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Editorial

The Inner Development Goals (IDGs)

Dr. Olga Olashyn is a Chief Sales Officer (CSO) and holds a Ph.D. in the realm of economic and social sciences, with a specific focus on consumer behaviour within the broader scope of sustainable food culture and food systems. Actively engaged in her professional pursuits, she consistently emphasizes and prioritizes sustainability issues. As a CSO, Olga Olashyn stands as a beacon of commitment to the principles of sustainability, intertwining her expertise and passion to advocate for and implement sustainable practices within her field.

The Inner Development Goals (IDGs) is a non-profit and open-source initiative that aims to promote sustainable and productive living. As a non-profit Inner Development Organization, the IDGs explore and teach science-based skills and qualities that help to live meaningful, sustainable, and productive lives.

The IDGs Initiative

The initiative explore, collect, and communicate science-based skills and qualities that help to lead sustainable, and productive lives. In doing so, the IDGs Framework is fundamental achieving the United Nations Sustainable Development Goals (SDGs). The IDGs provide an essential framework for transformative capabilities for sustainable development. The framework includes a guide to developing these necessary capabilities and is open source and free for anyone to access. It consists of five dimensions (see fig.1) and 23 capabilities and qualities that are central to human growth and development.

The role of IDGs in the sustainable food system.

The sustainable food system is a key issue for IDGs. A sustainable diet means that food is produced, processed, transported, and consumed in ways that conserve environmental resources, promote consumer health, and ensure social equity. The IDGs provide a comprehensive framework of skills and qualities that are critical to creating a sustainable food system. By developing skills such as mindfulness, collaboration, critical thinking, and responsibility, people can be empowered to make conscious choices about their diets and promote sustainable practices.

The importance of food culture in the context of IDGs and the sustainable food system.

IDGs also helps promoting a sustainable food culture. This includes conscious consumption of food, respect for regional and seasonal products, and responsible management of food to reduce foodwaste in households and enterprises. By developing our inner skills

https://www.innerdevelopmentgoals.org/framework

Figure 1. The IDGs 5 dimensions with the 23 skills and qualities

of mindfulness, self-discipline, and empathy, people can make more conscious choices about what and how to eat. This not only has a positive impact on human health but also on the environment and society as a whole.

Promoting cooperation and collaboration

A sustainable food system requires collaboration among different actors along the entire food value chain. IDGs foster the development of skills such as social intelligence, teamwork, and cross-cultural communication that are essential for effective collaboration. By developing these skills, we can work together to find solutions to address the challenges of the sustainable food system.

The role of customer behaviour in the sustainable food system.

customer behaviour plays a critical role in creating a sustainable food system. By making more conscious choices and demanding sustainable food products, consumers can have a positive impact on the entire value chain. IDGs can play an essential role in this by encouraging the development of skills such as critical thinking, responsibility, and ethical consumption. By strengthening these skills, consumers can make more informed choices and advocate for a sustainable food system.

Conclusion

The Inner Development Goals (IDGs) are an important initiative to help to develop the inner capabilities and qualities needed for a sustainable food system.

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By strengthening our decision-making, fostering a sustainable food culture, and developing collaboration and cooperation skills, we can significantly contribute to achieving the SDGs. At the same time, customer behaviour plays a critical role in creating a sustainable food system, and the IDGs can help to empower consumers to make more conscious choices and advocate for sustainable food. By integrating the IDGs into our lives, we can create a sustainable future together.

References

https://www.innerdevelopmentgoals.org/

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https://www.innerdevelopmentgoals.org/resources

Chemical analysis and consumer acceptance of oyster mushroom (*Pleurotus ostreatus*) rendang as a typical West Sumatra culinary innovation

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Keywords

oyster; mushroom; rendang; consumer; acceptance.

Rendang is one of the typical foods of the Minangkabau people in West Sumatra. The cooking process takes about 6-7 hours at a temperature of 80-90°C, which decreases the nutritional level. This long process enables the perfect cooking of the meat. White oyster mushrooms can be used as a substitute for rendang meat because the vegetable protein contains lots of fibre, and the texture is similar to meat. Based on the results of the hedonic test on 72 respondents under and above 45 years old, the oyster mushroom rendang cooked for 7 hours was the most acceptable. This cooking time variant had the highest customer acceptability for flavour, colour, fragrance, and texture. Additionally, the t-test analysis with the significance number corroborated this conclusion. Furthermore, a chemical comparison of white oyster mushroom rendang and beef rendang showed that white oyster mushroom rendang had less FFA and moisture content.

1. Introduction

Meat-based foods should be processed before consumption to destroy pathogens or microbes. The processing can also affect the nutrition and the level of toxicity (Kondjoyan et al., 2014). Most consumers select a cooking method that produces high-quality meat products with preferred textures and flavours (King & Whyte, 2006). The physical properties and quality are influenced by temperature and cooking time. The United States Department of Agriculture (USDA) recommends internal temperatures for several types of meat such as 62.8°C for steaks, roasts, and fish, 71.1°C for ground beef, 76.7 °C for chicken breast, and 82°C for whole chickens (King & Whyte, 2006).

During the cooking process, the properties of the typical meat protein and the structural profile of the texture are changed. This results in shrinkage of flesh fibres, damage to cell membranes, aggregation and gelling of myofibrillar and sarcoplasmic proteins, as well as shrinkage and dissolution of connective tissue

(Lorenzo & Domínguez, 2014)(Adeyeye, 2017). Excessive use of heat also results in unwanted changes in meat quality, such as loss of nutritional value due to oxidation and lipid changes in some segments of protein fractions (Lorenzo & Domínguez, 2014).

Rendang is one of the typical foods of the Minangkabau people in West Sumatra. The processing takes about 6-7 hours at 80-90°C (Rini, Azima, Sayuti, & Novelina, 2016). This long process is influenced by the amount of meat used (Yenrina, Andhika, Ismed, Rasjmida, & Triyani, 2015). Therefore, the meat, coconut milk, and spices should also be adjusted and this greatly affects the length of processing time (Tornberg, 2005). The long process of making beef rendang at high temperatures also has an effect on changes in the nutrition of the fresh beef itself, especially beef fatty acids. There was the highest increase in saturated lauric acid and the lowest increase in arachidic acid. Total trans fatty acids also increase during the rendang cooking process (Yenrina et al., 2015).

Mushrooms have been consumed for a long time in Ancient Greece to provide strength for soldiers in battle, and were claimed to be "Food Gods". For centuries, China appreciated the properties of healthy food referred to as "the elixir of life." In conclusion, mushrooms are part of human culture for thousands of years and are quite in demand because of their sensory characteristics, recognized as culinary ingredients (Chang & Miles, 2004; Smith, Rowan, & Sullivan, 2002).

Currently, mushrooms are popular because of their reduced calories, carbohydrates, fats, sodium and absence of cholesterol. Besides, they contain essential nutrients, such as riboflavin, selenium, vitamin D, protein, potassium, niacin, and fibre. Furthermore, they have nutraceutical properties such as prevention or treatment of Parkinson's, Alzheimer's, hypertension, and for those at high-risk stroke. Mushrooms act as antibacterial, lowering agents' cholesterol, and immune system boosters for the body. Besides, they are an important source of bioactive compounds used as a dietary supplement (Valverde, Hernández-pérez, & Paredes-lópez, 2017). In developing countries, mushrooms are an alternative protein food which makes them play an important role in fighting food insecurity. In the world of the food and drug industry, knowledge of these fungi can help identify new food sources or products and their use in traditional medicine. Therefore, further exploration of the use of mushrooms as a functional food ingredient is needed for socio-economic growth (Hussain et al., 2023).

White oyster mushrooms can be used as a substitute for meat in rendang because of the vegetable protein that contains lots of fibre (Wardani & Widjanarko, 2013). The fibre in mushrooms is good for obese sufferers and can be used as an alternative to fibre in green vegetables which children do not like and even vegetarians can eat. Even white oyster mushrooms are safe for consumption by diabetics, hypertension, or the elderly. Recent studies have proved that oyster mushrooms could be a protein-based meat analogue that mimics the aesthetic quality (structure, taste, and appearance) of animal meat (Mazlan et al., 2020). Besides, white oyster mushrooms have a delicious and savoury taste that is close to the taste of meat. The fibrous texture of white oyster mushrooms will be similar to meat fibres when cooked properly. Another plus is the beta-glucan content, which can boost immunity in humans (Baeva et al., 2019).

Based on the reduction of eleven sensory attributes by PCA (Principle Component Analysis), there are new sensory characteristics of rendang of West Sumatra that can be distinguished by a group of attributes such as the aroma, cooking time, spices ingredients, and flavours. This study results in the effect of cooking time on sensory qualities (Rini et al., 2016). The innovations in making rendang are currently very diverse, such as lokan rendang, chicken rendang, and egg rendang. However, for vegetarians and people with degenerative diseases, innovations in making rendang are also needed which are safe for their consumption. Therefore, this study is focused on determining the best cooking time based on consumer acceptance of oyster mushroom rendang and evaluating the chemical analysis between white oyster mushroom rendang and beef rendang. So, it will be possible to create a new West Sumatra culinary invention.

2. Materials and Methods

The research was conducted in Padang, West Sumatra, Indonesia according to the established COVID-19 standards. Padang is the capital of the West Sumatra Province and has many traditional food centres. Moreover, the population in Padang is more heterogeneous compared to other cities in West Sumatra. It has several stages, namely the rendang processing stage and the consumer acceptance testing phase.

2.1 Production of oyster mushroom rendang

Producing mushrooms and meat rendang is quite different because the main ingredient has been replaced. Therefore, all ingredients should be accurately formulated to give the best mushroom rendang (Schifferstein, Kudrowitz, & Breuer, 2020). The process is carried out with a basic formula, and the processing stages are as follows. The quantity of mushroom is considered to be the quantity of the protein and the lowest level of coconut oil that could be used and the sensory characteristics are as similar as possible to beef rendang. 1 gram of oyster mushroom contains 10-30% of protein but beef alone contains a maximum of 19% of protein.

2.1.1 Tools and ingredients preparation

Tools are the most important thing to support the process of making rendang, and they should be kept dry to avoid contamination. Cleaning and drying tools follow the instructions of helpful food hygiene information for daily life. The equipment used were bowls, cutting boards, a spatula, a knife, a pan, a digital scale, and a food processor. The ingredients used to make rendang should be fresh and good, and the list is given in Table 1. The fresh ingredients were bought from the first-hand seller, and the identification was conducted through colours, smells, and textures. All tools and ingredients were cleaned with running water and all tools were sterilized first with sterilizer and steam stations.

2.1.2 Weighing

The process of weighing the ingredients was carried

Table 1. The basic ingredient formulation (proportion) of rendang

Ingredients	Quantity(g)	Baker Percent (%)
Fresh oyster mushrooms	500	100
Chile	100	26.80
Shallot	43.2	11.57
Garlic	31.6	8.46
caraway	2	0.53
Coriander	13	3.48
Peppers	10	2.68
Galangal	64.9	17.39
ginger	54.5	14.60
Salt	15	4.02
Turmeric leaves	12	3.21
Lime leaves	2.2	0.58
Bay leaves	2.7	0.72
Lemongrass	20	5.36
Tamarind	2	0.53
Grilled roasted coconut	80	21.44
coconut milk	1200	321.62

Note: The percentage is counted based on Baker Percent. The Bakers Percent method is a calculation method that uses the main ingredient as a comparison.

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out to obtain the appropriate amount of raw material for making mushroom rendang. The weighing of materials was conducted using digital scales to obtain precise and accurate results. Digital scales can weigh down to the smallest (1 gram) to be more accurate. In weighing the materials, the condition of the scale should still be fit for use and should follow the recipe to give the best flavour. Table 1 gives the specific units of measurement of each ingredient. The accurate measuring of ingredients should be performed to maintain consistency and achieve the desired flavour profile.

2.1.3 Refinement stage

The main spices were refined using a food processor, including garlic, shallot, chilli, galangal, pepper, coriander, ginger, and salt. Before adding the seasonings, the food processor was designed to slice and chop the dry and hard food ingredients to create a smooth, thick blend. This phase was completed at a medium speed (approximately 1700 rpm) for 5 to 10 minutes.

2.1.4 Season stir

The primary seasoning in the stirring process was kept at a medium heat of 200 to 300°F to cook the spices without burning spices. All the spices were mashed except for the lemongrass. Then, it was stir-fried in a modest amount of oil. The oyster mushrooms were added after the spices produced a pleasant aroma, but the water content of the oyster mushrooms was first reduced manually by pressing them. All of this was combined, followed by the addition of coconut oil and grilled roasted coconut.

2.1.5 Cooking rendang

The prepared rendang seasoning was simmered with fresh oyster mushrooms over different cooking durations for 5, 6, and 7 hours on low heat, about 113 to 180°F, and was stirred frequently. The heat source was provided by a gas stove. To avoid overcooking the spice of rendang, it was stirred once every 10 minutes while cooking. The texture and colour of the rendang were evaluated to ensure it was cooked adequately.

2.2 Sample and Participant Characterization

The three different rendang samples (RJ5, RJ6, and RJ7) were assigned to participants by purposive sampling technique. Participants met the criteria for the distribution of age, gender, and knowledge regarding rendang, including taste, aroma, texture, and basic ingredients. The evaluation was carried out through random interviews according to the criteria. Respondents were about 72, including 46 females and 26 males. The distribution based on age was 41.67% of respondents aged less than 45, and 58.33% who were more than 45 years old. The samples (RJ5, RJ6, and RJ7) distributed to respondents had three processing time variants (5, 6, and 7 hours, respectively). All samples were given to all respondents in order to measure their preferences for texture, aroma and taste.

2.3 Data collection

2.3.1 Sample serving procedures

The first step in delivering samples is to establish a sensory evaluation approach tailored to meet individual requirements. This task was performed by a sensory specialist in the research team. Except for the variable(s) being evaluated, the serving methods and sample preparation processes were standardised. According to the Schifferstein et al (2020) study, the sensory specialist was instructed to pay careful attention when writing the test protocols. Additionally, they were asked to choose the serving containers and the number of samples to be served.

A standard size of one tablespoon was determined by providing samples from the same cooking process, hence the visual appearance and serving temperature are similar. Plastic serving containers measuring 10 x 15 cm were utilized for the experiment. During the organoleptic test, two enumerators were also present to state the requirements.

2.3.2 The organoleptic and overall acceptance test

This study performed ordinal scale and best-worst rank. The ordinal scale allowed one to determine the order in which the consumers ranked the items for the most accepted (the most liked) and the least accepted (the least liked) product out of the three available. Responses were then converted into individual scales for each sample: (1) the number of times a specific sample was indicated as the most accepted and the number of times it was considered as the least accepted were counted; (2) these numbers were subtracted (the most accepted were subtracted by the least accepted)(Pimentel, Gomes da Cruz, & Deliza, 2015).

The organoleptic test used the scoring analysis on taste, colour, texture, and aroma while the overall acceptance was determined by the hedonic test (Kristanti & Herminiati, 2019). The organoleptic assessment was carried out by 72 respondents which included 46 females and 26 males.

The hedonic test was performed to describe the degree of consumer acceptance and satisfaction with rendang. In order to classify the food processing time and age, the hedonic attribute scale with very like, like, ordinary, less like, and no like is used.

2.3.3 Methods of Scaling: category scales

Several different scaling methods were used to apply numbers to sensory experience, as shown in Table 2.
This method involved the selection of discrete response possibilities to signify the sensation intensity or the degree of liking and preferences.

2.4 Moisture content analysis

Water content analysis was carried out by comparing two types of rendang, beef rendang and oyster mushroom rendang. The drying method is done using an oven. Both samples were put in a porcelain and labelled BR (Rendang Beef) and OMR (Oyster Mushroom Rendang). The first stage was tool sterilization. The porcelain was then baked in an oven at about 105°C for 1 hour, placed in a desiccator for 15 minutes, and then weighed. After the tool is sterile, about 3 grams of sample were added and heated for 6 hours at a temperature of around 105°C before being placed in a desiccator for 30 minutes or until the temperature reached room temperature. This was done to maintain the constant weight of the sample). The percentage of humidity was calculated by the following formula.

$$\text{Moisture content (\%)} = \frac{\text{Sample initial weight} - \text{Sample final weight (g)}}{\text{Sample initial weight (g)}} \times 100\%$$

2.5 Fat content analysis

The reflux method was used to analyse beef rendang and oyster mushroom rendang. The boiling flask was sterilized by placing it in the oven at 105°C for 1 hour, then cooling it in a desiccator for 15 minutes and weighing (A g). The sample weighed around 2-3 g (X g). The sample was then placed in a filter sheet which can be made of filter paper wrapped with fat-free cotton. The filter sleeve was finally inserted into the socket, and the condenser was installed according to the size of the socket used.

About 100 mL of hexane was added to the boiling flask (pyrex) and refluxed (pyrex) and refluxed with a reflux condenser (pyrex) for about 5 hours until the colour of the last drop indicated no colour (resulting in a clear drop). The extract obtained was placed into an oven at 105°C for 1 hour or more until the mass remained constant. The flask was cooled in a desicca-

Table 2. Example of category scales in the questionnaire

Organoleptic properties	Levels of pleasure	RJ 01	RJ 02	RJ 03
Taste	very like likes Ordinary Less like No Likes			

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tor for 30 minutes and then weighed and labelled "B". The percentage of fat content was estimated using the equation below.

$$\text{Fat content (\%)} = \frac{B-A}{X} \times 100\%$$

2.6 Free fatty acids (FFA) analysis

3 grams of sample was weighed into a 25 ml Erlenmeyer flask, followed by the addition of 5 ml of 95% ethanol, and 3-5 drops of pp indicator (phenolphthalein). It is finally titrated with 0.1 N NaOH standard solution until the colour changed to pink (no changes were observed for 15 seconds). Three tests were performed. The percentage of free fatty acid content was calculated as follows:

$$\%\ \text{FFA} = \frac{\text{mL NaOH x Fatty acid molecular weight x 100\%}}{\text{Sample weight x 1000}}$$

3. Results

Table 3 shows the hedonic test results of the three samples (RJ5, RJ6, and RJ7).

The participants (aged 45 and above) were more inclined to make food choices based on health considerations. On the contrary, those under the age of 45 were less concerned with this correlation and were more focused on the concern of food preparation and knowledge, prices, and time (Chambers, Lobb, Butler, & Traill, 2008), as seen in Table 4.

Table 5-7 shows the results of the organoleptic test on taste variations in cooking time. Variations occurred because varied cooking significantly influences the flavour of the finished product. As a result, organoleptic testing on the flavour of rendang at various cooking durations was an essential element to analyse.

The colour of rendang also changes with variations in cooking durations £. Furthermore, food colour can affect the choice of food by consumers (Clydesdale, 1993). But, in this study, the rendang receipt was same for RJ5, RJ 6, and RJ7 but the cooking durations were different Table 8-10 shows the organoleptic results of colour variations in cooking time.

The texture also has a significant influence on the choice of food. The texture of the oyster mushroom should be precisely defined. It is estimated that the mushroom will be softer than the meat due to the replacement with oyster mushrooms of higher texture. Table 11-13 shows the organoleptic test results on texture variations in cooking time.

The smell of food is another important factor affecting consumer acceptance of food. The distinctive aroma of oyster mushrooms may or may not be liked by consumers. However, using the same spices can balance the aroma of oyster mushrooms and beef rendang for all the samples. Table 14-16 shows the organoleptic results on texture variations.

Tables 17 and 18 show the overall data analysis of the organoleptic test and the significant differences in the mean.

