyani Siringoringo, 2022; Latief et al., 2022).

The ARIMA method is selected due to the integration of the auto-regressive model with the moving average, the integration between the regressive which explains the movement of variables in the past, with the Moving Average, which sees the movement of variables based on residuals in the past, is expected to provide rainfall forecasts with a good and accurate level of fit (Mubarok et al., 2015).

6.2. Methods

This research utilized data from monthly rainfall observations at the Yogyakarta Province Climatology Station from January 2014 to December 2023, accessed through the official website https://dataonline.bmkg.go.id/. The rainfall data is then descriptively explored to see the seasonal rainfall pattern. ARIMA prediction modeling using STATA 17 application.

1. ARIMA Method

ARIMA combines the Autoregressive (AR) and Moving Average (MA) models and the differentiation process on time series data. The Arima model is formulated as follows

$$\Phi \mathrm{p}(B)^{s} \Phi \mathrm{p}(\mathrm{B})(1-B)^{d}(1-B)^{D} Zt = \theta q(B) \theta Q(B) at \quad (1)$$

dengan : (p, d, q) : orde AR (p), orde differencing (d), orde MA (q) fon non seasons data.

$\Phi p\ (B)$	: non-seasonal AR component with sequence (p)
$\Phi P\ (B)$	: seasonal component with sequence (P)
$\theta q(B)$	: non-seasonal MA component with sequence (q)
$\theta Q(B)$	: seasonal MA component with sequence (q)
$(1-B)\ d$	: non-seasonal differentiation with sequence (d)
$(1-B)^{D}$	: non-seasonal differentiation with sequence (d)
(D) Zt	: observation rate of t
at	: residual rate at t

2. Stationer

If the time series plot fluctuates around a line parallel to the time axis t, it can be assumed that the time series is stationary in the mean, if the condition of stationary in the mean is not met, it is necessary to differentiate the data. A data has met the condition of stationary in variance if the rounded value (λ) is already worth 1, or the lower and upper limit values have passed 1. If the stationary condition in variance has not been met, it is necessary to transform. The transformation introduced **in Wei's (2006)** book is the Box-Cox transformation, with the formula

$$T(Zt) = \frac{Z_t^{\lambda} - 1}{\lambda} \quad (2)$$

3. Autocorrelation function (ACF)

ACF is a coefficient that shows the linear relationship in time series data between Zt and $Zt\text{-}k$. The correlation between $\{Zt\}$ and $\{Zt\text{-}k\}$ is as follows

$$\text{Pk} = \frac{Cov\,(Zt, Zt-k)}{\sqrt{var(Zt)}\sqrt{var(Zt-k)}} \quad (3)$$

4. Partial autocorrelation (PACF)

PACF measures the level of correlation between pairs of data Zt and Zt-k after the influence of variables Zt-1, Z t-2, Z t-3,...Zt-k+1, the partial autocorrelation function can be calculated by the following formula

$$\text{Pk} = \frac{Cov\,[(Zt-\mathbf{Z}t),(Zt-k-\mathbf{Z}t-k)]}{\sqrt{var(Zt-\mathbf{Z}t)}\sqrt{var(Zt-k-\mathbf{Z}t-k)}} \quad (4)$$

Zt : $\beta_1 Z_{t-1} + \beta_2 Z_{t-2} + \ldots.. \beta_2 Z_{t-k}$

Zt-k : $\propto_1 Z_{t-k-1} + \propto_2 Z_{t-k-2} + \ldots.. + \propto_k Z_1$

10. Selection of best model

The criteria for selecting the best model can be based on the Mean Square Error (MSE) value and the Mean Value of the model.

$$MSE = \sqrt{\frac{\sum_{t=1}^{n}(Z_t - Z_t)^2}{n}}\ ; \quad (5)$$

$$MAPE = mean \sum_{t=1}^{n} \frac{(Z_t - \mathbf{Z}_t)}{(Z_t - \mathbf{Z}_t)/2}\ x\ 100\% \quad (6)$$

Moreover, the in-sample criteria can be done with Akaike Information Criteria (AIC).

$$AIC = In|\sum| + \frac{2pm^2}{n} \qquad (7)$$

6.3. Result and Discussion

Table 1 showed the rainfall data in Gunungkidul district from 2014 to 2023, the rainfall in that period fluctuates greatly due to various climatic factors, including temperature, humidity, and wind speed.

Table 1. Rainfall (mm) in Gunungkidul District 2014 to 2023

	2014	**2015**	**2016**	**2017**	**2018**
Januari	387.94	373.28	243.67	349.06	479.44
Februari	332.78	265.61	371.94	368.39	200.67
Maret	108.22	390.72	257.11	280.78	241.5
April	179.89	330.72	243.94	196.11	90.72
Mei	63.89	81.61	126.78	57.22	14.17
Juni	56.5	11.39	199.83	37.17	0.56
Juli	59.56	0.61	65.11	17	0.06
Agustus	0.83	0	82.11	4.28	-
September	0	0	210.83	44.28	-
Oktober	0.44	1.22	262.39	121.72	1.89
November	220.11	109.94	361.67	577.28	121.33
Desember	471.78	248.22	303.94	277.22	116.06
	2019	**2020**	**2021**	**2022**	**2023**
Januari	505.00	277	352.80	199.00	330.33
Februari	200.00	336	276.10	188.00	203.11
Maret	527.00	422	276.10	403.00	238.17
April	164.00	334	236.00	243.00	136.67
Mei	36.00	80	60.00	218.80	99.67
Juni	0.00	8	209.00	132.00	50.90
Juli	0.00	2	8.80	35.50	0
Agustus	0.00	24	33.90	53.00	0
September	0.00	12	133.60	26.50	0
Oktober	0.00	191	145.70	371.70	24.79
November	131.00	329	344.80	659.00	68
Desember	274.00	312	409.90	369.00	32

Theprediction of rainfall in Gunungkidul District for 2024 aims to provide a range of rainfall values (mm), so it can be a consideration for local governments to prepare adaptation strategies and drought disaster mitigation (Hikmah et al., 2023). Gunungkidul District's rainfall from 2014 to 2023 is presented in Table 6.1. Rainfall prediction begins with time series analysis to see the seasonal pattern of rainfall; seasonal patterns can help understand the characteristics of the data so that rainfall predictions are more accurate. Figure 1 presents the time series graph of rainfall in Gunungkidul District.

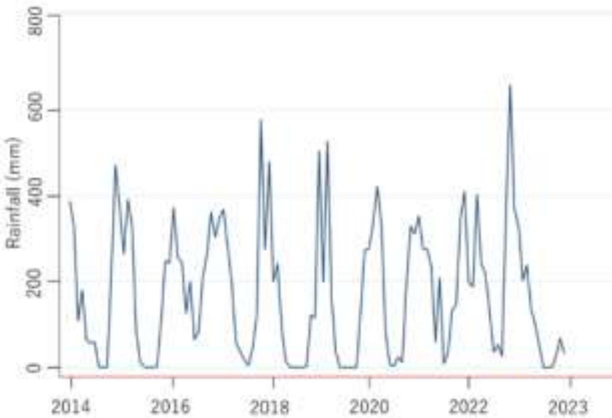

Figure 6. 1. Rainfall time series from January 2014 to December 2023

Based on Figure 6.1, it can be seen that the rainfall that occurs in Gunungkidul District has a seasonal pattern, characterized by high rainfall fluctuations in certain periods and low in the opposite pattern. The rainfall data is then tested for stationarity, the stationarity test aims to see the level of stationary data, stationary data has characteristics that do not change over time and have a constant variance average, the stationary test is carried out through the Augmented Dickey-Fuller Test, the results of the analysis are presented in table 2 below.

Table 6.2 presents the results of the Dickey-Fuller analysis; from the data obtained, a p-value of 0.00 is smaller than the alpha value (0.05). Which indicates that the data is stationary with the mean. In addition, the rainfall data in Gunugkidul District is stationary.

Table 6.2. Dickey-fuller test

Uji Dicky-Fuller	P-value
-2.889	0.000

So it does not require differentiation. Thus, the value of d is 0. The analysis continued with the Autocorrelation Function (ACF) to determine the value of the parameter q (the number of lags in the moving average), the higher the lag in the moving average indicates that the correlation of each variable is also higher, and vice versa. The results of the ACF analysis are presented in Figure 6.2 below.

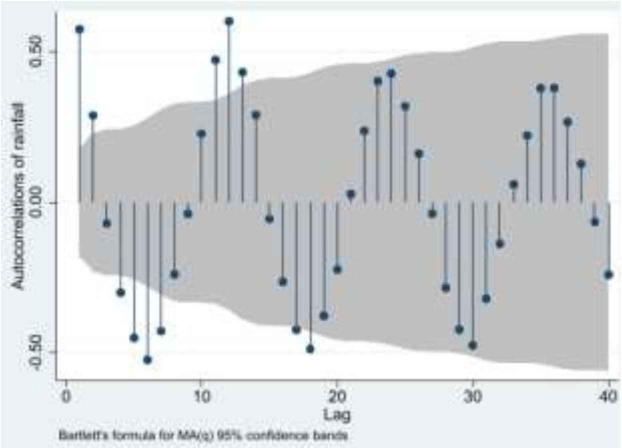

Figure 6.2. Result of Autocorrelation function (ACF)

Based on Figure 6.2, it is obtained that lags 1, 2, 4, 5, 6, 7, 11, 12, 13, and 19 in the moving average (MA) come out of the average line, the q order formed in the moving average is MA (1), MA (2), MA (4). The analysis continues with the Partial Autocorrelation Function (PACF), which aims to determine the value of parameter p for AR. In Figure 3, it can be seen that in AR, there are lags 1, 3, 4, 6, 11, 12, 15, and 28 that come out of the confidence line, the p order formed in AR is AR (1), AR (3), AR (4), the analysis continues with the selection of the best model, which is obtained from testing the white noise residual value and AIC value, the analysis results are presented in the table below.

Table 6.3. Residual white noise value and AIC (*Akaike information criteria*)

No	Model	Kesimpulan	AIC
1	ARIMA (1,0,1)	White noise	1503.898
	ARIMA (1,0,2)		1497.763
	ARIMA (1,0,4)		1494.275
2	ARIMA (3,0,1)	White noise	1477.485
3	ARIMA (3,0,2)		1486.233
4	ARIMA (3,0,4)		1467.666
5	ARIMA (4,0,1)	White noise	1478.976
6	ARIMA (4,0,2)		1481.345
7	ARIMA (4,0,4)		**1460.948**

In the ARIMA model, the white noise value is a random process that does not correlate in the residual series, this analysis is done through L-jung Box.

Residuals that meet the white noise criteria can be interpreted as identical and independent value; from the analysis results, it can be assumed that all models are included in white noise. AIC (Akaike information criteria) analysis selects the best model to predict the upcoming period. AIC is an estimate of the prediction error and the relative quality of the data set being tested. Prediction error is a common thing that occurs when the statistical model representation is assumed never to be 100% accurate so that there is some missing information, so AIC aims to estimate the amount of missing information, the higher the AIC value indicates that the model has more missing information. In contrast, the low AIC value indicates less missing information, so the selected model must have the lowest AIC value. Based on Table 3, the selected arima model is ARIMA (4,0,4) because it has the lowest AIC value compared to other models; the next step is the prediction of rainfall for the period January 2024 to December 2024; the prediction of rainfall is presented in the table below.

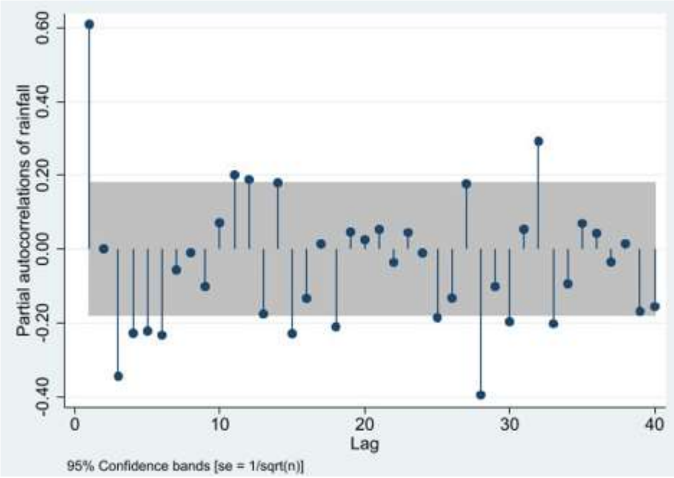

Figure 6.3. Result of Partial Autocorrelation function (PACF)

Table 6.4 showed that rainfall from January to December 2024 has a different value of fluctuation and diversity from the rainfall pattern from 2014 to 2023, seen from rainfall in the dry season (April - September).

Furthermore, this rainfall prediction model can be used as a reference in climate change mitigation efforts in Gunungkidul District; Gunungkidul's hilly landscape, kart soil, and dry season are reasons for the importance of mitigation programs. The climate change mitigation program that the Gunungkidul District government is intensifying is the Climate Village Program (PROKLIM), which aims to encourage implementation, innovation, and policy application appropriate for climate change adaptation and mitigation at the local and regional levels.

Table 6.4. Prediction of rainfall in 2024 in Gunungkidul District

Month	Rainfall forecasting(mm)
January	190.729
February	249.376
Maret	314.192
April	323.096
Mei	304.384
Juni	257.238
Juli	201.198
Agustus	148.296
September	110.727
November	93.9636
Oktober	98.5114
December	119.764

Climate Change Strategies and Mitigation

Based on (Badan Pusat Statistika Kabupaten Gunungkidul, 2021, 2022, 2023), There are four sub-districts (Panggang, Saptosari, Rongkop, and Girisubo sub-districts) that suffered from drought disaster, marked by red color blocks, drought caused the community difficult to access clean water to meet basic needs, as well as irrigation water for agriculture, this condition can be an indication of the importance of climate change mitigation and adaptation at the local level, climate change adaptation can be made through watershed management. Figure 6.4 also illustrates the Bribin watershed in Gunungkidul District, marked in blue, and the lake in light blue. Based on research (Endarto et al., 2016).

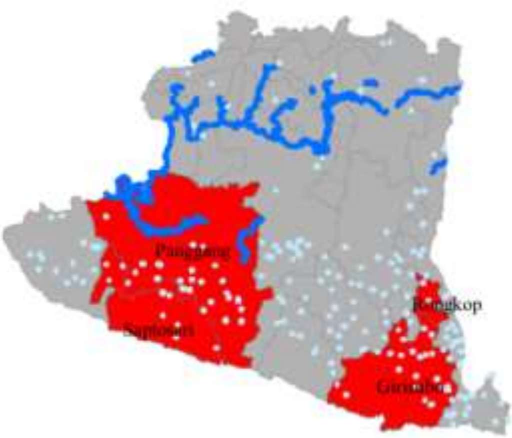

Figure 6.4. Bribin watershed and sub-districts suffering from drought in 2023

The sustainability of the Bribin watershed's upper reaches tends to be damaged due to solutional processes and human activities. The damage to the upper reaches of the Bribin watershed is inseparable from the biogeophysical characteristics of karst which has a subsurface flow that is prone to damage, this is exacerbated by the rampant limestone mining activities in the upper reaches that accentuate watershed damage, the impact is that the hydrological cycle downstream will also be disrupted (Haryono, 2008; Haryono & Adji, 2004). The proportion of artificial lakes spread in Gunungkidul District is dominated in the southern part, which generally experiences drought. This artificial lake aims to collect rainwater during the rainy season and provide water when it enters the dry season.

In addition, the proportion of lakes in the northern part of Gunungkidul District is much less than in the southern part, this is because the watershed in the northern part has a larger cross-sectional area than the southern part, the watershed regulates the regional hydrological cycle so that water availability in the dry season is higher. The importance of watersheds is such that they must be maintained and preserved. The key to watershed preservation is the integration of the role of the community in the rehabilitation of forests, land, and conservation of water resources, the participation of community groups and the perception of water needs is an important factor in watershed preservation efforts.

Furthermore, the local government also needs to tighten licenses for limestone mining and exploitation of karts and establish protected areas or cultivation areas in Gunungkidul District. Climate change adaptation can be made through rainwater harvesting using the rainwater collection pond (PAH) or bung method, construction of boreholes, and public wells. More simply, the community generally makes water storage using reservoirs or barrels. This adaptation strategy is expected to become a habitual action of local communities to deal with actual environmental changes or to achieve the desired conditions (Economic and Social Commission for Asia and the Pacific, 2020; Roekmi et al., 2018; Susanti et al., 2014). The ARIMA model that can describe the rainfall prediction in Gunungkidul District in 2024 is ARIMA (4,0,4), with an AIC value of 1460.948.

Furthermore, the adaptation and mitigation strategy for drought disasters in Gunungkidul District is revitalizing the functionality of the Bribin Watershed. The urgency of this revitalization is mainly in the southern region. Meanwhile, the community can adapt climate change through rain harvesting with simple tools such as barrels or drums and the construction of public facilities such as reservoirs, boreholes and public wells.

6.4. Conclusion

The ARIMA model that can represent the rainfall prediction in Gunungkidul District in 2024 is ARIMA (4,0,4) with an AIC value of 1460.948. Furthermore, the adaptation and mitigation strategy for drought natural disasters in Gunungkidul District is the revitalization of the functionality of the Bribin Watershed, the urgency of this revitalization is mainly in the southern region. Meanwhile, climate change adaptation can be carried out by the community through rain harvesting with simple tools such as barrels or drums and also the construction of public facilities such as reservoirs, boreholes and public wells

6.5. Suggestion

The research framework for predicting rainfall in Gunungkidul District needs to be further developed by considering other climate aspects, land use, land use change rates, and carbon stocks, with the expectation that a broader research framework can provide more accurate predictions.

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CHAPTER 7

K-SOLUBILIZING RHIZOBACTERIA AND RHIZOBIA FOR ECOLOGICAL AGRICULTURE

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ABSTRACT

Potassium (K) being the utmost essential nutrient is required for the development and growth of plants. Apart from enzymes activation, K is also involved in the transportation of several compounds and alteration of crop osmotic pressure. Although, K is ample element of soil but only 1-2% is captivated by plants directly. Farmers tend to apply high quantity of phosphorus (P) and nitrogen (N) fertilizers while K has been neglected in recent times. Legumes crops obtaining N by Biological Nitrogen Fixation (BNF) usually have a much more necessity of K as compared to others crops which are solitary dependent on the soil N and P for plant nutrition. Sufficient K supply is a key for legume nodulation since it directly influences on nodule growth and function by affecting nodule permeability and nitrogenase activity. In addition, it is also tangled in assimilation of ammonia, inter-conversion of amino acids, supply of carbon, and transduction of energy, respectively. The K-solubilizing and/ or mobilizing bacteria could be much useful for enhancing nodulation and growth in leguminous crops. It can be determined that sources of K (K_2SO_4 or KCl) combined with the most effective co-inoculants having K solubilizing and/ or mobilizing activity can improve production potential of chickpea (leguminous crop) by improving K nutrition of plant, nodulation efficiency and as well as soil K fertility.

Keywords: Co-inoculants, Leguminous crops, Nitrogen, Potassium, Potassium solubilizing/ mobilizing rhizobacteria, Rhizobia

7.1. Introductıon

1. Legume crops

Pulses have a distinct place in food related legumes crops having enormous level of protein thus play a key part in human diet. Pakistan is the densely peopled part of biosphere so financial capitals do not sustenance huge scale of population for the use of animal protein. Daily diet of humans may be enhanced by provision of pulses which are enriched in protein. The grain legumes being a rich cause of protein rather than animal protein are better choice in their regular food for the humans preferring vegetable protein. So, chickpea is one of the major high protein legume pulse crop.

Chickpea (*Cicer arietinum* L.) has been believed to originate in Turkiye (south-eastern), and spreads globally (van der Maesan, 1987). Now its plantation takes places in countries like Pakistan, India, Myanmar, Iran, Spain, Australia, Sudan and Bangladesh (NMCEI, 2009). Generally, chickpea has two kinds, Kabuli (white-seeds) and Desi types (brown seeds). Globally, the Kabuli and the Desi chickpea pays to about 20% and 80% of total production. Chickpea (Gram) is sown on an extensive series of Pakistani soils with moderately heavy soils to light one but typically sandy loams soils are preferred in deserts of Punjab i.e. Cholistan and Thal. Soils with sandy loam to clay loam texture is the most suitable for its cultivation. The soil should be free from excessive soluble salts. However, it is not suited under soil having pH more than 8.5 value.

2. Low yield factors

In Pakistan, several factors are contributing to low yield of chickpea. These include a bad soil structure, soil with low nutrient contents, shortage and poor-quality ground water, fungal diseases, excessive moisture, temperature stress at the stage of reproduction, ineffective species of *Rhizobium* and drought stress at early growth stages (Yamaguchi and Blumwald, 2005).

3. Potassium (K)

An indispensable macro-nutrient for progress and growth of crops affecting many fundamental physiological mechanisms is potassium (Clarkson and Hanson, 1980). After N, it is needed in the high quantity by crops. On the basis of dry weight, the potassium requirement for ideal plant development is 2-5% (Marschner, 1995). It performs a main character in plant water relations including opening and closing of stomata, rate of transpiration, maintenance of cell turgor and involved in other mechanisms such as translocation of assimilate, leaf movements and activation of enzyme. Moreover, photosynthesis, carbon translocation and nitrogen complexes from source into sink is significantly affected by potassium. However, deficiency of K results in disorder of various physiological functions including charge imbalance, enzyme inactivation, disturbance in water relations, yield reduction and lowered plant stress resistance.

Thus, for optimal productivity, modern crop production requires a higher K concentration, specifically at reproductive stage of crop plants. Though, this requisite is frequently not happened owing to the adversative plant/ soil features and K deficits happen consequently declines crop production. Additionally, the available K to the crop is repeatedly affected by the accessibility of further essential mineral nutrients.

4. Potassium in soil environment

In soil environment, K has 4 various sources. Among them, soil minerals (feldspar and mica) are the largest soil K component (90-98%) available in soil. Minimum concentration of this K source is available for plant uptake. Non-exchangeable K is the second largest soil K source (1-10 %) and is linked with 2: 1 type clay minerals. This K source acts as a K reserve within the soil.

The third soil K source is the readily available or exchangeable K (1-2%) and is available on the exchange complex or in the soil solution (Rehm and Schmitt, 2002). A fourth soil K source is the K bounded within the soil microbial mass and within soil organic matter (SOM). This soil K source is least available for plant uptake. The soil K source readily available and maximum uptake by plants roots is soil solution K and is then exchange by exchange K in soil. The total soils K content often exceeds twenty thousand ppm. Major fraction of soil K is found in the structural element of minerals present in soils and is not accessible to crop uptake.

5. Potassium uptake

Mass flow and diffusion are the key mechanisms for K uptake by plant roots via soil (Barber, 1962). Under normal soil conditions, diffusion is the major K uptake mechanisms for plants, as mass flow may only account for 1 to 3 percent of total potassium up-take (Rosolem et al., 2003). Although, significance of these both 2 procedures fluctuate with plant and soil limits like plant K requirements, root characteristics and rates of water flux within soil (Baligar, 1985).

6. Plant growth promoting rhizobacteria (PGPR)

Lately, microorganisms use to progress crop development has been enhanced globally (Shahzad et al., 2017; Arif et al., 2018). PGPR improve crops development and growth directly or indirectly by various mechanisms. The direct mechanisms includes solubilization/ mobilization of nutrients by production of phosphatases, siderophores, N_2-fixation, organic acids, enzymes and phytohormones (Gray and Smith 2005; Shahzad et al., 2017).

Whereas by depressing harmful effects of a pathogens either by activating plant confrontation to pathogen or by bashing out pathogens from root surfaces of plants and by synthesizing other pathogen suppressing substances or chitinases are the indirect ones. PGPR exert impact on growth of crop via different procedures of act and many authors have testified constructive result of inoculation on many plants (Hameeda et al., 2008; Yang et al., 2009). Our chief concern is to review the effects of PGPR (both potassium solubilizing rhizobacteria and rhizobia) containing K-solubilization trait on yield of different crops specifically leguminous crops including chickpea.

7.2. Methods

1. Existence of potassium solubilizing soil bacteria

Potassium can dissolve from rocks and minerals via microbial inoculants have influence on crop growth and have economical benefits. Muntz (1890) testified the 1^{st} microbial indication in K solubilization of rock. Bunt and Rovira (1955) also observed diversified soil microbes can solubilize the minerals related to silicates. Several soil microorganisms like *Clostridium pasteurianum, Bacillus extroquens* and *Aspergillus niger* were able to nurture (*in-vitro*) on biotite, micas, orthoclase, microclase and muscovite (Retimier, 1951).

Moreover, soil microbes including bacteria, actinomycetes and fungi were also grown even on highland surfaces of rocks (Gromov, 1957). Bacillus mucilaginosus was observed by Norkina and Pumpyanskaya (1956) to solubilize K from aluminosilicates and feldspar minerals. The silicate dissolving activity of gram-negative bacteria (*B. herbicola* and *Erwinia*) in combination with pseudomonas is examined by Duff and Webley (1959). Rhizospheric microorganisms can liberate silicaceous minerals from rocks, as confirmed by Webley et al., (1963).

2. Isolation of potassium solubilizing rhizobacteria

Aleksandrov et al., (1967) secluded various bacteria species to dissolve K like silicate bacteria. Heinen (1960) examined *Proteus* spp. and *B. caldolyticus* for the solubilization of quartz mineral. Similarly, quartz solubilization by *B. mucilaginosus* observed in lab experiments (Belkanova, 1985). K solubilizing rhizobacteria from various soil, rock and mineral samples were isolated. The isolates identified as *B. Mucilaginosus* based on physiological and morphological traits (Li et al., (1994). Raj (2004) recognized silicate solubilizing microbes from rice field and reported that under *in vitro* conditions, *Bacillus* spp. can solubilize silicate minerals with greater efficacy. Moreover, using specific K bearing minerals, K solubilizing rhizobacteria were isolated from cereal crop roots (Mikhailouskaya and Tchernysh, 2005). Hu et al., (2006) both reported to isolate potassium solubilizing rhizobacteria able of dissolving potassium from silicate minerals. Gopal et al., (2005) using altered Bunt and Rovira medium, isolated silicate solubilizers. Sugumaran and Janarthanam (2007) isolated potassium solubilizing rhizobacteria from rocks (mica, muscovite, and orthoclase), minerals and soils and observed that *Bacillus mucilaginosus* can solubilize higher K in case of muscovite mica. Thus, many of silicate solubilizing bacteria are recognized by various scientist as *Pseudomonas* and *Bacillus* species.

3. Microbial mineral potassium solubilizing potential

Potassium (K) bearing minerals nature affect the efficacy of diverse bacteria to solubilize K. The potential of a bacterium to solubilize potassium from different potassium minerals of soil with varying nature and properties was reported by different researchers. Yakhontova et al., (1987) investigated degradation strength of silicate minerals by the bacteria and showed that it was reliant on mineral structural and chemical configuration and K dissolving capability of HM-8841 measured by using Pegatolite and Kietyote (47 mg) and observed soluble K released of a 44.4 mg after incubation time of 38 hrs.

Sheng and Huang (2002) studied that pH, strain type and dissolved oxygen affect K release from minerals. Badr et al., (2006) testified degree of K solubilization by silicate rhizobacteria from 490 to 759 L^{-1} at 6.4 to 8.1 pH range by *B. mucilaginosus* isolated from soil, mineral and rock. K release exaggerated by aerobic environments, soil mineral properties and pH. Higher potassium release was observed in the aerobic compared to anaerobic soil conditions. The K release was in order of illite > feldspar > muscovite (Sheng and Huang, 2002). Singh et al., (2010) investigated the consequence of 3 PGPR (*Rhizobium, B. mucilaginosus*, and *A. chroococcum*) on their capacity to mobilize potassium from the waste mica mineral. The result reported that all PGPR strains were significantly enhanced assimilation and content of K, higher plant K uptake, greater biomass production, increase in chlorophyll concentration in plant. Among the tested PGPR, *B. mucilaginosus* showed a significantly higher K mobilization compared to *A. chroococcum* and *Rhizobium* strains.