Table 3. Respondents' choice of rendang

Sample	**Respondents**	**Percentage (%)**
RJ5	13	18.06
RJ6	15	20.83
RJ7	44	61.11
Total	72	100

Table 4. Choice of respondents based on age

Age	RJ5	RJ6	RJ7
Adults (<45)	9	9	12
Elderly people (≥45)	4	6	32
Total	13	15	44

Table 5. Respondent's choice of taste for 5 hours of cooking

Levels of pleasure	Respondents	Percentage (%)
very like	10	13.89
likes	48	66.67
Ordinary	14	19.44
Total	72	100

Table 6. Respondent's choice of taste for 6 hours of cooking

Levels of pleasure	Respondents	Percentage (%)
very like	12	16.67
likes	19	26.39
Ordinary	41	56.94

Table 7. Respondent's choice of taste for 7 hours of cooking

Levels of pleasure	Respondents	Percentage (%)
very like	43	59.72
likes	17	23.61
Ordinary	12	16.67
Total	72	100

Table 8. Respondent's choice of colour for 5 hours of cooking

Levels of pleasure	Respondents	Percentage (%)
very like	11	15.28
likes	46	63.89
Ordinary	15	20.83
Total	72	100

Table 9. Respondent's choice of colour for 6 hours of cooking

Levels of pleasure	Respondents	Percentage (%)
very like	13	18.06
likes	17	23.61
Ordinary	42	58.33
Total	72	100

Table 10. Respondent's choice of colour for 7 hours of cooking

Levels of pleasure	Respondents	Percentage (%)
very like	45	62.50
likes	14	19.44
Ordinary	13	18.06
Total	72	100

Table 11. Respondent's choice of texture for 5 hours of cooking

Levels of pleasure	Respondents	Percentage (%)
very like	10	13.89
likes	47	65.28
Ordinary	15	20.83
Total	72	100

Table 12. Respondent's choice of texture for 6 hours of cooking

Levels of pleasure	Respondents	Percentage (%)
very like	14	19.44
Likes	16	22.22
Ordinary	42	58.33
Total	72	100

Table 13. Respondent's choice of texture for 7 hours of cooking

Levels of pleasure	Respondents	Percentage (%)
very like	44	61.11
likes	17	23.61
Ordinary	11	15.28
Total	72	100

Table 14. Respondent's choice of aroma for 5 hours of cooking

Levels of pleasure	Respondents	Percentage (%)
very like	10	13.89
likes	48	66.67
Ordinary	14	19.44
Total	72	100

Table 15. Respondent's choice of aroma for 6 hours of cooking

Levels of pleasure	Respondents	Percentage (%)
very like	12	16.67
likes	16	22.22
Ordinary	44	61.11
Total	72	100

Table 16. Respondent's choice of aroma for 7 hours of cooking

Levels of pleasure	Respondents	Percentage (%)
very like	45	62.50
likes	15	20.83
Ordinary	12	16.67
Total	72	100

Table 17. Organoleptic test data analysis

Organoleptic components	RJ5		RJ6		RJ7	
	Means	SD	Means	SD	Means	SD
Taste	1.055556	0.578704	1.402778	0.7628657	0.5694444	0.7659366
Colour	1.055556	1.055556	1.402778	1.402778	0.5555556	0.5555556
Textures	1.069444	1.069444	1.388889	1.388889	0.5416667	0.5416667
Aroma	1.055556	1.055556	1.444444	1.444444	0.5416667	0.5416667

Table 18. T-test analysis

Organoleptic components	Comparison of RJ5 with RJ6		Comparison of RJ5 with RJ7		Comparison of RJ6 with RJ7	
	Q	Value	Q	Value	Q	Value
Taste	-2.5838	0.0118*	3.7925	0.0003**	5.0356	0.0000**
Colour	-2.5838	0.0118*	3.8549	0.0003**	5.1320	0.0000**
Textures	-2.3353	0.0224*	4.1686	0.0001**	5.1320	0.0000**
Aroma	-2.8815	0.0052*	3.9623	0.0002**	5.6113	0.0000**

**$p<0.01$

Table 19. The comparison of chemical characteristics between beef rendang and oyster mushroom rendang

	Water content (%)	Fat content (%)	Free Fatty Acids (%)
Beef Rendang	38.51	17.88	4.3
Oyster Mushroom Rendang	26.99	27.03	0.8

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4. Discussion

4.1 Consumer acceptance

The duration of cooking greatly affects the nutritional value of food (Fabbri & Crosby, 2016). The boiling process can reduce nutritional value because food ingredients directly exposed to boiled water will reduce nutrients, especially water-soluble vitamins (such as vitamin B complex and vitamin C) and protein. In contrast, the frying process uses high temperatures above 160ºC, which can reduce fat content and destroy vitamins and minerals. The weight of food after processing decreases ice due to the heat treatment, which reduces the volatile components.

Frying and roasting can reduce the weight of fresh food at a temperature of 90°c to 100°C more than cooking and boiling, more than 100ºC. Weight loss occurs in foodstuffs undergoing a cooking process. The tested food showed a decrease in weight (cooking loss), and the highest loss occurred in frying (Pathare & Roskilly, 2016)(Tornberg, 2005).

Processing food using high temperatures can cause water evaporation. The higher the temperature, the more water molecules come out of the surface and become gas. Some nutrients were lost, and food tastes were improved. The cooked food was free from certain toxic substances, especially vegetable ingredients. Different diseases were avoided since cooking can kill germs found in foodstuffs (Pathare & Roskilly, 2016) (Tornberg, 2005).

According to Tables 3 and 4, the mushroom rendang cooked for 7 hours was the most liked by respondents, with a percentage of about 61.11%. Respondents who were aged 45 and above have a higher percentage of likeness, naming around 72.72%. The age of 45 years and over is considered to have the potential to suffer from diabetes mellitus, hypertension, and heart disorders, especially those with an unhealthy lifestyle.

In addition to serving as an alternative to typical West Sumatra food, this oyster mushroom rendang is also safe for people aged 45 years and over compared to beef (Hou et al., 2019); (Sulistiyowati & Senewe, 2014). The plant-based foods, including fresh fruits and vegetables, whole grains, legumes, seeds, and nuts and lower animal-based foods, particularly fatty and processed meats could be healthier alternative diets (Cena & Calder, 2020). A higher intake of red meat or preserved meat in midlife is associated with a higher risk of having cognitive impairment in later life (Baleato, Ferguson, Oldmeadow, Mishra, & Garg, 2022; Jiang et al., 2020). Furthermore, many studies have concluded that oyster mushrooms can be a source of dietary fibre with a texture similar to meat.

Tables 5-16 explain that when further analysed, oyster mushroom rendang cooked for 7 hours is superior in terms of taste and colour, texture, and aroma. This is evidenced by the high choice of respondents, namely 62.5% and 61.11% selected to like the colour and texture of mushrooms cooked for 7 hours. The tendency to select this was because mushroom rendang resembled meat rendang in terms of its dark brown colour, texture, and aroma. Any limitations or potential biases in this sensory evaluation process were avoided by giving a piece of beef rendang for comparing the colour, texture, and aroma.

According to Table 17, the mean (average) and SD (standard deviation) ranges for the taste, colour, texture, and aroma of rendang cooked at 5, 6, and 7 hours do not exceed the number (minus). This is also supported by the results of the t-test in Table 18, explaining the differences in taste, colour, texture, and aroma between rendang cooked for 5 and 6 hours, 5 and 7 hours, as well as 6 and 7 hours with a value of <0.05 each. The t-test showed that the different treatment or cooking process affects consumer acceptance of oyster mushroom rendang.

4.2 Chemical analysis

The water content in food can differ from one another even though these foods are both similar types of food, such as beef rendang and oyster mushroom rendang. The water content in the food was analysed to determine the stability and quality of the two rendang. The presence of water in the meal can affect the resistance of rendang. If the water content is low, the growth of microorganisms in the food will be slow, which will result in the food being more durable. Based on the data in Table 19, it can be seen that the moisture content of oyster mushroom rendang was smaller than beef rendang.

The water content in oyster mushroom rendang is lower than in beef rendang. The low moisture content of oyster mushroom rendang is due to the slow cooking process of making rendang and drying the oyster mushrooms before cooking so that the rendang becomes dry, besides that the oyster mushroom rendang cooking process also takes hours, which causes the liquid in the rendang to blend with various spices until it becomes dry (Nurmufida, Wangrimen, Reinalta, & Leonardi, 2017). Cooking beef rendang in this study took about 3 hours, with a temperature of around 80-93°C, while cooking oyster mushroom rendang took around 7 hours. In fresh conditions, the water content of beef is 60-70% while the water content of oyster mushrooms is 90% (Elattar, & Awd-Allah, 2019).

The long cooking process causes the moisture content of rendang to decrease. The longer the food is exposed to heat, the less water will be in the rendang, this is due to the evaporation process. In terms of texture, aroma, colour, and taste between oyster mushroom and beef rendang, there were no significant differences but in the quality between these two rendang, the oyster mushroom is characteristically low-water-activity foods and might not support the growth of vegetative pathogens such as Salmonella (Liu, Roopesh, Tang, Wu, & Qin, 2022).

Fat is a source of energy needed by the body besides carbohydrates and proteins. Fat provides about 9 kcal/gram for the body. Based on the data obtained in Table 19, it can be seen that the average fat content of beef rendang is smaller than that of oyster mushroom rendang. Long cooking time also affects the fat content of rendang. The long cooking of beef rendang causes coconut milk to release oil and increases the fat content of rendang. Therefore, the fat in the oyster mushroom rendang is higher than the rendang fat (Faridah & Holinesti, 2021). Even so, the fat content in the oyster mushroom is still within the Indonesian national standard range, which is a maximum of 30%. Free fatty acids are values that indicate the amount of free fatty acids present in the fat after hydrolysis. The hydrolysis reaction can be caused by the amount of water, the activity of microorganisms, or the presence of enzymes. FFA is the result of the degradation of triglycerides as a result of oil defects.

The resulting FFA value is used to determine the degree of defect of the fat. Table 19 showed the average range of FFA content of beef rendang was 43% while the FFA content of oyster mushroom rendang was only 0.8%. The low FFA is related to the water content of the oil. If the water content in the oil is high, a hydrolysis reaction will occur which can increase the FFA level, and vice versa. The fat hydrolysis reaction can occur in the presence of water and heating. Fat hydrolysis can occur in saturated fat or unsaturated fat. At first, the fat will be hydrolysed to form glycerine and free fatty acids, then a further reaction will occur which causes the breakdown of glycerine and free fatty acid molecules. By triggering the heating process, the fat (triglycerides) is hydrolysed to form free fatty acids and glycerol. At heating temperature, fats (triglycerides) are hydrolysed into free fatty acids and glycerol. At too high a heating temperature, the bonds in glycerine can break, causing the release of two water molecules and the formation of acrolein compounds. Acrolein is volatile and forms fumes that can irritate the eyes. For edible foods with a high concentration of fat or oil, the maximum FFA is 2%.

The higher the FFA, the more food product has signs of fat defects. The high concentration of FFA in fats/oils in food indicates that the food is damaged, where at maximum levels the food is not suitable for consumption. Damage to fats and oils from hydrolysis will cause rancidity (Ramadhani, Widati, & Rosyidi, 2022). Rancidity will certainly affect the aroma and flavour of the rendang product. Moreover, the previous study explained that high amounts of FFA may have adverse effects on qualities of taste, colour, and shelf life, and may also cause significant levels of refining loss (Shi et al., 2018).

5. Conclusion

This study showed that the cooking time of oyster mushroom rendang affects the consumer's acceptance of texture, aroma, taste, and colour. The mushroom cooked for 7 hours is the most preferred by respondents, with a percentage of about 61.11%. From the distribution that likes mushroom rendang cooked for 7 hours, respondents over 45 years old have a higher percentage around 72.72% or 32 individuals.

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Conflict of interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analysis, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results

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Cricket powder (*Acheta domesticus*) as a lean pork meat replacer in cooked sausages

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The incorporation of insects in everyday foods is a developing area. Therefore, the aim of this study was to determine the optimal percent replacement (5.0, 7.5 or 10.0%) of lean pork meat with cricket power (CP) in cooked sausages. For this purpose, the quality and safety were evaluated through the following parameters: pH, moisture, water activity, TBA value, colour (L*, a*, b*), texture and sensory profile, microbiological status and microstructure during seven-day cold storage. The pH of cooked sausages with CP increased while the moisture decreased. At the end of cold storage TBA values of cooked sausages with CP were lower compared to the control. A dose dependent decrease in colour lightness (L*) and redness (a*) was observed after lean pork meat replacement in batters and cooked sausages. For both the texture profile analysis and sensory profile, the panel found an increase in the hardness and springiness of the cooked sausages with 7.5 and 10.0% CP. The microbiological status of the cooked sausages was not compromised by the addition of CP. Disruptions in the microstructure of both batters and cooked sausages were observed. Dose-depend size increase of fat globules and air bubbles in the batters with 7.5 and 10.0% replacement of lean pork meat was observed leading to their destabilization. Overall, the 5.0% replacement of lean pork meat with CP affects in most positive way all evaluated parameters of the cooked sausages. Higher percent replacement could be possible after evaluation of emulsion stability and gel formation of the insect-based hybrid meat products.

1. Introduction

1.1. History and future

Consumption of insects is a historically and geographically widespread phenomenon in Asian countries (Ho et al., 2022a). According to Regulation (EU) 2015/2283, insects intended for human consumption are considered "novel food" due to the lack of food history in the EU. In Europe, the house cricket (Acheta domescticus) was officially approved for usage in food products only in Switzerland (Federal Food Safety and Veterinary Office, 01 May 2017).

1.2. Physiology and rearing

The house cricket (*Acheta domesticus* - L. 1758, order Orthoptera, family Gryllidae) originates from South Asia. In the last decades, it had spread widely and turned into a cosmopolitan, omnivorous insect with potential for industrial rearing. Since they are cold-blooded, they require less energy to maintain homeostasis which results in more efficient feed conversion (Dobermann et al., 2017). House crickets need four to 12 times less feed than ruminants and half that of chickens and pigs to produce the same amount of protein (Cavalheiro et al., 2023).

1.3. Nutritional composition – benefits and risks

The dried house crickets are highly nutritional, containing a large amount of unsaturated fatty acids, including linoleic and α-linolenic acids, all nine essential amino acids as well as micronutrients (Calcium, Potassium, Magnesium, Vitamin A, etc.) (Dobermann et al., 2017). No matter their high nutritional value, the addition of insects in everyday food must be labelled and bolded according to Regulation (EU) 1169/2011 as they are source of chitin (Han et al., 2023).

Insects belong to arthropods (Arthropoda), therefore consumers suffering from an allergy to crustaceans (Crustacea) may experience an allergic reaction after consumption (Ho et al., 2022b).

1.4. Consumers acceptance

Over the past decade, a number of studies have been conducted to assess the degree of acceptance of insects as food by consumers. Since the consumption of insects (Entomophagy) is not traditionally advocated in Western countries such studies contribute to consumer acceptance and the development of products with added insects (La Barrbera et al., 2020). In general, a large part of consumers feel an aversion to the consumption of whole insects. Whereas the growing demand is driven by consumer curiosity about their sensory characteristics (Kulma et al., 2023).

1.5. Potential incorporation

Adding insects to daily foods in the form of powders/flours is proving to be the most suitable option for Western consumers. From the literature review, we found a significant number of publications from around the world aiming to incorporate insect powders/flours into various foods. The cricket powder was used in various bakery products, such as sponge cakes (Vlahova-Vangelova et al., 2022) and pasta (Ho et al., 2022a). Different authors reported a possible formulation of new hybrid meat products with cricket powder. Some of them suggest adding the cricket powder directly to the meat products (Smarzyński et al., 2019; Vlahova-Vangelova et al., 2021), others test the possibility of replacing part of the meat (Cavalheiro et al., 2023; Han et al., 2023). Therefore, the aim of this study was to determine the optimal percent replacement (5.0, 7.5 or 10.0%) of lean pork meat with cricket power in cooked sausages. For this purpose, the quality and safety were evaluated through the following parameters: pH, moisture, water activity, TBA value, colour (L*, a*, b*), texture and sensory profile, microbiological status and microstructure.

Table 1. Formulations of the cooked sausages

Sample/ Ingredient	Control	CP1.5	CP2	CP3
Lean pork meat (g)	1800	1650	1575	1500
Pork bacon (g)	1200	1200	1200	1200
Cricket powder – CP (g)	-	52.00	78.00	102.00
Water (ml)	-	98.00	147.00	198.00
Flaky ice (g)	450.00	450.00	450.00	450.00
Table salt (g)	60.00	60.00	60.00	60.00
Sodium nitrite (g)	0.21	0.21	0.21	0.21
Sodium tripolyphosphate (g)	6.00	6.00	6.00	6.00
Total amount (g)	3516.21	3516.21	3516.21	3516.21
Lean meat replacement (%/ g)	-	5.00/ 150	7.50/ 225	10.00/ 300
CP in final product (%)	-	1.50	2.00	3.00

2. Materials and Methods

2.1. Experimental design

For the production of the cooked sausages a chilled (48 h *post mortem*) lean pork meat (*M. semimebranosus, M. semitendinosus*), pork bacon (*M. pectoralis major*) and salting ingredients bought from the local and specialized merchants and cricket powder from Aceta domesticus (EntoSynergy Ltd., Bulgaria) were used (Table 1). The proximate composition of the cricket powder was: protein 58.10 (% DM), fat 14.43 (% DM), carbohydrates 12.90 (% DM), moisture 15.47 (%). Its pH was 6.83 and colour parameters were L* - 61.15; a* - 4.00 and b* - 17.74.

The chilled (0.0±0.5 °C) pork meat was grinded at 3 mm diameter mesh. The pork meat was finely chopped in a cutter machine (EMS Muller, MTK30, Saarbrucken west-Germany) with table salt, nitrite, tripolyphosphate and flaky ice. Upon achieving a homogenous batter, the cricket powder and respective amount of water based on the dry matter of the CP (85.43%) were added and mixed. The whole procedure for batter processing was repeated 4 times to obtain each of the 4 samples. One part of each batter was tested immediately to evaluate the influence of the "percent replacement of lean pork meat" factor. The second part was stuffed in polyamide casings. Sausages were steam boiled until a temperature of 72 °C in the centre was reached. The cooked sausages were stored at 0 – 4 °C for seven days without additional packing. The following analyses were carried out on the first and seventh days of cold storage.

2.2. pH determination

pH value was determined in triplicate using portable meat pH meter HI99163 (Hanna Instruments, USA) equipped with stainless steel probe for meat products (FC099). The pH meter was calibrated with 4.04 and 6.86 buffer solutions (Young et al., 2012).

2.3. Moisture and water activity (aW)

Moisture content was determined after drying at 104 °C until constant weight. The water activity was evaluated using Novasina AG CH-8853 (Zurich, Switzerland) at 20 °C (Vandeweyer et al., 2017).

2.4. Lipid oxidation

The secondary products of lipid peroxidation were determined by the 2-thiobarbituric acid assay as described by Botsoglou et al. (1994). Briefly, 10 grams sample is homogenized with 50 cm^3 0.9% NaCl for 3 min. A 50 cm^3 10% trichloroacetic acid is added to the solution to precipitate the extracted proteins. Solutions are filtrated and 4 cm^3 extract is mixed with 1% 2-thiobarbituric acid (freshly prepared). The mixture is heated at 70°C for 30 min. The absorbance of the solution is measured at 532 nm against black prepared with distilled water instead of extract. For this purpose, a dual beam UV-VIS spectrophotometer Camspec M550 (Spectronic CamSpec Ltd, United Kingdom) was used. The results are presented as mg MDA/ kg sample.

2.5. Instrumental colour determination

The CIELAB (L*; a*; b*) colour coordinates of the batter and the cross-cut surface of cooked sausages were determined as described by (Young et al., 2012) by colorimeter (Konica Minolta CR-410, Japan). Additionally, the total colour difference (ΔE) was calculated to compare the experimental samples (CP1.5; CP2 and CP3) to the control sample.