4. Mechanisms of potassium solubilization

Many bacterial strains have the capability for solubilization of silicate and potassium from minerals, soils and rocks. The possible mechanism for solubilization of potassium from various soil potassium containing minerals could be the release of oxalic and citric acids by bacterial isolates resulted in the decomposition or solubilization of natural silicates minerals and consequently assist in ionic form of K release within the soil minerals and rocks (Figure 1). While insoluble silicates minerals can solubilize due to exopolysaccharides, organic acids and carbon dioxide release by bacteria (Jones and Handrecht, 1967) using sand and Kaolin quartz as model materials. Moreover, mucilaginous capsules containing exopolysaccharides improved mineral dissolution process (Groudev, 1987). The silicates chemical leaching was done by use of organic and inorganic acids or by NaOH. The method was more effective in an alkaline medium. Bacterial strain also showed to enhance silicates dissolution by produce of organic ligands and additional hydrogen ions (H^+) and in few conditions by release of OH^-, polysaccharides and extra cellular enzymes (Hiebert and Bennett, 1992; Barker et al., 1998).

Welch et al., (1999) observed various extracellular polysaccharides that considerably improved the process of plagioclase dissolution at pH value of four but showed a minor consequence at pH seven. Vainberg et al., (1980) suggested dissolution of minerals mechanism in the culture media due to the development of organic acids. Berthelin (1988) stated that K solubilization by precipitated forms via synthesis of organic and inorganic acids from *Clostridium, Bacillus* and *Thiobacillus*. The production of acetate, oxalate and citrate by microbes can enhance mineral dissolution rate (Barker et al., 1998). Bacteria able to reason a widespread rocks weathering by the release of various organic acid as of gluconate production may promotes silicates minerals (Kaolinite, quartz and albite) dissolution by sub-surface bacteria (Vandevivere et al., 1994). Styriakova et al., (2003) examined silicate dissolving bacteria activity and reported that they performed a main part in release of potassium and Fe using Fe oxyhydroxides and feldspar. They also reported a mechanism of metal sorption at membrane level as well as direct precipitation of silicate by bacteria (Konhauser and Ferris, 1996).

Welch and Ullman (1993) reported the dissolution rate of plagioclase having organic acids were higher as compared to the inorganic ones. Moreover, during reproduction rhizobacteria release polysaccharides that interact with minerals for formation of bacterial mineral complexes resulting the degradation of minerals. Dissolution of aluminosilicates mineral or quartz can be enhanced by organic ligands include extracellular enzymes, chelates complex and metabolic byproducts produced microbially together with organic acids in field as well as laboratory (Huang and Longo, 1992). Sheng and He (2006) found the microbial production of organic acids (tartaric acids and oxalic acid) and polysaccharides (capsular) aids in dissolution of minerals (feldspar and illite) to potassium release. Similarly, Liu et al., (2006) reported solubilization of silicate minerals by *B. mucilaginosus* with same mechanism as described by Sheng and He (2006). Therefore, potassium solubilization helps in stress alleviation due to it's environmental safe and cost effective approach (Figure 2).

5. Rhizobia

Soil bacteria (gram-negative) have the capability to reason contamination in the compatible host legume plant root cells and then initiates development of N_2-fixing nodules (Prell and Poole, 2006). These soil microbes known as the *Rhizobium* (Singular: rhizobia). The biochemistry, genetics, physiology and ecology of the bacteria establishing symbiotic relationship with legume plants have been briefly investigated by various researchers. Sahgal and Johri (2003) stated the current situation of rhizobial classification and listed thirty-six species from 7 genera (*Azorhizobium, Allorhizobium, Bradyrhizobium, Methylobacterium, Sinorhizobium, Rhizobium* and *Mesorhizobium*). Among these PGPR, *Rhizobium* spp. performs most important part in improving development and legumes production via symbiotic N_2-fixation.

6. Nodulation

A site where symbiotic N_2-fixation occur as a result of series of interactions among leguminous crops and rhizobia is known as nodulation. Mostly *Rhizobium* can nodulate more than one host crop, whereas numerous other strains of bacteria frequently isolated from a single host crop only (Cooper, 2007). There are 4 key polysaccharides kinds released by rhizobia that perform their various function at various stages of formation of symbiotic association including host plant identification, formation of infectious thread, root colonization and invasion of nodules. On root hair surfaces, they are also found to be implicated in the formation of biofilm (Fujishige et al., 2006). Around the rhizosphere of legume plant, the efficacy of rhizobia affected by chemo-tactic and growth promoting complexes while their joint effect fallouts in colonization of root. The rhizobia are chemo-tactic to unfractionated legume epidermal exudates comprising flavonoids (Cooper, 2004).

Root exudates such as amino acids, hydroxyl aromatic acids, dicarboxylic and simple sugars can also origin to a solid chemo-tactic retort. The relation among legumes and rhizobia starts with attachment of bacteria through lectin binding to the root hairs. After colonization of root of legume plant, rhizobia produce signal molecules that transduced within the plant cells, ensuing in improving its development and growth. (Noel, 1992).

Therefore, a little technique that may be useful for improvement of root structure could ease the rhizobia to develop higher number of nodules in host plant. Lastly, plant hormones played a major part in the development and growth of nodules (Frankenberger and Arshad, 1995). Similarly, PGPR released by microorganisms have significant part in the symbiosis process, particularly in nodules formation through interaction of *Rhizobium* and legume host plant (Hirsch et al., 2001), or in straight crop development process (Kobayashi et al., 1995). However, inhibiting the process of nodulation is also due to ethylene production (Arshad et al., 2008).

7. Inoculation of *Rhizobium*

If inoculants of *Rhizobium* conditions remain improved, an efficacious N_2-fixation and symbiosis may be attained (Zahran, 2001). Under natural field situations, the isolation and screening of viable and extremely active strains from inherent rhizobial population to be used as inocula, could be ample valuable (Chatel and Greenwood, 1973).

Huang and Erickson (2007) verified efficacy of *Rhizobium leguminosarum* for enhancing the yield and growth of lentil and pea. Both observed improved seedling growth, nodule biomass and biomass of root and shoot in the pea crop. Pea grain yield was also improved. Seed treatment with *Rhizobium leguminosarum* showed rise in lentil shoot, nodule biomass and seedling height. Likewise, enhancement in peanut nodulation was detected by inoculation with *Rhizobium* (Dey et al., 2004). Likewise, Ahmad et al., (2008) described the consequence of diverse procedures of rhizobial inoculation on yield, seed protein contents and root nodulation of 2 varieties of lentil i.e. Masoor-93 and Massor-2002. The variables alike seed protein contents, root nodulation, N content of shoot and root of lentil crop, soil N-content and crop production were meaningfully affected by inoculation with *Rhizobium*. Likewise, some scientists have described noteworthy effect of rhizobial inoculation on growth, nodulation and yield of several leguminous plants (Huang and Erickson, 2007; Shahzad et al., 2017).

7.3. Result and Dıscussıon

1. Effects of potassium solubilizing rhizobacteria on different crops yield characters

Potassium solubilizing bacteria together with silicate rhizobacteria performs a main part in plant diet by increasing uptake of potassium by crops (Nianikova et al., 2002). Inoculation of silicate bacteria with organo minerals improved the yield characters of two crops (wheat and maize) was the first reported research work by Aleksandrov, (1958). After-words many other scientists all over the word worked on mineral solubilizing microbes to improve the yield characters of different field crops of Ciobanu, (1961),

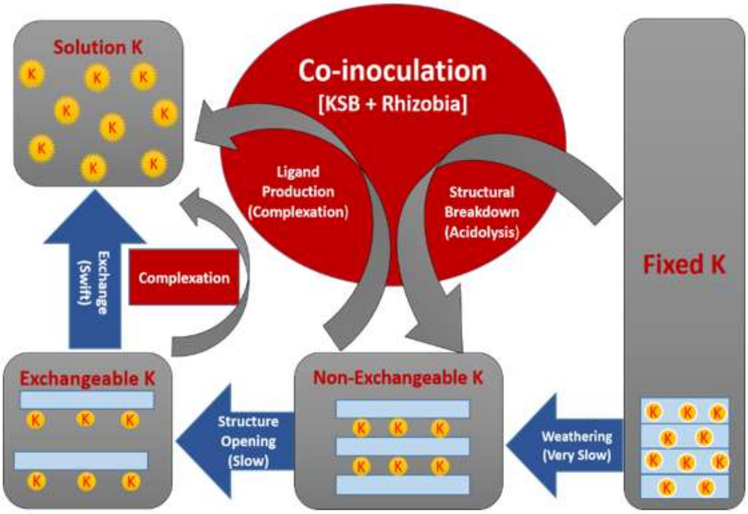

Figure 7.1. An overview of potassium solubilizing mechanism through bacterial co-inoculation (Siddiqui, A. R. 2021b)

Vintikova, (1964), Krieg and Holt (1984) and Kalaiselvi, 1999 reported higher cotton yield by treating with azotobacteria and silica bacteria, improvement in maize and lucerne crops with the inoculation of silicate bacteria, higher growth of gram seedling by applying potassium solubilizing rhizobacteria isolated from mineral and rock showing higher K release, and improved yield of rice was noted with silicate solubilizing bacteria inoculation respectively.

In his experiment, Kavya et al., (2023) showed that, with the right management techniques, the use of chemical fertilizers in conjunction with biofertilizers, such as potassium solubilizing bacteria (KSB), has the potential to save a significant amount of inorganic fertilizer while also greatly boosting paddy yield and growth. Another research by Kundu et al., (2023) found that in potassium-rich alfisols in semi-arid tropical regions, KSB may replace 25% of the RDK provided to nutrient-intensive crops like rabi sweet corn without compromising the crop's economic output. Moreover, Park et al., (2003) observed improvement in K bioavailability using bacterial inoculation by releasing organic acid and other chemicals that improve plants nutrient uptake and ultimately growth characters.

Chandra et al., (2005) testified the enhanced production from 15-20 % in tapioca and yam by applying K solubilizer in combination of different biofertilizers (*Rhizobium, Azotobacter, Acetobacter, Azospirillum* and P-solubilizing rhizobacteria). Zhang et al., (2004) examined the K-solubilizing bacteria effect on the sorghum crop and observed an improved biomass with P and K ratio in plants over control. Wu et al., (2005) detected noteworthy enhance in the maize development and nutrient uptake by *B. mucilaginosus* inoculation (K solubilizer) in combination with N_2-fixer i.e. *A. chroococcum* and *B. megaterium* (P solubilizer).

Mikhailouskaya and Tchernysh (2005) examined the inoculation effect of potassium mobilizing rhizobacteria under two different soil (severally eroded soil having low productivity with inoculation and temperately worn soil without the inoculation) and disclosed an increased (1.04 t ha^{-1}) wheat yield. Hence in another study by Jangir et al., (2023) explores the impact of potassium inoculants and black mica on soil microbial populations and enzymatic activity in maize cultivated soils. Microbial communities fueled by root exudates play essential roles in nutrient cycling, plant health, and soil structure. This study investigates the effects of potassium-solubilizing bacteria (KSB) and mineral potassium on microbial populations and enzymatic activity across different growth stages of maize.

The goal of Biswas et al., (2022) study was to determine how applying liquid biofertilizers—PSB, KMB, and/ or KSB isolate—would affect lettuce growth, yield, and absorption of nutrients in a greenhouse environment. The PSB, KMB, and KSB isolates, both alone and in combination, have had a significant impact on lettuce's biomass, leaf count, and nutritional content. According to Patil et al., study from 2022, treating seeds with microorganisms that dissolve potassium and zinc and function as seed inoculums improved the microbial population in the soil.

The crop's availability of nutrients will be enhanced by the organic acids that the microorganisms produce. Thus, a higher pod yield of 8.41 percent over RDF alone in groundnut was obtained by treating the seeds with microorganisms that solubilize zinc and potassium along with the state-recommended fertilizer. This improved the plant's nutrient content and groundnut uptake to the extent of 26.05, 31.70, 16.75, and 14.49 percent, respectively, of N, P, K, and Zn.

Supanjani et al., (2006) found that the integrated inoculation of bacterial strains that solubilize phosphorus and potassium increased the availability of P and K by 12–21% and 13–15%, respectively. Furthermore, peppers' fruit output and biomass increased from 23 to 30 percent, respectively. The use of bacteria that solubilize phosphorus and potassium was shown to be environmentally justified and may reduce the actual need for inorganic fertilizers.

In three different types of soils (calcareous, sandy, and clayey soils), Badr et al., (2006) investigated the effects of bacterial inoculation combined with minerals comprising potassium and phosphorus on sorghum. The dry matter yield and potassium and phosphorus absorption were found to have improved in clayey, calcareous, and sandy soils by 48, 65, and 58%, 71, 110, and 116%, and 42, 91, and 78%, respectively. In a field experiment, silicate-solubilizing bacteria boosted rice production (5218 kg ha-1) relative to the control i.e. 4420 kg ha^{-1} (Balasubramanian and Subramanian, 2006).

Based on efficacy of solubilization of K and P, 9 bacterial isolates inoculated using maize crop and finding confirmed an increase in nutrient uptake that ultimately improved maize growth and yield components compared to control. Maize root length enhanced by 59.66, 55.00, 54.33 and 53.67 cm by inoculating with KSB-11, KSB-62, KSB-42 and other reference K- solubilizing bacterial strain) respectively than control (Sheng and He, 2006). Similar results regarding increase in root length by inoculating *B. edaphicus* (K-solubilizing bacteria) reported by (Wu et al., 2005) in maize, (Ramarethinam and Chandra, 2005) in brinjal and (Sheng, 2005) in rape seed and cotton crops. Powell, (1975) suggested that non-symbiotic microbes (*Azotobacter*) may increase K uptake and consequently improve growth of crop plants. Further, non-symbiotic bacteria in rhizospheric would alter the chemical steadiness of K solubilization, so that the crop behave as sink of K. Particular K bearing minerals used to isolate KSB from the cereal crop roots surfaces (Mikhailouskaya and Tchernysh, 2005).

Alike consequences on improved uptake of potassium by plants were reported by Sheng et al., (2003), Zhang et al., (2004), Wu et al., (2005), Ramarethinam and Chandra (2005), and Han and Lee (2006). The potential of *B. mucilaginosus* (potassium solubilizing rhizobacteria) and *B. megaterium* (phosphate solubilizing rhizobacteria) was investigated. This study confirmed non-significance regarding direct application of K and rock phosphate either alone or in combination with reference to the K and P availability in soil. However, their co-inoculation (KSB and PSB) showed significant improvement in K and P bioavailable over control (Vassilev et al., 2006).

2. Legumes crops and potassium requirement

Legumes are a vital component of agriculture and natural ecosystems for food, fiber and fuel. Legumes crops can transmit out Biological Nitrogen Fixation (BNF) via symbiosis with nodule of root persuading rhizobacteria, thus a key element for development and growth of legume crops (Boyd and Peters, 2013) along with fertility of agriculture land. *Rhizobium* legume symbiosis has been the most investigated biological interaction of legume crops in nature (Rahmani et al., 2011). However, besides rhizobia, also further endophytic rhizobacteria have been originate inside nodules of legumes, including *Pseudomonas*, *Enterobacter* and *Bacillus* species (Kan et al., 2007).

The bacteria that fix N_2 generate ammonium via process catalyzed by nitrogenase enzyme using nutritional benefits from plants (Chianu et al., 2011). Therefore, legumes plants that obtain N_2 by biological nitrogen fixation normally would have a more need of potassium as compared to those which only depend on soil nitrogen and phosphorous. Substantial K supply is key for legume nodulation since it directly influence nodule growth and function (Weisany et al., 2013), enzyme activity involved in assimilation of ammonia, inter-conversion of amino acid, supply of carbon and transduction of energy, respectively. In photosynthesis, the key role of K makes it a dynamic supplier to effective N_2-fixation process (Mishra, 2001). With the increase in total N_2-fixed by bacteria, need for an energy resource to reduce N_2 to ammonium ion (NH_4^+) also increases. The nitrogenase enzyme is vital for the fixation of N_2 as K regulates activity of nitrogenase and nodule permeability in legumes. Potassium is the principal cation in the plant like Ca in the soil (Pettigrow, 2008). More than sixty enzymes are regulated by K in plant and even though it is not a structure part of any enzyme.

In arid and semi-arid region, K deficiency is not as widespread compared to nitrogen and phosphorous. In current years, primarily rich soil with more potassium content has now become debit in potassium accessibility due to exhaustive cropping pattern, leaching, erosion of soil, runoff and insufficient application of potassium (Sheng and Huang, 2002). During last fifteen years, in Pakistan, it is evaluated that soil K level in Punjab declined upto 3 mg K kg^{-1}. It means in the course of last 2 decades, in Punjab about 60 mg K kg^{-1} soil reduced, and consequently, once the soil K test levels considered satisfactory for plant productivity are now close to the threshold level of K deficiency in soil (Mian et al., 2009).

For a considerable amount of time, the use of mineral fertilizers has been linked to enhance agricultural plant development and higher production potential per unit area. However, the agriculture industry now faces greater financial and environmental expenses because of the ongoing practice of applying fertilizers unevenly. In some semi-arid places where soil-K supplies are gradually being depleted, a key crop production concern has been recognized as a potassium (K) deficit. The goal study by Siddiqui et al., (2021a) was to isolate and characterize K-solubilizing bacterial strains from the rhizosphere and chickpea root nodules. First, 50 rhizobacterial and 50 rhizobial strains were obtained using Aleksandrov's medium.

After a comprehensive qualitative screening using many physiological, morphological, and biochemical assays, just 25 strains remained from each of these collections. From these, five strains, each having rhizosphere and nodule origins, were selected by qualitative and quantitative investigation of several growth-promoting traits. The chosen strains showed improved growth conditions in addition to effective potassium and phosphate solubilization, as demonstrated by the usage of glucose substrate at 25 ^{o}C and pH 7. He discovered that strains JKR7 (rhizobia) and SKB3 (rhizobacteria) were the most effective K-solubilizers in this investigation on chickpea crop.

3. Influence of bacteria having ACC-deaminase on leguminous crops

Several aspects affect the root nodulation of legume with physico-chemical and host microsymbiont competition situations of the soil and existence of unknown and known biomolecules alike flavonoids, polysaccharides and hormones. In addition, phyto-hormones have chief character in evolving nodules in leguminous crop. It was renowned that ethylene holds a major position that affect the development of the rhizobia and legume relation. But it could work as an auto-regulator to regulate the nodulation in crop (Arshad et al., 2008). When ethylene used indirectly as 1-Aminocyclopropane-1-carboxylic acid or directly as a gas, works as an inhibitor of nodules on legume roots (Arshad et al., 2008). Nodulation negatively affected by endogenous production of ethylene.

However, production of ethylene inhibitors recovers nodulation process (Shahzad et al., 2017).

PGPR comprising ACC-deaminase may endorse development of crop by activity of ACC-deaminase (Arshad and Frankenberger, 2002; Shahzad et al., 2017). Under dry soil conditions, the result of root associated bacteria on *Pisum sativum* having ACC-deaminase was evaluated. Results confirmed that inoculation of PGPR having ACC-deaminase activity improved WUE, nodulation, and production of droughty peas (Belimov et al., 2009). Zafar-ul-Hye et al., (2007) secluded 27 isolates of plant growth promoting rhizobacteria showing ACC-deaminase activity from the lentil rhizospheric soil.

Results showed that under axenic environment, the isolates of PGPR promoted growth of lentil seedlings including their fresh weights, shoot and root length. Shaharoona et al., (2006) assessed the effectiveness of plant growth promoting rhizobacteria isolates with activity of ACC-deaminase on the process of nodule formation in mung bean by co-inoculated with rhizobia (*Bradyrhizobium*). Finding revealed that PGPR isolates co-inoculated with rhizobia improved nodulation compared to individual inoculation of rhizobia. PGPR inoculation having ACC-deaminase hydrolyzed endogenous ACC in-to α-ketobutyrate and NH_3 rather than acetylene and subsequently improved the process of nodule formation in mung bean.

Furthermore, Siddiqui et al., (2021a) examined a variety of characteristics in chickpea crop that promote plant development, including root colonization, siderophore synthesis, exopolysaccharide synthesis, chitinase activity, indole-acetic acid generation, and 1-aminocyclopropane-1-carboxylic acid deaminase activity. Under lab circumstances, the chosen bacterial strains were examined for their plant-growth-promoting properties. The strains SKB3 (potassium solubilizing rhizobacteria) and JKR7 (rhizobia) performed better overall than the other strains that were still in use. Thus, their findings imply that bacterial K-solubilizers might be applied in K-limited agroecosystems as a helpful K-supplement. Furthermore, using these K-solubilizers might contribute to reducing the harmful effects that chemical fertilizers have on the environment.

Tittabutr et al., (2008) assessed the impact of ACC-deaminase on river tamarind nodules. The ACC-deaminase-encoding genes (acdS) were cloned from bacterial strains (TAL1145) and BL3 and transferred to PGPR (TAL1145) in plasmids. Compared to the inherent gene (acdS), the BL3-acdS gene significantly increased the ACC-deaminase activity in PGPR (TAL1145). The

TAL1145 gene (acdS) was shown to be considerably more inducible by ACC than by mimosine, whereas the BL3 gene (acdS) was found to be inducible by mimosine but not by ACC. In comparison to TAL1145, the trans-conjugants of TAL1145 with intrinsic and BL3-acdS genes generated more nodules of a greater size.

As a result, the acdS gene increased ACC-deaminase activities and TAL1145's symbiotic effectiveness on river tamarind. Ma et al., (2003**)** described that **e**thylene hinders formation of nodules in numerous leguminous crops. To investigate this, isolation of ACC-deaminase gene, insertion mutants with mutations in ACC-deaminase gene (*acdS*) and its regulatory gene, a leucine-responsive regulatory protein like gene (*lRPL*) built and evaluated their capabilities to the nodulated pea. Results showed that both mutants not produced ACC-deaminase showed lowered nodule formation over parental strain. Thus, confirmed that the existence of ACC-deaminase in strains improved the pea nodulation during early growth stages by restraining ethylene levels in the roots of plant.

4. Co-inoculation with K-solubilizing plant growth promoting rhizobacteria and rhizobia

Numerous information which disclose that rhizobia efficiency may be improved by co-inoculation with PGPR. Co-inoculation with rhizosphere and symbiotic bacteria may enhance the nodules by many methods. For example, they can produce phytoalexin, siderophore chelating insoluble cations, antibiotics against pathogens and colonize root surfaces by out-competing pathogenic microorganisms, and hence improve the development and nodulation of the plant (Parmer and Dadarwal, 1999). It has been verified with Fahraeus slides that *A. brasiliense* results an enhance in the root hairs numbers of alfalfa crop and root diameter as well (Itzigsohn et al., 1993). Inoculation with *A. brasiliense* also enhance the root hair formation in common bean plant roots (Burdman et al., 1996).

Fluorescent pseudomonads have been detected to enhance the chickpea nodulation and so improving the Biological Nitrogen Fixation (Parmar and Dadarwal, 2000). Co-inoculation of *P. striata* with *Bradyrhizobium* has also been detected to improve Biological Nitrogen Fixation in soya-bean crop. The relations among rhizobia and PGPB could demonstrate to be antagonistic/ synergistic. This type of relations can be used for enhancing the BNF and the plant produce (Dubey, 1996). Some signs for the existence of PGP *Bacillus* strains in the root nodules of soya-bean plant (Bai et al., 2002).

It is concluded from the study of Siddiqui et al., (2021b) that co-inoculation of rhizobacteria and rhizobial K-solubilizers could be employed as a useful K supplement in potassium-limited agroecosystems like chickpea (leguminous crop). Furthermore, the use of these K inoculants may help alleviate the negative impacts associated with chemical fertilizer use on the environment.

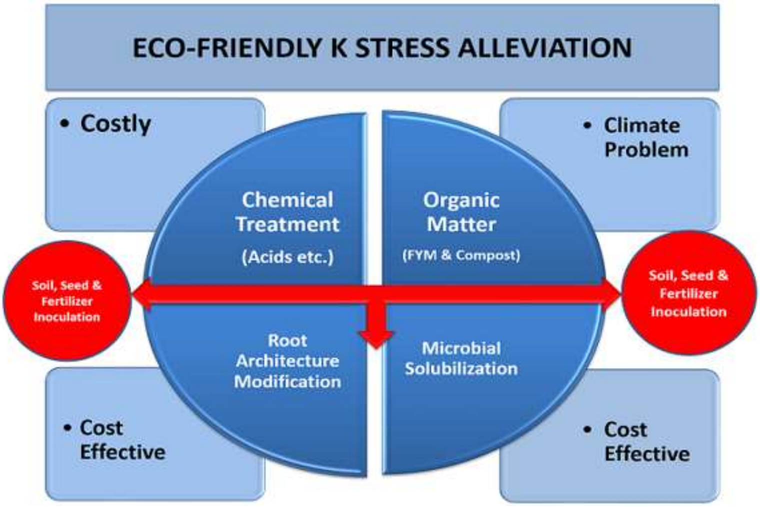

Figure 7.2. An overview of eco-friendly K stress evaluation through bacterial co-inoculation Siddiqui, A. R. 2021b)

This technique can also be used alone and as a nutritional partner of K fertilizers (K_2SO_4 or KCl) for different crops, depending upon the extent of crops K requirements. In this study, he found that strains SKB3 (rhizobacteria) and JKR7 (rhizobia) were the most efficient K-solubilizers when used alone or in-combination with K_2SO_4 instead of KCl, which may enhance salinity due to presence of chloride in the arid/ semi-arid regions.

Several researchers have testified that ACC-deaminase activity of PGPR strains coupled with rhizobial activity perform an imperious part in yield, uptake of nutrients and growth in peanut. There was noteworthy raise in nodule dry weight and number of peanuts by inoculation with plant growth promoting bacteria having ACC-deaminase activity (Jeffries et al., 2003). The raise in nodule numbers was due to growth in length of root and, subsequently, offering a larger contact to rhizobial strains and active sites numbers for nodules formation. Shaharoona et al., (2006a) stated that coinoculation with *Bradyrhizobium* and *Pseudomonas* meaningfully enhanced the overall biomass, nodulation and root length in the mung bean crop.

Coinoculation exposed the utmost auspicious enhance in nodules numbers and fresh and dry weight of nodules. Coinoculation with *P. putida* biotype A and *Bradyrhizobium* formed momentous enhance in numbers of nodules per plant as compared to untreated control and 48% enhance, over single inoculation with *Bradyrhizobium*. They proposed that enhance in nodules number might be because of ACC-deaminase activity in mung bean crop. Mirza B. et al., (2007) conducted an experiment to evaluate efficacy of coinoculation of chickpea with strains of *Enterobacter* and *Rhizobium*. They isolated rhizobial strains and *Enterobacter* from chickpea roots and nodules and combine used to enhance the nodules number and crop development. They described that coinoculation enhanced nodules number and chickpea crop growth in many treatments and enhance was reliant on host cultivar and coinoculation.

Rosas et al., (2006) explained the auspicious act of 2 strains of phosphate solubilizing *Pseudomonas* on the symbiosis strain of rhizobia (*B. japonicum* and *S. meliloti*) with soya-bean and alfalfa crops. The higher numbers of nodules and dry weight was noted in soya-bean when the coinoculation with a *B. japonicum* and *Pseudomona*s was carried out.

They noted that *Pseudomonas* provided P when budding with *Bacillus japonicum*. Similarly, Anandham et al., (2007) conducted an experiment to check the ability of coinoculation of the sulfur oxidizing bacteria with the strain of *Rhizobium* with no sulfur oxidizing ability in the groundnut crop. Clay alike pellet preparations (2.6×10^{7} cfu g^{-1}) of *Thiobacillus* strains were established and their efficacy to rouse the development of plant were checked in groundnut under both pot and field trials with sulfur deficit soil. Pot trials provided extra auspicious consequences on groundnut enhancing the fresh biomass, nodule numbers, pods per plant and dry weight. Coinoculation of *Thiobacillus* and *Rhizobium* strains under field trial detected suggestively extra numbers of nodules, dry weight of nodules and biomass of plant 136.8 per plant, 741 mg and 16 g per plant, respectively, on 80 days of crop sowing and enhanced the pod yield up to 19% in comparison with control. Likewise, inoculation of sulfur oxidizing rhizobacteria enhanced the available soil sulfur from 7.3 to 8.44 kg ha^{-1}. It is determined from outcomes that inoculation of sulfur oxidizing rhizobacteria with rhizobia results in synergistic effects endorsing the groundnut oil contents and yield in sulfur deficit soils.