2.6. Texture profile analysis (TPA)

The texture profile was represented by the plastic strength (PS) or hardness, structural strength (SS) or cohesiveness and springiness or elasticity. All measurements were conducted using an OB-05 penetrometer (Labor, Hungary) following the detailed recommendations of Vlahova-Vangelova et al. (2021).

2.7. Sensory profile

Before sensory evaluation, the cooked sausages were left at room temperature for 20 min and sliced right before the serving. The sensory characteristics of cooked sausages, appearance, texture, taste, smell, and colour of the cross-cut surface were evaluated by a five-member panel group. A five-ball hedonic scale was used (Civille et al., 2015). The scores from 1 to 5 represent how much the panellist like the tested sample: 1 – dislike extremely; 2 – dislike slightly; 3 – neither like nor dislike; 4 – like slightly; 5 – like extremely.

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2.8. Microbiological status

The suspensions and decimal dilutions of cooked sausages were done following ISO 6887-2:2017. Total viable count (TVC), Coliforms count, Enterobacteriaceae and Yeasts and Moulds count were evaluated according to the recommendations for surface planting and pour plate techniques (ISO 4833-1:2013/ Amd 1:2022; ISO 4833-2:2013/ Amd 1:2022).

2.9. Light microscopy

Sample cuts (2x2x1 cm) from the centre of cooked sausages and batter were placed in 10% formalin overnight to prefix the structure. Fixed samples were dehydrated using gradually increasing ethanol solutions (50, 70, 96 and absolute). Dehydrated samples were bleached using acetone then transferred in xylene for 12 h and embedded in paraffin. A 5 µm thick slice was cut from the paraffin block and stained with haematoxylin-eosin (Barbut et al. 2005). The observation was done using a light microscope (Olimpus BX-41TF, Japan) equipped with a digital camera (Olimpus SC30, Japan) at x100 magnification.

2.10. Statistical analyses

Results are presented as Means ± Standard Error of Means (SEM). Data for the batters were processed using a One-way ANOVA to evaluate the effect of percent replacement of lean pork meat with CP at P<0.05 level of significance (n=5). Two-way ANOVA with replications (Student's t-test) was performed to determine the effect of both factors (percent replacement of lean pork meat and storage time of cooked sausages) and their interaction at P<0.05 level of significance (n=5). The add-in Analysis ToolPak -VBA for Microsoft Excel 2016 software was used for both statistical analyses.

3. Results

3.1. Physical-chemical properties

The pH of the batter was significantly (P<0.05) lowered due to the replacement of the lean pork meat with CP in a dose-dependent manner (Table 2) despite the high pH value of the CP (6.83). After cooking all three samples with CP (CP1.5, CP2 and CP3) had higher (P<0.05) pH than the control. This trend was also observed after seven-day of cold storage despite the decreased values (P<0.05).

Regardless of the added water for a high dry matter of CP compensation, the moisture of the three batter samples (CP1.5, CP2 and CP3) decreased (P<0.05). The decrease in moisture content compared to the control was dose depend (Table 2). The established trend line was also observed in the cooked sausages. During the seven-day cold storage, the moisture decreased significantly (P<0.05) in all four samples.

Water activity (aW) of all cooked sausages was not affected (P>0.05) either by the replacement of lean pork meat with CP or the cold storage (Table 2).

Table 2. Physical-chemical properties of batters and cooked sausages during seven-day cold storage

Sample/ Parameter	Storage time (d)	Control	CP1.5	CP2	CP3
$pH_{(batter)}$ (-)	-	$6.32±0.03^{d}$	$6.19±0.01^{c}$	$6.16±0.01^{b}$	$6.10±0.01^{a}$
$pH_{(sausages)}$ (-)	1	$6.21±0.02^{a,y}$	$6.37±0.02^{b,y}$	$6.41±0.02^{b,y}$	$6.43±0.03^{b,y}$
$pH_{(sausages)}$ (-)	7	$6.14±0.02^{a,x}$	$6.21±0.02^{b,x}$	$6.21±0.02^{b,x}$	$6.21±0.03^{b,x}$
$Moisture_{(batter)}$ (%)	-	$28.38±0.03^{d}$	$27.87±0.06^{c}$	$23.82±0.04^{b}$	$17.29±0.04^{a}$
$Moisture_{(sausages)}$ (%)	1	$42.80±0.02^{d,y}$	$25.32±0.02^{c,y}$	$13.44±0.04^{b,x}$	$9.38±0.03^{a,x}$
$Moisture_{(sausages)}$ (%)	7	$11.80±1.47^{a,b,x}$	$11.35±0.82^{a,x}$	$13.40±0.04^{b,x}$	$14.90±0.48^{c,y}$
$a_{W(sausages)}$ (-)	1	$0.95±0.02^{a,x}$	$0.96±0.01^{a,x}$	$0.96±0.01^{a,x}$	$0.94±0.02^{a,x}$
$a_{W(sausages)}$ (-)	7	$0.95±0.03^{a,x}$	$0.95±0.02^{a,x}$	$0.95±0.03^{a,x}$	$0.94±0.01^{a,x}$

^{a,b,c,d} – superscripts show significant (*P*<0.05) differences between Means in the row

^{x,y} – superscripts show significant (*P*<0.05) differences between Means in the same column for each parameter

The TBA values of the cooked sausages on day one of cold storage vary from 1.12 to 1.23 mg MDA/kg. The control had the highest values of 1.23±0.02 and the lowest was in sample CP3 (P<0.05). During seven-day cold storage, TBA values in all cooked sausages increased significantly (P<0.05). Most significant was in control – from 1.23 to 1.40 or about 12%. The three samples with the replacement of lean pork meat with CP had no significant difference in TBA values - from 1.25 to 1.27 mg MDA/kg.

3.2. Instrumental colour determination

The results for the lightness (L*) of the colour of batters and the cross-cut surface of the cooked sausages during the cold storage showed a significant (P<0.05) CP dose depending on the decrease in values (Table 3). A similar decrease was also evaluated for the redness (a*) of both batters and cooked sausages. The yellowness (b*) of the batter was the highest in the control and lowest in CP3 (P<0.05) despite of the high b* values of CP. As for the cooked sausages with the replacement of lean pork meat with CP (samples CP2 and CP3) b* values of the cross-cut surface were higher (P<0.05) than the control (Table 3, day one). The colour difference (ΔE) of all samples was from 2.52 to 6.33 meaning that even an inexperienced observer could spot the difference (Figure 1).

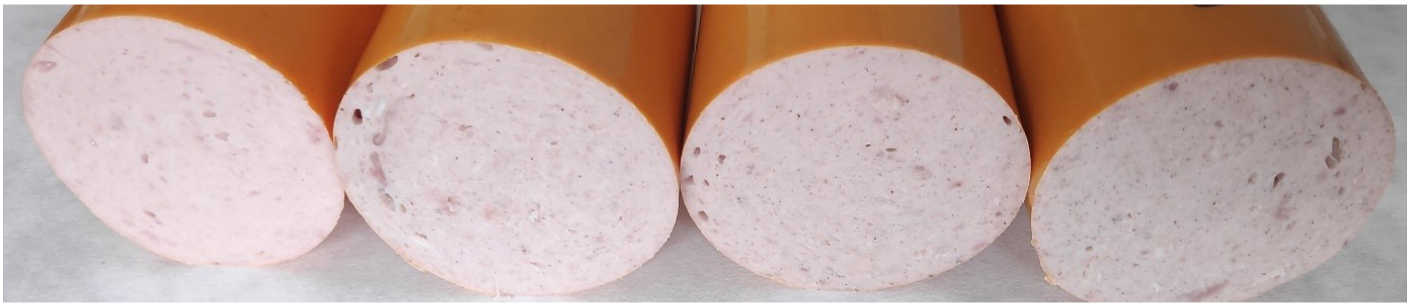

Figure 1. Photo of the cooked sausages – from left to right (Control; CP1.5; CP2; CP3)

Table 3. Colour of the batters and the cooked sausages during seven-day cold storage

Sample/ Parameter	Storage time (d)	Control	CP1.5	CP2	CP3
$L^*_{(batter)}$ (-)	-	63.59±0.34^{c}	63.10±0.25^{b,c}	61.89±0.13^{b}	60.62±0.12^{a}
$L^*_{(sausages)}$ (-)	1	65.29±0.29^{d,x}	63.52±0.10^{c,x}	62.72±0.60^{b,x}	61.67±0.11^{a,x}
$L^*_{(sausages)}$ (-)	7	65.61±0.04^{d,x}	63.74±0.11^{c,y}	63.13±0.09^{b,x}	61.84±0.15^{a,x}
$a^*_{(batter)}$ (-)	-	7.86±0.07^{d}	5.47±0.03^{c}	5.30±0.05^{b}	5.18±0.04^{a}
$a^*_{(sausages)}$ (-)	1	13.97±0.11^{d,y}	10.12±0.04^{c,x}	9.66±0.02^{b,x}	8.77±0.01^{a,x}
$a^*_{(sausages)}$ (-)	7	13.78±0.04^{d,x}	10.30±0.03^{c,y}	9.86±0.03^{b,y}	9.05±0.03^{a,y}
$b^*_{(batter)}$ (-)	-	12.09±0.15^{c}	11.43±0.04^{b}	11.06±0.09^{a}	11.17±0.08^{a}
$b^*_{(sausages)}$ (-)	1	8.18±0.14^{b,x}	7.86±0.05^{a,x}	8.34±0.02^{c,x}	8.77±0.03^{d,y}
$b^*_{(sausages)}$ (-)	7	8.16±0.09^{a,x}	8.06±0.02^{a,y}	8.32±0.02^{b,x}	8.31±0.03^{b,x}
$\Delta E_{(batter)}$ (-)	-	-	2.52	3.24	4.10
$\Delta E_{(sausages)}$ (-)	1	-	4.25	5.79	6.33
$\Delta E_{(sausages)}$ (-)	7	-	3.95	4.63	6.05

^{a,b,c,d} – superscripts show significant (*P*<0.05) differences between Means in the same row.

^{x,y} – superscripts show significant (*P*<0.05) differences between Means in the same column for each parameter

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3.3. Texture profile analysis (TPA)

The texture profile of all samples was significantly affected by the replacement of lean pork meat with CP. The highest value (P<0.05) for plastic strength (PS) was evaluated in batter CP3 (Table 4). After cooking and 24 h of cold storage PS values increased in all sausages due to the thermal denaturation of the proteins. Samples CP2 and CP3 were characterized by two-time higher PS than the control (P<0.05). After seven-day cold storage, the PS of all cooked sausages decrease significantly (P<0.05) but maintained the trend from the first day.

The structural strength (SS) of all three batters with CP (samples CP1.5, CP2 and CP3) was higher (P<0.05) that the control (Table 4). Similar results were observed for the cooked sausages on day one of cold storage. Opposite to the plastic, structural strength increased (P<0.05) during the seven-day of cold storage in samples CP2 and CP3.

On day one of the cold storage the highest values for the springiness of the cooked sausages were measured in sample CP3. It was 29.41% higher (P<0.05) than the control (Table 4) During seven-day cold storage the elasticity of all three samples with replacement of lean pork meat with CP increased significantly (P<0.05).

3.4. Sensory profile

The sensory panel awarded the highest scores to control and CP1.5 cooked sausages (Figure 2). The sausages CP2 had lower sensory scores due to the harder texture and darker colour of the cross-cut surface (Table 3, Figure 1). The cooked sausages produced with 10% replacement of lean pork meat with CP (CP3) had a hard, gummy texture, dark colour and uncharacteristic taste and smell.

3.5. Microbiological status

An increase (P<0.05) in total viable count (TVC) was evaluated on day one of sausages' cold storage which corresponded well with the increased percent of CP (Table 5). During the seven-day cold storage, TVC increased significantly (P<0.05) for all samples. The TVC of the control sausages remained the lowest (P<0.05). No coliforms were found at the time of the experiment.

The *Enterobacteriaceae* count in all tested sausages both on the first and seventh day of cold storage did not differ significantly (P>0.05). An increase (P<0.05) in yeast and mould count was observed during the seven-day cold storage in all sausages. The control and CP1.5 remained lower for yeast and mould count compared to CP2 and CP3 (P<0.05). Yeast and mould count was not affected (P>0.05) by the replacement of lean pork meat with CP on day one of the cold storage (Table 5).

Table 4. Texture profile of batter and cooked sausages during seven-day cold storage

Sample/ Parameter	Storage time (d)	Control	CP1.5	CP2	CP3
$PS^1_{(batter)}$ (g/cm^2)	-	1.20 ± 0.03^{a}	1.08 ± 0.02^{a}	1.08 ± 0.02^{a}	1.56 ± 0.02^{b}
$PS_{(sausages)}$ (g/cm^2)	1	$32.56\pm0.83^{a,y}$	$52.09\pm0.85^{b,y}$	$66.71\pm1.00^{c,y}$	$64.16\pm0.61^{c,y}$
$PS_{(sausages)}$ (g/cm^2)	7	$24.48\pm0.55^{a,x}$	$29.31\pm0.51^{b,x}$	$35.99\pm0.55^{c,x}$	$38.78\pm0.62^{d,x}$
$SS^2_{(batter)}$ (g/cm^2)	-	10.36 ± 0.47^{a}	11.72 ± 0.70^{b}	12.10 ± 0.61^{b}	11.63 ± 0.35^{b}
$SS_{(sausages)}$ (g/cm^2)	1	$195.03\pm2.21^{a,x}$	$306.51\pm3.07^{b,y}$	$300.29\pm2.90^{b,x}$	$375.81\pm2.24^{c,x}$
$SS_{(sausages)}$ (g/cm^2)	7	$189.20\pm1.62^{a,x}$	$229.39\pm2.29^{b,x}$	$513.60\pm3.45^{c,y}$	$590.49\pm2.78^{d,y}$
$Springiness_{(sausages)}$	1	$0.48\pm0.07^{a,x}$	$0.50\pm0.10^{a,x}$	$0.60\pm0.07^{a,b,x}$	$0.68\pm0.08^{b,x}$
$Springiness_{(sausages)}$	7	$0.44\pm0.07^{a,x}$	$0.99\pm0.07^{c,y}$	$0.77\pm0.05^{b,y}$	$0.99\pm0.06^{c,y}$

[1]Plastic strength; [2]Structural strength

^{a,b,c,d} – superscripts show significant (*P*<0.05) differences between Means in the same row.

^{x,y,z} – superscripts show significant (*P*<0.05) differences between Means in the same column for each parameter

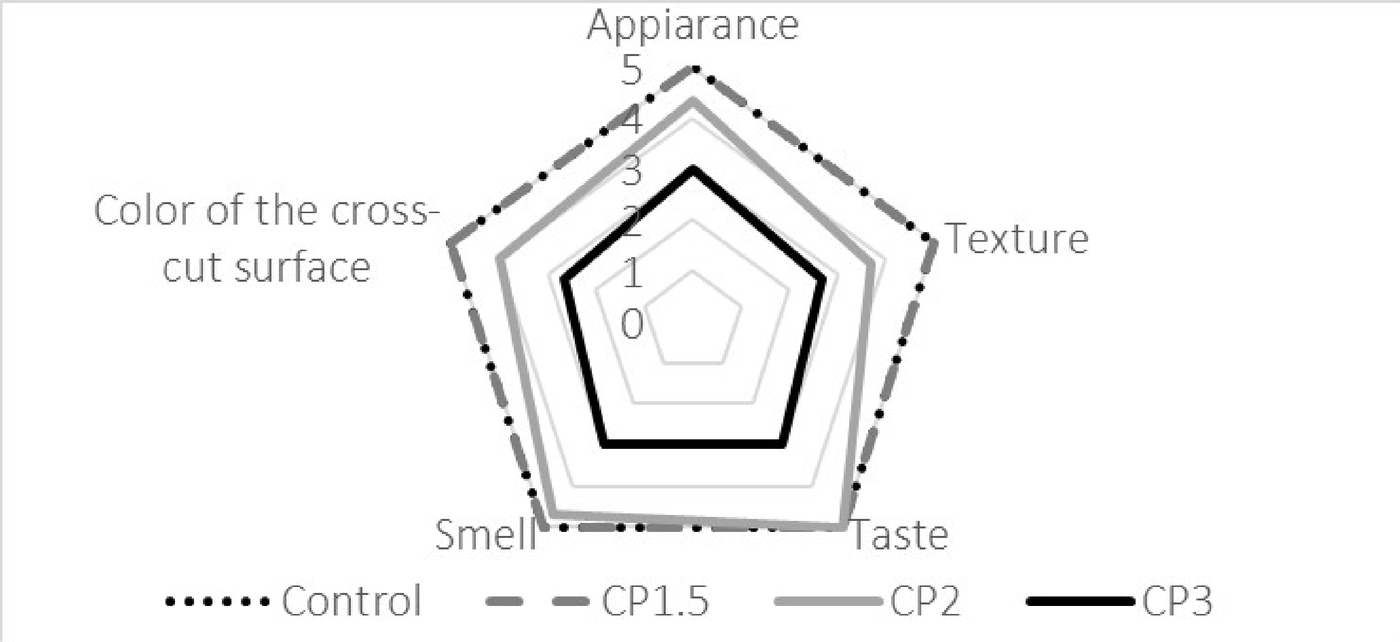

Figure 2. Sensory profile of cooked sausages at the first day of cold storage

Table 5. Microbiological status (lg CFU/g) of cooked sausages during seven-day cold storage

Sample/ Parameter	Storage time (d)	Control	CP1.5	CP2	CP3
TVC[1]	1	3.00±0.07^{a,x}	3.30±0.09^{b,x}	3.60±0.05^{c,x}	3.78±0.06^{d,x}
TVC	7	3.78±0.09^{a,y}	4.60±0.07^{c,y}	4.30±0.11^{b,y}	4.30±0.10^{b,y}
Coliforms	1	N.F.[2]	N.F.	N.F.	N.F.
Coliforms	7	N.F.	N.F.	N.F.	N.F.
Enterobacteriaceae	1	5.49±0.39^{a,x}	5.58±0.43^{a,x}	5.43±0.48^{a,x}	5.58±0.46^{a,x}
Enterobacteriaceae	7	5.16±0.28^{a,x}	5.20±0.45^{a,x}	4.87±0.19^{a,x}	5.11±0.27^{a,x}
Yeasts & Moulds	1	3.30±0.15^{a,x}	3.83±0.62^{a,x}	3.59±0.64^{a,x}	4.00±0.64^{a,x}
Yeasts & Moulds	7	4.53±0.33^{a,y}	4.49±0.16^{a,y}	5.07±0.32^{b,y}	5.20±0.38^{b,y}

[1]Total viable count; [2]Not found

^{a,b,c,d} – superscripts show significant (P<0.05) differences between Means in the same row.

^{x,y,z} – superscripts show significant (P<0.05) differences between Means in the same column for each parameter

3.6. Light microscopy

The microstructural images of the four investigated batters showed a matrix which consists of fat droplets wrapped in protein film, water and dispersed myofibrillar and connective tissue fragments (Figure 3). The formed fat globules in the control batter were properly distributed and approximately uniform in size. The shape and size of the globules were changed due to the addition of CP. This probably is the result of the rupture of the fat globules from the hard chitin fragments. Dose-depend size increase of fat globules and air bubbles in the batters CP2 and CP3 was observed leading to their destabilization.

After heat treatment, the microstructure of the control sausages was characterized by evenly distributed fat globules surrounded by a dense protein film and a strong gel matrix (Figure 4). The formed fat droplets and air bubbles were of regular shape and uniform distribution. Non-uniform distribution and formation of globules with different sizes and non-uniform

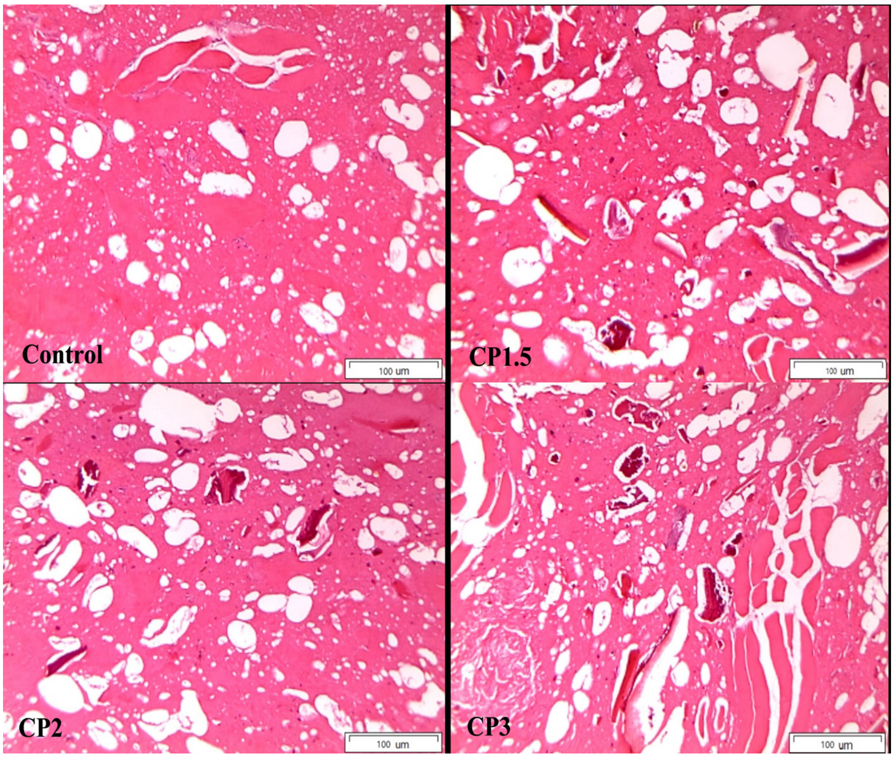

Figure 3. Microstructural images of batters stained with haematoxylin, x100 magnification

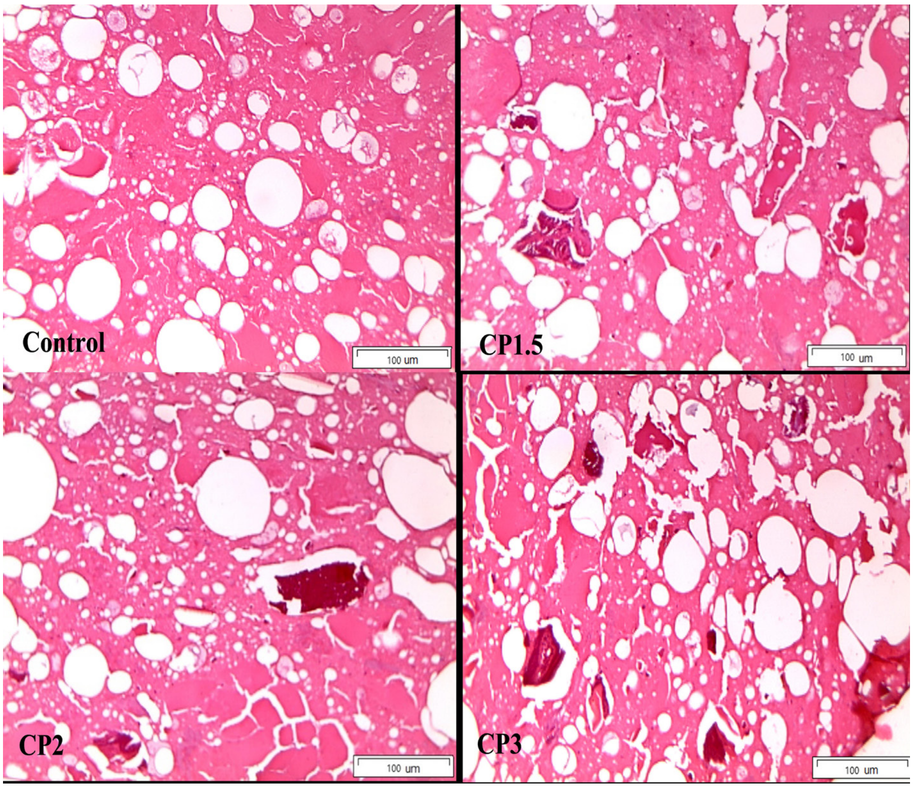

Figure 4. Microstructural images of cooked sausages stained with haematoxylin, x100 magnification

gel matrices were observed for the cooked sausages with CP (samples CP1.5, CP2 and CP3) (Figure 4)
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4. Discussion

The evaluated results oppose to reported an increase of pH value in raw filling mass for hybrid poultry products with the addition of CP (Vlahova-Vangelova et al., 2021; Kolev et al., 2022). At the same time, Ho et al. (2022a) and Cavalheiro et al. (2023) report no difference in the pH of cooked pork sausages with/without cricket powder. Our results could be explained by the used salting ingredients (nitrites, polyphosphates) which changed the buffer capacity of the batter. The found decrease of moisture in the cooked sausages (CP1.5, CP2 and CP3) was in agreement with the pH values, suggesting that furthering out the isoelectric point of meat proteins (5.3- 5.6) lead to an increase of water binding capacity (Kim et al., 2017).

The large amount of fat in meat products and the applied heat treatment favour the development of chain-radical processes of lipid peroxidation. Inhibition of these processes is essential for the safety of meat products (Botsoglou et al., 1994). Chitin, which renders insect exoskeletons, is known to possess antioxidant properties (Lucas-González et al., 2019; Psarianos et al., 2022). The antioxidant potential of cricket flour is another positive feature when using it as an additive in the meat industry. Its presence in the produced sausages was probably the reason for the reduced accumulation of secondary products of lipid peroxidation.

The observed deviations of colour (L*, a*, b*) were significantly affected by the lean pork meat replacement with CP. The colour of the batters and the cross-cut surface of cooked sausages were influenced by the originally darker colour of the cricket powder. Our results confirm the reported decrease in the lightness of the cross-cut surface colour in other hybrid meat products (Kolev et al., 2022; Cavalheiro et al., 2023). Other authors suggest that carbohydrates in insect powder/flours could promote Maillard reactions or enzymatic browning (Lucas-González et al., 2019).

The significant decrease in the redness (a*) of cooked sausages with a 10% replacement of lean meat is in agreement with the reported results by Ho et al. (2022a). Smarzyński et al. (2019) observed a green shade of the colour of cricket powder which could explain the decreased redness and increased yellowness (b*).

The observed greater plastic and structural strength are in agreement with the evaluated decrease in moisture content, the reported decrease of firmness by Ho et al. (2022a) and the increased dry and firm texture by Vlahova-Vangelova et al. (2021). The increased springiness/elasticity of meat products with added insect powders was reported previously (Ho et al., 2022a). This could be explained by the fact that the CP is characterized by a good water binding capacity sufficient to bind the added water and some of the free water found in the meat matrix. Leading to an increase in the hardness and springiness/elasticity of meat products (Kim et al., 2017).

The instrumental colour determination and texture profile analyses were in agreement with the sensory panel scores. Panellists reported a linear increase of firmness, chewiness and dryness of the cooked sausages with the increase of lean pork meat replacement with cricket powder. Also, an alteration in taste and smell was reported in cooked sausages with 7.5 and 10.0% replacement of lean pork meat. Cavalheiro et al. (2023) also report a bitter taste and aftertaste of hybrid meat products with cricket powder. Those findings confirm previous statements about hard and gummy texture, uncharacteristic darker colour and aftertaste in hybrid meat products (Smarzyński et al., 2019). All of the used additives in meat processing are potential sources of microbiological contamination and the cricket powder is no exception (Vandeweyer et al., 2017). A highly valuable property of chitin and its derivates is the antimicrobial effect which could not be confirmed by our results.

Scholliers et al. (2020) suggested that the gel matrix of the hybrid meat products will be affected due to the content of chitin and the different protein structure of insect flours. The microstructure images of both batters and cooked sausages showed a coalescence of air and fat droplets into larger agglomerates which could be due to their rupture by sharp chitin fragments. This phenomenon could also explain the harder texture of the cooked sausages with the replacement of lean pork meat with cricket powder.

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5. Conclusion

The presented results showed that the 5% replacement of lean pork meat with cricket powder affected in the most positive way the cooked sausages. Higher percent replacements led to a darker colour, hard, dry and chewy texture. The addition of cricket powder did not affect water activity and microbiological status, therefore did not compromise the safety of the cooked sausages. Further studies of the water and oil binding capacity of the cricket powder are needed. The stability of emulsions containing cricket powder should be studied for a better understanding of the mechanism of gel formation and overcoming texture flaws.

Conflict of interests

All the authors declare no conflict of interest.

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Evaluating essential micronutrient content, sensory acceptability & economic viability of formulated sesame (*Sesamum indicum*), pearl millet (*Pennisetum glaucum*) & groundnut (*Arachis hypogea*) food blend

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Keywords

Cereals; Sesame; Micronutrients; Food blending; Sensory evaluation; nutrition

Food blending involving legumes and cereals that has been widely explored, however, there is a paucity of evidence of the use of 'neglected crops' such as sesame oil seed in complementing cereals and legumes to alleviate micronutrient deficiency. A completely randomised design involving food blends as treatments and a cross-sectional survey for sensory acceptability of food blends evaluation was done. Proximate macro- and micro-nutrient composition of substrates and food blend mixes was done using the Association of Analytical Chemists (AOAC) method. Calcium, iron, and zinc were determined by a flame Atomic Absorption Spectrophotometer while potassium (K) was determined using a flame photometer. Sesame had significantly higher Ca (221.1mg/100g), K (149.1mg/100g), Fe (8.1mg/100g) and Zn (4.34mg/100g) compared to groundnuts. Food blends were formulated from sorghum, millet, sesame, and groundnuts. The food blend product had a significantly higher protein, fats, fibre, and micronutrient content compared to the control sample (Sorghum). Blend 5 yielded the best results in terms of K (83.56mg/100g), Ca (10.85mg/100g), Fe (8.79mg/100g) and Zn (0.79mg/100g) content as well as taste, flavour, and appearance although Zn content was relatively low. Sensory evaluation of the food blends showed that the taste, flavour, appearance, and texture were significantly different from the control sample. The blending of small grains with sesame significantly improves essential micronutrients especially Fe which met the WHO/FAO recommended dietary intake. Partial budget analysis shows that the rate of return was maximised by changing from Blend 4 to Blend 5 by 1164.7%. This study recommends the use of cheap, locally available sesame and millet to formulate food blends that can be used as complementary foods with high levels of micronutrients for children and adults.

1. Introduction

Undernourishment affects 11% of the global population, with a prevalence of 13% in low and middle-income regions (FAO, 2015). Deficiencies in micronutrients such as iron, zinc and vitamin A rank highest among the leading causes of death in developing countries (WFP, 2006). The Global Burden of Disease estimates show that among the 26 major risk factors of the global burden of disease, iron deficiency ranks ninth overall, zinc deficiency is eleventh, and vitamin A deficiency, is thirteenth (Grimm *et al.,* 2012).

There are about 1 billion people globally with iron deficiency anaemia and a further 1 billion with iron deficiency without anaemia (WHO and FAO, 2006). Undernutrition resulting from inadequate intake of nutrients and supplements is a prominent nutritional problem in Africa (Omoba et al, 2015) and is the major cause of Non-Communicable Diseases (NCDs). The prevalence of micronutrient deficiencies is high across all age groups but is much more pronounced among infants(MoHCC, 2014). Iron deficiency among children in rural areas stands at 37% and 27% for women (ZIMSTAT and ICF International, 2012). Nutritional deficiencies result in negative health outcomes for example stunting, wasting, obesity and increased incidence of infectious diseases).

Iron deficiency has a negative impact on the health and productivity of women (and of adult men) and in impairing the cognitive development in infants and young children (Darton-hill et al 2005). Zinc has recently been established as important for the treatment of diarrhoea but is likely to have a role, along with other micronutrients, in the prevention of both diarrhoea and respiratory diseases (Darton-hill *et al.,* 2005).

A positive calcium balance is also important throughout life, especially among children less than 2 years old, during puberty and adolescence, pregnant, lactating, and postmenopausal women, as well as elderly men.

In Zimbabwe, malnutrition in children is reported to be at 26% which is still very high compared to globally acceptable levels (UNICEF, 2020). In addition, only 4% of the children receive minimum acceptable diets (Global Nutrition Report, 2020). Micronutrient malnutrition is one of the most important health and welfare problems for infants, women of childbearing age, and young children in Zimbabwe due to inadequate food intake or illness. Common dietary patterns for children under 5 years are heavily characterized by 'Westernized' fast foods like potato fresh fried chips, red meats, pizza, and fried chicken Marume et al. (2022). Traditional dietary patterns, on the other hand, are characterized by a high intake of wild fruits, red meat, insects, worms, and maize meal in the form of porridge as well as thick porridge ('sadza' or pap) made from maize meal. These diets are mainly of high calorific value with very limited micronutrient content, resultantly consumption of these diets has made children more vulnerable to long-term conditions of stunting and wasting due to micronutrient deficiency.

In most developing countries, micronutrient malnutrition is common among children mainly because they are weaned abruptly into starchy foods that are bulky and deficient in essential macro and micronutrients (Charles, 2017). The formulation and development of nutritious complementary foods from locally and readily available cereals, oil seeds and legumes has received limited attention in many developing countries. This is despite the availability of drought tolerant and nutritious legumes such as sesame and groundnuts which can be used as food fortification vehicles to combat undernutrition. Sorghum, pearl millet, groundnuts and sesame are mostly grown in semi-arid regions of Zimbabwe and are regarded as cheap and readily available sources of food for many smallholder farmers (Rohrbach & Mutiro, 1997). Sesame is one crop that is rich in essential macro and micronutrients and is widely grown in Zimbabwe.

Despite legumes and small grains being highly nutritious, most rural communities are unaware of their potential in addressing undernutrition among poor resourced and vulnerable groups. There is potential for local communities to fully utilize these crops through value addition and food blending to enhance food security and nutrition. Due to the changing climatic conditions where rainfall patterns have become highly unreliable, the growing of sesame and groundnuts among resource-constrained communities has become common since these crops are stress-tolerant and do not require commercial inputs such as fertilizers and fertile soils. This is because over 60% of Zimbabwe's agricultural land lies in marginal regions where these crops are widely grown. Sesame is widely grown for commercial purposes mostly in the South-Eastern parts (Mwenezi district, Masvingo province) and North-Western parts (Mt Darwin and Muzarambani districts in Mashonaland Central Province) because of its high nutritional value whilst groundnuts are also widely grown by women for processing especially into peanut butter and oil for household consumption whilst surplus is also commonly sold.

There is also a pronounced paucity of literature and empirical evidence regarding the blending of native cereals, legumes, and oil seeds. These small grains have been primarily consumed as sole starchy diets with limited essential micronutrient content resulting in undernutrition. Food blending studies have not exhaustively targeted specific micronutrients such as zinc, iron, and calcium. It has primarily focused on proteins and other macronutrients such as energy and fats. Food blending has been widely reported and done using cereals and legumes, for example, pearl millet, maize, and sorghum (Muhimbula *et al.,* 2011); maize, roasted pea, and barley (Fikuri *et al.,* 2017) and maize, Bambara nuts, and groundnuts (Mbata *et al.,*2009). To the best of our knowledge studies that have considered 'neglected high-value crops such as sesame (oil seed) which is rich in micronutrients, especially zinc, calcium, and iron are non-existent.

This is because conventional complementary foods in Zimbabwe are costly and unaffordable to most consumers particularly those in rural communities hence the need for use of localised food blending initiatives using readily available food crops such as sesame and groundnuts. It is hypothesised that the nutritional composition of the formulated food cereal product is rich in micronutrients (iron, calcium, and zinc) and that it meets the FAO/WHO recommended nutrition guidelines as compared to sole cereal, oil seed and legume grains. The main objectives of this study were to: develop blended food cereal from sorghum, pearl millet, groundnuts, and sesame as well as to determine the proximate, mineral contents of each product, and to; evaluate the sensory attributes of the food blends.

2. Materials and Methods

2.1 Research design

The study used a mixed method approach whereby a quantitative research technique involving a controlled experiment and a qualitative strand involving a survey were combined in a single study. A simple Complete Randomized Design (CRD) was used during the allocation of six treatment combinations that were formulated. A cross-sectional survey consisting of a 100-member panel of consumers was employed to conduct a sensory evaluation of the food blends. The Organoleptic evaluation scored the taste, flavour, appearance, and texture of the formulated cereal blends.

2.2 Sampling and collection of raw materials

Simple random sampling was used to select farmers from which substrates were purchased from Mbare Agriculture Market in Harare. A total sample of 10 traders selling the selected raw materials were randomly selected. Three samples of each (sorghum, pearl millet, groundnuts, and sesame) (10kg) were bought and made into respective composite samples of sorghum, pearl millet, groundnuts, and sesame.

2.3 Statistical data analysis

The data on micro and macronutrient content were subjected to parametric analysis of variance (ANOVA) whilst the scores on organoleptic tests were analysed using the non-parametric test of Kruskal Wallis test using IBM SPSS version 26. The Least Significance Difference (LSD) at 5% was used for the post hoc test.

2.4 Formulation of the fortified food cereal

2.4.1 Roasting and Milling of Food Substrates

After cleaning the samples, a 5kg sample of sorghum and pearl millet was roasted/pre-heated at 70oC for 10 min and left to cool at room temperature. as similarly done by Muhimbula *et al.,* (2011. The cereals and legumes were then milled using a Deluxe Blender AE-099 and sieved through screen No. 1 for fine and uniform particles. Cereal grains and legumes instantized by roasting were coarse ground using a Deluxe Blender AE-099 and sieved through ISI Mesh No.1 (1 mm) to obtain a paste of uniform particle size.

2.4.2 Cereal-legume blends mixes

The mixing ratios were adopted with some modification as similarly used by Muhimbula et al (2011) in which the inclusion of cereals was from 50% to 90%

and that of legumes ranged from 10% to 30%. Six food blends were formulated by mixing different ratios of millet, sorghum, sesame and groundnuts and labelled as B1- B6. These treatments were replicated three times. These were compared to a traditional straight sorghum cereal used as a control. The treatments were supplemented with sugar as energy supplements to improve the sensory attribute of the formulated foods and some salt.

2.4.3 Preparation of fortified food cereal

The cereal formulation blends were prepared from composite flours using the standard recipe of flour -100g, water -300ml, and sugar -20g. About 250ml was boiled and 100g of each flour blend was added. The mixture was stirred to avoid lumping and cooked for 30-35mins until it thickens. The cereal was left to simmer for 5min before being served after adding 10g of sugar and 2g of salt to taste. Muhimbula et al (2011) used sugar and oil as additives to enhance the taste of the food blend in line with WHO dietary guidelines.

2.5 Proximate Analysis

Standard methods by the Association of Analytical Chemists (AOAC, 2000) were adopted to conduct proximate analysis. Standard methods by the Association of Analytical Chemists (AOAC) were adopted in the analysis of sesame, groundnuts, sorghum and pearl millet as similarly used in another study by Horwitz & Latimer (2005). Energy, moisture, ash and crude protein content were calculated as follows:

Energy in (Kcal) = 4 x protein value+ 4x carbohydrate value + 9 x fat value. The crude protein (CP) content of sesame, groundnuts, sorghum, pearl millet and the six food blend ratios were determined by the micro-Kjeldahl procedure (AOAC, 2000) using a conversion factor of 6.25. The moisture content of the finger millet samples was determined using oven-drying. The ash content of the sesame, groundnuts, sorghum, pearl millet and food blends was determined by oven drying at 550 °C for 8 hours, subsequently followed by decomposition in a muffle furnace.