Effect of coinoculation with *Bacillus japonicum* A1018 and a gus A-marked strain of *Pseudomonas fluorescens* 2136, *Pseudomonas fluorescens* WCS375, *A. agilis* 124 and *A. lipoferum* 136 was evaluated on soya-bean crop (Chebotar et al., 2001). The gus A-marked rhizobacteria efficaciously colonized the tips of roots and near the surface on the root tips. *P. fluorescence* 2136 had the extreme activity of colonization on soya-bean roots either inoculated with *B. japonicum* A1018 or inoculated alone. Coinoculation of *B. japonicum* A1018 and *P. flouresens* 2136 enhanced the colonization of *B. japonicum* A1018 on roots of soya-bean, numbers of nodules and acetylene reduction activity at ten (10) and twenty (20) days after inoculation.

The effect of rhizobacteria *A. chroococcum*, *P. flouresens* and *A. brasiliense*, sole and in coinoculation with *G. mosseae and Rhizobium* species was observed by Siddiqui and Mahmood (2001) on chickpea development. In case of sole/ single inoculation, *G. mosseae* performed excellent in enhancing the growth of plant and lessening nematode reproduction than any other tested organism. Use of *A. brasilense* induced alike enhance in the growth of plant to that produced by *Rhizobium*, while application of *A. chroococcum* was better than *A. brasilense* in enhancing the development of nematode infected plants.

But combined application of *P. flouresens* and *G. mosseae* was better in enhancing the growth of plant and lessening the nematode reproduction than any other treatment. Likewise, Sindhu et al., (2002) stated that coinoculation with 4 *Bacillus* strains MRSA18, MRS12, MRS27 and MRS 31 enhanced the shoot dry mass of green gram extra than single inoculation with *Bradyrhizobium* specie. Similarly, Yuming et al., (2003) coinoculated three strains of *Bacillus* species with *B. japonicum* under natural field and greenhouse experiments. These strains enhanced the nodules, weight of root, weight of nodule, grain yield and total nitrogen. The strain *Bacillus thuringiensis* (NEB 17) was the most active in enhancing the soya-bean crop yield. Effects of the coinoculation dose of 2 plant growth promoting rhizobacteria strains, *S. proteamaculans* 1-103 and *S. liquefaciens* 2-69, with *B. japonicum* on soya-bean nodulation, development and fixation of nitrogen were examined below axenic trial. The coinoculation of plant growth promoting rhizobacteria expressively enhanced the nodules numbers, dry weight of plant and nitrogen fixed (Bai et al., 2002).

Madhaiyan et al., (2006) reported that the dual inoculation of *Rhizobium* with methyl-bacterium pointedly enhanced the plant development, nodules numbers and crop production contributing traits in crop of groundnut in comparison with single *Rhizobium* application. Figueiredo et al., (2007) done a trial in a greenhouse to check the capacity of plant growth promoting rhizobacteria on nodules numbers, BNF and *Phaseolus vulgaris* L. cv. Tender Lake growth. Rhizobium tropici was added to the disinfected seeds both singly and in conjunction with a strain of rhizobacteria that promotes plant development. It was shown that beans that were co-inoculated with *P. polymyxa* and *Rhizobium tropici* had greater levels of leghemoglobin, nitrogenase activity, and N2-fixing efficacy, resulting in increased symbiotic efficacy. Nodulation and nitrogen fixation were aided by *P. polymyxa* and *Rhizobium* strain inoculation.

All studies evidently verified that the co-inoculation with K- solubilizing and/ or mobilizing rhizobacteria and rhizobia could be extremely beneficial for enhancing the development, production and nodules numbers of leguminous crops/ plants. Overall, these findings imply that bacterial K-solubilizers and/ or mobilizers may be applied in K-limited agroecosystems as a helpful K-supplement. Furthermore, using these K-solubilizers and/ or mobilizers might contribute to reducing the harmful effects that chemical fertilizers have on the environment.

7.4. Conclusion

1. Co-inoculation of potassium solubilizing bacteria (KSB) and *Rhizobium* can solubilize and/ or mobilize K-containing soil minerals to increase plant available K fraction in the soil.
2. Plant growth promotion and stress alleviation activities associated with co-inoculation can provide an additional advantage for the crop production under stress conditions.
3. Improvement of K related plant traits and increased K contents in plant tissues can be confidently correlated with improved K fertilization of various crops including chickpea (leguminous crop) as a result of co-inoculation.
4. Better yield and growth parameters on applying K_2SO_4 for K fertilizer along with co-inoculation has been proved K_2SO_4 a better K fertilizer as compared to KCl for irrigated as well as rainfed areas of arid/ semi-arid regions.
5. Co-inoculation along with K_2SO_4 application also guaranteed better utilization of applied K fertilizer, as indicated by higher K use efficiency, to ensure sustainable utilization of limited nutrient reserve.
6. Integrated use of co-inoculation with K-solubilizing and/ or mobilizing bacteria and rhizobia can show a promising improvement in plant growth, nodulation, symbiotic N fixing efficiency, and yield of crop by fulfilling K-requirements as this technology is more sustainable, economical and environmental friendly.

7.5. RECOMMENDATIONS

1. By adopting this cost-effective approach, the financial burden of potassium and nitrogen fertilizers can be reduced/or minimize.
2. Limited potassium (K) reserves can be utilized more efficiently for sustainable development of agriculture.
3. This approach can also be extended for other crops that having higher K requirements like maize, sugarcane, sugar-beet, potato, alfalfa etc., in different types cropping systems in the world including Pakistan.
4. It can also be included in commercial package of other biofertilizers as well as chemical fertilizers for N and P nutrition.
5. It introduced a new area of future research for agricultural scientists which may open new horizons in the advancement of the field of "K-biofertilizers" in the world including Pakistan.
6. It also demanded the revision of fertilizer recommendations of chickpea crop to optimize the amount of various fertilizers and soil amendments, depending upon the soil nutrient status and environmental conditions.

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Brief Curriculum Vitae

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CHAPTER 8

VALORIZATION OF KENAF SEEDS AS POTENTIAL FOOD INGREDIENT WITH HEALTH BENEFITS

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ABSTRACT

Originating from kenaf seed, kenaf seed gum (KSG) is an innovative seed gum candidate. The health benefits of KSG were assessed in comparison to those of commercial guar gum (GG) and locust bean gum (LBG), with regards to their bio-functional and antioxidant properties. The cholesterol and bile salt binding capacities of KSG were 7.01 mg/g and 82.58% which were comparable to commercial seed gums. However, KSG revealed lower glucose absorption capacity compared to commercial GG and LBG. In addition, the antioxidant properties of the KSG were comparable to those of commercial seed gums, as measured by Ferric Reducing Antioxidant Power (FRAP) and DPPH radical scavenging activity. This research offers fundamental insights that can be utilized to investigate the potential of KSG as an unconventional seed gum, particularly in the food industry.

Keywords: guar gum, *Hibiscus cannabinus*, kenaf seed, locust bean gum.

8.1. Introduction

In the food, pharmaceutical, and cosmetics sectors, gums are water-soluble polysaccharides. Because of their accessibility, affordability, and advantageous properties, seed gums are widely utilized in the production of commercial hydrocolloids (Naji et al., 2012; Niknam et al., 2018). The distinctive physical and chemical characteristics of seed gums define their function as emulsifiers, stabilizers, and thickeners (Vilaró et al., 2018). Commercial applications frequently utilize guar gum (GG) and locust bean gum (LBG) as seed gums on account of their viscosity characteristics (BeMiller, 2019). Particularly for the production of novel food items that offer health benefits and a pleasant flavor, the food industry has a significant demand for seed gums (Douaire & Norton, 2013).

Koocheki et al. (2022); Qian et al. (2012); Razavi et al. (2014) have documented a multitude of methods for the isolation of seed gums derived from diverse sources. The physicochemical attributes of gums can be affected by the extraction and purification methods used (Rashid et al., 2018). Furthermore, in addition to the physicochemical attributes, a substantial understanding of the functional and antioxidant properties of the seed gum is required when they are incorporated into food systems. This is due to the fact that their interactions with other components can significantly alter the microstructure and properties of the end food products (Alba et al., 2018).

As a cordage commodity, kenaf (*Hibiscus cannabinus* L.) has been utilized primarily for many years (Monti, 2013). On a global scale, this natural fiber holds significant importance owing to its adaptability to diverse weather conditions (Akinrotimi & Okocha, 2018) and its extensive utilization in industry, including but not limited to paper and pulp production, textile manufacturing, bio-composites, insulation mat development, and absorption material production (Monti, 2013). Presently, it is cultivated in numerous tropical and subtropical nations across the globe (Mariod et al., 2017).

After harvesting, kenaf seeds, which are a by-product of kenaf plant production, are frequently discarded (Chan et al., 2013). Replanting utilizes a mere 2% of the seedlings that are produced (Wei, 2019). Potential food industry constituents include kenaf seeds, which are rich in fat, protein, and fiber (Ibrahim et al., 2019; Karim et al., 2020). Kenaf seed applications are the subject of an expanding body of research, which includes kenaf seed oil (Chan & Ismail, 2009; Monti, 2013; Yazan et al., 2011), defatted kenaf seed meal (Chan et al., 2013), milk and tofu derived from kenaf (Ibrahim et al., 2020; Karim et al., 2020) and kenaf seed protein concentrates (Ibrahim et al., 2021; Mariod et al., 2010). Recently, a study on the physicochemical attributes of KSG has been conducted (Nevara et al., 2022).

Converting kenaf seed into a valuable compound would benefit the environment and food security. Due to limited information on kenaf seed gum (KSG), which could be a valuable, low-cost seed gum source for the food industry, research on health benefits of KSG is crucial. Therefore, this work aims to examine the bio-functional and antioxidant properties of KSG and compare them to the commonly used seed gums (GG and LBG) to demonstrate the potential of KSG as a novel gum.

8.2. Methods

1. Raw materials

Kenaf (*Hibiscus cannabinus* L.) seeds variety V36 were kindly donated by The National Kenaf and Tobacco Board (LKTN) located in Kangar, Perlis, Malaysia. The seeds underwent precleansing to eliminate larger contaminants, including dust, chaff, stones, and immature seeds, prior to being washed. Three times under flowing tap water, the seeds were rinsed. Following that, they underwent a five-hour drying process in an oven set at 40°C. Until subsequent use, the seeds were stored at room temperature (25±2°C) after being sealed in plastic bags. Commercial guar gum (G4129) and locust bean gum from *Cerratonia siliqua* seeds (G0753) were purchased from Sigma-Aldrich (USA).

2. Kenaf seed gum extraction

The extraction and purification of KSG were conducted based on the prior investigation (Nevara et al., 2022). The extraction method is shown in Figure 8.1.

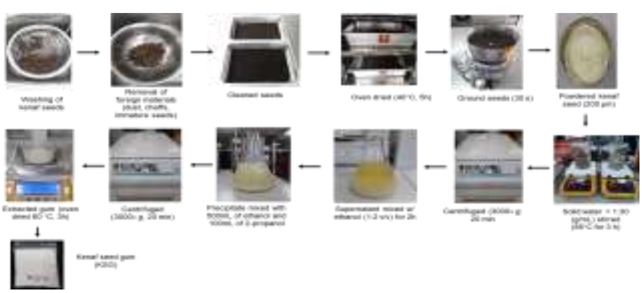

Figure 8.1. Extraction of kenaf seed gum

8.3. Yield of kenaf seed gum

It was discovered that the yield of KSG extracted from kenaf seeds could reach 21.13%. A similar rate of yield, 22%, was documented for fenugreek seeds in a study by Brummer et al. (2003). On the contrary, the yield of KSG was found to be greater than that of several other seed gums, including *Prosopis spp.* (14.2%) (López-Franco et al., 2013), *Lepidium sativum* (3.50–8.97%) (Razmkhah et al., 2016), *Prosopis juliflora* (16%) (Azero & Andrade, 2002), and *Ipomoea turpethum* seeds (23%) (Singh et al., 2003).

The variations in the yields may be explained by biological and developmental factors, including species, seed origin, or endosperm development stage (Estévez et al., 2004). Furthermore, the variability in yield may also be impacted by the solvent composition, processing conditions, and the extraction method employed (Oliva et al., 2010).

8.4. Bio-functional properties of kenaf seed gum

Table 8.1 shows the glucose, cholesterol, and bile salt absorption capacities of KSG compared to as commercial gums such as GG and LBG.

Table 8.1. Bio-functional properties of KSG, GG, and LBG

Parameters	KSG	GG	LBG
Glucose absorption capacity (mg/g)	42.05 ± 0.89 [b]	53.89 ± 2.07 [a]	50.99 ± 1.59 [a]
Cholesterol absorption capacity (mg/g)	7.01 ± 0.06 [a]	6.76 ± 0.01 [b]	6.90 ± 0.09 [ab]
Bile salt binding capacity (%)	82.58 ± 0.49 [a]	83.30 ± 1.27 [a]	57.61 ± 1.33 [b]

Note: Each value is the means of three independent measurements. Significant differences ($p \leq .05$) were indicated by different letters in the same row. KSG = Kenaf Seed Gum; GG = Guar Gum; LBG = Locust Bean Gum

1. Glucose absorption capacity (GAC)

A notable difference in GAC was observed between KSG and commercial gums (Table 8.1). The highest GAC value was found in GG (53.89 mg/g), followed by LBG (50.99 mg/g) and KSG (42.05 mg/g). The GAC analysis indicates the hyperglycaemic effect in vitro of the studied seed gums. The results showed that commercial GG and LBG had higher GAC values than KSG. It may be attributed to their water absorption and gel-forming properties, which slow gastric emptying and increase satiation (Mudgil et al., 2014). The GAC of plant fibre defines the ability to bind glucose at low concentrations and slow its transport through the intestinal lumen (Bhinge et al., 2017). It reduces postprandial hyperglycaemia by inhibiting α-glucosidase and α-amylase (El-

Beshbishy & Bahashwan, 2012; Lim & Loh, 2016). Furthermore, foods containing guar gum reduced the desire to eat, appetite, and hunger (Butt et al., 2007).

3. Cholesterol absorption capacity (CAC)

The findings indicated that the CAC of KSG differed significantly ($p \leq .05$) from that of GG but was comparable to that of LBG (Table 1). KSG had the highest CAC (7.01 mg/g), followed by LBG (6.90 mg/g) and GG (6.76 mg/g). The study demonstrates the cholesterol-lowering effects of non-conventional seed gum (KSG). Cholesterol-lowering effects are often associated with edible thickening agents such as GG (Butt et al., 2007; Sharma et al., 2018).

The mechanism is related to increased bile acids excretion in faeces and reduced enterohepatic bile acid, which can stimulate bile acids production from cholesterol. Consequently, the concentration of liver free cholesterol decreases (Rideout et al., 2008). The KSG showed the highest CAC value, indicating its ability to absorb cholesterol. Furthermore, it has been closely related to reducing cardiovascular risk (Nsor-Atindana et al., 2012).

4. Bile salt binding capacity (BSBC)

Bile acid functions as a precursor to cholesterol. Bile acid can be absorbed by gums in the small intestine and subsequently excreted (Qiao et al., 2021). Bile acid absorption promotes the conversion of cholesterol to bile acid, hence reducing total cholesterol levels and the risk of cardiovascular disease (Zhu et al., 2018). Therefore, gums may have physiological activities that reduce blood fat levels. Over 90% of bile acids in the body are inbound forms (especially sodium salts). Therefore, sodium cholate hydrate was replaced with bile acid to determine the BSBC of the gums.

Table 8.2 showed that KSG had comparable BSBC with GG with 82.58% and 83.30%, respectively and both these values were significantly ($p \leq .05$) higher than in LBG. According to a study by Kim & Kim (2017), the BSBC of β-glucan isolated from various varieties of Jeju barley was approximately 25%. The findings of current study reveal a considerably higher BSBC value compared to the values reported for β-glucan extracted from Jeju barley. This suggests that KSG exerts a more pronounced hypocholesterolemia effect.

8.5. Antioxidant properties of kenaf seed gum

Table 8.2 showed the antioxidant properties of KSG compared with GG and LBG. Phenolics play a significant role in enhancing the body's antioxidant capacity. Thereby reducing the risk of chronic diseases caused by excessive free radicals (Jin et al., 2018).

Table 8.2. Antioxidant properties of KSG, GG, and LBG

Parameters	KSG	GG	LBG
Total phenolic content (mg GAE/g)	0.053 ± 0.002 [a]	0.014 ± 0.001 [b]	0.016 ± 0.000 [b]
DPPH radical scavenging activity (μM TE)	126.69 ± 2.30 [a]	128.88 ± 1.27 [a]	126.79 ± 1.51 [a]
ABTS radical scavenging activity (μM TE)	13.98 ± 0.08 [b]	14.44 ± 0.24 [a]	14.52 ± 0.24 [a]

Note: Each value is the means of three independent measurements. Significant differences ($p \leq .05$) were indicated by different letters in the same row. KSG = Kenaf Seed Gum; GG = Guar Gum; LBG = Locust Bean Gum

In Table 8.2, the determination of TPC of gums revealed that KSG exhibited the highest phenolic content (0.053 mg GAE/g), which was significantly higher ($p \leq .05$) than LBG (0.016 mg GAE/g) and GG (0.014 mg GAE/g). The lower phenolic content of GG and LBG in the current study is consistent with a Hamdani and Wani (2017) who studied composition of GG and LBG. The variation in TPC values could be attributed to the seed coat, as KSG was extracted from whole kenaf seeds, while commercial seed gums were primarily extracted from dehulled seeds. The seed coat of pigmented seeds, which comprises an estimated 10% of the total seed weight, is more abundant in phenolic compounds than that of light-colored seeds, which have a lower TPC (Singh et al., 2017). Furthermore, Segev et al. (2010) reported that coloured chickpea seeds had up to 13 times more TPC than beige and regular cream coloured seeds, indicating their potential as functional food sources.

According to Ma et al. (2013), lipid oxidation generates highly active free radicals, which can promote the transformation of normal cells into cancer cells in the human body. Gums can eliminate free radicals from the human body, so the antioxidant capability is crucial to determine its worth (Jin et al., 2018). Three of the most commonly used methods were selected to estimate various antioxidant capabilities. Radical scavenging ability was determined using DPPH and ABTS assays, while ferric-reducing adsorption capacity was assessed using the FRAP assay (Thaipong et al., 2006).

The results obtained using three different methods are shown in Table 8.2. The results showed that KSG (126.69 μM TE) has a comparable DPPH radical scavenging activity to that of GG (128.88 μM TE) and LBG (126.79 μM TE).

The electron donation or release of hydrogen to free radicals by different hydroxyl groups in the gum structure, which subsequently terminates the radical chain reaction, could potentially be the principal mechanism by which gums exert this activity (Kia & Ganjloo, 2018; Yang et al., 2016). On the contrary, the ABTS radical scavenging activity of the gums showed significant differences ($p \leq .05$), with KSG (13.98 μM TE) exhibiting lower activity than GG (14.44 μM TE) and LBG (14.52 μM TE). This could be attributed to the gum extraction pre-treatment, which involved washing and drying the kenaf seeds prior to extraction. These procedures may lead to the loss of water-soluble antioxidants, resulting in a reduction in their antioxidant activity (Jin et al., 2018). FRAP assays assess the reducing power (Benzie & Strain, 1999) and antioxidant capacity of the sample through chain breaking (Ghiselli et al., 1995).

In principle, at an acidic pH, the iron complex of tripyridyltriazine is essentially reduced from $Fe\ (TPTZ)^{3+}$ to $Fe\ (TPTZ)^{2+}$. The reduction to an intensely blue reaction mixture is accompanied by a colour change that can be quantified spectrophotometrically (Hamdani & Wani, 2017). KSG and GG showed comparable reducing power with 0.006 μM TE and 0.004 μM TE, respectively, more significant than LBG (0.002 μM TE) (Table 2). The result revealed that KSG has the ability to donate electrons to react with free radicals and convert them into stable molecules (Kia & Ganjloo, 2018). The reducing power of seed gums in the current study was in agreement with the previous research on coloured chickpeas (Segev et al., 2010).

8.6. Conclusion

Carbohydrate-protein gum was extracted from kenaf seed using an aqueous extraction method with a yield of 21.0%. The mixture of protein and polysaccharides in KSG resulted in health beneficial properties to those of commercial GG and LBG. KSG demonstrated comparable cholesterol and bile salt binding capacity, but lower glucose absorption capacity compared to commercial GG and LBG. In terms of antioxidant properties, KSG had higher TPC for antioxidant properties, but similar antioxidant activity with GG and LBG, except for ABTS radical scavenging activity. This study provides information on a novel KSG to support future potential applications of KSG in the food industries.

8.7. Recommendation

More studies on various aspects of kenaf seed gum are recommended in the future. These include: (i) Comparison of innovative, sustainable and green extraction techniques (e.g., ultrasonic microwave assisted extraction) on kenaf seed gum versus conventional solvent extraction method; (ii) Effect of fortification on food quality; (iii) Functional properties in various food applications; and (iv) Stability and shelf life in food products.

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Brief Curriculum Vitae

Gita Addelia Nevara, S.TP., M.Sc, Ph. D. born on 3 October 1988 in Silungkang, West Sumatera, Indonesia, is an accomplished food scientist and educator. She earned her Bachelor's degree in Food Technology from the Faculty of Agricultural Technology at Andalas University in 2011. Recognizing her passion for food science, she pursued her Master's degree in Food Science from the Faculty of Food Science and Technology at Universiti Putra Malaysia (UPM), and graduated in January 2016. During her Master's program, she was the recipient of an LPDP scholarship from the Ministry of Finance, Republic of Indonesia. Gita Addelia Nevara's academic achievements and commitment to food science and education led to her appointment as a lecturer in the Department of Nutrition at Universitas Mohammad Natsir Bukittinggi, Indonesia, in December 2017. She was passionate about sharing her knowledge and skills with her students, inspiring them to pursue their own careers in food science. In October 2019, Gita Addelia Nevara was awarded a joint full scholarship from DAAD (German Academic Exchange Service) and SEARCA (Southeast Asian Regional Centre for Graduate Study and Research in Agriculture) to pursue her Ph.D. in Food Science at UPM and graduated in 2023. Her dedication to research has been exemplary, as evidenced by the five publications she has successfully published during her Ph.D. program. In recognition of her outstanding research contributions, Gita Addelia Nevara was awarded two travel awards to present her research findings at an international conference in Cambodia and the World Food Congress in Singapore in 2022. In 2023, she was awarded DAAD Summer School Scholarship at the Heidelberg Institute of Global Health (HIGH), Heidelberg University, Germany. Gita Addelia Nevara's academic achievements, combined with her passion for food science and education, make her a valuable asset to the academic community. Her research and teaching are sure to have a positive impact on the food industry for years to come.

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CHAPTER 9

Observation of Morphological Features of Six Soybean [*Glycine max* (L.)] Varieties: Insights into Plant Growth and Development

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ABSTRACT

This study focuses on morphological observations of six soybean cultivars, namely Grobogan, Anjasmoro, Dega 2, Yellow Gepak, Dega 1, and Dering 1. The research location was carried out at the UNMA Research Field, while detailed morphological observations of soybean plants were made at the Plant Laboratory of the Faculty of Agriculture, Padjadjaran University. In this study, a completely randomized design approach was used to ensure the objectivity and validity of the observations. Seeds of the six cultivars were obtained from DP3K Majalengka Regency. Observations involved a number of unique characteristics of soybean plants, such as seed condition, plant height, leaf morphology, flower morphology, harvest age and yield. The success of soybean planting was found to be influenced by several factors, including seed type, planting method, maintenance and environmental conditions. The ideal environment for soybean growth involves rainfall of about 100-200 mm per month, soil pH ranging from 6.0-6.5, relative humidity of about 60-70%, shade levels of less than 30%, and the altitude of the planting site is in the range of 350-500 m above sea level. The important role of seed conditions is evident from the differences in weight and growth success between cultivars. Plant height was an important parameter, with Grobogan and Anjasmoro achieving greater height than other cultivars. Leaf morphology showed similarities between cultivars, except for Anjasmoro which stood out with broader leaves. Flower and anther development showed variation among cultivars, with Anjasmoro having the potential for higher yields. Variability in harvest age and yield was also observed, with Grobogan having a relatively short harvest age but high yield. Pod development is an important stage in the plant life cycle, affecting the quality of the seeds produced.

Keywords: Cultivar, Morphology, Soybean, Growth, Observation.

9.1. Introduction

The morphology of soybean (*Glycine max* (L.) Merrill) plants shows significant diversity among different cultivars. Although some cultivars may appear similar, morphological differences can be carefully identified. An in-depth recognition and understanding of the morphological characteristics of different soybean cultivars is very important to achieve optimal production in different growing regions (Chen et al., 2023).

There are three types of soybean cultivars based on age, namely early, mid, and deep. However, there are discrepancies between recorded harvest age and variety descriptions, influenced by environmental factors and planting practices. This variation provides an additional dimension in understanding soybean crop characteristics (Rahma & Marina, 2023).

In Indonesia, there are 62 different soybean cultivars, and selecting cultivars that are suitable for the planting location is key to obtaining profitable yields. Harvesting age is the main parameter, with early, mid and deep cultivars having different harvesting ages. However, it should be noted that recorded harvest ages often do not align with official descriptions, as they are influenced by environmental factors and differences in planting practices (Marina et al., 2023).

Increasing the yield potential of local soybeans is a major focus of the contribution of the Agricultural Research and Development Agency (Balitbangtan). Cultivars such as Grobogan, Anjasmoro, Deja 2, Yellow Gepak, Dega 1, and Dering 1 showed impressive yields, exceeding the 2.0 tons per hectare threshold. Grobogan and Anjasmoro, in particular, stood out with large seeds, marking a positive achievement in producing high-yielding varieties. For example, the Grobogan Variety and Anjasmoro Variety stand out with large seeds, weighing about 16-21 g per 100 seeds, comparable to the average imported soybean seed weight of 17 g per 100 seeds. These advantages provide a positive achievement in producing high-yielding varieties that not only meet yield potential standards but also compete significantly with imported varieties.

However, there are challenges in the description and identification of soybean cultivars, especially in the context of determining the selection of superior seeds across cultivars. Variations in harvest age that are not in line with official descriptions and the influence of environmental factors and differences in planting practices contribute to the complexity in choosing the optimal cultivar for each planting location (Harti et al., 2023).

The application of intercropping systems, especially by using Azolla Liquid Nutrition, is an interesting alternative in optimizing soybean plant growth. Azolla Liquid Nutrition, which contains natural nutrients, can have a positive impact on the availability of plant nutrients and at the same time increase agricultural productivity (Kusuma, 2023).

The results of this study are expected to provide a better understanding of the morphological response of soybean to Azolla Liquid Nutrition in the context of sustainable agriculture. Morphological research on soybean plants with intercropping systems is currently still limited to several aspects, such as plant height, number of branches, and leaf condition. Therefore, this study responds to the need to describe the plant parts of six soybean cultivars through more detailed morphological observations. By making in-depth observations of morphological characteristics, this study aims to provide a more comprehensive picture and clearly distinguish each soybean cultivar.

Thus, the results of this study are expected to provide a deeper insight into the growth and development of soybean plants, as well as make a positive contribution in increasing productivity and selecting cultivars that are suitable for local conditions. Through a better understanding of soybean plant morphology, farmers and researchers are expected to make more informed decisions in selecting optimal cultivars, thus supporting the development of sustainable and competitive soybean agriculture.