2.6 Micronutrient analysis

The analytical method described by Bamigboye *et al.,* (2010) was adopted for the analysis of minerals in the samples. Potassium (K), Calcium (Ca), Iron (Fe), and Zinc (Zn) analysis was carried out using Atomic Absorption Flame Emission Spectrophotometry (AA-6701F). Certified Standard Reference Material Number BCR- 191 provided by the Institute of Reference Materials and Measurements of the European Joint Research Centre was used for the method and results validation (AOAC, 2005).

2.7 Sensory acceptability evaluation

Simple random sampling was done from a population

Table 1. Cereal-legume blend formulations for the fortified food product

Main Ingredients	Formulation name	Mixing ratios (in grams)
Sorghum, groundnut, Sesame	B1	60g Sorghum + 20g Groundnut + 20g Sesame
Pearl Millet, groundnut, Sesame	B2	65g Pearl millet + 25g Groundnut + 10g Sesame
Sorghum, Pearl Millet, groundnut, Sesame	B3	60g Sorghum + 20g Pearl millet + 5g Groundnut + 15g Sesame
Sorghum, Sesame	B4	80g Sorghum + 20g Sesame
Pearl Millet, Sesame	B5	70g Pearl millet + 30g Sesame
Pearl Millet, Sorghum, groundnut, Sesame	B6	60g Pearl millet + 10g Sorghum + 15g Groundnut + 15g Sesame
Sorghum	Control	100g

of 180 students in the Faculty of Science, Department of Food, Nutrition, and Family Sciences, University of Zimbabwe. A sample of 100 students was selected as panellists' using the hat method. Generally, these panellists were students in the age category of 24 – 35 years. In terms of gender, 33 students were females whilst 67 were males in their second and third year of university undergraduate degree studies. Half of the panellists were trained to conduct sensory evaluation whilst the other half were not trained as similarly done by Muhimbula et al (2011)

3. Results

3.1 Macro and micronutrient content in substrates used.

3.1.1 Carbohydrate content

Significant differences ($p<0.05$) were observed in the carbohydrate content of the oil seed and the legumes. There was no statistically significant difference ($p<0.05$) between the cereals (sorghum and pearl millet).

3.1.2 Protein content

There were significant differences in the level of protein ($p<0.05$) between the groundnuts, sorghum, pearl millet and sesame. However, there was also a significant difference between the protein content of groundnut (16.6g/100g) and sesame (18.8g/100gthere was no significant difference ($p>0.05$) in protein content between the cereals (see Table 2).

3.1.2 Crude fibre content

There was no significant difference ($p<0.05$) in crude fibre levels of all the samples tested. Pearl millet had the highest fibre content (Table 3) among the cereals while the legumes had groundnut with the highest fibre content (see Table 2).

3.1.3 Fat content

There were significant differences in fat content between cereals and legumes ($p<0.05$). A significant difference ($p<0.05$) was also recorded between groundnuts and sesame, with the highest amount of fat recorded in sesame (see Table 2).

3.1.4 Moisture content

All the samples had a low moisture content of less than 12g/100g (see Table 2). However, there were significant differences in moisture ($p<0.05$) across all samples of cereals and legumes analysed.

3.1.5 Ash content

Cereals had higher amounts of ash as compared to groundnuts and sesame samples.

3.2 Mineral composition of substrates used in food blend formulation.

3.2.1 Potassium content

There were significant differences ($p<0.05$) across all the samples in terms of potassium content (Table 3). The potassium content in sesame was high (149.69mg/100g).

3.2.2 Zinc content

There were no significant differences in zinc content among the three samples of groundnut, pearl millet and sesame ($p>0.05$). However, the only significant difference ($p<0.05$) in the amount of zinc among the samples was noted in the sorghum sample which recorded (2.35mg/100g). The raw samples showed substantial zinc content which is an essential micronutrient that could be complemented in the blended cereal food product developed.

3.2.3 Iron content

There was a significant difference ($p<0.05$) in iron content between the samples of raw materials analysed. Sesame had the highest amount of iron (8.05mg/100g). This meant that the inclusion of sesame in the food blend would contribute more in terms of iron content.

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Table 2. Macronutrients and essential micronutrients proximate composition of raw materials used in product formulation.

Sample	Ash (g/100g)	Moisture (g/100g)	Fat (g/100g)	Protein (g/100g)	Fibre (g/100g)	Carbohydrates (g/100g)	Potassium (mg/100g)	Zinc (mg/100g)	Iron (mg/100g)	Calcium (mg/100g)
Groundnut	$4.6^{a}\pm 1.53$	$6.50^{a}\pm0.05$	$40.50^{a}\pm14.5$	$25.5^{a}\pm0.99$	$9.95^{a}\pm 3.98$	$12.96^{a}\pm 0.85$	$174.1^{a}\pm24.6$	$3.24^{a}\pm0.8$	$4.47^{a}\pm0.5$	$7.84^{a}\pm0.04$
Pearl millet	$38.89^{b}\pm34.13$	$4.65^{b}\pm0.50$	$12.00^{b}\pm1.41$	$9.00^{b}\pm0.14$	$5.65^{b}\pm 3.93$	$41.83^{b}\pm 1.12$	$159.8^{b}\pm5.2$	$4.34^{b}\pm0.1$	$6.38^{b}\pm2.3$	$4.81^{b}\pm0.6$
Sesame	$4.44^{a}\pm 1.39$	$3.57^{c}\pm0.16$	$53.50^{c}\pm2.12$	$18.8^{c}\pm0.14$	$4.34^{c}\pm1.71$	$4.64^{c}\pm 0.75$	$149.7^{c}\pm19.7$	$4.34^{b}\pm0.8$	$8.1^{c}\pm1.1$	$221.1^{c}\pm27.8$
Sorghum	$29.78^{c}\pm22.99$	$7.53^{d}\pm0.76$	$10.50^{b}\pm1.41$	$8.55^{b}\pm0.07$	$3.07^{c}\pm 0.44$	$40.57^{b}\pm1.27$	$153.6^{d}\pm6.5$	$2.35^{c}\pm0.9$	$5.19^{d}\pm0.1$	$4.48^{b}\pm0.02$
P-value	0.31	≤0.001	0.01	≤0.001	0.24	0.01	0.013	0.029	0.168	<0.001
F-value	1.40	134.84	15.88	524.06	2.07	16.23	13.98	5.12	169.7	

Means having different superscripts within the same column are significantly different at $p\leq0.05$ +- =Standard deviation of the sample mean.

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Table 3. Macro and micronutrient content of the different cereal blends formulated.

Cereal Blend	Moisture (g/100g)	Ash (g/100g)	Fat (g/100g)	Protein (g/100g)	Fibre (g/100g)	Carbohydrates (g/100g)	Potassium (mg/100g)	Zinc (mg/100g)	Iron (mg/100g)	Calcium (mg/100g)
B1	$4.90^{a} \pm 0.14$	$3.28^{a} \pm 0.39$	$45.5^{a} \pm 2.12$	$19.69^{a} \pm 0.08$	$2.13^{a} \pm 0.14$	$24.53^{a} \pm 0.01$	$13.06^{a} \pm 0.00$	$0.65^{a} \pm 0.1$	$6.3^{a} \pm 0.1$	$11.79^{a} \pm 0.02$
B2	$3.95^{b} \pm 0.71$	$2.71^{b} \pm 0.04$	$41.0^{b} \pm 1.41$	$19.34^{a} \pm 0.04$	$1.58^{a} \pm 0.02$	$31.42^{b} \pm 0.01$	$11.5^{b} \pm 0.01$	$0.62^{a} \pm 0.01$	$7.43^{b} \pm 0.01$	$6.9^{b} \pm 0.02$
B3	$5.70^{c} \pm 0.14$	$5.37^{c} \pm 3.00$	$35.0^{c} \pm 1.41$	$14.72^{b} \pm 0.05$	$2.73^{a} \pm 0.01$	$36.84^{c} \pm 0.00$	$12.74^{a} \pm 0.02$	$0.59^{a} \pm 0.07$	$5.48^{a} \pm 0.01$	$8.98^{b} \pm 0.01$
B4	$6.15^{d} \pm 0.35$	$3.13^{a} \pm 0.17$	$36.0^{c} \pm 1.41$	$15.47^{b} \pm 0.13$	$3.62^{b} \pm 0.02$	$35.63^{c} \pm 0.01$	$14.17^{c} \pm 0.00$	$0.40^{b} \pm 0.11$	$4.72^{c} \pm 0.04$	$8.47^{b} \pm 0.07$
B5	$4.10^{e} \pm 0.14$	$3.47^{a} \pm 0.03$	$49.5^{d} \pm 2.12$	$20.12^{a} \pm 0.08$	$2.10^{a} \pm 0.01$	$20.71^{d} \pm 0.01$	$83.56^{d} \pm 0.25$	$0.79^{a} \pm 0.11$	$8.79^{b} \pm 0.04$	$10.85^{a} \pm 0.05$
B6	$4.40^{e} \pm 0.21$	$3.12^{a} \pm 0.17$	$49.5^{d} \pm 10.61$	$18.69^{a} \pm 0.08$	$2.34^{a} \pm 0.07$	$21.95^{d} \pm 0.01$	$12.31^{a} \pm 0.0$	$0.89^{c} \pm 0.04$	$7.02^{b} \pm 0.03$	$7.69^{b} \pm 0.04$
Control	$7.15^{f} \pm 0.21$	$2.37^{b} \pm 0.17$	$34.0^{c} \pm 2.83$	$8.55^{c} \pm 0.07$	$6.24^{c} \pm 0.01$	$41.69^{e} \pm 0.01$	$82.00^{d} \pm 0.32$	$0.63^{a} \pm 0.001$	$6.45^{a} \pm 0.03$	$2.78^{c} \pm 0.01$
P value	≤0.001	0.33	0.03	≤0.001	≤0.001	≤0.001	≤0.001	≤0.004	≤0.001	≤0.001

Means with different superscripts within the column are significantly different at p<0.05.
+- =Standard deviation of the sample mean is an estimate of how far the sample mean deviate the from population mean.

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Fig 1. Picture of the samples of the six food blends (B1-B6)

3.2.4 Calcium content

Sesame had the highest amount of calcium from the analysis (221mg/100g). However, the analysis showed that there was a significant difference ($p<0.05$) between the calcium levels of cereals versus the oil seeds with sesame recording the highest.

3.3 Proximate macro- and micro-nutrient analysis of the food blends

3.3.1 Moisture content

Significant differences in moisture ($p<0.05$) content across all the cereal blends were observed (Table 3). All the formulated blend samples had lower moisture content as compared to the control (100% sorghum flour).

3.3.2 Ash content

There was a significant difference ($p<0.05$) between the ash content of the food formulation blends except for B4, B5 and B6. The highest ash content was found in blend B3 (5.37g/100g) and the least ash content was in the control diet which had 2.37g/100g.

3.3.3 Fat content

There is relatively a high level of fat) in the cereal blends compared to raw samples (Table 3). In addition, statistically significant differences ($p<0.05$) in fat content between the different cereal blends were recorded. However, cereal blends B3, B4 and the control showed no significant differences ($p>0.05$). The food blends had significantly higher levels of fat across all formulations compared to the raw samples and were within the range of FAO/WHO recommended nutrition intake guidelines of 29-70g.

3.3.4 Fibre content

There was a significant difference ($p<0.05$) in content between the formulated cereal blends and the control (100% sorghum flour). However, the control flour (sorghum only) had the highest fibre (6.24 g/100g), while among the cereal flours; blend B2 had the lowest fibre content. Blend B4 had a relatively high fibre percentage (3.62 g/100g) as compared to the other formulated blends.

3.3.5 Protein content

Formulated food blend B5 had the highest protein content followed by B6 (Table 3). Of the formulated cereal blends, B3 had the lowest protein content among the samples analysed. The control (Sorghum only) sample had the lowest protein content of 8.55g/100g (Table 3) and the finding was significantly different ($p<0.05$) from the rest of the formulated blends.

3.3.6 Carbohydrate content

The formulated blended food cereal contained carbohydrates in the range of 20.71g/100g -36.84g/100g (Table 3). Values obtained in this study for carbohydrates (Table 3) suggest that carbohydrates may not be sufficient to meet requirements but the high level of fat in the product can supplement the low carbohydrate in the product.

3.4 Essential micronutrient composition of the fortified food cereal product

Results from Table 3 show that there was a significant contribution of essential micronutrients from sesame particularly Fe in the blended cereal food product. The level of Fe in the fortified cereal was within the FAO/WHO average recommended nutrient intakes of 3.9mg to 19.2mg for both children and adults. Sesame and pearl millet are assumed to be the significant Fe contributors based on their nutrient composition (Table 3). Relatively high quantities of potassium, iron and calcium were found in the formulated food cereal product samples compared to the control (100% sorghum flour). Results show that significant amounts of potassium of up to 83.56 mg/100g in cereal blend B5 were harnessed in the food blend product while the other blends ranged between 11 mg/100g and 13 mg/100g. However, Zinc content was low (0.4 mg/100g - 0.89 mg/100g) (Table 3) in the formulated cereal food product as compared to the raw materials (Table 3). Zinc, Calcium, and Potassium levels in the food blend were significantly lower than the recommended FAO/WHO nutrition guidelines.

Iron and calcium were found in relatively high quantities (4.72 mg/100g – 8.79mg/100g) in the blend food product than in substrates used during formulation whilst K was very low. The B5 and B6 cereal blends yielded the best results in terms of Fe, K, Ca, and Zn content. The two blends (B5 and B6) had high acceptability through taste; flavour and appearance although Zn content was relatively low (0.4 mg/100g – 0.89 mg/100g). Sesame had high concentrations of Ca and Fe in the raw materials and was the major source of the minerals in the food blend.

3.5 Sensory evaluation of the food cereal blends.

Blends B3, B1 and B5 were highly acceptable upon ranking by the panellists with percentage acceptance levels of 94%, 87% and 81% for semi-trained panellists, respectively) Sensory evaluation analysis was done on all the food cereal blends using the Kruskal-Wallis H test which showed that there was a statistically significant difference in taste, flavour, appearance, and texture between the different food cereal formulations. The Chi-square and p-values for appearance; taste, flavour and texture were $\chi2$ (6) = 86.271, p = 0.001 for appearance, $\chi2$ (6) = 146.86, p = 0.001 for taste, $\chi2$ (6) = 221.06, p = 0.001 for flavour, and $\chi2$ (6) = 101.76, p = 0.001 for texture (Table 4). The mean ranks for the different formulations are shown in Table 7. The highest mean rank for taste was noted on Blend 4 followed by B3 with the least in terms of taste being the control.

A post hoc LSD test for the mean scores between the formulations revealed that appearance blends B2, B4 and the control were significantly different ($p<0.05$) from the other blends. In terms of taste, B2 was significantly different ($p<0.05$) from all other blends. Blend B5 is recommended in terms of all the organoleptic tests (texture, appearance, taste and flavour).

3.6 Economic profitability of cereal-pulse food blending

A partial budget analysis shows the costs and benefits associated with a specific change in each food blending formulation. Results from Table 5 show that a change from formulation Blend 4 (B4) to Blend 5 (B5) gave a marginal rate of return of 1164.7% which was the highest amongst all the blends with Blend 3 (B3) being second best with 428% marginal rate of return. Therefore, the B5 blend is recommended since it is more profitable. This means that an additional unit increase in Pearl millet and Sesame in the blend (B5) recouped 1US$ and resulted in 11.647 more units of micronutrients (Fe, Zn, Ca and K) complimented.

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Table 4. Non-parametric test results of sensory evaluation of formulated food blends

Blend name	Taste	Flavour	Appearance	Texture
B1	319.14	325.56	339.11	294.14
B2	350.00	355.83	346.31	296.31
B3	402.07	530.45	458.82	306.19
B4	466.89	390.22	261.94	270.69
B5	377.89	385.04	394.36	435.88
B6	384.45	339.64	402.39	366.14
Control	153.04	123.02	250.56	484.13
P value	<0.001	<0.001	<0.001	<0.001

*mean ranks for Kruskal-Wallis non-parametric one-way analysis of variance.

Table 5. Partial budget analysis results for the profitability of the different food blends

Variables	Control	B1 Blend	B2 Blend	B3 Blend	B4 Blend	B5 Blend	B6
Sorghum (20 kg)	$8.00	$4.80	------	$4.80	$6.40	-----	$0.80
Pearl millet (20 kg)	-----	------	$5.20	$1.60	------	$5.60	$4.80
Groundnuts (20 kg)	-----	$3.20	$4.00	$0.80	------	------	$2.40
Sesame (20 kg)	-----	$5.00	$2.50	$3.75	$5.00	$7.50	$3.75
Labour	$50.00	$50.00	$50.00	$50.00	$50.00	$50.00	$50.00
Milling	$5.00	$8.00	$8.00	$10.00	$6.00	$6.00	$10.00
Packaging	$20.00	$20.00	$20.00	$20.00	$20.00	$20.00	$20.00
Total Variable Costs (TVC)	$83.00	$91.00	$89.70	$90.95	$87.40	$89.10	$91.75
Total Revenue	$120.00	$160.00	$160.00	$170.00	$140.00	$180.00	$170
Net Income (NI)	$37.00	$69.00	$70.30	$79.05	$52.60	$90.90	$78.25
Δ VC	-----	$8.00	-$1.30	$1.25	-$3.55	$1.70	$2.65
Δ Revenue	-----	$40.00	$0.00	$10.00	$30.00	$40.00	-$10.00
Δ NI	-----	$32.00	$1.30	$8.75	-$26.48	$38.30	-$12,65
Marginal Rate of Return (MRR)	-----	0.352	0	4.28	-5.276	11.647	-2.0367

*NB: The figures were calculated in US$ terms.

4. Discussion

4.1 Macro and micronutrient content of substrates

There were no significant differences (p<0.05) in carbohydrate content between groundnut and sesame. This could be because sesame and groundnuts have high oil content that is easily converted into energy. These results were however lower than those reported by Durojaiye *et al.,* (2016), of 65 – 75g/100g carbohydrate in sorghum mainly because cereals are prime energy sources compared to legumes and oil seeds.

Carbohydrate content was lower than values reported by Bamigboye *et al.,* (2010), that is 21.4g/100g ± 0.12 and those reported by Oyerinde, (2017) of 15.2 g/100g. The carbohydrate content of groundnuts was lower than that of those reported by Temba *et al.,* (2016) of 19g/100g. Rehman *et al.,* (2016), postulated that cereals are rich in carbohydrates and low in protein, a result that is similar to that of Muhimbula *et al.,* (2011) recorded. Temba *et al.,* (2016) concluded that cereals have significant amounts of fibre and other minerals as compared to other crops as similarly reported in this study hence the need to include cereals in the complementary food blend. These results are in line with other findings by Ogungbenle & Onoge, (2014) where sesame had fat content ranging over 40%. Moisture content was reported to be generally high in substrates hence the need for heat treatment of substrates to improve palatability and shelf life. The lower the moisture content, the longer is storage stability (Kindiki*et al.,* 2015). The value for ash content obtained in sesame is comparable to those reported by Bamigboye *et al.,* (2010), while the values for ash in groundnuts were higher than findings by Temba *et al.,* (2016). The level of ash constitutes the component where minerals are harnessed.

These results were comparable to findings by Bamigboye *et al.,* (2010). Potassium levels in cereals were lower than those reported by Omoniyi & Abdulrahman(2018) which ranged between 366.67% for pearl millet and 400.00% for sorghum. With regards to sesame, the amount of zinc found in the sample analysed was not significantly different from those obtained by (Bamigboye *et al.,* 2010) who recorded 4.46mg/100g in raw sesame while this study recorded 4.34mg/100g (Table 4). Pearl millet had a significantly high amount of iron (6.38mg/100g) among the cereals (Table 4).

The findings however were slightly different from Bamigboye *et al.,* (2010) who recorded 3.83 ± 0.75 mg/100g of iron in a sample of raw sesame. This result could be attributed to the different varieties of cereals, legumes and oil seeds used. Sesame contributed the highest level of micronutrients (Fe, Ca & Zn), this justifies the inclusion of sesame in the formulation of complementary diets for both children and adults. The findings in this study were similar to findings reported by Bamigboye *et al.,* (2010) who recorded (281.1 ± 0.68mg/100g) calcium level in raw sesame. The raw materials proved to contain significant amounts of calcium and if used in the formulation of food cereal there is potential to harness Ca into the final product. Nedumaran *et al.,* (2015) also concluded that legumes play a vital role as sources of micronutrients such as, calcium, iron, phosphorus, and other minerals necessary to combat undernutrition.

4.2 Macro and micronutrient content of food blends

The food blend formulation substrates had higher moisture which was slightly higher than that of the formulated cereal food blends. The roasting of cereal ingredients done during product formulation could have resulted in the lower moisture content of the cereal food product (Muhimbula *et al.,* (2011); Fikuru et al. (2017)). The low moisture content of food samples is a desirable phenomenon since microbial activity is reduced at low moisture levels. Similar results were obtained by Sampath, (2015) who concluded that roasting improves colour, extends shelf life, enhances flavour and reduces the anti-nutrient factors of cereals and legumes. The highest ash content was found in blend B3 (5.37g/100g) and the least ash content was in the control diet which had 2.37g/100g. This was is at variance from findings by Sampath, (2015) who reported that the ash content of raw and roasted maize flours was 1.23g/100g and 1.51g/100g respectively.

The food blends had significantly higher levels of fat across all formulations compared to the raw samples and were within the range of FAO/WHO recommended nutrition intake guidelines of 29-70g. High fat content is attributable to the inclusion of oil seed (sesame) and groundnuts in this study as similarly reported by Fikuri et al (2017) where fats were in-

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creased in the food blend as the proportion of roasted pea to maize and malted barley was increased. Fats contribute substantially to the energy value of foods as well as provide essential fatty acids (Chukwuma *et al.,* 2016). The formulated fortified cereals showed an overall low fibre content ranging from 1.58 g/100g to 6.24 g/100g as similarly reported by Solomon, (2005) who concluded that compounded diets of cereal and legumes had fibre content of less than 10g/100g. Similarly, Ezeokeke & Onuoha, (2016) recorded similar quantities of fibre in a cereal and legume flour blend. However, Solomon (2005) reported findings which are at variance from this study probably due to the differences in varieties and geographical location of the sources of substrates.

4.3 Macro and micronutrient content of formulated food product

The lower values for zinc content in the product could have been due to some loss of the minerals during the processing of the flours and the presence of anti-nutritional factors such as phytate and tannins as similarly reported by Gibbs et. al., (2011). There is a need therefore to complement the zinc content in the food blend using commercially available zinc fortification vehicles and supplements. Consumption of nuts, seeds, beef, and milk products can augment zinc levels in the diets of infants and adults.

Iron and calcium were found in relatively high quantities (4.72 mg/100g – 8.79mg/100g) in the blend food product than in substrates used during formulation whilst K was very low. This is mainly attributed to the high levels of Fe and Ca identified in sesame. This result could also be because of heat treatment and further processing which reduced the anti-nutritional factors such as phytates and tannins (Ezeokeke & Onuoha 2016) thereby releasing more minerals in the food blend. The low levels of zinc in the food blend product could be because of the heat treatment that denatures the essential mineral.

4.4 Sensory acceptability of food blend

Blends B3, B1 and B5 were highly acceptable upon ranking by the panellist with percentage acceptance levels of 94%, 87% and 81% for semi-trained panellists, respectively). The highest mean rank for taste was noted on Blend 4 followed by B3 with the least in terms of taste being the control (sorghum). This is mainly because B3 and B4 blends constitute both groundnuts and sesame which improves the taste of food as similarly reported by Ezeokeke & Onuoha (2016) in a study involving feeding older infants with maize-soya bean and banana complementary food in Nigeria. Oil seeds (sesame) and legumes (groundnuts) improve the smoothness of the food blend and delay the swelling of the starch granules thus restricting too much binding of water to the starch (Muhimbula *et al.,* 2011). In addition, oils and fats from sesame and groundnuts improve the flavour/taste of food (Fikuri *et al.,* 2017) as similarly observed in blends B3, B4 and B5. Unlike the other blends, the control (Sorghum) alone yielded the least score in terms of taste as expected because generally sorghum alone is not palatable, but it improves with an increase in concentration of legumes and oil seeds. Blend B5 is recommended in terms of all organoleptic tests (texture, appearance, taste, and flavour). These results are consistent with Mbata et al. (2009) who reported high overall acceptability of complementary processed food formulated from maize–Bambara and ground nut.

4.5 Economic viability of formulated food blend

The higher marginal rate of return associated with food blend B5 makes economic sense in that it had the highest ratio (30g) of sesame which has high nutritional value. Likewise, Pearl millet which is rich in minerals had the highest concentration (70g) compared to other blends. These findings are similarly echoed by Ezeokeke and Onuoha (2016) in which the cost of producing the maize-soya bean and banana complementary feed formulated is about N50-N100 (US$0.50 cents) per gram cheaper than commercially available cereal (Nestle Cerelac) in a study involving feeding older infants in Nigeria. Hence complementary food blends can be fed to infants at a much cheaper rate compared to commercially available cereals and mineral supplements.

5. Conclusions

Empirical evidence from the study proves that legumes such as sesame and groundnuts contain high levels of proteins, fats and micronutrients as compared to sole cereals (pearl millet and sorghum). Similarly,

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cereals dominated in carbohydrate levels. The analysis of essential micronutrients in legumes also supported the underlying hypothesis that legumes are rich in micronutrients as compared to cereals. The food blend product has a higher content of micronutrients as compared to sole cereals as previously hypothesised that cereals fortified with sesame and groundnuts have significantly high micronutrients relative to sole legume and cereal food crops. However, potassium was low in the formulations as compared to the control while calcium, iron and zinc were higher in the food blend than in the substrates. The amounts of micronutrients recorded in the blended food product were found to be within the recommended WHO daily consumption levels. The B5 formulation consisting of millet and sesame only emerged as the best blend for optimising essential micronutrients (K, Fe, Ca) in cereal-based diets. Sensory evaluation of the food blends shows that blends B3, B5 and B6 scored high on taste, flavour and appearance and were preferred more by consumers. Sesame is a rich crop in both macro and micronutrients hence a good source of complementing low micronutrient cereal-based diets. A partial budget analysis showed that a change from formulation Blend 4 (B4) to Blend 5 (B5) gave a marginal rate of return of 1164.7%% which was the highest amongst all the blends with Blend 3 (B3) being second best with 428% marginal rate of return.

This study recommends the use of cheap, locally available sesame and millet to formulate food blends that can be used as complementary foods with high levels of micronutrients for children. There is also an urgent need for policymakers to support and scale up household-level value addition and food blending initiatives to address the challenges of undernutrition. Promotion of the use of small grains and legume food crops in household food blending should be prioritised targeting rural communities. Further studies can explore the bioavailability of the blended food product, analysis of anti-nutritional factors and evaluation of the shelf life of the blended food product.

Declaration of conflict of interest

Authors have no conflicts to declare.

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The impacts of different pea protein isolate levels on Physiochemical, textural, and sensory evaluation of ready-to-cook plant-based minced meatballs from oyster mushroom

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Keywords

Pea protein isolate; Plant-based minced meatball; Texture; Nutritional value; Sensory evaluation.

The effects of different ratios of pea protein isolate (PPI) (5%, 10%, 15%, and 20% w/w) on ready-to-cook plant-based minced meatballs made from oyster mushrooms were investigated. Increasing the PPI ratio resulted in higher protein content, while values for lightness (L*), yellowness (b*), hardness, adhesiveness, and chewiness decreased compared to the control. Sensory evaluation indicated that all treatments received overall liking scores ranging from 6.50 to 7.23. The study demonstrated that incorporating 10% PPI led to optimal production of plant-based minced meatballs with high protein content (10.79 g/100 g), low-fat content (2.08 g/100 g), and an overall liking score exceeding 7.0, indicating acceptability. These findings confirm that PPI is a practical alternative to meat proteins for producing plant-based meat products.

1. Introduction

The Food and Agriculture Organization (FAO) has highlighted a concerning report on global hunger. In the year 2020, an estimated 720 to 811 million people, equivalent to one in three individuals worldwide, experienced hunger, as stated by the FAO. This alarming statistic emphasizes the pressing issue of food insecurity. Furthermore, with the projected global population reaching 9.80 billion by 2050, the challenges related to food security are expected to intensify (FAO, IFAD, UNICEF, WFP, & WHO, 2021). However, there is a limit to the resources available for food production, and overuse of these resources will have unfavorable effects on food production. This in turn has increased the search for plant-based protein ingredients to replace animal-based proteins (Zhu & Begho, 2022). There is a clear consumer trend towards plant protein-rich diets, driven by the recognized sustainability and health benefits of plant-based eating, as well as the need to address the environmental impact of animal agriculture (Gravel et al., 2023). In addition, the United Nations has recommended a significant decrease in the consumption of red meat and a transition towards plant-based diets to promote a healthy and sustainable diet for the increasing global population (United Nations, 2022).

Consequently, plant-based meat products have garnered substantial attention as alternatives to traditional meat due to their positive impact on the environment, human health, and animal ethics (Yang et al., 2023). According to the report by Grand view research (2023), the global plant-based meat market size had a market value of USD 4.40 billion in 2022 and is expected to grow at a compound annual growth rate (CAGR) of 24.9% from 2023 to 2030 (Fig. 1). Especially, meatballs, burgers, and meat patties are highly accepted and consumed worldwide (Turgut et al., 2017). Most of these food items are made with beef as their primary ingredient. Oostindjer et al (2014) reported that red meat contained a high content of fat, especially saturated fat. Consuming more than 500 grams of red meat per week increases the risk of various diseases, including cancer, obesity, and cardiovascular disorders. Yiannakou et al. (2022) reported that individuals with high intakes of red meat have an increased association between colorectal cancer risk and saturated fatty acids (SFAs) and monounsaturated fatty acids (MUFAs), which are the primary types of fat found in red meat. Therefore, plant-based meat products are an important alternative for individuals who prioritize their health. Plant-based meat ingredients such as mushrooms, soy protein, pea protein, wheat gluten, and insects are processed in combination with flavoring additives to produce a final product that tastes like meat (Kyriakopoulou et al., 2019; Sha & Xiong, 2020). The oyster mushroom (Pleurotus eryngii) is highly popular and in high demand in many countries, primarily due to its meaty texture, long shelf life, firm flesh, cap and stem consistency, delightful taste, remarkable flavor, and ease of cultivation (Sardar et al., 2022). Nakpatchimsakun et al (2023) reported that oyster mushrooms are a good alternative for plant-based minced meatball production due to their richness in sulfur-containing amino acids and fiber. They can help achieve a meaty flavor and texture, which are widely accepted by consumers.

Moreover, mushrooms are rich in biological activity components, which can provide many health benefits, including an antitumor property (He et al., 2020). However, some studies consider that replacing more than 60% of meat with plant-based meat can cause a deficiency of nutrients (van der Weele et al., 2019), especially protein (Lima et al., 2023). Therefore, a challenge in creating plant-based minced meatballs with both high protein content and satisfactory meat-like characteristics involves the development of meat alternatives using ingredients like mushrooms, pea protein, and other plant-based sources.

Pea (*Pisum sativum* L.) is one of the most abundant and sustainable alternative sources of protein, especially in good quantities of most of the essential amino acids (Das et al., 2023). Pea has been a promising source of plant-based protein. It is commonly utilized in various food applications as protein isolates produced from pea flour through protein solubilization and concentration processing steps (Boye et al., 2010). Pea protein isolate (PPI) has the potential to be used for plant-based meat production because of its low cost, availability, low allergenicity, and high nutritional value (Lam et al., 2018). In addition, pea cultivation has a lower greenhouse gas intensity per unit of nutritional density compared to animal foods; its cultivation requires a negligible amount of nitrogen fertilizer, and has a less negative impact on biodiversity due to low pesticide use (Sajib et al., 2023).

In this context, the main objective of this experiment was to investigate the influence of different pea protein isolate levels on the qualities to improve the physicochemical properties, texture, and sensory evaluation of ready-to-cook plant-based minced meatballs made from oyster mushrooms. The findings of this study could have practical applications in the food industry in the development of healthier plant-based meat and promote a sustainable environment.

2. Materials and Methods

2.1 Preparation of raw materials

Pea protein isolate was purchased from Krungthepchemi (Bangkok, Thailand) (Composition: 80g protein, 6.90g fat, 5.60g carbohydrate, and 4.40g dietary fiber, per 100g). Beef meat (red meat)and king oyster mushrooms were purchased from a supermarket in Bangkok. The raw materials were ground using a meat mincer with a 6 mm center square hole knife (SIR1-TC8 VEGAS, Italy) and stored at -18°C.

2.2 Plant-based minced meatball production

The plant-based minced meatballs (PBMM) were pro-

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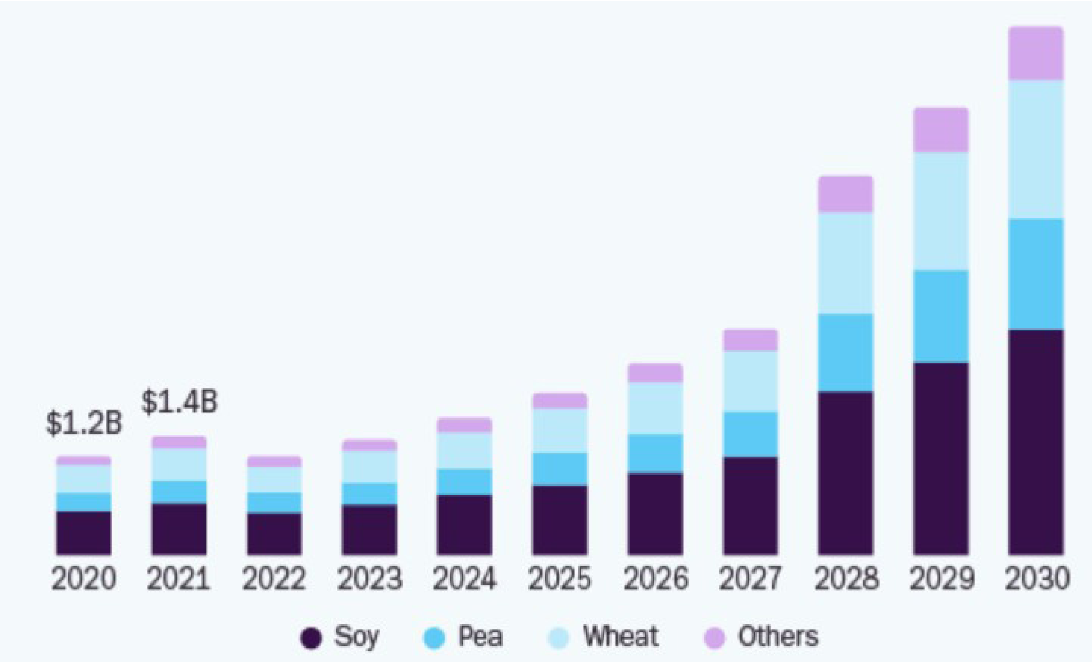

Figure 1. The global plant-based meat market size, 2020-2030 (Source: Grand View Research, 2023).

duced following Nakpatchimsakun et al (2023), which was used to produce plant-based minced meatballs. Each composite ratio contained ice water (~4°C) 57%, 18% potato starch, 3.50% vegetable oil, 0.20% calcium chloride, 0.30% salt, 2.50% baking powder, and 1.50% moisture content (MC) in order to make 100g of ground oyster mushroom. All ingredients were homogenized in a food processor for 3 min at low speed; deionized water was used throughout the study. This step was carried out to fully hydrate the sample. Pea protein isolate (PPI) at four different ratios (5, 10, 15, and 20% w/w) was added to the samples. The commercially available plant-based minced meatball was served as a control. The ground raw materials in each group were mixed and emulsified using a refrigerator at a temperature of 0°C–4°C for 3 hours. This temperature range ensures optimal emulsification for producing meatballs. Subsequently, the mixture was shaped into round forms with a diameter of 2.50 cm and a weight of 15 g. It is important to note that the internal end-point temperature of the minced meatballs should not exceed 4°C. The minced meatballs were pan-fried in canola oil (preheated to 180°C) for 5 min. The internal end-point temperature (75°C) of the minced meatballs was measured by inserting a digital thermometer with an accuracy and resolution of ±1°C and 0.10°C, respectively. After cooking, the minced meatballs were placed on a paper towel for 10 min to remove excess oil from their surface. Before further analysis, all minced meatballs were naturally cooled at room temperature (25°C ±2°C) for 15 min (Wang et al., 2023).

2.3 Instrumental analysis of samples

2.3.1 Analysis of moisture and protein content

The moisture and protein content were measured in triplicate according to the methods of the Association of Official Analytical Chemists (AOAC, 2019). Moisture content was measured according to the AOAC method 952.08. Samples were dried in a hot air oven (Binder, FD 115, Germany) at 105°C for 24 hours or until constant weight comes, and moisture content was estimated by comparing the mass before and after drying. Protein content was determined using the macro-Kjeldahl method (method 992.15, N ×6.25).

2.3.2 Color analysis

The color of the fried samples was measured directly on the surface of meatballs using a Hunter Lab apparatus (Hunter Lab, UltraScan PRO, USA) (Wang et al., 2023), which measured three parameters: L*(lightness), a*(redness) and b*(yellowness) values. The L*, a*, and b* values were recorded as the average of ten measurements.

2.3.3 Texture profile analysis (TPA)

Texture profile analysis was determined according to Nakpatchimsakun et al. (2023). Briefly, a compression test was performed on a TA.XTplus Texture Analyzer (Stable Micro Systems, TA.XT PlusC, UK) fitted with a 100 mm cylindrical probe (P/100) set to 50% depth and load cell of 50 kg. The cooked samples were cooled to room temperature for 30 min and measured for pre-test speeds 1.0 mm/sec, test speeds 2.0 mm/sec, and post-test speeds 5.0 mm/sec, respectively, the compression value was 50%, trigger force type was automatic, and the triggered ability was set at 5.0 g. The following parameters were quantified; hardness, adhesiveness, cohesiveness, springiness, and chewiness. Results are the mean of at least ten reproducible runs for each treatment per batch.

2.3.4 Sensory analysis

The sensory evaluation of fried samples was carried out at the Department of Applied Science, Suan Sunandha Rajabhat University, Bangkok, Thailand, using a sensory evaluation questionnaire. Samples were served to 50 untrained panelists experienced in the sensory evaluation of foods. The inclusion criteria were panelists who were between 18 and 60 years old, were regular minced meatballs, plant-based meat consumers, and had no history of food allergy. Panelists with asthma or an allergy were excluded. The samples were served on disposable paper plates; the samples were pre-coded with three random digit codes and presented to the panelists in random order at a temperature of approximately 40°C. Panelists were provided with drinking water to clean their mouths between consecutive tastings. They were instructed to first visually evaluate the acceptability of product appearance and color and then to bite and swallow each sample before scoring it for odor, taste, texture (firmness), and overall liking using a 9-point hedonic scale (1 = disliked extremely, 5 = neither like nor dislike, and 9 = like extremely) according to Nakpatchimsakun et al. (2023).