9.2. Methods

This research was conducted from April to October 2022, focusing on morphological observations of six soybean cultivars, namely Grobogan, Anjasmoro, Dega 2, Yellow Gepak, Dega 1, and Dering 1. The research location was at the UNMA Research Field, while morphological observations were carried out in detail at the Plant Laboratory of the Faculty of Agriculture, Padjadjaran University. The research methodology adopted a completely randomized design approach to ensure objectivity and validity of the results.

9.2.1. Research Materials

The research materials were seeds of the six cultivars obtained from two different sources. Grobogan, Anjasmoro, Dega 2, Yellow Gepak, Dega 1, and Dering 1 cultivars, obtained from DP3K Majalengka Regency, and Azolla POC obtained from previous research with the best dosage of 400 ml.

9.2.2. Research Procedure

The research process included planting in the UNMA Research Field, followed by morphological observations involving aspects such as the shape and arrangement of roots, leaf tips, leaf bases, leaf repetition systems, and other morphological characteristics. The overall study aimed to provide a deeper understanding of the growth and development of soybean plants of the six cultivars observed. With a research period spanning several months, it is expected that the data collected can provide comprehensive insights into morphological variations among soybean cultivars.

Soybean plant care includes aspects of watering, fertilization, pest and disease control, and weed control. Watering is done once a day, with 250-500 ml of water per plant in the morning. Fertilization uses NPK as much as 5 grams per plant. Plants on the 21st day after seed sprouting. Pest control was conducted in the fourth week after planting.

Observations were made on the six soybean cultivars, including plant height growth, number of branches, leaf morphology, flowering age, number of flowers, and pod formation. Plant height was recorded weekly for the first six weeks. Flowering age was recorded when flowers started to appear. All observations aimed to provide a holistic picture of the performance and growth characteristics of each soybean cultivar during the study period.

In this study, observations on leaf color were made on plants aged 1, 2 and 3 months. Using a color scale of 1. light green, 2. green, 3. dark green, and 4. yellow, observations were made by selecting 5 leaves from the bottom, middle, and top of each plant, repeated 3 times. In addition, leaf shape and area were observed on 2-month-old plants. Leaf area measurements were taken on the outermost 10 leaves of each trifoliate using millimeter block paper.

The number of flowers per plant was counted for 5 consecutive days, starting when one flower bloomed. This observation was made on 5 plant samples, which were then calculated as an average. Observations of soybean flower anther were made using a splitting needle and tweezers. Involving 10 flower buds, the number of anther and anther centerline were measured with a 200x magnification microscope.

Data analysis was conducted using ANOVA at the 5% level to see differences between cultivars. This analysis will be followed by Duncan's test to determine significant differences among the cultivars. In addition, plant height growth will be presented in graphical form to provide a visual representation of growth comparisons between cultivars (Smith & Jones, 2020). With this approach, it is expected that the results of the analysis will provide in-depth insights into the characteristics and differences that may exist among the soybean cultivars studied.

9.3. Result and Discussion

The soybeans grown exhibit unique characteristics for each cultivar. The success of soybean planting in this study was influenced by several factors, including seeds, planting methods, care, and environmental conditions. Environmental factors considered suitable for soybean plant growth include rainfall of about 100-200 mm per month, soil pH ranging from 6.0-6.5, relative humidity of about 60-70%, shade levels of less than 30%, and planting locations at 350-500 m above sea level.

1. Seed Condition Six Cultivars of Soybean

Soybean plants grow optimally in hot, open areas, at an altitude of 400-600 m above sea level. Dry conditions in hot climates are very favorable for soybean growth. In Indonesia, soybean is usually planted during the dry season, especially after rice harvest, or if there is still some rainfall. The temperature during the study ranged from 28-38°C, which is suitable for the early stages of flower formation to the development of soybean pods.

Tabel 9.1. Seed Weight Grouping of Six Soybean Cultivars

Cultivars	Weight of 100 seeds (g)	% Seeds Grown
	Large Seed Soybeans	
Grobogan	17,8-18,2	90
Anjasmoro	14,8-15,3	85
	Small Grain Soybeans	
Dega2	10,5-11,1	92
Yellow Gepak	10,2-11,0	66
Deja 1	10,5-11,1	99
Dering 1	10,3-10,9	97

Before planting, soybean seeds were observed through measuring the weight of each 100 seeds. The observation of the weight of 100 seeds indicated the existence of two groups, namely soybean plants with small seeds and large seeds. The two cultivars included in the large seed category are Grobogan and Anjasmoro (see Table 1). For example, the 100-seed weight of Anjasmoro soybean cultivar grown in Binjai, Langkat, North Sumatra, reached 17.5 grams. On the other hand, soybean cultivars Dega 2, Yellow Gepak, Dega 1, and Dering 1 have small seeds, but despite this, their productivity reaches 1.6 tons per hectare (Afriyanti et al., 2014).

A comprehensive overview of the seed weight and sprouting success percentage of the six soybean cultivars was observed. The Grobogan cultivar showed a relatively high seed weight, ranging from 17.8 to 18.2 grams, with a sprouting success rate of 90%. Meanwhile, Anjasmoro had a lower seed weight, ranging from 14.8 to 15.3 grams, with a percentage of seeds that successfully sprouted around 65%. Cultivars Dega2, Yellow Gepak, and Deja 1 had smaller seed weights, ranging from 10.3 to 11.1 grams, but showed high sprouting success rates of 99%, 97%, and 92% respectively.

However, the cultivar Dering 1 has a lower germination success rate, reaching about 66%, despite having a similar seed weight to Yellow Gepak and Deja 1. Some of the factors that affect seed germination involve germinability, cleanliness, non-wrinkled physical form, intact seed anatomy, and suitability to the growing season. Seed quality is also affected by genetic, environmental and seed status factors. Genetic factors include innate traits, while seed status includes various aspects such as seed performance, maturity level, storage duration, seed health, seed size and weight, chemical composition, moisture content, and seed dormancy (Jauhari & Majid, 2019).

2. Plant height

The growth development of six cultivars of soybean plants for seven weeks. Until the plants reached 7 weeks of age, growth continued, followed by an increase in plant height. Grobogan and Anjasmoro cultivars in particular achieved greater height compared to the other cultivars.

The Anjasmoro soybean cultivar showed the most dominant height compared to the other four cultivars observed. After flowering, soybean plants tend not to experience additional upward growth, so observations were not made after week six. Plant height in the following weeks had a tendency to remain stable. It should be noted that the Anjasmoro soybean cultivar planted in Bogor has reached a height of 64-68 cm according to previous planting results (Jauhari & Majid, 2019).

3. Leaf Morphology

Soybean leaves are called trifoliate because they are formed by 3 leaflets in one stalk. Observations of soybean leaf morphology were made by paying attention to the development of the color scale, shape, and area of each leaflet. Data on the observation of leaf morphology of six soybean cultivars are documented in Table 9.2.

Tabel 9.2. Leaf Morphology of Six Soybean Cultivars

Kultivar	Color Scale, Leaf, Month			Shape	Leaf Area, cm2
	1	2	3		
Grobogan	1,6±0,2[a]	3,1±0,3[b]	3,8±0,3[b]	Oval	9,4±0,9[a]
Anjasmoro	1,5±0,1[a]	2,8±0,2[a]	3,5±0,3[b]	Oval	9,9±0,1[b]
Deja 1	1,4±0,1[a]	2,6±0,3[b]	3,3±0,2[b]	Oval	9,1±0,7[a]
Dering 1	1,4±0,1[a]	2,7±0,2[b]	3,7±0,2[a]	Oval	9,1±0,7[a]
Dega 2	1,4±0,1[a]	2,5±0,2[b]	3,2±0,1[a]	Oval	9,1±0,6[a]
Yellow Gepak	1,5±0,2[a]	3,0±0,2[b]	3,6±0,3[b]	Oval	9,2±0,7[a]

Four color scales, namely 1. light green 2. green 3. dark green 4. yellow Numbers followed by the same letter in a column indicate that they are not significantly different based on Duncan's test at the 95% confidence level. sd = standard deviation.

Although the leaf shape of the six cultivars.The leaves of the soybean cultivars show significant similarities to each other, but when compared based on length and width ratio, the leaf morphology of the cultivars can be described as an oval shape. In this category, the leaves of the Anjasmoro cultivar stand out with a wider size compared to the other four cultivars. During the three-month observation period, soybean leaves tended to change color towards dark green as the plants aged.

The results of the leaf color scale in the first month showed significant differences, especially in the Grobogan cultivar which showed a dark green color, in contrast to the other four cultivars. The Black Malika soybean cultivar began to show a dark green color in the second month after planting, while the leaves of the Anjasmoro cultivar maintained a bright green color until the third month. This phenomenon of leaf color change is caused by factors such as chlorophyll levels, physiological properties, and different growth in each soybean cultivar (Nur’aini & Rachmawati, 2022).

5. Flower Morphology

The selection of varieties for superior seeds must pay attention to important elements in the flower structure, especially the stamens or anther. In one series of flower bud development, the blooming process does not occur simultaneously, so variations in flower bud size can be found. The development of flower buds from emergence to bloom takes between one and four days.

The soybean plant flower, as its reproductive organ, is an important focus for observation. The flower bud blooming process is then followed by the formation of soybean pods. The Anjasmoro variety showed the potential to have a higher number of soybean pods compared to the other four varieties. This finding is in line with the highest number of branches found in the Anjasmoro variety. The Anjasmoro variety also showed the highest number of flower buds and branches among the other varieties.

The color of the corolla of soybean flowers in all varieties is almost uniform, which is light purple to dark purple. The presence of dark purple color on Black Malika soybean varieties also act as anthocyanins in the seed coat of Black soybean, according to the information in Table 9.3.

Tabel 9.3. Flower Observations of Six Soybean Cultivars

Cultivars	Flowering Age (Days)	Number of Flowers	Number of branches	Flower Shape	crown color
Gerobogan	38-40	35-40	6±1	Butterflies	purple
Anjasmoro	36-40	30-50	9±1	Butterflies	purple
Deja 1	34-39	30-40	5±1	Butterflies	purple
Dering 1	34-38	25-35	4±1	Butterflies	purple
Dega 2	36-39	30-45	5±1	Butterflies	purple
Yellow Gepak	34-36	25-35	4±1	Butterflies	purple

Soybean flower buds are found in the axils of branches and at the ends of branches forming a series like panicles. Each panicle group consists of 5-7 flower buds. Soybean flower buds begin to appear after the plants are 30-38 days old, depending on the soybean variety and planting method. The number of flower buds per plant varies depending on the variety planted, the number of branches, and the care method. The Grobogan variety was the first to flower at 30 days of age, faster than the other four varieties. Meanwhile, the Deja 1, Dega 2, Dering 1 and Yellow Gepak varieties started flowering at 38 days of age.

Soybean flowers are distributed along the main stem, from the top to the bottom, and also appear on branches and sub-branches. The process of pollination in soybeans occurs through kleistogamy, which is when the flowers are still in bud before blooming. Sometimes, soybean plants can have flowers that remain closed after pollination, known as kleistogamous flowers. Kleistogamous flowers are very small, inconspicuous, have no prominent color appeal, and do not produce honey or aroma. Generally, kleistogamous flowers are located at the bottom of plants that have short stems (Shilpashree et al., 2021).

6. Anther

In flower buds, there is a part called stamen, which consists of two main parts, namely the stalk or filament and the anther or anther. The stamen serves as the male reproductive organ in flowering plants. Inside the anther, microspores develop into pollen. Normally, soybean flowers have ten anther, but during observation, flower buds with eight or nine anther were found. Variations in the shape and size of the anther in soybean flower buds were observed and are clearly illustrated in Figures 2A and B. Average centerline

The anther of the six soybean cultivars ranged from 278.00 ± 17.51 μm to 354.67 ± 59.67 μm, which is detailed in Table 4. Data on the number of anther per 10 flower buds and anther midline for each soybean cultivar can be seen in the table. The number of anther varied across cultivars, with Dega 2 cultivar showing the lowest value and Anjasmoro cultivar showing the highest value. Similarly, the anther centerline reflected the average size of the anther, with the Anjasmoro cultivar having the longest size. Further analysis showed significant differences in anther size between cultivars, which could be identified through the mean values recorded.

The longest anther was found in the Anjasmoro cultivar, although the difference was not significant with Grobogan. The anther size is influenced by genetic traits and flower condition. Flowers from healthy plants tend to have large anther size. Large anther usually contains more microspores compared to smaller anther (Browne et al., 2018). The number of microspores and pollen in the anther tends to be in line with anther size (Hale et al., 2020).

Tabel 9.4. Amount of Anther in every 10 buds and Dıameter Soybean Anther

Kultivar	Jumlah Antera Tiap 10 Kuncup Bunga	Garis Tengah Antera		Rerata±sd
		Min	Maks	
Gerobogan	88-92	294,0	363,7	343,56±33,18[b]
Anjasmoro	88-95	294,0	411,3	354,76±59,67[b]
Deja 1	95-99	262,8	310,4	326,03±16,61[b]
Dering 1	87-92	261,0	310,6	284,97±21,18[b]
Dega 2	85-95	248,7	410,6	278,02±17,15[a]
Yellow Gepak	83-92	261,0	300,6	243,33±13,19[a]

Numbers followed by the same letter in a column indicate not significantly different based on Duncan's test at the 95% confidence level. sd = standard deviation.

Variations in soybean anther shape range from apple-like to sub-oblate. The apple-like anther is smaller than the sub-oblate anther, as shown in Figure 2C. An anther that has a diameter of more than 300 µm tends to be found in flower buds on plants that are in good health.

7. Harvest age and yield

Differences between the six soybean cultivars included 100-seed weight, plant height, number of branches, flowering age, and number of flower buds per plant, as shown in Table 4. Malika Black Soybean shows differences with the other four cultivars because its seeds have a black color, in accordance with the findings of Murtinah et al. (2020). In addition, when the flowers begin to bloom, Grobogan and Anjasmoro have purple flower crowns. Meanwhile,kultivar lain seperti Deja 1, Dega 2, Dering 1, dan Yellow Gepak menunjukkan kesamaan dalam hal berat biji, tinggi tanaman, serta warna dan bentuk daun.

Tabel 9.5. Harvest Age and Yield of 6 Soybean Cultivars

Cultivar	Harvest time (Hari)	Yiald average (ton/ha)
Gerobogan	76-80	2,60-2,70
Anjasmoro	82-92	2,00-2,25
Deja 1	85-90	1,50-2,00
Dering 1	82-92	1,50-1,60
Dega 2	85-90	2,00-2,00
Yellow Gepak	82-92	1,60-1,70

Gerobogan memiliki rentang umur panen antara 76 hingga 80 hari, dengan rerata hasil berkisar antara 2,60 hingga 2,70 ton per hektar. Anjasmoro showed a slightly longer harvest age, ranging from 82 to 92 days, with an average yield of about 2.00 to 2.25 tons per hectare. Cultivar Deja 1 has a harvesting age of between 85 to 90 days, with average yields ranging from 1.50 to 2.00 tons per hectare. Dering 1 has a similar harvesting age to Anjasmoro, which is 82 to 92 days, with an average yield of about 1.50 to 1.60 tons per hectare. Dega 2 shows a harvesting age between 85 to 90 days, with an average yield of about 2.00 tons per hectare. Yellow Gepak has the same harvest age range as Anjasmoro and Dering 1, which is 82 to 92 days, with average yields ranging from 1.60 to 1.70 tons per hectare.

From this data, it can be seen that the Gerobogan cultivar has a relatively shorter harvesting age, but produces high average yields. In contrast, Anjasmoro, despite having a longer harvesting period, showed a slightly lower average yield. Deja 1 and Dega 2 show comparable harvest ages and average yields, while Dering 1 and Yellow Gepak have similar harvest ages, but the average yield of Yellow Gepak is slightly higher.

8. Soybean Pod Development

Soybean plants undergo pod formation starting from 48 to 52 days of age, according to variations in the type and harvest age of each cultivar. Initially, the pods that form are less than one centimeter long and light green in color. Over time, the pods continue to grow in length and size. The seed filling process also occurs gradually and lasts for 30-35 days.

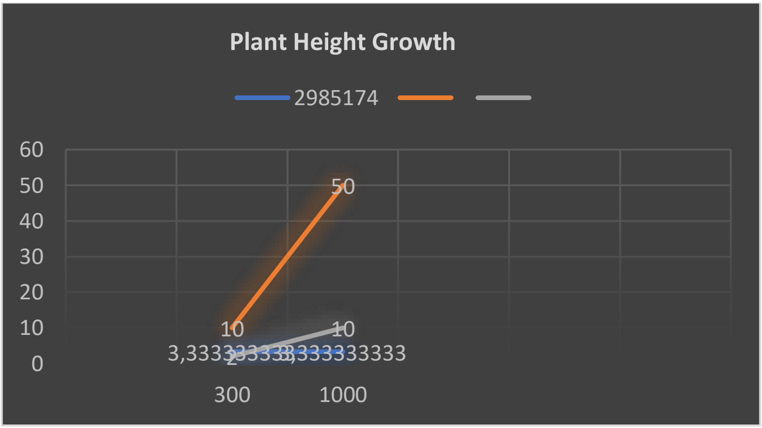

Figure 9.1. Plant Height Growth of 6 Soybean Cultivars in 7 days

After the seed filling process, the next stage is pod maturation. This ripening stage is marked by changes in the color of the pod skin and seeds, as illustrated in Figure 3. The color of the pods changes from bright green to dull green, light brown, and finally reaches brown. This color change is accompanied by a decrease in the water content of the pods. In the early stages, when green in color, the pods are feel wet and have a high moisture content. However, after a month or so, the pods dry out. This drying process goes hand in hand with the drying of the soybean plants and leaves which begin to appear yellow to brown.

Figure 9.2. The 6 Varieties of Soybean Flower Buds. Description: a = Gerobogan, b = Anjasmoro, c = Deja, D = Dering, e = Dega 2

In addition to the discoloration of the pods, the soybean seeds inside are also transformed during this process. The pod maturation and drying process is an important stage in the soybean life cycle, affecting the quality and condition of the seeds produced.

Figure 9.2B. Variations in Antenna Shape of Various Soybean Varieties

Soybean seeds undergo transformation throughout the growth process, starting with initially soft green seeds. As the size increases, the seeds will experience compaction to form seeds that have a yellowish white color. The brown color of the soybean pods indicates that the seeds inside have reached the maturity stage and are ready to be harvested. The end of the dry season, especially from September to early October, is considered the optimal period for harvesting soybeans.

Figure 9.3. Soybean Pod Seeds

The pod morphology of the six soybean cultivars appears to be similar in growth stages, with more prominent differences seen during the harvesting process. In particular, the cultivars Grobogan and Anjasmoro showed larger seeds compared to the cultivars Deja 1, Dega 2, Dering 1 and Yellow Gepak. These differences in seed size may be a relevant factor in cultivar selection and also affect the yield and quality of the seeds produced.

9.4. Conclusion

Soybean plants of the six cultivars observed have unique characteristics, both in terms of seed condition, plant height, leaf morphology, flower morphology, to harvest age and yield. The success of soybean planting is influenced by several factors, including seed type, planting method, care, and environmental conditions (Ghassemi-Golezani & Farhangi-Abriz, 2018). Environmental factors that are considered suitable for soybean plant growth, such as rainfall of about 100-200 mm per month, soil pH of around antara 6,0-6,5, kelembaban relatif sekitar 60-70%, tingkat naungan kurang dari 30%, dan lokasi penanaman berada pada ketinggian 350-500 m di atas permukaan laut. Anomali cuaca dapat mempengaruhi masa tanam dan pertumbuhan tanaman kedelai (Cortés et al., 2018).

The importance of seed condition can be seen in the differences in 100-seed weight and sprouting success percentage between cultivars. Grobogan and Anjasmoro cultivars showed relatively high seed weight, while other cultivars had small seeds. However, cultivars with small seeds such as Dega 2, Yellow Gepak, Deja 1, and Dering 1 showed high growth success rates. Plant height is an important parameter in cultivar selection, and Grobogan and Anjasmoro cultivars achieved greater height compared to other cultivars. Leaf morphology showed similarities between cultivars, with the Anjasmoro cultivar standing out in terms of wider leaf size.

Flower and anther development were important aspects of this study. The Anjasmoro cultivar showed potential to have a greater number of soybean fruits and the longest anther size. Harvest age and yield also differed between cultivars, with Gerobogan having a relatively shorter harvest age but producing a high average yield. These variations provide valuable information for cultivar selection to suit farmers' needs.

In addition, soybean pod development is an important stage in the plant life cycle, affecting the quality and condition of the seeds produced. Grobogan and Anjasmoro cultivars exhibit larger seeds compared to other cultivars, which may affect soybean yield and seed quality.

9.5. Implication

The results show that soybeans exhibit unique characteristics for each cultivar, and their successful cultivation is influenced by several factors, including seeds, planting methods, care and environmental conditions. Variability among cultivars indicates the importance of selecting varieties that suit local conditions. The ideal growing environment includes rainfall, soil pH, relative humidity, shade level, and certain altitude. Weather anomalies need to be considered in the selection of optimal planting times (Carver & Walker, 2015). Recommendations involve selecting the right seeds, optimizing the use of cultivars according to the local market, and careful monitoring and maintenance of crop conditions. Suggestions involve further research, farmer education, collaboration with researchers, and the application of modern agricultural technologies. By following these recommendations and suggestions, it is expected that soybean farming can become more efficient and sustainable, increasing yields and supporting farmers' welfare.

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Brief Curriculum Vitae

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CHAPTER 10

HOUSEHOLD BUSINESS TRANSFORMATION: APPLICATION OF DIGITAL MARKETING IN INCREASING SALES OF AGRICULTURAL PRODUCTS

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ABSTRACT

In the era of globalization and the development of information technology, the transformation of household businesses in villages has become a necessity to compete in an increasingly competitive market. The application of digital marketing emerges as a strategic step to increase the visibility and sales of village products. Villages as production centers have unique natural potential and local crafts, but often struggle to penetrate the global market due to limited accessibility and minimal understanding of modern marketing. The application of digital technology in the context of marketing opens up great opportunities for household businesses in villages to reach a wider market, increase competitiveness, and optimize local economic potential. With digital marketing, businesses can expand their market reach through online platforms such as social media, marketplaces, and e-commerce websites. This not only introduces village products to global consumers, but also builds a strong brand image and increases direct interaction with customers. Digital marketing also enables personalized customer engagement through feedback, testimonials, and direct interaction, increasing consumer trust in village products, and creating deep engagement and customer loyalty. Through the transformation of household businesses with digital marketing, significant economic growth is expected to occur in villages, reducing dependence on local markets, increasing income, and strengthening the overall village economic ecosystem. Despite the positive impact of digital marketing, there are still some household businesses in Kagok Village that have yet to utilize it. Lack of understanding, unwillingness to adopt digital technology, and lack of knowledge about digital marketing are the main obstacles. Therefore, community service is directed at providing assistance in the application of digital marketing, focusing on the stages of inculturation, discovery, devine, design, and destiny. The results of community service using the ABCD (Asset-Based Community Development) approach and digital marketing strategies provide significant benefits. Through training and socialization, business actors in Kagok Village can improve their skills in digital marketing, open new opportunities, and increase household business income. These efforts aim to achieve economic independence and increase community understanding of the importance of digital marketing in supporting local business growth.

Keywords: Digital_Marketing, Agricultural Products, Asset-Based.

10.1. Introduction

In the era of globalization and ever-evolving information technology, transformation of household businesses is a must in order to compete in an increasingly competitive market. One of the strategic steps that can be taken is to implement digital marketing as a tool to increase the visibility and sales of village products. Villages as potential production centers have unique natural resources and local crafts, but often struggle to penetrate the global market due to limited accessibility and lack of understanding of modern marketing.

The application of digital technology in the context of marketing provides a great opportunity for village households to reach a wider market, increase competitiveness, and optimize local economic potential. With digital marketing, household businesses can expand their market reach through online platforms, such as social media, marketplaces, and e-commerce websites. The use of digital media not only introduces village products to global consumers, but also builds a strong brand image and increases direct interaction with customers. In addition, digital marketing provides the ability to engage customers more personally through feedback, testimonials, and direct interaction. This not only helps increase consumer trust in village products, but also creates deeper engagement and consumer loyalty (Sumantri, K., Marina, I., Dinar, & Kurniati, E. 2021).

Through the transformation of household businesses by implementing digital marketing, significant economic growth in villages is expected. By exposing the uniqueness of local products online, village communities have the opportunity to reduce dependence on local markets, increase income, and strengthen the overall village economic ecosystem (Munfariz, R., Marina, I., & Sumantri, K. 2022; Sundari, 2019). Therefore, it is important for rural household businesses to understand and apply digital marketing concepts to capitalize on the full potential of this transformation.

Digital marketing is an effective option for Micro, Small, and Medium Enterprises (MSMEs) in expanding market reach, both at the national and international levels. In the context of digital marketing, prospective customers or buyers can access product or service information via the internet, providing opportunities for sellers or business owners to interact with prospective buyers without being constrained by time or location restrictions (Tuten, T. L., & Solomon, M. R. 2017).

New Media theory supports the concept of digital marketing by stating that optimizing the use of social media can increase market share, encourage increased productivity, and increase sales turnover. The theory identifies three main concepts about Digital Marketing, namely New textual experience, New ways of representing the world, New relationships between subjects and media Digital marketing has the potential to open new markets or reach markets that were previously difficult to reach due to constraints such as time, communication methods, and distance. (Smith, A. N., & Fischer, E. 2011).

Through the series of data and theories that have been described, it can be concluded that the application of digital marketing has a strategic role in the transformation of household businesses, especially Micro, Small and Medium Enterprises (MSMEs) in Kagok Village, Banjaran District, Majalengka Regency. Digital marketing is not just an option, but a fundamental need to expand market reach and improve competitiveness.

The importance of digital marketing has proven effective in overcoming the obstacles faced by business actors, especially in the context of MSMEs. Through the use of social media, marketplaces, and various other digital platforms, businesses can overcome time barriers, communication methods, and distance that were previously an obstacle. The application of New Media theory also provides a strong conceptual basis, confirming that social media optimization can increase market share, productivity, and sales turnover.

Pandemic conditions that affect economic activity also make digital marketing a relevant and reliable solution. In a situation of social restrictions, business actors can continue to carry out buying and selling transactions and utilize the marketplace as an easily accessible means of online sales. Research data that has been conducted by Zebua & Sunaryanto (2021), Jasri et al. (2022), and Marjukah (2022) show that digital marketing can have a significant positive impact on increasing MSME income.

However, there are still several household businesses in several villages, especially Kagok Village, that have not utilized the potential of digital marketing. Lack of understanding, lack of courage to adopt digital technology, and lack of knowledge about digital marketing are the main obstacles. Therefore, community service activities are directed at providing assistance in the application of digital marketing, focusing on the stages of inculturation, discovery, devine, design, and destiny.

Thus, this community service aims to overcome the challenges of low quality Human Resources (HR) and lack of knowledge in marketing products online in Kagok Village. Through counseling, training, and guidance, it is hoped that the community can improve their abilities in digital marketing, open new opportunities, and ultimately increase household business income. All of these efforts are geared towards achieving economic independence and increasing the community's understanding of the importance of using digital marketing to support local business growth.

10.2. Sources, Methods and Techniques of Data Collection

In this service, we involved 60 respondents with diverse backgrounds. They come from various sectors of society, including housewives who develop processed agricultural products, farmer groups that cultivate medicinal plants, Micro, Small and Medium Enterprises (MSMEs), PKK women, village officials, and the Development Consultative Body (BPP). The two methods used in the implementation of this activity, first of all, were carried out through counseling to provide a conceptual understanding of digital marketing. Next, a hands-on stage was conducted to ensure the direct application of the concepts that had been taught. By involving respondents from various backgrounds, this service aims to have a holistic and relevant impact on the entire community of Kagok Village, Banjaran District, Majalengka Regency.