2.3.5 Analysis of nutrition values

Based on the results from step 2.3.4, a nutritional analysis was measured in triplicate to compare nutritional differences between the commercially available beef minced meatball, plant-based minced meatball, and the developed plant-based minced meatballs according to the Association of Official Analytical Chemists (AOAC, 2019). Total energy, moisture, total fat, protein, carbohydrate, dietary fiber, ash, and sodium (Na) were included. The moisture and protein content (g/100 g) was the same procedure as described in the previous method section 2.3.1. Crude fat content (g/100 g) was measured in accordance with method 948.15 by extracting a known weight of the sample with petroleum ether, using a Soxhlet apparatus. In determining ash content (g/100 g), samples were burned at 550°C±25°C for 4 h in a muffle furnace in accordance with method 945.46. Dietary fiber (g/100 g) was measured using the Enzymatic-Gravimetric Method following method 985.29. Sodium content was determined through extract preparation and titration in accordance with method 985.35. The results were expressed as mg NaCl/100 g of samples. Carbohydrates and Total energy were calculated based on Equations (1) and (2).

$$\textbf{Carbohydrate (g/100 g)} = 100 - \textbf{Protein} - \textbf{Fat} - \textbf{Fiber} - \textbf{Ash} \quad (1)$$

$$\textbf{Total Energy (kcal/100 g)} = (4 \times \textbf{g protein}) + (4 \times \textbf{g Carbohydrate}) + (9 \times \textbf{g Fat}) \quad (2)$$

2.3.6 Data analysis

Three batches of each treatment were performed, and each sample was measured in triplicate unless otherwise stated. The data were expressed as means ± standard deviations of each sample. The data were analyzed using analysis of variance facilitated by the IBM SPSS® version 23 software (IBM SPSS Inc.; USA). Duncan's multiple range test was used to determine multiple comparisons of mean values with a statistically significant difference established at $p < 0.05$.

3. Results and discussion

3.1 Moisture and protein content

The moisture and protein content of the plant-based minced meatball with different pea protein isolate (PPI) levels are shown in Table 1. There was a significant difference between the different treatment levels

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Table 1. Moisture and protein content of the plant-based minced meatball with different pea protein isolate levels

Treatments	Moisture, % wb	Protein, % db
Control	67.300.30^{a}	8.210.03^{e}
5% PPI	58.250.50^{b}	9.150.02^{d}
10% PPI	56.811.20^{bc}	10.60 0.00^{c}
15% PPI	55.84 0.90^{c}	12.600.06^{b}
20% PPI	52.322.00^{d}	15.800.30^{a}

PPI = pea protein isolate; Control = the commercially available plant-based minced meatball
wb = wet basis; db = dry basis
Mean ± SD with different lowercase superscripts in each column are significantly ($p<0.05$) different

of moisture and protein content ($p<0.05$). Moisture content is an important factor that can affect the storage properties of food, as it is the factor most strongly linked to microbial growth (Vera Zambrano et al., 2019). The results showed that samples with the addition of PPI had a lower moisture content than that of the control. The lowest moisture content belonged to PPI at 20% w/w, while the highest value was observed at 5% w/w. The increase in PPI led to a decrease in the final moisture content of the final product. This could have been due to the higher water-holding capacity of PPI (Lee et al., 2023). Protein was the main constituent of the PPI (80g/100g), therefore it determined these properties. Water binds to hydrophilic groups of protein side chains via hydrogen bonds. Thus, moisture content depends on the water-holding capacity of proteins (Kaleda et al., 2021). Lee et al. (2023) also reported the same finding. The moisture content of meat analog products decreased within the PPI ratio range of 55.6% to 59.5%. Protein content is an essential macro-nutritional measure for assessing plant-based meat products (Yang et al., 2023). By increasing the PPI, the protein content increased from 9.15% (5% PPI) to 15.80% (15% PPI) on a dry basis (db), respectively. These values were notably higher compared to the commercially available plant-based minced meatball. Because the PPI is an excellent source of protein. Pea proteins mainly exist as globulins (65–80%), which are also the main components in pea protein isolate products (Meng & Cloutier, 2014). Hence, the use of PPI in the food industry for the formulation of new food products is very interesting because of its nonallergenic characteristics, despite its high nutritive value and good functional properties (Meng & Cloutier, 2014). This study revealed that pea protein isolate can be a favorable ingredient for the development of plant-based minced meatballs and other novel food products that offer health benefits to consumers.

3.2 Color

Color is an important factor in assessing the acceptability of plant-based meat products. According to the results in Table 2, there was a significant difference ($p<0.05$) in the lightness (L*), redness (a*), and yellowness (b*) of the plant-based minced meatball with varying levels of PPI. The addition of PPI resulted in higher L* and b* values for the plant-based minced meatball compared to the control, while the a* value decreased. The control sample had a reddish-brown color, while the plant-based minced meatball with added PPI had a brown color, as shown in Fig. 2. Because the control sample is a commercially available plant-based minced meatball made from soy protein containing protein as a component, the color change occurs due to a Maillard browning reaction involving amino acids and reducing sugars. The heat from the frying process acts as an accelerator for this reaction (Nakpatchimsakun et al., 2023). In contrast, the experimental plant-based minced meatball made from oyster mushrooms, which have a lower protein content compared to soy protein, exhibits a lighter appearance compared to the control sample. However, it should be noted that the increase in PPI can significantly enhance the lightness of the resulting plant-based minced meatball product. The 20% PPI showed the highest lightness, followed by 15%, 10%, and 5% PPI, respectively. The high protein content of PPI may lead to an increase in the size and quantity of internal air cells in the product. This is attributed to the swelling of proteins caused by the uptake of water and accommodation between the protein chains, resulting in the formation of air cells within the product and contributing to its enhanced lightness (Muhialdin & Ubbink, 2023). This can be attributed to the protein's functionalities, such as emulsification, foaming, and water-holding capacities, which play important roles in the formation of the meat structure (Sajib et al., 2023). Similar effects of an increase in pea protein isolate-amylose/amylopectin on lightness and yellowness have been reported for pea protein-based meat substitutes (Chen et al.,)

3.3 Texture properties

The texture is one of the most important qualities of plant-based meat products (Xia et al., 2022). To determine the effect of PPI on plant-based minced meatballs, the hardness, adhesiveness, cohesiveness, springiness, and chewiness of samples were tested by a texture analyzer. Hardness relates to the maximum force required to compress the sample, adhesiveness is the amount of work required to overcome the attractive forces of the food to another contact surface, cohesiveness indicates the strength of internal bonds, springiness is how much the sample recovers after deformation, and chewiness is the energy required to chew solid food until it can be swallowed (Chandra & Shamasundar, 2015). As illustrated in Table 3, increasing the PPI ratio resulted in a decrease in hardness, adhesiveness, and chewiness compared to the control. Proteins are the main components contributing to the three-dimensional internal structure of meat products, which are held with hydrophobic interactions and stabilized by hydrogen and disulfide bonds (Kaleda et al., 2021). Therefore, using oyster mushrooms

Table 2. Color parameters of the plant-based minced meatball with different pea protein isolate levels

Treatments	L*	a*	b*
Control	21.401.20^{d}	4.420.40^{a}	6.400.50^{c}
5% PPI	23.520.92^{c}	1.600.20^{c}	6.900.50^{c}
10% PPI	25.001.00^{b}	2.22 2.30^{b}	8.230.30^{b}
15% PPI	25.511.10^{ab}	2.302.30^{b}	8.700.73^{ab}
20% PPI	26.350.44^{a}	2.300.13^{b}	9.100.32^{a}

PPI = pea protein isolate; Control = the commercially available plant-based minced
L*= lightness; a*= redness; b*= yellowness
Mean ± SD with different lowercase superscripts in each column are significantly (p<0.05) different

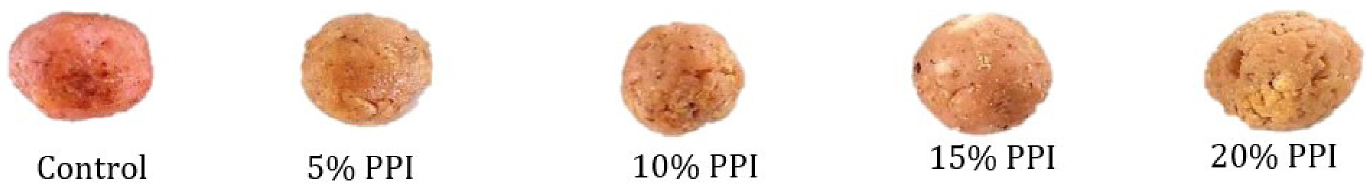

Figure 2. Color of the commercially available plant-based minced meatball (control) and plant-based minced meatball with different pea protein isolate levels (5%, 10%, 15%, and 20%, w/w).

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in plant-based minced meatballs results in a meaty texture that is lower compared to using soybeans as a meat substitute. However, adding PPI can indeed help improve the texture of plant-based minced meatballs made from oyster mushrooms. Due to the presence of PPI, it can fill the interstitial spaces within the network (Alves & Tavares, 2019). Especially, incorporating 15% to 20% PPI can result in hardness, cohesiveness, springiness, and chewiness that closely resemble those of the most well-controlled sample. The results agree with Xia et al. (2022), who found that the hardness, springiness, and chewiness of meat analogues decreased by adding pea protein powder. A similar observation was found in fibrous meat analogs from oat-pea protein blends by Kaleda et al. (2021). Furthermore, Mena et al. (2020) also reported that hardness is an important determinant for consumers and producers in assessing the texture of meat products, where lower hardness is generally preferred by elderly consumers. These results suggested that can be used as a tenderizer (texture modifier) in PPI plant-based meat for the elderly by reducing the force required to masticate. This is because the elderly prefer soft and easy-to-swallow foods over hard and chewy foods due to their weakening of teeth and jaw muscles (Lee et al., 2023). Similar to previous studies, the involvement of pea proteins considerably decreased the chewiness of meat analogs (Xia et al., 2022).

3.4 Sensory evaluation

The PPI was the most important parameter affecting the sensory liking of plant-based minced meatballs. Table 4 shows that overall liking scores for all PPI ratios slightly decreased ($p<0.05$) compared to the control, whereas appearance, odor, taste, and texture (firmness) scores had no significant differences ($p>0.05$). The sensory evaluation results of plant-based minced meatballs with different ratios of PPI indicated that acceptability scores of all sensory attributes ranged from 6.43-7.23 (like slightly-like moderately). This demonstrates the acceptance of consumers towards the product. Giménez et al. (2008) reported that an average value of 6 on a 9-point hedonic scale is the minimum acceptability limit for consumers liking a product. Additionally, it was also observed that the plant-based minced meatball with 5%-10% PPI tended to increase the overall liking scores more than those with 15%-20%. The sensory liking of the PPI-meat product followed a similar trend as the taste scores.

Grasso et al. (2019) also reported that no significant differences in taste attributes were observed in the hybrid sausage containing PPI. A similar observation was found in taste and odor liking scores of fibrous meat analogs from oat-pea protein blends (Kaleda et al., 2021). Besides, Giménez et al. (2008) established a minimum acceptability limit for consumer liking of a product using an average value of 6 on a 9-point hedonic scale. This might have been due to the combination of oyster mushroom and pea protein isolate, which provides a meat-like flavor. He et al. (2020) and Nakpatchimsakun et al. (2023) reported that oyster mushrooms were rich in sulfur-containing amino acids, which helped to achieve a meaty flavor. Pea proteins are primarily utilized as raw materials to produce meat substitutes. This is due to their excellent fat and water binding capacity, as well as their ability to form stable emulsions. These properties contribute to the creation of a desirable meat-like texture for meat products (Broucke et al., 2022). Therefore, it can be inferred that the inclusion of oyster mushrooms and PPI in plant-based minced meatballs could enhance consumer acceptance. Analysis of texture and sensory scores suggests that incorporating an appropriate amount of 10% PPI can improve the overall acceptability of plant-based minced meatballs. However, the excessive addition of PPI resulted in reduced adhesiveness, cohesiveness, and overall liking scores of the product.

3.3 Nutritional values

The nutritional values of the plant-based minced meatball with 10% PPI are shown in Table 5. The moisture contents and other nutritional values of the developed plant-based minced meatballs differed significantly from those of the commercially available plant-based minced meatballs. The moisture content of this product was 56.32 g/100 g lower than that of the commercially available plant-based minced meatball. These results fairly agree with the reported literature (Lee et al., 2023). The calculation of total energy in 100 g of the developed product revealed a lower energy content compared to commercial products, with values of 371.48 kcal and 429.07 kcal, respectively. This difference in energy content can be attributed to variations in protein, total fat content, and carbohydrate levels between developed and commercial products. This was due to the main ingredients, such as oyster mushroom and pea protein isolate of the developed product, which have low fat. According to the recommendations of the Food and Agriculture Organization (FAO), the total energy content of this product should ideally align with that of meat foods, which is around 4.27 kcal/g.

Additionally, the FAO (2004) suggests that the recommended energy intake for the average healthy individual per meal should be within the range of 400–500 kcal. However, it's important to note that these are general guidelines, and individual energy requirements may vary based on factors such as age, gender, weight, height, activity level, and specific health goals. Protein is an important nutrient in people's diets, and the protein content is one of the most vital properties for assessing the quality of plant-based meat products. The addition of PPI ingredients affected the protein content. The developed product had higher protein content compared to the commercial products; on the other hand, fat content decreased. The developed product will be beneficial for consumers who aim to control their weight and build muscle in their bodies for better health. This could have been due to the PPI being a source of protein (65–80%; Meng & Cloutier, 2014). Ferawati et al. (2021) reported that the protein content of the raw material plays an important role in nutritional values and texture formation in meat products. For fat, it was observed that this developed product had a 7.25 times lower amount of fat than the commercial. Therefore, this product could be claimed as low fat according to The public health ministry (1998), which stated that food claimed as low fat must contain fat < 3 g/ 25 g serving size in meat, fish, and shellfish – fried and dry packed product. It seemed that the fat content decreased when the level of PPI increased. According to Chen et al. (2021), the reported fat content of 0.27 ± 0.01 g/100g (dry basis) falls within the lower end of the range, indicating a relatively low-fat content. In addition, the developed product also contained 77.40 g of carbohydrates and 6.76 g of dietary fiber per 100 g. Based on the sodium analysis, the developed product contained 521.54 mg/100 g, which was 1.47 times lower than that of the commercially available product. The study findings reveal that the developed plant-based minced meatballs offer health benefits to consumers.

4. Conclusion

PPI has gained considerable interest in the agri-food market as a plant protein source, driven by consumer perceptions of plant-based products as ethical, healthy, and environmentally friendly. In this study, we evaluated the feasibility of producing plant-based minced meatballs with PPI as a raw material. PPI was utilized to enhance the plant-based minced meatball made from oyster mushrooms. The increase in the PPI ratio resulted in higher protein content in plant-based minced meatballs while decreasing moisture, lightness, and redness. However, the addition of PPI contributed to texture qualities (hardness, cohesiveness, springiness, and chewiness) and overall liking scores that closely resembled those of the well-controlled sample. PPI protein can promote the formation of a stable and elastic network structure in plant-based

Table 3. Texture parameters of the plant-based minced meatball with different pea protein isolate levels

Treatments	Hardness (N)	Adhesiveness (N x sec)	Cohesiveness	Springiness (cm)	Chewiness (N × cm)
Control	29.10 ± 5.73^{a}	1.501.00^{c}	0.300.04^{a}	0.400.10^{ab}	3.530.90^{a}
5% PPI	15.633.52^{c}	0.740.63^{a}	0.300.04^{a}	0.410.10^{a}	2.000.40^{b}
10% PPI	15.892.10^{c}	0.200.10^{b}	0.220.02^{b}	0.300.05^{b}	1.000.20^{c}
15% PPI	21.73 2.66^{b}	0.400.20^{ab}	0.300.03^{a}	0.430.08^{a}	2.820.80^{a}
20% PPI	22.422.40^{b}	0.300.30^{c}	0.200.05^{b}	0.400.10^{ab}	1.510.70^{b}

PPI = pea protein isolate; Control = the commercially available plant-based minced meatball
Mean ± SD with different lowercase superscripts in each column are significantly ($p<0.05$) different

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Table 4. Sensory liking of the plant-based minced meatball with different pea protein isolate levels

Treatments	Appearance[ns]	Color[ns]	Odor[ns]	Taste[ns]	Texture[ns]	Overall liking
Control	7.301.23	7.101.24	7.13 1.40	7.131.30	6.901.20	7.40 1.30[a]
5% PPI	7.001.30	6.901.12	7.001.23	6.701.40	6.931.14	7.231.30[a]
10% PPI	7.001.50	6.631.20	6.701.23	6.831.34	6.601.30	7.191.33[a]
15% PPI	6.901.40	6.731.22	6.631.60	6.531.50	6.601.30	6.501.30[b]
20% PPI	6.701.50	6.601.40	6.501.40	6.431.33	6.601.33	6.501.30[b]

PPI = pea protein isolate; Control = the commercially available plant-based minced meatball
Mean ± SD with different lowercase superscripts in each column are significantly (p<0.05) different; ns = not significantly (p>0.05) different

Table 5. Nutritional values of developed plant-based minced meatballs and commercially available plant-based minced meatball based on 100 g

Nutritional values	Developed plant-based minced meatballs	The commercially available plant-based minced meatball
Moisture (g)	56.32 ± 0.40[b]	67.90 ± 0.84[a]
Total energy (kcal)	371.48 ± 0.04[b]	429.07 ± 0.17[a]
Protein (g)	10.79 ± 0.03[a]	8.77 ± 0.02[b]
Total fat (g)	2.08 ± 0.01[b]	15.09 ± 0.08[a]
Carbohydrate (g)	77.40 ± 0.05[a]	64.56 ± 0.07[b]
Dietary fiber (g)	6.76 ± 0.03[a]	5.04 ± 0.08[b]
Ash (g)	2.97 ± 0.01[b]	6.55 ± 0.04[b]
Sodium (mg)	521.54 ± 2.26[b]	765.45 ± 3.12[a]

Mean ± SD with different lowercase superscripts in each column are significantly (p<0.05)

meat products. Especially for 10% PPI, it was the most suitable for producing plant-based minced meatball products. Furthermore, our findings indicate that the addition of PPI has a positive impact on the nutritional values of plant-based minced meatballs, especially with higher protein content and lower energy and fat content compared to commercially available plant-based minced meatballs. This could potentially reduce the risk of non-communicable diseases (NCDs).

Therefore, this study demonstrates that PPI can be considered a desirable ingredient for the development of novel foods that offer health benefits to consumers. Further studies are needed to determine the effect of PPI on the microstructure, investigate the mechanisms, and provide more opportunities to expand the utilization of PPI in plant-based meat products.

Ethics statements

This study was approved by the Ethics Committee of Suan Sunandha Rajabhat University (Approval no. COE. 1-004/2023).

Conflict of interest

The authors declare no conflict of interest.

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Empowering women agripreneurs through precision agriculture technology adoption: An integrative review of literature

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The use of precision agricultural technology has been shown to increase yields while decreasing the farmer's exposure to risk. Despite women's important involvement in agriculture in many nations, there remains a technological gap between the genders. Particular focus on agriculture's essential role in alleviating poverty and hunger. The literature gap in precision agriculture technology adoption by women agripreneurs needs to be addressed. This study presents an integrative review of the literature aimed at identifying the factors that influence precision agriculture technology adoption among women and proposes recommendations for mitigating the gap. The review highlights precision agriculture technology adoption theories and various factors. Also, it discovered several social and policy implications, as well as training programs, to close the gap. The recommendations given to policymakers are to connect younger, technically-savvy women with older, less technically literate women farmers to address the digital literacy divide. Future research can test the empirical relationship between precision agriculture technology adoption variables on women agripreneurs specifically on various technologies used in agriculture and find the viability. By addressing the gap women agripreneurs will be equipped to adopt precision agriculture technology and digital agriculture, which will ultimately benefit the rural farming community and achieve sustainability.