10.3. Design of Analysis

The approach used in this activity follows the Asset-Based Community Development (ABCD) concept developed by John McKnight. This concept emphasizes the active participation of the community in problem solving by recovering their resources. The ABCD method consists of five stages, namely inculturation, discovery, design, define, and destiny. The service team adopted all these stages in their activities in Kagok Village, Banjaran Sub-district, Majalengka Regency, understanding that this process involves resource recovery and active community involvement.

The problems to be addressed with partners, namely household businesses in Kagok Village, have been identified and outlined in Table 10.1 based on discussions with partners. The mentoring activities began with a Focused Group Discussion (FGD) with relevant parties, such as the Secretary of Bangga Village, BUMDes Management, Head of BPD, and household business owners.

In this FGD, problems and potentials owned by household businesses are carefully identified to determine strategic steps in implementing digital marketing.

Table 10.1. Tabulation of Partner Problems and Solutions

Partner Issues	Solution Offered	Activity Stages
- **Low quality of human resources business actors** - **Lack of knowledge marketing**	Socialization and debriefing Training materials Digital Application Marketing	- Stage 1 (Inculturation) - Stage 2 (Discovery) - Stage 3 (Devine) - Stage 4 (Design) - Stage 5 (Destiny)

After problem identification, the service team will continue with the implementation of the ABCD stages, starting from inculturation to understand local values and potential. The discovery stage will involve in-depth exploration of the potential owned by household businesses, while the design stage will include strategic planning for the application of digital marketing. The define stage will determine the concrete steps to be taken, and the destiny stage will evaluate the impact and changes that have occurred.

With this approach, it is expected that the service activities can make a significant contribution to increasing the understanding and application of digital marketing for household businesses in Kagok Village, creating a positive impact in increasing the income and economic independence of the local community.

1. Debriefing Preparation

Preparation includes the preparation of training materials by the service team on digital marketing, complete with illustrations and several examples of the process of creating and utilizing social media. The goal is to make it easier for business actors to understand the concept of digital marketing.

2. Activity Implementation

The mentoring activities took place in Kagok Village, specifically at the residence of one of the BUMDes administrators, held face-to-face with household business actors who were accompanied by the village secretary, BUMDes management, and the Chairman of the BPD. Facing partner problems related to lack of knowledge in improving the ability to market products online, the service team offers a solution by applying digital marketing technology methods through the use of social media marketplaces and several other social media platforms. The steps taken to implement this solution to overcome partner problems are as follows:

1. First Stage: The service team conducted a review of the location of the activity through initial observations on four types of household businesses.
2. Second Stage: The service team held discussions about the problems faced by partners and provided material by applying digital marketing methods, providing an understanding of various types of social media, and providing guidelines for their use.
3. Third Stage: The service team provides an understanding of digital marketing applications, so that business actors can create or use one or more digital marketing platforms that have minimal costs.
4. Fourth Stage: The service team organizes training activities to create social media accounts such as Facebook, Whatsapp, Instagram, and other online sales sites. Some of the steps taken include:a.
   a. Creation of social media accounts.
   b. Guidelines on how to use social media correctly.
   c. Instructions on how to upload products.
   d. Guidelines for promoting products with interesting sentences.
   e. Instructions on responding to customers and managing orders.

Operationalization of Activity Implementation

1. The division of tasks in the implementation of activities is operationalized by dividing responsibilities among team members, where each member has different expertise in accordance with the assigned tasks. The details of the tasks for each team member are as follows:
2. Submission of materials will be carried out by the team leader and member 1.
3. Social media application simulation training will be organized by member 2, member 3, member 4, and member 4..

10.4.Result and Discussion

1. Profile of household businesses in Kagok Village

Farmer women's group (KWT) is a group of farmer women who live in Kagok Village, Banjaran District, Majalengka Regency. This farmer group was formed in 2004 with an inaugural year in 2017 known by Hj, N, Tohiroh, S.Ag., M.Pd. which has 30 members consisting of 1 chairman, 1 secretary, 4 sexes and 27 other members. Household entrepreneurs in Kagok Village are generally of productive age in the range of 28-31 years and have moderate levels of education. In general, the marketing strategy used is still traditional.

Table10. 2. Characteristics of informants

Business Group	Business Type	Length of business	Description
R1	Traditional Medicinal Drinks	>2 years	When you first opened your business, you used conventional marketing
R2	Tuber chips	>2 years	When you first opened your business, you used conventional marketing
R3	Cookies	>2 years	When you first opened your business, you used conventional marketing
R3	Dried Ginger Powder	>2 years	When you first opened your business, you used conventional marketing

The process of making cassava chips lasts for 3 hours, adjusted to the number of orders received. The selling price of one packet of cassava chips is IDR.5,000. The main raw material, cassava, is obtained from the village itself or neighboring villages. If the supply is insufficient, cassava is also purchased at the market. In addition to cassava, some additional ingredients used include cooking oil, curly chili, white sugar, and salt. The products are sold conventionally at kiosks and online.

The main products produced are processed products from medicinal plants grown in the home yard, which are used for food, drinks, and basic ingredients for making cakes and snacks. One of the problems faced is related to product packaging or labeling. The production cost of one production is around IDR.100,000 with a profit of around IDR.150,000.

2. Activity result

Community service in Kagok Village household businesses, which are engaged in handicrafts and food businesses of chips and ginger, has been carried out by utilizing several approaches to overcome the problems faced by partners. The steps in overcoming these problems are described in detail through the following stages:

1. Phase One; the service team provides material by applying digital marketing technology, providing an understanding of the types of social media, and how to use them.
2. Second Stage; the service team conducts in-depth discussions about the problems faced by partners.
3. Stage Three; the service team provides an understanding of digital marketing applications, so that business actors can create or use digital marketing platforms that are affordable.
4. Fourth Stage; the service team organizes training in making social media applications such as Facebook, Whatsapp, Instagram, and other online sales sites. The steps include creating social media accounts, how to use social media correctly, how to upload products, how to promote products with interesting sentences, and how to respond to customers and handle orders.
5. Fifth stage; the service team made a return visit to evaluate whether there was an increase in income after the implementation of the digital marketing strategy (Hidayat, B., et al. 2021).

The series of stages and implementation of community service activities in Kagok Village, Banjaran District, Majalengka Regency, in four household businesses, were carried out in accordance with the ABCD approach. The initial stage involved inculturation by identifying village assets and potential through initial observations with a focus on business actors in Kagok Village on March 13, 2023. The service team visited the Bangga Village Secretary, BUMDes Management, BPD Chairman, and household business actors. The interview findings show that Kagok Village has abundant natural resource potential, but the impact of the Covid-19 pandemic has led to less optimal utilization of village potential, especially in terms of local raw materials and marketing. Observation of village potential is the first step that needs to be taken in supporting the implementation of service activities (Hidayat, B., et al. 2021).

The second stage, the discovery stage, began with a session on digital marketing materials for household businesses in Kagok Village. The material covers the development of the number of MSMEs using digital marketing as a sales and promotion medium, which continues to grow not only in promotion and sales, but also in other aspects In accordance with these developments, the next session details digital promotion in marketing and how to use it. Digitalization of marketing emphasizes the use of digital-based promotions, with the Devotion Team providing an understanding of the importance of digital marketing in marketing products (Jasri, et al. 2022; Murti, et al., 2023)

After the material briefing, the service team continued with a discussion session, which was conducted through a focus group discussion (FGD). The discussion aims to explore more in-depth information with intensive interaction between the service team and household business actors. In this interaction, it was found that the sales process still uses traditional methods, namely providing product information to surrounding neighbors and passing on to other relatives. Some business actors, such as only selling products if there are orders and avoid making products without orders because they are worried that the products will not sell.

After obtaining this information, the service team designed a work program that would be implemented in Kagok Village in two meetings. At this stage, business owners conveyed various problems they faced, including capital, marketing, labeling, and the availability of raw materials that were difficult to obtain. Household businesses generally consist of groups of 4-5 people, but the problem of business income only being enjoyed by the group leader caused some group members to quit and some chose to run their own businesses. As a solution, the Service Team suggested that business actors utilize digital marketing and marketplaces to facilitate product marketing and increase production. (Amsuri, A., & Vadhila, A. 2021)

The third stage, the define stage, is a phase where the Service Team provides an understanding of the applications needed in digital product marketing. The team provides training on the use of social media tools and applications, so that business actors can create or use online sales sites at minimal cost through these applications. One of the social media applications introduced was Facebook, which is the largest marketplace in Indonesia. Although business owners generally have the Facebook application, they have not fully utilized it as a marketing medium due to limitations in operating it.

Household business owners are having difficulty understanding and mastering the Facebook application as a marketing medium, and many of them have not fully optimized its use. The business owners hoped to expand the promotion of their products within and outside the Kagok Village area, especially considering that their product sales had decreased dramatically. Therefore, the service team conducted socialization first to introduce the concept of digital marketing and the use of marketplaces. By utilizing digital marketing and marketplaces, it is expected that products can be marketed widely, which in turn can increase community income. (Suryani, A., & Sulisworo, D. (2019).

At this stage, the Service Team conducted a sharing session with household business actors to show the difference in turnover and income before using the marketplace and after using the marketplace. The service team wants to know the percentage of income increase due to this assistance. However, the obstacle faced is the availability of increasingly scarce raw materials. Similar constraints are also faced by several other household businesses, where production is only carried out according to consumer orders.

The Fourth Stage, which is social media application training (design stage), is carried out by the service team by compiling a training program to create one of the social media applications such as Facebook, Whatsapp, Instagram, and other online sales sites. In this stage, there are several steps that are applied, including creating social media accounts, how to use social media correctly, the process of uploading products, strategies for promoting products with interesting sentences, and tactics for responding to customers and handling orders. For example, the service team provides assistance to market the products of household businesses through marketplace media or online stores, specifically using the Facebook platform, which was created by Mark Zuckerberg, is a social media that is popular among various ages on Facebook can attract new visitors and help in completing transactions. Registration on this platform can be done by opening the page www.facebook.com. Facebook provides a space to upload photos/videos, which can be utilized as a tool to market products. Thus, consumers who are interested in the upload can directly comment or send a message to make a transaction. (Hadi, M. N. 2020).

In the last or fifth stage, which is called ensuring (destiny) or evaluation, the Service Team assesses all service activities, from the define stage to the implementation of direct promotion practices using the marketplace. The evaluation results show that this assistance model provides great benefits for household businesses. Although the increase in sales volume has not been significant because the online store has not been operating for a full month in the marketplace, promotion through the marketplace has proven effective.

Through the mentoring process, especially in terms of product promotion through the marketplace, there seem to be positive benefits for business actors, especially for household businesses that wish to expand their product range. By applying several approaches, household businesses were able to create effective promotions, resulting in an increase in sales volume of products, and automatically increasing the production of their industrial products. This can be seen from the average sales that were previously less than IDR.1,000,000 now increased to an average of IDR.2,000,000 after the implementation of digitalization through the marketplace (Hidayati, R., et al. 2020).

10.5.Conclusion

Household businesses in Kagok Village, especially those run by women farmers' groups (KWT) and the tumahan industry, can be summarized as having common characteristics, such as a productive age between 28-31 years, a moderate level of education, and traditional marketing strategies. The existence of this KWT, which was established in 2004, shows the commitment of its members in developing household businesses in crafts and food, such as chips and ginger.

The community service measures applied to improve the performance of these businesses have proven effective. An ABCD (Asset-Based Community Development) approach was used involving inculturation, assessment, definition, and social media application training. In addition, socialization efforts and digital marketing training, including the use of marketplaces such as Facebook, Whatsapp, and Instagram, provided new understanding and skills to business actors.

The process of making cassava chips is a concrete example of the results of this activity. Despite facing obstacles, such as product labeling, difficulties in supplying raw materials, and problems in marketing, assistance through the ABCD stages has succeeded in providing significant solutions. The implementation of digital marketing and the utilization of marketplaces have helped business actors to expand product reach, increase sales, and overall increase production and income of the household industry.

The final evaluation showed that this mentoring model provided great benefits to the household businesses, even though the online store had not been operating for a full month on the marketplace. With a holistic approach, the businesses managed to create effective promotions, increase sales volume, and automatically increase the production of their industrial products. This conclusion illustrates that the application of digitalization through the marketplace has a positive impact in advancing household businesses in Kagok Village (Marina, et.al. 2023).

10.6. Implication

The implications of the results of this community service are very significant for the development of household businesses in Kagok Village. Through the application of the ABCD approach and digital marketing strategies, especially in utilizing the marketplace, business actors can overcome various obstacles faced, such as product labeling, difficulty in supplying raw materials, and problems in marketing.

The concrete steps taken, such as the provision of digital marketing materials, in-depth discussions on problems, training on social media applications, and evaluation of income increases, provide evidence that this approach is effective and can be adopted by other household businesses. Thus, the results of this service can be a relevant model for empowering village communities in facing economic challenges, especially during a pandemic.

The positive impact of the application of digital marketing and the use of marketplaces can be seen in the increase in sales and production of home industry products. This creates new opportunities for businesses to expand the reach of their products, increase income, and overall improve the economic well-being of families.

In addition, the success of this assistance also shows that the integration of digital technology in household businesses, especially through social media and marketplaces, can be an effective solution in dealing with the changing marketing paradigm in the digital era. These implications are also relevant for household enterprises in other villages that may face similar constraints.

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Brief Curriculum Vitae

Dr. Ida Marina is a lecturer at the Faculty of Agriculture, Majalengka University, she was born in Cianjur on February 27, 1984. She earned her doctoral degree in Agricultural Science at Padjadjaran University, Bandung, in 2018. In the last five years, she has written prominent articles, such as "Optimizing Soybean Cultivation Efficiency" and "Competitiveness Analysis of Bok Choy Plant" in various international publications. He is also active in community service, involved in the "Toga Plant Processing" program and the "Regional Inflation Control Program Assistance."

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CHAPTER 11

NOISE AS AN AIR POLLUTANT AND CLEAN ENERGY FOR SUSTAINABLE AGRICULTURE

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ABSTRACT

This chapter delves into the pervasive issue of noise pollution and its impacts on health, quality of life, and society. It introduces an innovative solution: sound energy harvesting, which utilizes the vibrational energy of soundwaves. This technology surpasses conventional boundaries, fostering sustainable urbanism by integrating technology, and sustainability. Key to its success is collaboration across diverse disciplines, regulatory frameworks, and community engagement The article chapter examines the environmental impact of noise, particularly focusing on energy generation from sound. Detailed explanations of sound and noise's physical aspects, including transduction, piezoelectricity, electrostatic and triboelectric effects, provide a comprehensive understanding. The chapter introduces the innovative concept of harnessing sonic energy as a potential solution. By exploring the synergy between noise reduction technologies and the conversion of noise-induced vibrations into usable energy, this study proposes a novel approach to address both the environmental challenges posed by noise pollution and the escalating energy demands within modern agriculture. This chapter addresses the underexplored issue of noise pollution within agricultural contexts. Employing an interdisciplinary approach encompassing environmental science, agronomy, and energy engineering, the research contributes to the development of sustainable practices that harmonize agricultural ecosystems and human communities. One of the key applications is crop management systems driven by sensors using noise-harvested energy that would optimize resource use and crop yields through real-time monitoring of soil conditions without traditional power sources.

Keywords: Agriculture, clean energy; pollutant;

11.1. Introduction

In the heart of urban existence, a growing concern emerges – the environmental degradation that plagues our cities and nature (Ilić, 2015; Ilić & Maksimović, 2021), including noise pollution (Ilić et al., 2018a, 2018b, 2018c, 2018d, 2021; Božić et al., 2020; Farooqi et al., 2022a; Popović &Ilić, 2023a), degradation of air pollution (Gašić et al., 2010; Lammel et al., 2010a, 2010b; 2011; Ilić et al., 2018; Maksimović et al., 2018a, 2018b; Božić et al., 2019; Ilić et al., 2019, 2020; Mrazovac Kurilić et al., 2020a, 2020b; Radović et al., 2021; Ćirišan et al., 2022; Ilić et al., 2023a; Huntrieser et al., 2023), soil degradation and pollution (Ilić et al., 2020, 2021a, 2021b, 2021c, 2021d, 2022; Stojanović Bjelić et al., 2022, 2023; Farooqi et al., 2023), water pollution (Stojanović Bjelić et al., 2021; Farooqi et al., 2021a, 2021d, 2022b, 2022c; Ahsan et al., 2021; Riaz et al., 2021; Saraswat et al., 2023; Stojanović Bjelić et al., 2023; Khalid et al., 2023), waste generation (Nešković Markić et al., 2019, 2021, 2022, 2023) and non-ionizing radiation of area in urban zone (Popović et al., 2019, 2021; Popović & Ilić, 2023b). A worldwide spike in industrialization has led to an increasing amount of noise and noise pollution (Mir et al., 2023), as a form of air pollution (Ilić & Maksimović, 2021).

Noise pollution, a byproduct of the rapid urbanization and industrialization that define our era, infiltrates every corner of our lives (Ilić et al., 2018a; Božić et al., 2018; Farooqi et al., 2020; Popović & Ilić, 2023a). The symphony of honking horns, whirring machinery, and boisterous conversations disrupts not only our auditory senses but also the very tranquility essential for human well-being (Ilić et al., 2018b; Farooqi et al., 2020; Popović & Ilić, 2023a). In addition to city noise, noise is also present in the vicinity of agricultural areas and animal farms (Bond, 1970). In the intricate dance between environmental challenges and sustainable solutions, the resonance of noise pollution near agricultural landscapes presents a unique opportunity for innovation.

Agricultural lands, traditionally seen as havens of tranquility, are increasingly subjected to the discordant notes of noise pollution from nearby highways, urban expansion, and industrial activities (Heimlich & Anderson, 2001; Rustiadi et al., 2021). This auditory intrusion, beyond disrupting the serenity of rural landscapes, has tangible repercussions for crop health. Studies indicate that prolonged exposure to high noise levels can stress plants, hinder pollination processes, and impede overall crop productivity (Francis et al., 2012; Newport et al., 2014; Margaritis & Kang, 2017). Noise, which can have a negative impact on crop health, can also serve as a source of energy (Sun et al., 2017; Choi et al., 2019; Yuan et al., 2019).

The aforementioned jeopardizes the production of health-safe food, a highly intricate process contingent upon numerous factors. One of the most pivotal determinants is the energy source employed in production. The predominant share of energy utilized in production emanates from non-renewable sources such as coal and oil. This type of energy is notorious for engendering significant waste and pollution. The incorporation of renewable energy in agricultural production holds the potential to curtail production costs, augment profits, and mitigate the emission of harmful gases.

Furthermore, the utilization of renewable energy sources may attenuate the risk associated with escalating fossil fuel prices, which constitute a primary energy source in agriculture. Additionally, renewable energy sources can provide a stable energy reservoir in rural areas (IEA, 2019). This contradicts the principles of sustainable development. The environmental protection principles delineate the concept of sustainability, encompassing the preservation of natural wealth (Ruggerio, 2021).

The utilization of clean energy has a positive impact on food safety (Haines et al., 2007; Aithal & Aithal, 2016). It is imperative to increasingly invest in the development of affordable and clean energy sources, as they contribute not only to food safety but also to the overall health of our planet. The application of these energy sources enables a substantial reduction in harmful gas emissions, thereby contributing significantly to a sharp decrease in global pollution (Banjac et al., 2002; Ellabban et al., 2014; Rita et al., 2021). The prerequisite for food safety is based on the responsible utilization of land, water, and biodiversity (Ilić & Maksimović, 2021), as well as the implementation of efficient waste management systems (Nešković Markić et al., 2021) and the minimization of carbon dioxide (Ilić & Maksimović, 2021; Razmjoo et al., 2021).

Examples of sustainable practices include recycling, the use of alternative energy sources, sustainable forestry, and eco-friendly agriculture. Unfortunately, this principle has never been fully implemented in practice. In the pursuit of a more sustainable and environmentally friendly way of life, accessible and clean energies play a crucial role. These energies are essential not only for food production but also for its distribution and preservation. In addition to traditional energy sources, such as coal and oil-based fuels, which contribute to environmental pollution (Ilić et al., 2020b; Stojanović Bjelić et al., 2021; Ilić & Maksimović, 2021; Radović et al., 2022), the world is increasingly turning to more accessible and cleaner energy sources, such as solar and wind energy, while technology for harnessing noise energy is also being developed in recent times. Solutions often emerge from unconventional sources, and noise's transformation into an energy resource is no exception.

Pioneering efforts in sound energy harvesting reveal the potential across multiple dimensions. Rather than a mere pollutant, sound becomes a valuable energy source (Sun et al., 2017; Choi et al., 2019; Yuan et al., 2019). Advanced techniques can convert disruptive sounds into useful electric energy, turning disruption into productivity. Central to this concept is the conversion of acoustic vibrations into usable energy (Gayakawad et al., 2016; Pillai & Deenadayalan, 2014).

Through specialized materials and technological strategies, sound energy harvesting offers significant advantages. For instance, it can serve as an alternative energy source in areas with limited access to the grid, as agricultural areas. In light of the persistent challenge of noise pollution (Ilić et al., 2018a, 2018b, 2018c, 2018d, 2021; Božić et al., 2020; Farooqi et al., 2020, 2022a), sound energy harvesting emerges as a beacon of hope (Sun et al., 2017; Choi et al., 2019; Yuan et al., 2019). This groundbreaking idea represents the marriage of environmental preservation and technological advancement.

Through such synergy, the future holds the promise of being less cacophonous and more energy-empowered, fostering a sustainable and improved world. Sound energy harvesting transcends its role as a mere energy source (Gayakawad et al., 2016; Pillai & Deenadayalan, 2014); it introduces a new urban aesthetic where technology aligns with environmental harmony. Noise, once an irritant and polluter (llić et al., 2018a, 2018b, 2018c, 2018d, 2021; Božić et al., 2020; Farooqi et al., 2022a), now becomes a contributor to urban design. In the present day, our existence is within a realm of noise, where acoustic energy has become an essential source of environmental energy (Yuan et al., 2019). Researchers are interested in it because sound energy contains two types of mechanical energy—potential and kinetic—which means it has the capacity to do work (Sound Energy, 2023).

The chapter highlights the innovative combination of beneficial effects of mitigating noise pollution on the agricultural landscape with the potentials of transformation through energy produced from this ever-present source yet very often neglected. The critical analysis and the subsequent development of a framework to translate sonic disturbances into a renewable energy resource point towards a new approach not only to environmental management but underline a strategic pivot towards the promotion of agricultural sustainability.

The noise reduction cut through producing clean energy becomes an interesting story within the rising environmental challenges. Incorporating technologies for harvesting sound energy thus offers the advantage of helping to alleviate the impacts of noise on agricultural productivity as well as contributing to a mix of renewable energy sources necessary for eco-friendly farming (Khan et al., 2021).

It is in line with the new paradigm of energy and sustainable development goals, focusing on innovative and sustainable energy solutions to reduce the carbon footprint, thus promoting an ecological balance (Global Sustainable Development Report, 2019). A proposition of a framework for the leveraging of the sonic energy in agriculture far exceeds the concept but is really built into the realms of the practicalities of the contemporary technological strides and policy-making in the environment.

An interdisciplinary approach is therefore implied between acoustical engineers, agronomists, and sustainability scientists towards developing efficient systems that can convert sounds into energy which is applicable to the developing scenarios in agriculture (Smith & Jones, 2022).

The second calls for formulation of supportive policies that will encourage adoption of such technologies to grow an environment where sustainable practices are not only encouraged but economically viable (Doe & Green, 2020). It is this articulation of the potential of sound energy as a sustainable resource within the agricultural sector that paves the way for the transformational journey to the harmonious balance between the human endeavors and the natural world. It moves noise pollution to its opportunistic side by calling together stakeholders from diverse disciplines and backgrounds to work in synergy in imagining a future for farming—a future where agriculture flourishes, not so much because of our technological creativity and our caring for sustainability.

11.2. Noıse and generatıng of energy from noıse: harnessıng the power of sound

1. Sound and noise as a physical phenomenon

Sound can be described as oscillation of environmental particle, phenomenon that can be detected by human sense of hearing in the range from 16 until 20000 Hz depend on intensities. The human ear is most sensitive in the range between 2000 and 5000 Hz, where it registers the lowest intensity of detected sound. Sound can be represented as oscillations of the particles along the medium that are transmitted in the form of mechanical waves, travel from the source. The way and speed of propagation depends on the elastic properties of the medium through which sound propagates. To the ear, sound is most often transmitted through the air, only in special conditions through water. Sound waves can propagate through any gas, liquid or solid body. Propagation of the sound requires material medium (Popović & Ilić, 2023a).

Sound occurs in elastic environments as mechanical oscillations of material parts. Dynamic of this particles can be described with deformations, displacement, speed and acceleration. The basic condition when sound is treating as noise is the existence of a subject who perceives it and experiences various unwanted psychophysical sensations that have a harmful effect on him. Noise is one of the main factors that cause reducing quality of life, especially in urban areas, where it is permanently present and affects many aspects of everyday life. Noise in the environment or communal noise is created by all sources of uncomfortable sound that occur in the human environment. It occurs in residential and non-residential buildings and settlements. Communal noise does not include noise generated at the workplace and in industrial plants (Popović & Ilić, 2023a).

2. Sound spreading

Depending on the direction of oscillation of particles in the medium during propagation, sound waves are classified into longitudinal (in the direction of propagation), transverse (normal to the direction of propagation), surface (particles oscillate in the boundary layer between two environments), extensional (propagate in the form of a change in thickness material) and flexional (propagating in the form of material bending). The last two types occur in environments where one dimension of the material is of negligible relative to the other(s), such as extending through plate and bars (Popović & Ilić, 2023a).

Transverse sound waves are created by the oscillation of particles in elastic solid media. Longitudinal waves occur in all types of elastic media, including gases, where particles oscillate in the direction of sound propagation, forming disturbances through the gas in the form of changes in density and pressure. A surface wave is a combination of longitudinal and transverse sound waves. Due to the conditions for treating sound as noise in the environment, the propagation of sound waves through air (gaseous environment) will be discussed below. Spreading of the disturbance as elastic deformation of the medium as a sound wave, moves with the speed of sound (*c*), since with the frequency (*f*) or period (*T*) of oscillation and the wavelength (λ) is described its periodicity. Considering air as an ideal gas, fast disturbances, such as sound waves, can be described by an adiabatic process, and temperature dependence on speed of sound is given as:

$$c = c_0\sqrt{\frac{T}{273}}, \tag{1}$$

where T is the absolute temperature and c_0 is the speed of sound at T=273K (θ=0°C). By switching to the temperature θ expressed in °C, the linear dependence of the speed of sound on the temperature is obtained:

$$c = 331 + 0.6\theta, \tag{2}$$

where $c_0 = 331\, m/s$ is speed of sound in air at normal atmospheric pressure at a temperature of 0 °C (Popović & Ilić, 2023a).

An oscillating sound source causes density changes in the environment. Moving in one direction, the source pushes particles directly next to it causing densification of the particles belong that layer which further push the next layer. This is mechanism of disturbance transferring from one layer to another. By moving the source in the opposite direction, right next to the source, a dilution appears that is filled with particles from the adjacent layer. The maximum deviation of particles from their equilibrium position during oscillation in an elastic medium is called displacement amplitude (A) (Young et al., 2012).

Sound propagation through air is followed by pressure fluctuation related to the atmospheric pressure (p_a), and its variations are synchronized with the change particles position. Apart from the elastic properties of the environment (air), the maximum pressure (pressure amplitude) is proportional to the amplitude of particle movement and depends on the wavelength. Disturbances in space move as the surface of particles with same phase of oscillation is wave front. Wave front approximately is of the same form as the source in its vicinity, while far from the source it becomes flat (Popović & Ilić, 2023a).

3. Sound intensity

In accordance to their nature, sound waves transfer energy from a source to a distant location. The energy carried by a sound wave is conveniently described by sound intensity (*I*). Sound intensity is the time-averaged frequency of energy transport per unit area of the wave front normal to the direction of propagation, which determines the energy of the particles of the elastic medium that spreads along with the sound wave front (Popović & Ilić, 2023a).

Intensity of the sound decreases proportionally with the surface of the wave front, moving away from the source. Beside definition as amount of energy that passes through a unit area, intensity is also a vector quantity that determines the direction of the flow. The spatial distribution of the sound intensity vector represents the direction of propagation and the amount of energy (Praščević et al., 2018; Popović & Ilić, 2023a). The energy of the sound wave originates from the sound source and is directly proportional to the power of the sound source. It is defined as the energy that per unit of time passes through an arbitrary surface that includes the source (Popović & Ilić, 2023a).

A point sound source emits spherical waves. It represents the simplest model, often used in assessments, but also as a component of more complex sound source models. The geometric description of this model, which emits sound uniformly in all directions, is a sphere (radius r_s) whose radius is much smaller than the wavelength of the emitted sound $r_s \ll \lambda$. According to the definition, the intensity of spherical waves emitted from the power source P_0 at a distance r will be:

$$I = \frac{P_0}{4\pi r^2}. \tag{3}$$

From the given relation, we find that the intensity of sound waves emitted isotropic decreases with the square of the distance (Fig. 1a). This relation is very important from the aspect of protection from as one of its step. In the case of wave propagation predominantly in one direction, the intensity decreases much more slowly then $1/\mathrm{r}^2$, and also in closed rooms where reflection becomes relevant is not valid (Popović & Ilić, 2023a).

a b c

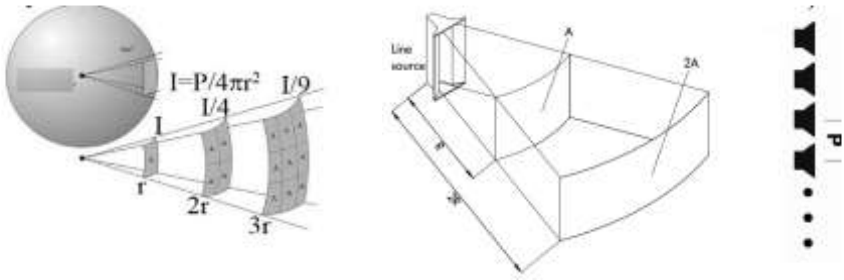

Figure 11. 1. Sources of sound a) point sources where intensity of emitted sound decreases with 1⁄r^2 , b) line source, c) line system construction (C4 System Specifications)

Realistic sources can only emit sound in all directions equally under certain conditions and frequency range. They are mostly directional sources, whose emitted energy through a surface depends on its orientation related to the source (Fig. 1b). The direction where the radiation is most intensive represents the main axis of the sound source, while in other directions it is less. The quantity that describes sound intensity change with the direction of propagation is called the direction factor (Γ) and determines the directivity of the source:

$$\Gamma = \frac{I(\theta)}{I_0}, \tag{4}$$

where I_0 and I are the intensities at the same distance, respectively in the direction of the main sound axis along which $\theta = 0°$ is taken and at some angle θ related to main sound axis. The directionality of the source is shown graphically with a factor diagram (Popović & Ilić, 2023a). Different forms of loudspeaker systems with controlled forms of directional in space can be modeled using a group of point sound sources. In order to achieve the greatest directivity, speaker columns are mostly used today, which consist of a series of equal speakers arranged along the line. The line source system (Fig. 1c) is used for sound spreading along large areas during public events (concerts). In general, a line array of speaker columns is made of a series of spherical source speakers, which overlap after a certain distance to form a complex sound field.

The directivity of a line system depends on its construction, the number of speakers n, distance between them$d$, from frequency f and speed of the sound in the air c (air temperature), expressed through the dependence:

$$\Gamma(\theta) = \left(\frac{sin\left(\frac{\pi f}{c} dsin\theta\right)}{nsin\left(\frac{\pi f}{nc} dsin\theta\right)} \right)^2 . \tag{5}$$

Apart from the geometrical dependence and number as well as distance between the speaker units, the directionality of the displayed system directly depends on the frequency as well. For example at a certain angle from the main axis of the speaker and at the same distance from it, the intensities will differ for sounds of frequencies 2000 and 5000 Hz (Fig. 2) (Popović & Ilić, 2023a).

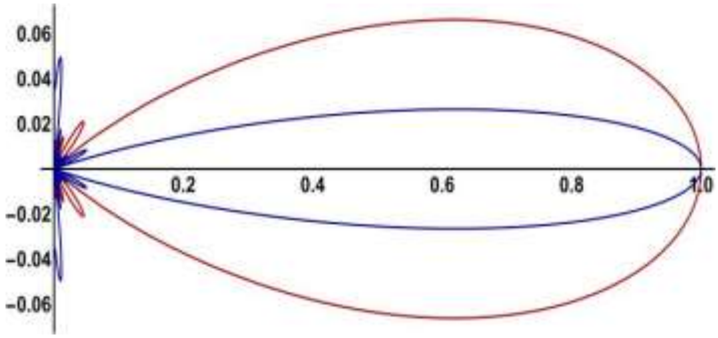

Figure 11. 2. Polar plot of line system sound, containes from 10 loudspeakers at the 60 cm distance, for 2000 Hz (red line) and 5000 Hz (blu line) (Popović & Ilić, 2018)

Sound waves energy change along with its intensity can be caused by deviation of direction propagation (Popović & Ilić, 2023a). Following phenomena occur when sound waves hitting a physical barrier:

- Reflection, which implies a sudden change of direction due to encountering with an obstacle or a discontinuity of the conductive medium, where the reflected angle is equal to the incident angle.
- Diffraction occurs at the edges of physical obstacles where sound waves are bent. One specific illustration of diffraction is the narrowing of the shadow zone behind an obstacle. Diffusion is another example, when wave falls on a hole of small dimensions compared to the wavelength.

Bending the direction or refraction of the sound waves are phenomena that occurs at the boundary between two media or due to the inhomogeneity of the medium through which the wave propagates. Temperature gradient (Fig. 3a) can cause bent of the sound propagation direction by height either presence of a wind (Fig. 3b), which is sometimes necessary to take into account during assessing the impact on the environment (Popović & Ilić, 2023a).

Caused by viscosity sound wave is losing energy during propagation through the air (for example propagation of sound through narrow tubes), where heat dissipation occurs in the materials through which the sound propagates by taking a part of the energy of the air, also for audible frequencies molecular losses happened (water vapor acts catalytically) (Popović & Ilić, 2023a).

a b

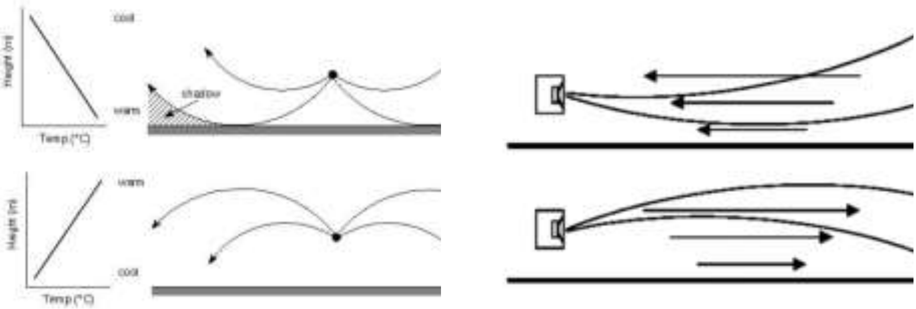

Figure 11.3. Sound waves bending a) generated from point source during opposite direction of temperature gradient, b) generated from directed source in along different directon of wind (C4 System Specifications)

The space where reflection of sound wave does not happen is called free space. For simplicity, estimates have often been made under the condition that there are no reflections or absorptions of the progressive wave moving away from the source. In the real case, such conditions do not exist, but represent an idealization for the sake of simplifying the calculation. This means that the space where the sound propagates is free from obstacles in all directions. An ideal free space can only be realized in laboratory conditions, where the walls of the laboratory are covered with materials that effectively absorb sound. In the best case, when obstacles don't exist along the way of the wave front, reflection from the ground is possible (Popović & Ilić, 2023a).

4. Mechanisms of acoustic energy collecting

Energy of sound waves in general transforms in heat due to the viscosity of environment through which it propagates. If the sound wave is absorbed means that fluid–structure interaction process occurs. If acoustic energy harvesting (AEH) is required, all dissipation is desired to be minimized, including that interaction with components of collector. In order to increases efficiency degree several steps between conversions from acoustic to electric energy should be optimized. For many approaches including piezoelectric or triboelectric as much as possible amount of acoustic energy should be converted into elastic deformation energy of materials through interaction of sound carrier with materials.

Further, elastic energy need to be efficiently transformed into electric. Largest interaction of waves with mechanical oscillators expects in resonance, inducing their largest energy absorption. Acoustic novel metamaterials found important place in construction of acoustic energy harvesting systems. These innovative engineered materials show low sound transmission loss and strong strain energy confinement properties at low frequency range. Acoustic metamaterials provide characteristic of potential sound insulation, while harvesting is based on the localization of the inflow wave and wave-guiding to improve energy localization (Qi et al., 2016). They allowed focusing sound waves, carrying energy which should be transformed into elastic deformation of transmitting subsystems.

These materials are designed to manipulate with the sound wave front to achieve sound pressure amplification by reshaping wave front of incoming waves and concentrate it in order to assure sound waves flow through certain part of the space. Thus localized energy in small volume provides enlarging gradient of pressure. Proposed metamaterial for tuning wave energy for harvesting (Carrara et al., 2013) is two dimensional regularly tiled arrays of stubs on plane with an internal defect. Irregularity breaks lattice symmetry by moving one stub from array. Defect region of sonic crystal can behave as a resonant cavity. For purpose of sound harvesting, it is place where sound pressure is amplified and used for excitation of piezoelectric beam in resonance when incoming sound frequency is matching with defect resonance.

Due to the low power density obtain form AEH, it is not as popular as other types of energy harvesting. Currently, several mechanisms are of acoustic energy harvesting are available, and mostly based on transduction, piezoelectric, electrostatic or triboelectric effect. Effective pressure of the sound wave is very low. For example 80 dB of sound level produce pressure of 0.2 Pa. Interaction of acoustic wave with a small size structure with such a small impulse is weak, and mostly not enough to efficiency provide energy exchange. Intensity as well as sound pressure decreased with distance from the source. Therefore, collector for harvesting of the sound waves should be near source and properly constructed to avoid losses. Because of this acoustic resonators are used to augment sound pressure in order to achieve stronger interaction, for example with structure that transformed deformation into electric energy.

The typical example of sound resonator is Helmholtz which can be used for strong amplification of specific frequency. Helmholtz resonators (HR) are used to amplify or absorb sound. In one experiment, researchers drew on this property to capture and amplify sounds at a railway station. Converted sound into electric energy with the aid of an electricity generator module was enough to operate small electronic devices (Sound Energy, 2023). Simply HR can be described as rigid container, nearly spherical shape cavity with a small neck through which sound passed and comes out through larger hole on the opposite side. Tones that are not in resonance with this device are damped, while only certain narrow band frequencies are amplified. Resonant frequency of Helmholtz resonators depends on cavity volume and geometrical characteristics of neck length and its cross-section. In resonance sound pressure inside cavity is almost uniformly distributed. The end of HR is flexible and allows achieving a large difference of sound pressure compared to the ambient. Viscous damping, followed by energy dissipation, significantly occurs in the neck of HR. Simulation shows that because of high speed of resonators neck and lower ratio of pressure amplification is expected (Yuan et al., 2019).

Incoming sound pressure can also be amplified with quarter-wavelength tube resonator. Distributions of sound pressure and particle velocity make it effective for acoustic energy harvesting, especially recognized for applicability as AEH in low frequency domain. Quarter-wavelength straight tube resonator closed on one end with piezoelectric element inside the tube amplified incoming sound at resonant frequencies, which further drive oscillation of piezoelectric plates along with their deformation (Bin Li et al., 2013).

Eigenfrequencies of standing acoustic wave in straight tube with open and closed end depend on number of mode and tube length. Exciting of the first mode with the lowest frequency occurs if quarter wavelength of resonant frequency is equal to the tube length, therefore resonator named quarter-wavelength. Maximum acoustic pressure exists at closed end of the tube, where expected particle velocity is zero, while at the opposite open end velocity of sound carrier particle is the largest, but the sound induced pressure is zero. To enlarge efficient of AEH build from quarter-wavelength resonator, piezoelectric cantilevers are placed along the tube in its interior, where they feel pressure difference as the consequence of pressure spatial distribution. In order to achieve maximum efficiency of energy harvesting, eigenmode frequency of piezoelectric cantilever must be equal to resonant frequency of the tube.

Also, for the same purpose largest sound pressure gradient is desirable which is accomplished by placing plate near the tube inlet to induce large deflection followed plate displacement during vibration. Beams positioned near closed end of the tube are inefficient due to the interruption of particle motion (Li et al., 2013). Currently, usage of techniques for AEH is limited because of low efficiency and complexity as well as robustness of equipment required to accomplished resonance cavity.

5. Piezoelectricity and Beyond: The Basis of Sound Energy Harvesting?

At the very foundation of sound energy harvesting lies the remarkable principle of piezoelectricity, a phenomenon that forms the cornerstone of this innovative technology (Li et al., 2021; Xiao et al., 2023). Piezoelectricity, derived from the Greek words "piezo" (meaning "to press" or "squeeze") and "electricity," refers to the ability of certain materials to generate an electric charge in response to mechanical stress or deformation. This extraordinary property was first discovered by Pierre and Jacques Curie in the late 19th century and has since become the cornerstone of various technological applications, including sound energy harvesting (Afreen et al., 2021).

The crux of piezoelectricity lies within certain crystalline and ceramic materials, such as quartz, lead zirconate titanate (PZT), and polyvinylidene fluoride (PVDF). These materials possess a unique atomic structure that gives rise to the piezoelectric effect. Within the crystal lattice of these materials, positive and negative charges are slightly displaced from their equilibrium positions when mechanical pressure is applied. This displacement leads to the separation of charges, resulting in an electric potential difference across the material (Nivedhitha & Jeyanthi, 2023). When sound energy harvesting happens, the piezoelectric effect is harnessed to capture the mechanical vibrations carried by sound waves. The process begins with the placement of piezoelectric elements strategically within the energy harvesting device. These elements are carefully selected for their specific piezoelectric properties, ensuring optimal energy conversion.

As ambient noise, such as traffic or machinery sounds, generates mechanical vibrations in the environment (Ilić et al., 2018a, 2018b, 2018c, 2018d, 2021; Popović & Ilić, 2023), the piezoelectric elements within the harvesting device respond by undergoing minute deformations, that lead to the separation of charges within the material, generating an electric potential across the piezoelectric elements. Generated potential, although small in magnitude, becomes the building block for the subsequent stages of energy conversion.

Piezoelectric materials serve as the "primary converters" in this process, transmuting mechanical vibrations into electrical signals. However, the conversion mechanism doesn't stop here. To ensure that the generated electrical signals are transformed into usable energy, additional stages are required (Trivedi & Koley, 2023).

In essence, the principle of piezoelectricity serves as the catalyst for the sound energy harvesting (Nivedhitha & Jeyanthi, 2023). It transforms a previously untapped energy - ambient noise - into an actionable form of electricity. The significance of piezoelectricity in this context extends beyond its technical prowess; it embodies a paradigm shift in energy harvesting by leveraging an omnipresent resource that has, until now, been largely ignored.

Beyond piezoelectricity, researchers are exploring alternative mechanisms and materials to further enhance sound energy harvesting. Triboelectricity, for instance, involves the generation of electric charge through friction between dissimilar materials (Rani et al., 2023). Acoustoelectric effects, which involve the modulation of electrical conductivity in response to sound waves, also hold promise. These extensions of the technology open the door to even greater efficiency and versatility, propelling sound energy harvesting into a realm of boundless possibilities.

The concept of sound energy harvesting relies on the foundational principle of piezoelectricity, which transforms ambient noise into a source of renewable energy (Nivedhitha & Jeyanthi, 2023). This principle, honed over decades of scientific exploration, exemplifies the fusion of physics, materials science, and engineering in the pursuit of sustainable energy solutions. As technology continues to develope, the potential applications of sound energy harvesting expand, offering a glimpse into a future where the sounds that surround us become a catalyst for a greener and more energy-efficient world.

Piezoelectricity is found as electric charge separation in solid materials without inversion symmetry, as a consequence of electromechanical interaction. It is reversible process which means that strain induces electric field producing and vice versa when applied electric field generates mechanical strain in crystal, mostly used in production of ultrasound waves. For AEH in piezoelectric materials is caused charge accumulation across device, producing electric field and voltage proportional to the applied stress. Example of inducing electrical energy from a mechanically excited piezoelectric element is harvesting mechanical vibration of varying amplitude by employing capacitive impedance. For optimal power produce, used electrical circuit in purpose for energy harvesting contains ac-dc rectifier with output capacitor, electrochemical battery and switch-mode dc-dc converter that controls energy flow into battery (Sil et al., 2017).

Experimental results testing of acoustic harvester systems based on a cantilever piezoelectric embedded in HR, used for extracting sound energy from loudspeakers at different distance, for example generates 198,7 mV at sound intensity of 100 dB obtained in laboratory conditions. Maximal efficiency realized through maximum output voltage is found at resonant frequency, which depends on elastic and geometrical characteristics of piezoelectric membrane. Energy conversion using piezoelectric element depends on its electromechanical coupling factor proportional to piezoelectric coefficient. Higher electromechanical coupling of piezo crystal has better energy harvesting performance, mostly found in single crystal. Anisotropy of crystal can play strong rule in piezoelectric effect.

Commonly used piezoelectric materials include polyvinylidene difluoride, lead zirconate titanate and barium titanate (Yuan et al., 2019). Piezoelectric converter of acoustic wave energy used for AEH in Helmholtz resonator shows low performance, as a consequence of uniform distribution of pressure over resonator cavity followed by absence of strength to stronger excite cantilever beam. Conical like shape Helmholtz resonator with piezoelectric plate shows significant improvement of efficiency. With change of HR shape higher sound pressure difference on the elastic piezoelectric bottom is achieved and improvement of AEH performance (Khan & Izhar 2016a). Pair of mechanically coupled cavities is found as better performance for harvester device. Dual Helmholtz structure, consists of double neck-cavity components, have enhanced acoustoelectric coupling in extended bandwidth. Volume optimization of the second cavity can significantly increase generated voltage up to 400% (Peng et al., 2013). Strengthened electromechanical coupling can be accomplished by utilize two coupled piezoelectric cantilever beams, closely placed next to each other, and having magnet on their ends to boost their mutual interaction.

6. Triboelectric generators for acoustic energy harvesting

Charge transfer between two objects during their contact or sliding one over another is called triboelectric effect. It is not rare that exchange of charge happens among objects made from the same materials, as also between different states of matter. The origin of this effect is different and depends on materials contacted in transfer.

Some of the studied mechanisms that lead to triboelectrification will be analyse. Electronic structure of the materials and its crystallographic orientation, interface electronic states, forces during sliding and colliding velocities of involving particles as well as environmental factors affect to amount of charge transfer process. Bounded electrons feel average inner potential dependent on atomic structure, but together with dipole interaction induced by electron approaching to the surface, form potential barrier necessary that they exceed from one to another material. This is known as work function, found having the strong impact on triboelectric effect. Whereby when materials with different work functions are in touch, electrons would prefer crossing from material with lower work function into one with larger. In deformed solids with piezo or flexoelectricity characteristics can be induced electric field due to the nonhomogeneous charge distribution. Significantly larger impact on tribolectric effect on nanoscale during sliding or contact between objects has flexoelectricity, when dielectric materials exhibits spontaneous electric polarization by a strain gradient.

Multilayer structure composed of thin film materials laminated vertically which exhibits triboelectric effect is known as triboelectric nanogenerator (TENG). Layer contains multiholed paper, coated with copper layer used for electrification generating charge upon polytetrafuorethylene (PTFE) membrane (Fan et al., 2015). Incoming sound induced membrane vibration as a consequence of periodical change air-pressure difference between two sides. Shape and magnitude of layer deformation depends on excitation frequency. Sound of different frequencies exciting vibration mode with specific shape of layer deformation having different contact surface between cooper and PTFE.

The maximal contact between these two surfaces is responsible for charge generation process. Charge affinity for electrons of cooper and PTFE are dissimilar. PTFE attracts stronger free electron from cooper becoming negative since cooper stay positively charged. Thereafter, surfaces forming inner dipole moment which alters with cyclical change of contact surface. As a result of membrane vibration, electrification and electrostatic induction processes are alternately changed.

7. Sound harvester by electromagnetic mechanism

Mostly used voltage generators are based on electromagnetic induction, moving permanent magnet relative to motionless coil. Induced voltage depends on rate of magnetic flux change through the coil. Acoustic harvester based on Helmholtz resonator made of stainless steel with electromagnetic converter contains coil, permanent magnet and interface circuit. Coil is fixed above the HR and aligned with permanent magnet, tide with the light sheet on the top of the cavity. When resonator is in resonance with sound that enters the cavity, magnet is driven moving with light sheet on its top causing relative motion of the magnet and coil. Therefore, the magnet flux inside coil changes periodically with vibration of light sheet (Khan 2016a; Khan 2016b).

8. Thermoacoustic Engines

These types of engines convert heat into sound energy and finally into electric. Using thermoacoustic engines is well-known as easy and reliable technology for application. However, it does rely on an external power supply to drive its energy harvesting process, unlike the others. Among its applications is the recovery of automobile exhaust waste heat to reduce emissions, which is then converted to sound energy from which electric energy is harvested (Sound Energy, 2023).

However, in real-world application these methods for acoustic energy harvesting are limited. One reason is that some methods work with only a narrow band of frequencies, whereas many of the sounds available for trapping from in modern life environment are in the broadband frequency range. Limitation of this method is that the areas used for collecting sounds, as in the case of acoustic metamaterials, are typically very small, such not a large amount of energy can’t be collected (Sound Energy, 2023).

For the most effective transformation of acoustic energy into electric power, the utilization of an AEH (Acoustic Energy Harvesting) device becomes essential. This device enables the concentration of incoming acoustic energy, based on utilization of piezoelectric, electromagnetic, or triboelectric mechanisms for energy conversion. Following this conversion process, a power management circuit is engaged to rectify voltage, regulate output, and ensure impedance alignment. On the external front, a power-conserving component, like a supercapacitor, is implemented in the order to storage of harvested energy (Yuan et al., 2019). The schematic diagram of an AEH system is shown in Fig. 11.4.

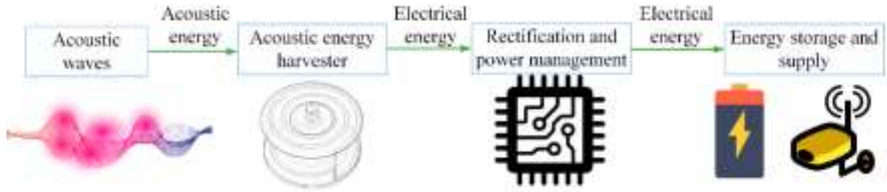

Figure 11.4. Schematic diagram of an acoustic energy-harvesting (AEH) system (Yuan et al., 2019)

9. Transduction Mechanisms: From Vibrations to Voltage

Within the realm of sound energy harvesting, the process of transduction emerges as the vital link that translates the subtle vibrations of ambient noise into measurable electric voltage. This process serves as the cornerstone of the technology, where the convergence of complex engineering and scientific principles occurs to metamorphose acoustics into a valuable energy source (Ahmad et al., 2022).

At the center of the transduction mechanism lays the application of piezoelectric elements – materials possessing the unique capability to generate electric charge in response to mechanical stress (Eghbali et al., 2020; Jiang et al., 2020; Farooqi et al., 2022a). These materials, often having structure of crystals or ceramics, become physical deformed when being exposed to sound waves, causing separation of positive and negative charges within their atomic structure. Consequently, charges are separated and an electric potential is generated across the material. The integration of piezoelectric elements within resonators takes the transduction process to a refined level. Resonators serve as acoustic amplifiers, magnifying the delicate mechanical vibrations received from the noise source. Their intrinsic design ensures that the resonant frequency of the device aligns with the incoming sound waves, thereby intensifying the efficiency of energy conversion. This frequency-tuned resonance not only maximizes the mechanical stress on the piezoelectric material but also facilitates a coherent and effective energy extraction process (Liu et al., 2021; Iqbal & Khan, 2023).

Of particular note is the adaptability of the transduction process to various noise sources. In urban landscapes, noise originates from diverse sources, each with distinct frequency characteristics (Božić et al., 2020; Farooqi et al., 2020, 2022a). The transduction mechanism can be tailored to target specific ranges of sound frequencies, rendering it customizable to efficiently capture the most abundant and relevant acoustic energy present in a given environment (Ilić et al., 2018a, 2018b, 2018c, 2018d, 2021; Popović & Ilić, 2023).

The voyage from the initial sound wave to the final electric voltage output encompasses a sophisticated interplay of material science, mechanical engineering, and acoustics. This harmonious coordination across disciplines manifests in the efficient conversion of ambient noise vibrations into usable electrical energy. As the transduction mechanism continues to evolve, researchers relentlessly strive to enhance its efficiency, broaden its applicability, and unlock new vistas for sustainable energy generation from the auditory landscape that envelops us.

11.3. Noise Pollution, Energy Production, and Agricultural Prosperity

In the expanses of rural landscapes, where the symphony of nature traditionally reigns, the intrusion of noise pollution introduces a jarring discord. This cacophony, primarily emanating from industrial activities, transportation, and energy production, disrupts the harmonious balance of rural ecosystems. However, emerging research suggests a silver lining: the potential to harness noise pollution as a catalyst for the production of clean energy, thereby transforming a source of disruption into a vehicle for agricultural prosperity (Sun et al., 2017; Choi et al., 2019; Yuan et al., 2019). The detrimental impacts of noise pollution on agriculture are multifaceted, affecting both plant growth and animal welfare. Studies have documented the adverse effects of excessive noise on plant physiological processes, including photosynthesis, respiration, and flowering times, ultimately compromising crop yields (Jahanbakhshi et al., 2017). Similarly, noise pollution has been shown to affect animal behavior adversely, leading to decreased productivity in livestock and poultry due to stress and discomfort (Injaian et al., 2018; Alimohammadi et al., 2018).

Amid these challenges, the paradigm of clean energy emerges as a beacon of hope. The conversion of noise pollution into clean energy presents an innovative approach to mitigating environmental stressors while simultaneously enhancing agricultural sustainability. Technologies such as piezoelectric devices, which convert mechanical stress (including noise vibrations) into electrical energy, are at the forefront of this transformation. The electricity generated can power agricultural operations, reduce reliance on fossil fuels, and contribute to a lower carbon footprint for the agricultural sector (Chel & Kaushik, 2011). The integration of clean energy solutions in agriculture not only addresses the issue of noise pollution but also sets the stage for a broader shift towards sustainable agricultural practices. Solar and wind energy, for instance, offer silent, renewable alternatives to traditional energy sources, further reducing the acoustic footprint of energy production. The adoption of such technologies can lead to a more resilient agricultural sector, one that thrives in harmony with its environment and is less vulnerable to the vicissitudes of climate change and environmental degradation.

Table 11.3. Examples of Utilizing Noise Energy.

Description	Technology	References
Explored the scope of scavenging electrical energy from noise pollution and reviewed various energy harvesting techniques.	Review of energy harvesting techniques	Singh et al., 2021
Investigated the effectiveness of a piezoelectric energy harvester for a vehicle wheel using stochastic resonance to optimize energy harvesting from on-road noise.	Piezoelectric energy harvester	Zhang et al., 2016
Comprehensive review of sound energy harvesting, focusing on principles, examples, and enhancement methods of sound energy harvesters.	Review of sound energy harvesters	Choi et al., 2019
Developed a triboelectrification-based thin-film nanogenerator for harvesting acoustic energy from ambient environments.	Triboelectric nanogenerator	Yang et al., 2014

In the recent years, it has become an area of increasing interest to sustainable agriculture toward inventive techniques of harnessing other energy sources. Amongst these, the notion of using the energy of noise generated by agricultural activities as a potential renewable source of energy is the most peculiar. This idea opens new perspectives for the solution of noise negative influence on the agricultural environment while creating the possibility for additional clean energy production. The table below gives a picture of how noise energy utilization technologies in agriculture are diverse and promising, bringing up efficiency and sustainability in the agricultural practice. Specific applications where noise energy is used particularly in agriculture are given in Table 1. These studies highlight the diverse approaches and technological advancements in the field of energy harvesting from noise, particularly within agricultural settings. By exploring these methodologies, researchers and practitioners can gain valuable insights into the potential for incorporating noise energy harvesting technologies to enhance sustainability and efficiency in agricultural practices. The farmers will have the chance to add energy efficiency to their activities and reduce their environmental footprint if they take up this innovative use of noise, which until now has been only viewed as a negative factor.

The narrative of noise pollution in rural landscapes is thus evolving. Once a source of disturbance, it now holds the potential to be repurposed into an asset for energy production, driving innovation in sustainable agriculture. This dual approach of mitigating noise pollution while harnessing clean energy underscores the interconnectedness of environmental challenges and solutions. It exemplifies how, through ingenuity and technology, obstacles can be transformed into opportunities for growth and prosperity in the agricultural sector. The transition from noise pollution to clean energy represents a significant leap towards sustainable agriculture. It illustrates the possibility of a harmonious coexistence between industrial advancement and environmental stewardship, where the echoes of progress do not drown out the melodies of nature but instead contribute to a more sustainable and prosperous agricultural future (Jahanbakhshi et al., 2017; Injaian et al., 2018; Chel & Kaushik, 2011; Alimohammadi et al., 2018).

1. Symbiotic Energy Farming: Powering Agriculture with Sonic Harvest

Energy captured in the transportation noise through Symbiotic Energy Farming by Nance has proved an innovative energy conversion of agriculture into a sustainable activity. The method has been identified by Filip and Simu (2011), and Wang and Song (2006) in their piezoelectric nanogenerators that capture and change noise to the electrical power by means of the nanogenerators. These advancements enable efficient, space-conserving energy production suitable for agricultural environments.

The real-world application in which such a technology has been applied is precision agriculture where Jones et al. (2012) demonstrated how crop management systems driven by sensors using noise-harvested energy would optimize resource use and crop yields through real-time monitoring of soil conditions without traditional power sources. In addition, Smith & O'Keefe (2016) exhibited automated irrigation systems that control sonic power for changing the direction of water distribution in line with the crop's needs, hence efficient for the distribution of water and prevention of over-reliance on such resources.

Green et al. (2017) also establish that sonic energy can support greenhouse activities by reducing dependence on fossil fuels through the powering of temperature control and shading systems that can favour the energy-efficient cultivation of crops. Basically, Symbiotic Energy Farming tends to minimize noise pollution while at the same time fostering a sustainable agricultural ecosystem. It represents a shift to the holistic sustainability in farming that lays emphasis on the integration of the renewable sources of energy to complement the productivity and health of the environment. This approach underlines the way in which agriculture can morph in its function within ecological stewardship by marrying technological innovation to sustainable practices for a greener future.

2. Noise Pollution in Agricultural Proximity

Agricultural landscapes, once serene, have started becoming besieged by an ever-growing menace: noise pollution, as the shadow of urbanization stretches farther and the web of transportation networks densifies. The emergence of noise pollution presents a far-reaching problem, reaching further than simple irritation, that it can cause damage to the complex balance, that is necessary for the yielding of plants and the proper functioning of farm animals (Ilić et al., 2018a, 2018b, 2018c, 2018d, 2021; Božić et al., 2020; Farooqi et al., 2022a; Popović & Ilić, 2023a)They further illustrate how pioneer studies have shown how plants respond by stress to constant exposure to elevated noise levels, disturbing the crucial process of pollination, and hence diminishing agricultural output that feeds the world (Francis et al., 2012; Newport et al., 2014; Margaritis & Kang, 2017; Yuan et al., 2019). The urban soundscapes intruding into the rural domains not only highlight a sophisticated response, which knits conservation with agricultural productivity, but remain unique in a piercing contrast to a disappeared natural serenity.

3. Energy Production from Agricultural Commotion

In such existences of innovation and environmental guardianship, there arises the potential to transmute the very disturbances wrought through agricultural noise pollution into a bastion of sustainable energy. Highways will be looking forward to a new life as nodes, hitherto of nothing but incessant cacophony among the cultivated land, that could generate energy. (Poe & Filosa, 2012; Arhun et al., 2019; Minea & Dumitrescu, 2022) The piezoelectric technology, therefore, is the awakening of the embedded materials into the road surfaces in order to vibrate in response to moving traffic that would otherwise be passed across them to produce electric currents (Sil et al., 2017; Yuan et al., 2019; Trivedi & Koley, 2023). Such symbiosis helps to reduce not only the adverse effects of noise pollution but also leads to the creation of a renewable energy stream and embodies sustainable future principles. It's that agricultural tumult's vibrancy will revolutionize energy and has kept us at the edge of one of the greatest global revolutions in the alignment of the march of progress with the rhythms of the natural world. This exploration of noise pollution and energy production in agricultural settings highlights the complex interplay between urban expansion, technological innovation, and environmental stewardship. The research field regarding energy harvesting from noise in transportation is on the rise and does offer hopeful solutions for noise reduction in the environment, besides contributing to the energy matrix. Urbanization to agricultural sanctuaries of cities has challenges that can be solved by integration of sustainable energy solutions as a critical mechanism in promoting resilience in our food systems and ecological balance. The future agriculture will be based on a holistic approach to cater for the dual challenge in noise pollution and energy sustainability while embracing technological advancements, providing sustainability to the environment. Success will need collective contribution in innovation, conservation, and sustainability.

11.4.Conclusion

This inquiry addresses the underexplored issue of noise pollution within agricultural contexts. Employing an interdisciplinary approach encompassing environmental science, agronomy, and energy engineering, the research contributes to the development of sustainable practices that harmonize agricultural ecosystems and human communities. The proposed framework envisions a symphony of possibilities that transcends the discordant notes of noise pollution into a melody of innovation and ecological resilience. The main challenge in this study represents energy density and efficiency. The allure of sound energy harvesting, while captivating, has been met with the entangle puzzle of energy conversion. Unlike conventional energy sources, ambient noise carries a relatively low energy density. Yet, this very challenge has spurred researchers to explore new ways to amplify efficiency.

The key question regarding the utilization of sound for electricity generation encompasses various aspects, including the optimization of energy conversions and the use of different metamaterials. Activities in the field of Acoustic Energy Harvesting (AEH) aim to minimize dissipation and maximize the conversion of acoustic energy into elastic deformation of materials, which is then transformed into electrical energy. Metamaterials, such as two-dimensional regularly tiled arrays of stubs, can be employed to tune wave energy for sound harvesting. However, challenges such as low power density, low efficiency, and the complexity of devices limit the practical application of these technologies. The principles of piezoelectricity and the triboelectric effect, where materials generate an electric charge in response to mechanical stress, are crucial to this technology, with various resonators like Helmholtz resonators and quarter-wavelength tube resonators playing a significant role in absorbing and amplifying sound waves for energy harvesting.

Beyond technicalities, the applications of sound energy harvesting unfurl in a wide variety of possibilities. The harmonious integration of sound energy harvesting into the urban fabric. Roads that pulse with traffic, subways reverberating with activity, and city centers echoing with human activity—all become virtuoso contributors to the generation of clean and sustainable electricity. The implications reach beyond city limits, extending a lifeline to remote and energy-starved regions, ushering in the promise of powering previously inaccessible corners of the world.

The promotion of clean energy sources as a matter of energy harvesting can also be said to be a precondition for ensuring that food is safe for human health in general. In view of the environmental impacts of food production, clean energy sources are indeed very necessary in order to limit carbon dioxide and other pollutants into the environment. Secondly, clean energies could bring down the cost of production of food and therefore its price, making it affordable to the poor countries. Clean energy sources from noise, solar, wind, hydro, geothermal, and biomass energies will have increasingly more prominence as the mainstream source of energy in many countries as time goes by. In agriculture, this will minimize the associated greenhouse gas emissions and hence a reduction in the risk of climate change. Implementation of clean energy sources in agriculture will have a positive impact on biodiversity, water quality, and soil health.

This could also mean better quality products, since clean energy sources may possibly allow their purer integration in food production, hence may act in favor of raising organic products and preventing that chemicals could enter that can harm human health. The research and interdisciplinary work would be further required to mitigate the noise pollution and capture clean energy within the agriculture setting. It is in the integration of technological innovation with ecological wisdom that a future will be unlocked whereby agriculture thrives—contributing to the healing of the planet.

11.5. Implication/Recommendation/Suggestion

1. Implications

- **Ecological Resilience**: The integration of sonic energy into sustainable agriculture holds the potential to enhance ecological resilience by reducing the adverse impacts of noise pollution on plant health and biodiversity.
- **Energy Transition**: As we transition towards cleaner energy sources, the adoption of sonic energy harvesting technologies serves as a bridge between environmental conservation and renewable energy production.
- **Urban-Rural Symbiosis**: Sonic energy initiatives create opportunities for urban and rural symbiosis, fostering collaborative efforts to address environmental challenges and meet energy demands sustainably.

2. Recommendations

- **Research and Development**: Governments and research institutions should invest in further research and development to refine and optimize sonic energy harvesting technologies for widespread implementation in both urban and rural settings.
- **Policy Integration**: Policymakers are encouraged to integrate incentives and regulations that promote the deployment of sonic energy technologies, particularly in regions where noise pollution adversely affects agricultural productivity.
- **Public Awareness**: Initiatives to raise public awareness about the dual benefits of noise reduction and clean energy generation should be implemented to garner support and participation from communities.
- **Collaborative Partnerships**: Encouraging collaboration between energy companies, agricultural stakeholders, and environmental organizations can

expedite the implementation of sonic energy projects and ensure their effectiveness.

3. Suggestions

- **Pilot Programs**: Governments and private entities should consider initiating pilot programs to assess the feasibility and effectiveness of implementing sonic energy projects in specific regions, with a focus on monitoring ecological impacts and energy production.
- **Educational Outreach**: Educational institutions can play a crucial role in training the next generation of professionals in fields related to sonic energy, sustainable agriculture, and environmental science, fostering innovation and awareness.
- **Incentivizing Agricultural Adoption**: Providing financial incentives to farmers who adopt sonic energy technologies can accelerate the integration of these solutions into mainstream agricultural practices, benefitting both farmers and the environment.
- **Global Collaboration**: Given the global nature of environmental challenges, countries should collaborate on research, technology transfer, and best practices to maximize the positive impact of sonic energy on sustainable agriculture worldwide.

Implications, recommendations, and suggestions outlined above emphasize the need for a comprehensive and collaborative approach to leverage sonic energy for sustainable agriculture. By aligning research, policy, and public engagement, we can cultivate a future where the harmonious convergence of technology and environmental protection propels us towards a more sustainable and resilient agricultural landscape.

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CHAPTER 12

DROUGHT STRESS IN CEREAL CROPS AND ITS MITIGATION FOR SUSTAINABLE PRODUCTION

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ABSTRACT

Cereals are grasses belonging to the monocot family Poaceae. The majority of the world's population relies on three main crops like wheat, maize and rice as staple food and such crops are known as cereal grains. The majority of the world's cereal grains come from three regions: Asia, the Americas, and Europe. Both biotic and abiotic stresses, brought about by climate change, have a major negative impact on agricultural output. Drought emerges as a pivotal factor that significantly constrains sustainable agricultural production, posing a notable threat to crop yields. Drought stress is well recognized as a constraining element that interrupts several characteristics of plant growth and development, exerting a substantial impact on the sustainable production of crops and overall sustainability. Plants have evolved many adaptive strategies to boost their tolerance to the detrimental impacts of drought stress. This adaptive techniques is classified into three primary categories: stress avoidance, escape, and tolerance. Mitigating the adverse effects of drought stress requires a multi-pronged approach. Best management practices, transgenic plants with drought-tolerant traits, and conventional breeding methods aim to improve water efficiency and crop resilience. Strategies involving plant growth regulators, seed priming, and Osmo-protectants show promise in enhancing drought tolerance.

Keywords: Abiotic stress, adoptive strategies, cereals, drought, sustainable production.

12.1. Introduction

Cereals are grasses belonging to the monocot family Poaceae, sometimes referred to as Gramineae, mostly grown for their edible parts. Cereal grains such as wheat, rice, corn, sorghum, barley, oats, and millet are essential. The main goal of growing these cereals is to harvest the edible components of the caryopsis, which comprise the bran, germ, and endosperm. Aridity, high temperatures, salt, mineral toxicity, and little water are some of the stresses that these plants have evolved to thrive in (Giordano et al., 2021; Kumari et al., 2021).

The protein, carbs, minerals, amino acids, fiber, and micronutrients like zinc, magnesium, and vitamins included in cereals make them an important part of people's diets all over the world (O'Neil et al., 2010; Papanikolaou and Fulgoni 2017). The majority of the world's cereal grains come from three regions: Asia, the Americas, and Europe. American farmers often focus on maize and sorghum, but their Asian counterparts tend to rice, sorghum, millet, and wheat. The European continent is more concerned with growing oats, barley, and rye. Although cereal consumption habits vary across industrialized and developing nations, they both rely on cereals as a major dietary source. Olugbire et al., (2021) found that whilst less developed nations use 68-98% of their cereal production for human use, wealthy nations use roughly 70% for animal usage.

Table 12.1. Area and production of cereal crops in the world during last three years (2019-21)

Crop	Area (Million hectare)			Production (Million tons)		
	2019-20	2020-21	2021-22	2019-20	2020-21	2021-22
Maize	194.05	197.28	199.64	1117.56	11120.65	1194.80
Rice	160.39	162.56	162.90	497.74	504.94	506.04
Wheat	216.20	221.86	224.49	763.49	775.82	792.40

USDA Global Market Analysis report (2021)

At least three quarters of the world's grain supply comes from only three cereal crops: rice, wheat, and maize. Table 1 displays the acreage and production of cereal crops worldwide over the last three years. Table shows that during the year 2019-20, 2020-21 and 2021-22, maize was grown on an area of 194.05, 197.28 and 199.64 (Mha) with a total production of 1117.56, 111120.65 and 1194.80 (MT), respectively. Rice was grown on an area of 160.39, 162.56 and 162.90 (Mha) with a total production of 497.74, 504.94 and 506.06 (MT), respectively. While wheat was cultivated on an area of 216.20, 221.86 and 224.49 (Mha) with a total production of 763.49, 775.82 and 792.40 (MT), respectively. The tabulated data for the cereal production in region (Table 2) shows that Asia produces 1475402 (MT) cereal followed by America (77743 MT) and Europe (549679 MT).

According to the data shown for the top five cereal crop producing countries, the United States produces 383.9 MT of maize, followed by China with 272.8 MT, Brazil with 88.5 MT, Argentina with 60.5 MT, and Ukraine with 42.1 MT. India comes in at 195.4 MT, Bangladesh at 56.9 MT, Indonesia at 54.4 MT, and Vietnam at 43.8 MT, with China at the top of the list. China, India, Russia, and the United States of America are the top five wheat producers, with 136.9, 109.6, 76.0, 44.8, and 36.5 MT of wheat produced, respectively, according to Table 12.2.

Table 12.2. List of production of cereal in region and top five countries during 2021

Cereal Production (000 tonnes) in region				
Region	Maize	Rice	Wheat	Cereals
Africa	96637	37189	29219	216017
Americas	592356	37735	99666	777433
Asia	378856	70148	340462	1475402
Europe	141848	3784	269184	549679
Oceania	537	437	32345	52115

Cereal production (000 tonnes) in top five countries										
Crop	1st	Yield	2nd	Yield	3rd	Yield	4th	Yield	5th	Yield
Maize	USA	383.9	China	272.8	Brazil	88.5	Argentina	60.5	Ukraine	42.1
Rice	China	214.4	India	195.4	Bangladesh	56.9	Indonesia	54.4	Vietnam	43.8
Wheat	China	136.9	India	109.6	Russia	76.0	USA	44.8	France	36.5

Source: FAO. 2022. Trade: Crops and livestock products. In: FAOSTAT. (Rome. Cited October 2023)

Both biotic and abiotic stresses, brought about by climate change, have a major negative impact on agricultural output, hence the two go hand in hand. Changes in yearly rainfall, average temperature, heat waves, CO_2 and ozone concentrations, weed growth, pests or microbes, wind composition, and the occurrence of natural disasters like landslides, floods, and drought are just a few ways in which climate change affects the sustainability of agricultural practices around the world. Both of these things make the world's food supply less stable (Raza et al., 2019; Bagale, 2021). According to Wang et al., (2018), the majority of the world's population relies on three main crops like wheat, maize and rice as staple food and such crops are known as cereal grains.

The increasing demand for food is a major cause for concern throughout the world due to the increasing population and the need of preserving the environment (Noya et al., 2018). The world's food supply has to be increased by around 70% (Pye-Smith, 2011) and maintained at a pace of 2-3% each year (Hawkesford et al., 2013) if it is to meet the predicted demands of the 9 billion people who will inhabit the planet by 2050. While maize, wheat, and rice are the three primary cereals, their sustainable productivity has grown at a slower rate over the last decade, with wheat showing the least gain. Nevertheless, the problem is exacerbated by the fact that there is far less arable land available and the amount of water needed to grow these crops is also decreasing. Additionally, the use of agricultural commodities, such as biofuels, contributes to the problem (Hawkesford et al., 2013).

12.2. Abiotic stresses and sustainable crop production of cereal crops

Drought, extreme heat, flooding, waterlogging, soil acidity, salinity, mineral toxicity, and nutrient deficits are some of the main abiotic stressors that climate change is predicted to amplify and that might impact agricultural output. Crop plants are negatively affected in growth, development, and production by the intensifying abiotic stresses brought about by climate change and environmental degradation. Climate change is anticipated to pose significant threats to the sustainable cultivation of key cereal and leguminous crops, as a result of the rising occurrence of extreme weather events.

If abiotic stressors in sustainable production are not effectively handled, the resulting losses might surpass 40% (Bailey-Serres et al., 2019), posing a persistent risk to world food security. In order to feed a projected 9.3 billion people by the year 2050, the Food and Agricultural Organization (FAO) has emphasized the need of increasing food production by 60%. With biodiversity dwindling and natural resources being used at an alarming rate, it is imperative that this goal be achieved without endangering the environment. Cultivating resilient crop types and utilizing suitable agricultural production practices are critical for ensuring long-term sustainability in the face of climate variations. For this, you need in-depth knowledge of the traits and mechanisms that contribute to stress tolerance.

Table 12.3. Effect of abiotic stress on crops

Crop	Abiotic stress	Stress detail	Effect/yield loss	Reference
Rice	**Temperature**	40 ˚C	Delay and decrease in the emergence	Akman (2009)
		Diurnal temp 24–32 ◦C (control) 26–39 ◦C (high temp.)	21–55% yield decreased	Chen et al., (2020)
	Salinity	EC 10 dS m^{-1}	Decreased root and shoot length	Krishnamurthy et al., (2016)
		3.8 to 6.4 dS m^{-1}	50% Yield decreased	Dramalis et al., (2021)
		4 dSm-^{2}	28.8% yield deceased	Thitisaksakul et al., (2015)
Wheat	**Temperature**	45 ˚C 30/25 ◦C, day/night >32/22 ◦C, day/night	Reduced photosynthesis Reduced chlorophyll Low protein synthesis	Prasad and Djanaguiraman (2014); Djanaguiraman et a., (2018); Sun et al., (2018)
	Salinity	100 to 175 mMNaCl	Reduction in spikelets per spike Delayed in spike emergence Reduced fertility	Munns and Rawson (1999)
		0−200 mMNaCl	25-70% yield decreased	162
Maize	**Temperature**	35/27 ◦C in day/night 14 days before reproductive to silking stage	Cob weight decreased low sugar content	Suwa et al., (2010)
		28/20 ◦C (control) 38/30 ◦C (high temp.) for 15 days	7-17% yield decreased	Hussain et al., (2019)
	Salinity	1, 50, 100 mMNaCl	Reduced development Decreased green light emission Increased concentrations of ROS Adjuvant 1,4-benzoxazin-3-one aglycones	Forieri et al., (2015)

The resilience of agriculture in the face of climate change will depend on how well crops can handle a number of non-living variables, any one of which might cause a precipitous drop in agricultural production. When plants are exposed to abiotic stresses, they are unable to grow, develop, reproduce, and generally be productive. There are built-in mechanisms in plants that enable them to endure certain kinds of stress. These systems are present throughout the plant and are triggered by cellular-level physiological and metabolic activities. However, various crop species and cultivars may have varying degrees of tolerance and adaptability to non-living environmental variables (Mickelbart et al., 2015).

Understanding how plants adapt is critical for identifying traits associated with resistance to abiotic stresses. In order to develop plant varieties that are resistant to abiotic stress, scientists have merged a number of genes and proteins linked to tolerance and reduction of its effects. Two studies, one by Kumar and one by Rani et al., (2020), have recorded this change (2020). The capacity of agricultural plants to react to various abiotic stresses can be enhanced by genetic modification using stress-responsive genes, according to research (Singh et al., 2018; Bailey-Serres et al., 2019). Many gene identification efforts have focused on Arabidopsis and other model plants. It is imperative to expedite the acquisition of fundamental information in order to enhance the resilience of agricultural plants to abiotic challenges in specific growing settings. It is necessary to investigate the untapped potential of stress adaptation in order to enhance the productivity of important food crops.

12.3.Drought stress

Drought emerges as a pivotal factor that significantly constrains sustainable agricultural production, posing a notable threat to crop yields (Khan, 2013). Furthermore, as a key impediment in the journey towards sustainable plant growth, drought disrupts essential processes like respiration, photosynthesis, and stomatal movement, thereby impacting the overall sustainability of crop cultivation. In the face of drought stress, plants mobilize their adaptive mechanisms, encompassing sustainable morphological and structural adjustments, the expression of genes promoting drought resistance, synthesis of sustainable hormones, and the production of osmotic regulatory substances. These sustainable measures collectively help reduce the harmful impacts of drought stress, promoting a more sustainable approach to crop production. Plants experience several environmental pressures during their growth and development, occurring in both natural and farmed environments. Of all the stressors, drought is particularly notable for its severity and its major influence on plant output.

Table 12.4. Genes responsible for drought tolerance in cereal crops

Host Plant	Gene Responsible	Function	Reference
Wheat	TaNAC69	Enhanced resistance to aridity	Budak et al., 2013
Maize	NF-YB2	During periods of drought, it increases crop productivity and the rate of photosynthesis.	Vandenbroucke et al., 2013
Rice	AP37, OSNAC10	There was an increase in both drought tolerance and grain yield.	Oh et al., 2013

According to Brodersen (2019) and Abbasi (2010), water is a significant component of plant tissues, accounting for 80-95% of the fresh biomass. It is also necessary for several physiological activities, such as metabolism, growth, and development. For this reason, many plants, especially those in areas prone to drought, view drought as their primary environmental stressor (Anjum, 2010; Diatta, 2020). Throughout history, it has been recognized as the leading cause of global food insecurity and a major contributor to devastating famines (Okorie, 2019). Depletion of water resources and rising food demand due to rapid worldwide population increase worsen the negative effects of drought on agriculture (O'Connell, 2017). Variables such as evapotranspiration, the water-holding capacity of the rhizosphere, and the uneven and unpredictable distribution of rainfall are among the many that affect the occurrence of drought (Devincentis, 2020).

Moreover, under some circumstances, plants encounter difficulty in assimilating water from the soil, even when there is an enough amount of moisture in the root zone. This occurrence is referred to as physiological drought or pseudo-drought (Salehi-Lisar, 2020). The complex nature of this situation highlights the need to promptly devise sustainable ways to alleviate the effects of drought on agriculture and global food security. Plants inhabit a dynamic environment that often influences their growth and development.

Plants undertake physiological, morphological, or metabolic alterations to limit the damages caused by stress and adapt to challenging situations. Plant stress refers to the modifications in biochemical and physiological processes that result in harm and, eventually, the death of plants (Atkinson & Urwin, 2012). The geographical distribution and productivity of plants are significantly influenced by drought, salt, and temperature, which are key environmental variables (Ghatak et al., 2017). These variables also influence the quality of agriculture, which poses a risk to food security (Parkash & Singh, 2020).

Since just 3.5% of the Earth's total land area is unaffected by environmental conditions, the long-term effects of non-living stressors on agricultural productivity are large (Lobell et al., 2011; FAO, 2013). In the next 30 years, scientists predict that the average global surface temperature will rise by around 0.2 degrees Celsius per decade. By the end of this century, scientists predict that the average global temperature will have risen by 2.5 to 4.5 degrees Celsius. The rising atmospheric concentrations of greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), are responsible for this rise (Wang et al., 2018). In 2018, the Food and Agriculture Organisation (FAO) found that drought caused 83% of the damage and loss in agriculture from 2006 to 2016 (FAO, 2018).

Some plants are very sensitive to short-term changes in water availability and have a limited capacity to cope with unfavorable environmental conditions. The most important cereal crop in the world, wheat (*Triticum aestivum* L.), is farmed in different parts of the world using different techniques, including irrigation and rainfed systems. This makes it susceptible to drought. Despite its complex genetic structure, wheat is a great model crop to study drought tolerance in (Cheng et al., 2016).

12.4. Impact of drought stress on sustainable production of cereal crop

Droughts cause water shortages because the earth loses all of its water content. Soil water deficits, surplus water (soil water potential below plant water potential), and high soil salinity (ions altering water potential) are all potential causes of physiological drought. According to Osakabe et al., (2014), when plants are unable to get water, it's called physiological drought. When plants experience water stress, they adjust in many ways. These include defensive mechanisms, changes to their morphology, anatomy, biochemistry, and physiology; and both short-term and long-term changes to their development and growth (Abobatta, 2019).When plants experience a lack of water or heat, they adjust physiologically and morphologically to survive (Lamaoui et al., 2018).

Root system enlargement, stomata number and conductance reduction, leaf area reduction, leaf thickness increase, and leaf rolling or folding are all adaptive responses that reduce evapotranspiration (Earl & Davis, 2003; Lamaoui et al., 2018; Kapoor et al., 2020). The plant's adaptive response is closely related to these changes. Drought slows plant development and yields because it upsets water balance, decreases CO_2 absorption, amplifies cellular oxidative stress, damages cell membranes in impacted tissues, and, in rare cases, inhibits enzyme activity. Plants may change their water interactions to keep their cells active even when water is scarce.

The production and storage of appropriate solutes, including free amino acids, carbohydrates, and proline, is an example of osmotic adjustment. This is crucial for the plant's metabolic processes because it allows the cell volume and turgor pressure to remain constant even when the water potential drops. When stress is reduced, osmotic adjustment helps metabolic processes go back to normal (Izanloo et al., 2008). Despite research on how various crop species, like wheat, recover from drought stress (Osakabe et al., 2014), very little is known about how osmolyte dynamics, membrane integrity, oxidative stress, or antioxidative mechanisms play a role in this process.

The importance of plant metabolic changes under drought in connection to wheat grain yield was highlighted in the study by Siddiqui et al., (2017). This emphasizes the need of studying the mechanisms that lead to drought tolerance. Because plants aren't getting enough water during a drought, photosynthesis slows down or stops altogether. Reduced CO_2 transport through the stomata and mesophyll are the primary causes of this. Reduced stomatal mobility might be another cause of the drop in photosynthetic activity (Abid et al., 2018). As a result of reduced CO_2 absorption, Rubisco activity drops, which in turn lowers nitrate reductase and sucrose phosphate synthase activity and makes it harder to make ribulose-bisphosphate (RuBP) (Singh & Thakur, 2018).

Drought-induced water shortage significantly affects the chlorophyll concentration, which is a vital photosynthetic property essential for sustained crop production (Gregorová et al., 2015; Alghbari & Iksan, 2018). Drought stress hampers the production of chlorophyll in leaves and changes the ratio of chlorophyll a to chlorophyll b. This has a domino effect, causing a decrease in photosynthetic activity, chlorophyll levels, and the effectiveness of photosystem II. The combination of these alterations, together with disruptions in the opening and closing of stomata and disturbances in the water balance of plants, lead to a decrease in total plant output, presenting difficulties for the practice of sustainable agriculture. An important outcome of stress caused by drought is the heightened generation of reactive oxygen species (O_2 and H_2O_2), leading to the oxidation of lipids and substantial loss of chlorophyll. In addition, drought stress decreases the amount of crucial proteins in the Calvin cycle, such as Rubisco, which further impacts the long-term productivity of crops (Anjum et al., 2011).

The reduced photosynthetic rate during drought affects the generation of carbohydrates, resulting in decreased amounts of sucrose in leaves and impeding the transportation of sucrose to other parts of the plant. This interruption not only impacts the current efficiency of the plant, but also presents difficulties for the future viability of crop cultivation. The inversion of sucrose in vacuoles, caused by drought, together with the adjustment of osmotic potential, also hampers the progress of reproductive growth. Drought circumstances lead to a reduction in cell division in developing embryos/endosperms, which ultimately causes a drop in the intensity of cell division. This can result in germ abortion, which poses a danger to the sustainability of agricultural production (Andersen et al., 2002).

12.4.1. Effect of drought on plant growth

Drought stress is well recognized as a constraining element that disturbs several facets of plant growth and development, exerting a substantial impact on the sustainable production of crops and overall sustainability. Seed germination, plant health, coleoptile length, and leaf area are crucial elements that significantly influence the development of plants. Seed germination, specifically, is extremely susceptible to dryness, affecting the early phases of plant development (Kapoor et al., 2020). Observable indications of water constraint during the early growth phase encompass not only diminished seed germination but also leaf dehydration. Drought stress has an adverse impact on plant growth, causing a decrease in the length of shoots and the fresh weight of hypocotyls as a result of inadequate water supply (Abobatta, 2019). The development of buds and flowers is also hindered, mostly due to the nutritional deficiency in the arid soil.

The root system plays a crucial role in responding to drought stress situations. Plants react to water scarcity by improving their root structure, aiming to obtain water from lower layers of soil (Lisar et al., 2012). The inherent variability in the structure of the plant's root system is a vital factor in its ability to withstand drought, since it enables the plant to retain a greater amount of water. In addition, roots have a vital function in perceiving the presence of water and adjusting their development accordingly (Kudoyarova et al., 2011).The plant leaf, which plays a crucial function in facilitating photosynthesis, becomes a central point of attention due to its pivotal contribution to plant development.

One strategy for avoiding drought is to reduce the area of the leaves (Earl & Davis, 2003; Anjum et al., 2011; Kapoor et al., 2020). Xu et al., (2010) found that a drop in cell division rate causes a loss of cell turgor, which in turn suppresses leaf development, resulting in a decrease in leaf area.

According to Nuttall et al., (2017), when plants are exposed to abiotic stress, like dryness, it can cause the spikelets and distil florets to terminate or develop little grains. Less nutritional distribution and enzyme activity in sucrose and starch synthesis are associated with lower grain filling (Farooq et al., 2009). As an example, consider wheat: dryness shortens the period between fertilization and maturity, which impacts the dry weight at maturity (Wardlaw & Willenbrink, 2000). This highlights the vital importance of the length of the stress factor. Drought stress reduces barley's grain yield via altering the plant's tiller and spike counts as well as the quantity and weight of grains produced per stalk.

Durum wheat grain yield is adversely affected by post-pollination dry stress. This causes a dramatic drop in grain weight, protein production, and weight per thousand grains when drought and salt stress are present (Houshmand et al., 2014).There are three main ways in which soil water deficit conditions affect plant growth, reducing crop output: (1) lowering the harvest index, (2) decreasing the efficiency of radiation usage, and (3) decreasing the canopy's absorption of photo synthetically active radiation (Earl & Davis, 2003). These findings emphasize the critical need for long-term agricultural sustainability measures to mitigate drought's detrimental effects on crop productivity.

12.4.2. Effect of drought on seed quality

According to Saradadevi et al., (2017), agricultural yields throughout the world are drastically reduced every year due to the severe effects of drought stress. Overall nutrient intake and nutrient levels in plant tissues are both reduced by drought-induced water shortage. Lack of water has a significant impact on nutrient transport, especially from the plant's roots to its aerial parts (Garg, 2003). In most cases, nitrogen levels are elevated, phosphorus levels are significantly reduced, and potassium content is unaffected by drought stress (Garg, 2003). Dwarf wheat cultivars have higher nitrogen and sulphur contents during the water-scarce booting and anthesis phases of winter wheat production. This suggests that nutritional responses to drought may vary among wheat types (Alghabari et al., 2015).

Starch synthesis, an essential step for the strength of grain storage, is extremely responsive to elevated temperatures and dry conditions. The heat treatment of wheat grains can effectively decrease the accumulation of starch, especially when applied at temperatures ranging from 30°C to 40°C (Ni et al., 2018). The impact of abiotic stress on the dietary fiber content of wheat and barley grains seems to vary. Some studies indicate a reduction in β-glucan content when exposed to high temperature and drought stress, while others suggest an increase (Jansen et al., 2013). Drought stress on durum wheat affects grain yield and enhances protein content, resulting in enhanced gluten strength and increased quality of bread-making in a drought setting (Li et al., 2013).

While drought circumstances may cause a minor decrease in certain features connected to the quality and content of gluten, suggesting possible changes in protein level, the overall effect on parameters associated with gluten strength is considerable (Magallanes-López et al., 2017). A separate investigation conducted on durum wheat cultivated in natural conditions revealed that exposure to both salt and drought stress resulted in a noteworthy augmentation in grain protein content, wet and dry gluten contents, and SDS-sedimentation volume.

Notably, salinity stress had a more pronounced effect compared to drought stress (Houshmand et al., 2014). Li et al., (2013) showed insignificant increases in flour protein content and SDS sedimentation volume when analyzing the influence of drought stress on durum wheat. Nevertheless, the dry condition led to a substantial rise in gluten-related factors, such as lactic acid retention capacity and mixograph peak time. The occurrence of drought stress resulted in a notable increase in the intensity of flour yellowness (Li et al., 2013). These findings emphasize the intricate connections between drought stress and the nutritional quality of cereals, emphasizing the significance of creating sustainable approaches to improve the ability of crops to withstand and maintain their nutritional content in response to changing climatic circumstances.

12.5.Factors contributing to drought stress

Anticipated future acceleration of global climate change is expected as a result of the ongoing rise in air temperature and atmospheric CO_2 levels. This is projected to cause changes in rainfall patterns and distribution, as indicated by studies conducted by Yang et al., (2019) and Yin et al., (2018). Insufficient rainfall is the main cause of drought stress. However, the situation might worsen when water evaporates from the soil due to factors including high temperatures, harsh light, and dry winds. This can further intensify current drought stress conditions (Cohen et al., 2021).

Climate change is anticipated to result in severe drought conditions across vast regions worldwide. Salinity stress is acknowledged as a prominent factor contributing to water shortage in plants, alongside drought (Mostofa et al., 2018). This section briefly highlights many aspects that contribute to the occurrence of drought stress. The confluence of these environmental stresses presents obstacles for plant viability and agriculture, underscoring the necessity for preemptive actions to tackle the repercussions of climate change on water accessibility and plant well-being.

12.5.1. Global warming

Although certain aspects of climate change, such as increased photosynthetic rates due to increasing CO_2 levels, may have potential advantages for agricultural output, the overall effect is mostly harmful to both natural and agricultural ecosystems (Brown, 2018). Climate change-induced increases in air temperatures might result in the thawing of glaciers, potentially resulting in inundation of agricultural fields characterized by little or nonexistent inclines (Cook et al., 2014). Moreover, the melting of glaciers leads to the reduction of water reservoirs, so restricting the amount of water accessible for agricultural purposes. The decline in yearly cumulative precipitation caused by global warming is especially significant in rain-fed agricultural regions worldwide (Warner et al., 2014).

Global warming not only affects soil conditions but also has a direct influence on plants. The rise in global temperatures due to global warming intensifies the already existing water scarcity problems in different agricultural systems worldwide, leading to internal water loss in plants (Sultan et al., 2019). According to Ray et al., (2019), if the projected rise in air temperature of around 2°C over current levels takes place by the end of this century, it is estimated that roughly 20% of the global population would experience a significant shortage of water. Within the realm of sustainable crop production and cereal agriculture, these climate-related difficulties present substantial risks. The decline of water storage facilities, increased temperatures, and changes in precipitation patterns all contribute to water scarcity, which in turn stunts agricultural development.

Water shortages, higher temperatures, and shifting climatic patterns offer more substantial limits than the possible advantages of rising CO_2 for photosynthesis. Tackling these climate-induced issues is essential for guaranteeing the long-term viability of agricultural production systems and safeguarding food supplies in light of a shifting climate. The use of adaptable and robust agricultural techniques is crucial in order to counteract the detrimental impacts of climate change on cereal crops and foster the development of sustainable food production.

12.5.2. Rainfall anomalies

Regions that depend exclusively on rainfall for food production are anticipated to experience more strain in comparison to areas equipped with irrigation systems that utilize canals, rivers, and water channels (Konapala et al., 2020). In regions dependent on rainfall for water supply, periods of drought are strongly correlated with the seasonal distribution of precipitation. This increases the likelihood of water scarcity during particular years and certain time intervals.

Human activities, such as industrialization, deforestation, and urbanization, have a substantial impact on the distribution of rainfall and the amount of water available for plants, hence contributing to climate change (Fatima et al., 2020).In places such as Pakistan, there is a pattern of irregular and increasingly frequent rainfall throughout the early spring and winter seasons. Conversely, there is a trend of reduced or nonexistent rainfall during the early fall and summer seasons, leading to drier and hotter conditions.

Drought stress has a particularly negative effect on summertime plant growth and development because to increased atmospheric water requirements, increased transpiration and evaporation rates, and decreased rainfall availability. The adverse effects of drought stress are intensified throughout the summer season as a result of these circumstances. Nevertheless, the allocation and strength of precipitation within and between years are essential factors in water resource management for vegetation and the identification of drought stress in many instances (Karandish et al., 2016).

12.5.3. Monsoon patterns variability

According to Ali et al., (2016), the monsoon system is a key player in delivering summer rainfall to various areas of the planet. This system is impacted by temperatures. But the way things are going, places that rely on rainwater would see a 70% drop in summer rainfall by the turn of the 22nd century. The decline in question is ascribed to anticipated alterations in precipitation patterns resulting from a gradual rise in atmospheric CO_2 levels. These changes have the potential to negatively impact agricultural yields, resulting in substantial economic losses and widespread flooding in heavily populated nations (Reddy et al., 2015).

The unpredictability of monsoon rainfall has a substantial influence on the moisture level of the rhizosphere, which in turn affects plant production in certain regions of the world by altering the intensity, frequency, and duration of rainfall. Currently, over two-thirds of the world's population experiences food insecurity as a result of significant fluctuations in dry and wet seasonal rainfall caused by changes in monsoon patterns (Aryal et al., 2020). The intrinsic unpredictability of rainfall, along with recent climate changes, may exacerbate water scarcity or flooding issues in some geographical regions.

Given the direct influence on agriculture, it is crucial to establish crop production methods that correspond with the behavior of the monsoon and move to sustainable practices. Effective management and careful crop planning are crucial ways to deal with changes in monsoon patterns, whether transitioning from little to abundant rainfall or vice versa. The purpose of this adaptive method is to effectively manage the uncertainty and possible extremes that come with monsoon behavior, in order to promote resilience and sustainability in agricultural activities.

12.6.Plant responses to drought stress

Plants have evolved many adaptive strategies to boost their tolerance to the detrimental impacts of drought stress (Batool et al., 2020). The adaptive techniques may be classified into three primary categories: stress avoidance, escape, and tolerance. Plants exhibit a wide range of responses, both at the molecular level and in the overall plant structure, when faced with drought stress (Galindo et al., 2020). These adaptations are essential for plants to live and flourish in situations with restricted water availability, demonstrating the impressive ability of plants to respond to environmental constraints with resilience and complexity.

12.6.1. Escape mechanism

Plants employ adaptation strategies such as accelerated growth, shortened life cycles, self-reproduction, and seasonal growth before to the driest period of the year (Álvarez, 2018). Early blossoming is a notable adaptation mechanism among these tactics and is often regarded as one of the most efficient escape mechanisms in plants (Tekle, 2016). It is important to understand that early flowering might help plants survive drought, but it can also shorten the entire growth season and reduce production in some circumstances (Blum, 2011).

12.6.2. Avoidance and tolerance mechanisms

Plants utilize the avoidance strategy to uphold a high water potential. This involves minimizing water loss through stomatal transpiration and enhancing water absorption from mature root systems (Dobra et al., 2010). Plants are able to keep their tissues well-hydrated because of xeromorphic features like hairy leaves and a waxy covering called a cuticle. Nevertheless, when these features are overdeveloped, plants can have smaller reproductive and vegetative portions and lower output (Boulard et al., 2017; Wasaya et al., 2018).On the other hand, photosynthetic apparatus-level adaptive tolerance mechanisms limit the formation of new leaves and reduce leaf area.

Trichome growth on leaves is an exterior trait that helps plants survive in dry environments when water is scarce. Research conducted by Zhang et al., (2019) and Tiwari et al., (2020) has demonstrated that trichomes can reduce the rate of water loss through transpiration by lowering leaf temperature through light reflection and providing an extra barrier. According to Tzortzakis et al., (2020), plants that can withstand periods of low water availability primarily adapt by changing their root systems, which includes root size, density, length, proliferation, expansion, and growth rate.

Along with stomatal closure-related metabolic and biochemical changes, other common mechanisms include osmotic adjustment, antioxidant defence systems, solute accumulation, and more. In addition, according to López-Galiano et al., (2019), plants can improve their resilience to drought stress by growing more roots relative to shoots. Plants utilize many adaptation mechanisms at both the leaf and root levels to deal with water deficiencies, demonstrating the intricate and adaptable nature of their responses to drought stress.

12.7. Alleviation approaches for mitigating drought stress

Implementing best management practices, such as optimizing sowing time, managing plant population, selecting suitable genotypes, and employing effective soil and nutrient management strategies, can mitigate grain yield losses in field crops under drought stress (Parry et al., 2005; Adeyemi et al., 2020). Another highly highlighted method for reducing the impact of drought stress is the use of transgenic plants that include features that make them more resistant to drought. This strategy has gained significant attention.

Current endeavors involve the utilization of traditional breeding methods, molecular techniques, and genomic approaches with the objective of cultivating plants that are resilient to drought conditions (Oliveira et al., 2020). The primary objective is to improve the efficiency of extracting water, the efficiency of water usage, the conductance of stomata, and the ability to make osmotic adjustments, among other characteristics (Naeem et al., 2020). Other tactics include the utilization of contemporary and effective watering techniques, the implementation of proper planting methods, the use of mulching and contouring, the integration of osmo-protectants, and the inoculation of plants with specialized microbes to boost their ability to withstand drought (Solis et al., 2018).These initiatives attempt to reduce the negative impacts of drought on crop output and climate, promoting a more resilient and sustainable agricultural system in response to changing climatic circumstances.

12.7.1. Selection and breeding strategies

Conventional breeding methods have historically focused on empirical yield selection but face challenges due to low heritability and significant genotype-environment interactions in major staple crops (Scopel et al., 2013). Despite these limitations, conventional breeding practices continue to be employed for yield improvement (Aslam et al., 2015). In order to increase the ability of crops to withstand drought, scientists highlight the need of using traditional breeding methods that involve evaluating randomly chosen offspring for enhanced tolerance to drought-induced stress (Ali et al., 2017). This approach is especially successful in controlled environments, where evaluating cultivars that are resistant to erratic drought responses becomes more feasible (Araujo et al., 2015).

The examination of root structure, water levels, and osmotic potentials through genetic analysis is essential for finding characteristics that contribute to crop productivity in drought situations (Shavrukov et al., 2017). To improve water use efficiency (WUE) in crop breeding, it is advantageous to concentrate on yield-contributing characteristics that have a high heritability. This method allows for the targeting of differences in WUE that exist among various types and cultivars (Vishwakarma et al., 2017). Genotypes and cultivars that are vulnerable to drought and lack adaptation have poor water use efficiency (WUE), necessitating breeding interventions to improve sustainable agricultural output (Fang and Xiong 2015).Genomic-assisted breeding employs Marker Assisted Selection (MAS) and Genomic Selection (GS) as crucial methods to enhance drought tolerance in crops. Molecular marker-assisted selection (MAS) entails the identification of molecular markers that are linked to certain traits, hence enabling more precise selection in breeding operations.

In contrast, GS utilizes genomic markers throughout the entire genome, enabling the identification of superior lines without the requirement of extensive phenotyping (Varshney et al., 2014). Despite being relatively new in comparison to MAS, this strategy has potential for improving drought resistance in crops, as demonstrated by its use in maize breeding at the International Maize and Wheat Improvement Center (CIMMYT) (Crossa et al., 2014). Current research efforts are investigating the application of genomic selection (GS) in more crops, including sugarcane, legumes, and wheat (Gouy et al., 2013; Varshney et al., 2013). The objective of these sophisticated breeding techniques is to utilize the genetic diversity present in agricultural species, with the goal of enhancing their capacity to withstand drought conditions and promoting the long-term viability of crop production.

12.7.2. Molecular and genomic perspective

Biological and molecular reactions are crucial in mitigating the negative consequences of water stress, including activities like transcription, stimulation of stress-responsive genes, and the existence of Abscisic acid (Osakabe et al., 2020). Breeding initiatives focused on improving drought tolerance also try to address other forms of stress by introducing stress-responsive genes through genetic modification (Rai and Rai 2020; Liu et al., 2020). Nevertheless, the upregulation of these genes is frequently linked to a decrease in plant growth rates, which restricts their practical usefulness. Hence, it is imperative to devote additional focus towards comprehending the molecular and genetic underpinnings of drought resistance, in order to guarantee effective adaptation to demanding circumstances (Hussain et al., 2018).

The utilization of genomic and associated technical methods shows potential in the identification of stress-tolerant genes, hence aiding their preservation in subsequent breeding programs (Medina et al., 2016). The study of stress-tolerant genes involves analyzing and duplicating genes associated with stress, which helps us gain valuable knowledge about specific traits. Researchers agree that the most effective method for enhancing plants' ability to withstand abiotic stress, such as genetic engineering, is a comprehensive approach that combines marker-assisted selection, molecular techniques, and traditional breeding (Nakashima et al., 2014; Bhatnagar-Mathur et al., 2008; Cho and Hong 2006). This integrated approach addresses the complexity of stress response mechanisms, emphasizing the need for a multifaceted strategy to enhance plant resilience to adverse environmental conditions.

12.8. Strategies for alleviating drought for sustainable cereals crop production

Different approaches are used to mitigate the negative impacts of drought stress and improve the long-term productivity of cereal crops. The use of exogenous regulators, chemicals, synthetic hormones, and substances in agriculture is beneficial for enhancing drought tolerance at various phases of cereal plant growth.

12.8.1. Seed priming

Seed priming is a crucial short-term method used to mitigate the negative impact of drought on plants. It entails commencing the process of germination and preparing seeds for the emergence of the radicle. The pre-sowing procedure greatly improves the germination process, leading to greater rates and more consistent growth compared to seeds that have not been primed. Seed priming has demonstrated efficacy in alleviating the effects of drought stress in cereals such as wheat, maize, and chickpea (Khan et al., 2019; Nawaz et al., 2013). Significantly, in the context of water scarcity, the application of Osmo-priming with CaHPO4 and KCL in directly sown rice (DSR) has shown favorable results, resulting in higher crop production and productivity (Farooq et al., 2013; Nawaz et al., 2016). Seed priming has advantages such as greater water use efficiency (WUE), optimum plant growth, increased crop yields, and improved ability to withstand drought. This makes it a significant technique for promoting sustainable agricultural production in areas with low water availability (Delač et al., 2018).

Table 12.5. Tolerance mechanisms in cereal crops through seed-priming treatments.

Priming Method	Crop	Protective Effects	References
$CaCl_2$ Hydroand Osmopriming	Rice	Phenol and flavonoid accumulation, antioxidant system, and stand establishment enhancement are the main areas of attention in the study.	Hussain et al., 2017
SNP Osmopriming		The buildup of compatible solutes improves relative water content (RWC), photosynthetic capability,	Farooq et al., 2009

Priming Method	Crop	Protective Effects	References
		membrane stability, and antioxidant enzyme activity.	
On-farm priming	Maize	Maintains an ideal temperature for the process of seed germination, resulting in shorter emergence time.	Finch et al., 2017
Osmopriming	Wheat	Facilitates the retention of relative water content (RWC), promotes the formation of proline, increases chlorophyll levels, and accelerates leaf emergence.	Tabassum et al., 2018
$CaCl_2$Osmopriming		Decrease in leaf photosynthetic capacity, buildup of osmolytes, increase in leaf area, relative water content, and grain yield	Ashraf et al., 2011

RWC: Relative water contents, LPO: Lipid peroxidation, LA: Leaf area, SNP: sodium nitroprusside.

12.8.2. Plant growth regulators

There is promise in increasing drought tolerance through the use of synthetic and natural plant growth regulators. By controlling the plant's internal water balance and increasing protein synthesis, gibberellic acid (GA) prevents seedlings from hypocotyl length loss caused by water stress (Ashraf et al., 2011). Enhancing agricultural production in drought circumstances is achieved by the administration of exogenous compounds such as abscisic acid, uniconazole, brassinolide, and jasmonic acid. Cytokinin benzyl adenine regulates drought resistance mechanisms, increasing antioxidant enzyme activities (Miura and Tada 2014). Salicylic acid enhances drought tolerance, increasing catalase activity and proline accumulation. In maize, polyamine contents rise under drought stress. Phyto-hormones like ethylene and brassinolide play crucial roles in plant tolerance, regulating defense systems and reactive oxygen species production (Tanveer et al., 2019).

12.8.3. Osmoprotectants

Osmoprotectants are vital for controlling different plant stressors and ensuring the proper functioning of internal physiological systems necessary for survival in challenging environments, such as limited water availability (Seleiman, 2019). Subcellular structures are protected by the buildup of important osmoprotectants such proline, trehalose, mannitol, fruton, and glycine betaine during tough development conditions. When applied exogenously or through seed treatment at different growth stages, these compounds enhance antioxidant enzyme activity and mediate osmotic adjustments, contributing to increased drought tolerance in plants (Yang and Guo 2018). When Proline is sprayed to the leaves, it increases the amounts of free proline inside the plant, which in turn improves its ability to withstand drought conditions (Semida et al., 2020). In addition, the use of polyamines, such as spermidine, has demonstrated efficacy in enhancing the ability of crops like barley (*Hordeum vulgare* L.) and wheat to tolerate water stress (Sallam et al., 2019).

12.8.4. Hydrogel: A water absorbing polymer

An effective method for decreasing the frequency of watering is the use of hydrogel, a polymer that is applied to soil in agricultural systems. Hydrogel conditioning helps plants live and finish their life cycles even in settings when water is scarce, which is especially helpful in dry and semi-arid regions (Tu et al., 2018). In regions where rainfall alone cannot meet water requirements, protecting available soil moisture becomes crucial to combat soil degradation. The application of hydrogel to soil enhances physical, chemical, and biological soil traits, positively impacting plant growth and development (Abobatta 2018). By mitigating water loss and hydraulic conductance in the soil, hydrogel extends the survival time of plants under drought stress, ensuring sufficient soil moisture (Jerszurki et al., 2017). This makes hydrogel application especially advantageous in arid, semi-arid, and drought-affected areas, promoting water conservation in the rhizosphere. Furthermore, the polymer-amended soil exhibits lower hydraulic conductivity compared to plain soil, and the reduced evaporation in such soil further contributes to water conservation (Saha et al., 2020).

12.8.5. Nanoparticles: Coping drought stress

Nanoparticles (NPs) exhibit distinctive characteristics, including specific particle geometries, adjustable pore dimensions, potential reactivity, and a large surface area. Their role in plants is to regulate the activity of antioxidant enzymes like SOD, CAT, and POD while also preferentially targeting certain cellular organelles (Seleiman et al., 2020). Nanoparticles of titanium dioxide (TIO2 NPs) boost plant superoxide dismutase (SOD) activity, for instance.

Various agricultural plants have demonstrated enhanced drought tolerance when treated with trace elements and oxide nanoparticles. According to Siddiqui et al., (2020), silicon (Si) nanoparticles can reduce the harmful effects of abiotic stressors. Proline, chlorophyll, carbs, carotenoids, and relative water levels are among the development and physiological traits that are improved by using ZnO and silica nanoparticles. Zirconium oxide nanoparticles reduce salt stress and drought in wheat, whereas silicon nanoparticles increase drought tolerance in wheat (Rizwan et al., 2019). Seed reservoirs are stimulated by ZnO NPs during early development, which improves drought tolerance. One of the many uses of nanoparticles is to increase plants' tolerance to drought; for example, TIO2 nanoparticles, in conjunction with Ag and Cu NPs, reduce the effects of drought stress on lentils and other plants (Maswada et al., 2020).

12.8.6. Metabolic engineering and stress tolerance strategy

Enhancing drought tolerance in crops is crucial for sustainable agriculture. Metabolic engineering, particularly through the raffinose biosynthesis pathway, proves to be an optimal strategy (Naghshbandi et al., 2019). By stimulating the expression of galactinol synthase gene (AtGolS2) under drought stress, plants accumulate raffinose and galactinol, enhancing drought tolerance and protecting against oxidative stress. Research conducted on rice and soybean demonstrates that employing the technique of metabolic engineering not only enhances the ability of transgenic plants to withstand drought, but also enhances their grain production (Selvaraj et al., 2017). Thus, the utilization of AtGolS2 metabolic engineering is seen as a valuable method to enhance grain output in the presence of water scarcity (Honna et al., 2017).

Table 12.6. Tolerance mechanisms to drought enhancement through phytohormones in cereal crops

Host Plant	**Phytohormones**	**Mechanism**	**Yield Dynamics**	**References**
Rice	Gibberellic Acid (GA)	Proline, APX, photosynthesis, maximum WUE, and CAT contents, expanded roots, and dwarf plants	10–30% increased	Wu et al., 2016
Rice	ABA	There was an increase in soluble	16% increased	Yu et al., 2013

		sugar, SOD, ABA, and proline, and a decrease in stomatal density, size, and leaf area; nevertheless, the roots were longer.		
Maize	ABA	Better ability to withstand drought and increase ABA accumulation	Increased	Lu et al., 2013
Barley	Cytokinins	By exhibiting enhanced resistance to dehydration, transgenic barley plants demonstrated enhanced drought tolerance.	Increased	Pospíšilová et al., 2016

Temporal terms: The acronyms WUE, APX, CAT, SOD, and ROS stand for water usage efficiency, ascorbate peroxidase, catalase, and reactive oxygen species, respectively

12.9. Conclusion

Drought poses a complex challenge to sustainable crop production, intensified by climate change and various abiotic stressors. Rising temperatures, altered rainfall patterns, and anthropogenic activities contribute to prevalent drought stress conditions, particularly affecting rain-fed agricultural areas. Climate change-induced consequences, such as glacier melting and water reservoir shrinkage, further escalate water scarcity issues. Monsoon variability and its projected decrease add to the challenges, impacting food security for a significant portion of the global population. Adaptive mechanisms in plants, including stress avoidance, escape, and tolerance, vary across molecular and plant levels. Mitigating the adverse effects of drought stress requires a multi-pronged approach. Best management practices, transgenic plants with drought-tolerant traits, and conventional breeding methods aim to improve water efficiency and crop resilience. Strategies involving plant growth regulators, seed priming, and Osmo-protectants show promise in enhancing drought tolerance.

Hydrogel amendments, nanoparticles, and metabolic engineering offer innovative solutions to conserve water and enhance plant resilience. In conclusion, a comprehensive and integrated approach, combining technological advancements, breeding strategies, and sustainable practices, is crucial to address the intricate challenges of drought on global food security. These efforts contribute to resilient and sustainable crop production amid evolving climatic conditions.

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