1. Introduction

"Food and agriculture organization" (FAO) of the United Nations, has framed an agenda to achieve sustainable development goals (SDG) for the year 2030. The SDGs are interconnected to achieve the overall vision of a "better world". According to the FAO (2018, 2011), the access that women farmers have to crucial agricultural resources such as land, credit and capital, information, and other inputs is generally lower than that of men farmers, thereby creating a gender gap in the agricultural sector. The earlier studies state that the digital divide still exists (Galperin & Arcidiacono, 2021; Huber, 2021; Khan et al. 2022). On average, women make up 43% of the agricultural labour force in low- and middle-income countries, yet their access to resources, rights, and services are limited, holding back prosperity for all (CGIAR, Consultative

Group for International Agricultural Research, @ the UN Food Systems Summit +2 Stocktaking Moment - CGIAR, 2023). Women make significant contributions to agriculture around the world, but their work often goes unrecognized and undervalued (Chakma & Ruba, 2021; Multani & Sanghvi, 2017). Women have less control over land and are less likely to own livestock (Beg, 2019; Mendham & Curtis, 2010). The contribution of women in the agriculture sector is highlighted in labour, ownership of land, and livestock. The earlier studies investigated systematic literature reviews on the sociocultural factors influencing the gender digital divide (Acilar & Sæbø, 2021). The societal awareness of agricultural technology adoption among women is not understood and explained as expected toward the positive transformation of women. When women get technology awareness their productivity increases, they act autonomously, make decisions, and increase their standard of living which will lead to women's empowerment (Mobarok et al., 2021). The main objective of this present study is to review the literature on precision agriculture technology, factors involved in adopting the technology, theories on technology adoption, and provide social and policy implications on adopting the technology. The study also provides a research agenda for future researchers. This study shows particular interest in women adopting precision agriculture technology to overcome the problems and implications.

Precision Agriculture and traditional cultivation are substantially different in practice. Farmers in traditional agriculture apply the same unit of pesticides, fertilizers, and irrigation throughout fields at set times and intervals, based on regional recommendations. Even within the same field, there are always variances in biological, physical, and chemical characteristics. Fields are treated uniformly without regard for intrinsic differences, resulting in misuse of inputs in productive areas and underuse in poor regions. This wasteful use of land, water, fuel, fertilizers, and pesticides raises costs and has a negative impact on the environment (Nowak 2021). Precision agriculture uses Variable Rate Application (VRA) to optimize input for farmland variances. VRA requires detailed spatial data from Geographical Information Systems (GIS) and crop lifecycles using Global Positioning System (GPS) and remote sensing across fields and locales. Precision irrigation, yield mapping and monitoring, and information management systems are some of the precision farming tools. Precision agriculture makes data-driven management decisions to create cost-effective, environmentally friendly, sustainable modern farming solutions (Misara et al., 2022).

Precision agriculture (PA) is a road map to attain sustainable development through technology. Precision agriculture in developed countries benefitted from the practical implementation throughout the world. The literature revealed precision agriculture (Balogh et al., 2020; Bandumula, 2017; Dunne et al., 2021; Singh, 2020), Precision Farming (Armenta-medina & Ramirez-delreal, 2020; Azhagesan, 2020; Kendall et al., 2022; Navarro et al., 2020; Rajani et al., 2018; Singh & Elyamani, 2012), Precision livestock (Akter et al., 2017; Linaza et al., 2021; Nyaga et al., 2021) have proven that it increases productivity. Precision agriculture typically relies on technologies such as GPS, drones, sensors, and data analytics software to collect and process data. Precision agriculture has a significant impact on agriculture in many ways.

Research is required to find the inclusive technology diffusion efforts, to determine the characteristics of technology and adoption modality, rights of men and women, and how their empowerment differ (literacy and socioeconomic status) can facilitate women's rights to technology within the household (Theis et al., 2018). The "gender digital gap" reduces their productivity and contributions to agriculture and society. Economic and social developmental goals can also be achieved. Eliminating gender agricultural inequalities would boost agricultural output, reduce poverty and hunger, and boost the economy (FAO 2011). The hypothetical question is does women are adopting precision agriculture. What are the factors that influence the adoption of technologies and the problems faced by women to adopt? This study drags the attention toward women adopting agriculture technology. The main objective of this study is to collect and review the earlier works published in the area of precision agriculture technology and women in agriculture from a global perspective, hence the gap and future research agenda can be attained. The purpose of this study is to find the domain of technologies used in the previous literature like precision agriculture on animal husbandry, precision agriculture on crops, and social media as precision technology to promote agribusiness by women agripreneurs. Data-driven precision agriculture maximizes crop yields and reduces waste.

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It can assist farmers in deciding when to sow, fertilize, harvest, and use water and other resources. It reduces pesticide and fertilizer use, which helps to attain an eco-friendly environment and to attain sustainability. Moreover, it helps to reduce the cost, workload, and saves time for women by automating farming activities. This will indirectly help women to concentrate on other household and family work which leads to empowerment and self-reliance.

2. Review of Literature

2.1 Agripreneurship

Agripreneurship is the profitable combination of agriculture and business. Agripreneurship refers to entrepreneurship in agriculture. It was identified that agriculture entrepreneurship is majorly synced with farm innovations and farm entrepreneurship (Dias et al., 2019; Lans et al., 2013). Agripreneurs must acquire modern skills and agripreneurial competencies that are required for a successful business (Igwe, 2020; Lopez-Garcia & Chin, 2005; Otache, 2017; Ouko et al., 2022). "Agripreneurs may be defined as innovators, create new ideas in doing things in agriculture sectors and drive the change in the economy" (Ndedi & Feussi, 2018). Agripreneur is termed as a business owner and self-employed who seeks out to create wealth in agriculture industry (Aleke et al., 2011; Nagalakshmi & Sudhakar, 2013). The activities of agripreneurship or agriculture-related business were dominated by the male gender in the society even though the contribution of women was restricted to household and agricultural activities (Obosha, 2020; Satpathy & Kumari, 2023).

2.2 Women Agripreneurship

Women agripreneurs should be the key players in rural development (Halim et al., 2020). Women have an important role in income-generating activities in agriculture at present, however, existing technologies have to be provided to farm women for increasing farm productivity and empowerment (Anderson, 2021; Patil & Babus, 2018). Satyavathi et al. (2010) emphasized that women play a crucial role in all farm-related activities starting from land preparation to marketing. Technology-driven strategies in agriculture help farmers to transform economic incentives and growth (Etten, 2022). Digital agricultural practices including geographical flexibility and innovation capacity are important for identifying new opportunities and awareness of technology (Gaihard & Brennen, 2022). Nowadays technology-driven agriculture is adopted in many developed and developing nations, hence study deals with the conceptual research of existing literature review on the area of "Precision agriculture" and "Women Agripreneur" is essential.

2.3 Definition and scope of women agripreneurship

Agripreneurship is defined as a concept linked with the marketing and manufacturing of various agricultural products and inputs. An agripreneur is someone (woman) who starts, organizes, and runs a firm in the agricultural sector. Agri-entrepreneurship, also known as Agripreneurship, adds value to agricultural resources by utilizing rural human resources (Sharma et al., 2019). Women's empowerment of farmers and agripreneurs generates revenue and enables self-sufficiency. Sustainable agribusiness ventures are considered to have the ability to generate job-led economic, social, and environmental benefits. (Buragohain & Deka, 2018; Singh et al., 2022; Mulupi et al., 2023).

Further, individual women empowerment leads to the increase national sustainable economy. Women comprise about 43% of the agricultural labor force in developing countries, and up to 50% in some regions (Bhandari, 2017; Stapleton, 2023). Agriculture has enormous potential for increasing production and productivity through value addition. It is consequently critical to train the unemployed, with a special emphasis on rural women, in agri-business management (Kaur et al., 2018; Fapohunda, 2023).

2.4 Precision agriculture and women agripreneurship

Empowered women who adopt PA reinvest in their communities, boosting self-reliance, wealth, and food security. The development community should encourage female agricultural entrepreneurs with high-impact PA applied projects (Mamkwe & Lulu Genda, 2023). Urbanization in developing nations is changing agricultural demand. Digitizing value chains make pricing and shipping data more transparent (Balezentis et al. 2023). These food system shifts create opportunities for technology driven agripreneurship, entrepreneurship in agriculture on the farm and beyond (Adeyanju et al. 2023). Women have less access to market information, business consulting services, financial assets, and mentors than men (Avnimelech & Rechter, 2023). Women make up nearly half of the agricultural workforce in developing nations, yet females own just one-third of emerging market small- and medium-sized firms and 15% of agricultural extension agents (Welsh et al., 2023). Economic empowerment empowers women to invest in their families and communities, fostering self-reliance, wealth, and food and nutritional security. Hence, this paper focuses on precision agriculture technologies and fosters women's adoption.

3. Review Methodology

According to (Tranfield et al., 2003) systematic literature review methodology we applied inclusion and exclusion criteria. The data was collected from the published articles in Scopus, and Web of Science databases with the search keywords "agripreneur" "precision agriculture technology" and "women agripreneur". The articles were randomly selected based on the keywords "precision agriculture", and "women in agriculture and technology". Initially, in the database Scopus, 47 with English language, Open-source articles, subject area agriculture and bioscience, and business management and accounting were selected. Similarly, in Web of Science, 59 documents with social science citation index and agriculture and business economics papers were selected. In precision agriculture, 24 articles were selected based on the keyword "precision agriculture", from 2018 to 2022 and similarly, "women in agriculture and technology" 18 articles were selected from 2018 to 2022, only 5 years were considered for this study to find the recent trends of the research area. Finally, we studied the complete text of all the collected papers to identify all possible relevant studies that were strictly related to the research topic. Out of 42 articles, Scopus listed articles are 25, and WOS of Science 17 articles were selected for the thorough review. The cumulative papers referred for this study are 42 comprising both precision agriculture and women in technology. The research work was carried out during the month of July 2022. The data collected was reviewed based on the various factors to adopt technologies, and theories deployed.

4. Results

4.1 Precision Agriculture Technology factors to adopt

Precision agriculture adoption of technologies is perceived as complex due to its various attributes such as environmental sustainability, production quality profitability, and efficiency of resource use. Social factors like age and experiences of farmers as drivers and challenges of precision agriculture technology adoption (Lee et al., 2021; Ofori & El-Gayar, 2021). Linaza et al. (2021) found that artificial intelligence technology in agriculture enhanced monitoring conditions, decision support at the farm level, and production optimization. Katke (2019) found that precision agriculture adoption could lead to growth possibilities for Indian agriculture, but the social and financial welfare of the farming network are facing significant challenges. The lower adoption level of smart agriculture technologies was due to a lack of perceived practical usefulness, understanding, information, and awareness (Bukchin & Kerret, 2020; Chuang et al., 2020). Technology adoption helps small farmers to contribute substantially to food security and poverty alleviation. Indian farmers must use unique and current technologies and approaches for food demand and supply stability (Shankarnarayan & Ramakrishna, 2020). Yatribi (2020) called for more relevant treatment and testing of individual factors, organizational factors, technological factors, and institutional factors as covariates or moderating variables for technology adoption.

4.2 Precision agriculture on animal husbandry

Precision agriculture on animal husbandry requires the use of automatic monitoring systems to detect animal illnesses, monitor animal development and behaviour, track milk production, and monitor the physical environment (Monteiro et al., 2021). Technology usage in the agriculture domain has resulted in precision agriculture, digital agriculture, and analytics for yield (Sinyolo, 2020; Upendra et al., 2020). According to Zhang et al. (2019), cleaner production techniques will not be utilized until farmers see the value in that technology.

4.3 Precision agriculture on crops

Agriculture 4.0 enables modern techniques such as

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crop growth monitoring, nutrition, health labelling, and collaboration among different players in the agricultural value chain (Ahmad & Zaman, 2020; Manda et al., 2020: Raj et al., 2021). precision agriculture can help farmers use less water and fertilizer by applying them only where and when they are needed, reducing the risk of runoff and pollution. Technologies such as plant sensors for nutrients, soil, geographical information systems, water management, satellite imagery, and crop-soil simulation models were recognized for site-specific management. Precision agriculture research was crop specific to corn, sugarcane, wheat, cotton, grape, and soybean as the crops that have been researched more often in literature (Cisternas et al., 2020). The impacts of improved seed adoption were not the same among adopters (Sinyolo, 2020). Precision farming technologies related to agriculture resulted in better agricultural production (Helfer et al., 2019; Soma et al., 2019). By using precision agriculture techniques, farmers can improve yields, reduce costs, and minimize the environmental impact of farming operations. It can also help farmers identify and treat crop diseases and pests more effectively, leading to higher yields and healthier crops.

4.4 Social media as precision technology to promote agribusiness

Nurlaela et al. (2020) studied young agripreneurs' use of new media for horticulture promotion, where the majority were using WhatsApp for their daily communications. Female farmers who intend to adopt WeChat-based social media marketing are more likely to be influenced by social factors than male farmers (Han et al., 2021). The integration of social media, digital technologies, and the public's demand for transparent government could lead to a fresh phase of possibilities for rural regions (Foronda-Robles & Galindo-Pérez-de-Azpillaga, 2021). Social media platforms like WeChat (Han et al., 2021), Facebook, Youtube, Twitter, WhatsApp, Instagram, Trip Advisor, Flicker (Madila et al., 2021), and blogs (Arun, 2021) to help farmers or agripreneurs for decisions making from production to marketing the farm produce. Mittal and Mehar (2016) have found that the information provided by animated videos in mobile applications reduces the gap between farmers and technology through updated information and eventually has the potential to increase productivity. Research can also be concentrated on various social media adoptions to improve agribusiness online.

4.5 Women agripreneurs

The relationship between precision agriculture technology adoption and women agripreneurs is important (Dash et al., 2022; DeLay, et al., 2022; Dhanya et al., 2022; Madhumitha et al., 2020). Precision agriculture technology adoption has the potential to increase agricultural productivity, reduce input costs, and improve efficiency and profitability in farming operations (Nowak, 2021; Pathak et al., 2019; Thompson et al., 2019). It can also help farmers manage resources more sustainably, reduce environmental impact, and adapt to changing weather patterns. Increasing the adoption rates among women in agriculture can be achieved by reducing the obstacles they face (Kendall et al., 2022; Remteng et al., 2021; Ruzzante et al., 2021). Women with access to information, training, education, and awareness of climate change and its possible sustainable solutions could enhance their empowerment. The digital divide in South Asian countries like Nepal, India, Bangladesh, and Pakistan is primarily due to factors such as the urban-rural divide, gender disparity, religious and cultural barriers, and social and educational inequalities, including income and access to education (Jamil, 2021). Chuang et al. (2020) found the moderating effects of gender on farmers' knowledge and adoption of smart agriculture technology. The intermediating role of attitude with the relationship between knowledge and practice could be studied further. Ball (2020) suggested that women farmers need separate organizations and programs that reduce inequalities and provide opportunities for education, networking, and government support. Muhammad et al. (2020) argued that there was a lack of opportunities for women to learn about advanced technologies in agriculture for better production of crops, fisheries, and the dairy sector for sustainable development. Female farmers benefit more from precision agriculture adoption than male farmers and the new agricultural technologies and innovative spirit of farmers regarding adoption are required (Shahraki, 2019; Sinyolo, 2020; Yatribi, 2020). Women's perception of agricultural innovative behaviour in Thailand is determined by their perceived possibilities and abilities in the context of existing norms Kawarazuka and Prain (2019). Nepalese women have been given space to engage in quality agriculture, although their engagement is limited to production and primary processing (Upreti et al., 2018). There are some factors like personal, institutional, and organizational factors that influence agripreneurship. Farmers with information via mobile phones can reduce the information gap and increase productivity, but women still have a long way to go to adopt this information into action (Addo, 2018). The various trends, patterns, and gaps for future research are given in Table 1.

There is an interrelationship between all the domains mentioned above, in the context of women adopting technology the major drawback in general is literacy and awareness to adopt technology. From the above-detailed review, various factors hinder women from adopting precision agriculture technology are as follows

1. Lack of access to technology: Women, especially in rural areas, may have limited access to technology due to a lack of infrastructure, availability, and affordability of devices such as smartphones, laptops, and internet connectivity (Muhammad et al., 2020).

2. Digital illiteracy: Women may lack the necessary skills and knowledge to effectively use technology (Hay, 2021; Jarial & Sachan, 2021). This includes basic digital literacy, as well as specific skills related to precision agriculture technology.

3. Gender bias: In some cases, women may face discrimination (Drucza & Peveri, 2018) and biases that prevent them from accessing and using technology.

Table 1. The gaps for future research

Results	Trend and patterns	Gap for future researchers
Precision Agriculture Technology factors to adopt	Socioeconomic factors, Technological factors, information resources, farmers' perception, behavioural factors	Age, education, family size, activity experience, ability to collect and interpret information, access to information, perceived profitability with increased use of technology by women farmers, intention to adopt technology by women risk aversion, type of technology adopted on various technologies used separately can be studied further.
Precision agriculture on animal husbandry	This trend has the potential to stimulate additional research into the use of novel biometric sensors, block chain, and big data technology for the joint benefit of livestock farmers, customers, and farm animals.	The three main problems in efficiently monitoring animal welfare are expense, validity, and timing of monitoring findings (technology view). Studies can be on the awareness and adoption level of women on these technologies can be done in the future.
Precision agriculture on crops	The future trend of Precision farming will use machine learning and image analysis extensively. Chatbots, drones, robotics, irrigation systems, and agricultural health monitoring will use machine learning. IoT, big data, differential GPS, and non-contact sensors will impact precision agriculture.	Concerning women in adopting precision agriculture on crops the variation evaluation, crop yield, performance, and nutrient level, can be studied technically. Socioeconomic factors to adopt technology can be studied further.
Social media as precision technology to promote agribusiness	Various social media platforms like Facebook, WhatsApp, Twitter, LinkedIn, and country-wise social media can be included.	Descriptive analysis, content analysis, and sentimental analysis can be studied in the future
Women agripreneurs	Social, economic, and technical factors can be studied	How do all these factors influence the adoption level in particular to the various technologies?

Source: Authors

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This could be due to cultural or societal norms that limit women's roles and opportunities.

4. Time constraints: Women may have multiple roles and responsibilities, including caring for family members and household chores, which can limit the time and energy they have available for learning and using technology (Pierotti et al., 2022).

5. Lack of support networks: Women may lack the necessary support networks, including mentorship and peer networks, to effectively adopt and use technology (Muhammad et al., 2020).

Addressing these challenges will require targeted efforts to increase access to technology, improve digital literacy and skills training for women, and address gender biases and cultural barriers. Additionally, providing support networks and mentorship opportunities can help women overcome the challenges associated with technology adoption, women empowerment and achieve sustainable development goals.

Training programs can help women in various ways to reduce the digital divide and adopt precision technology through training which includes:

1. Building technical skills: Training programs can help women Agripreneurs in developing their technical skills related to precision agriculture technology, digital literacy, and farm management (Ball, 2020).

2. Enhancing decision-making abilities: Training programs can help women improve their decision-making skills related to crop management, market analysis, and financial management (DeLay, et al., 2022, Kendall et al., 2022).

3. Providing networking opportunities: Training programs can help women build networks with other agripreneurs, experts, and policymakers in the agriculture sector, which can lead to collaboration, knowledge sharing, and access to resources (Jamil, 2021).

4. Boosting confidence: Training programs can help women build their confidence and self-esteem, which can lead to more active participation in decision-making and entrepreneurship activities (Sinyolo, 2020; Yatribi, 2020).

5. Improving access to finance: Training programs can help women in understand financial management and access finance for their businesses, which can help in scaling up their operations and generating more income (Nowak, 2021).

Overall, training programs can empower women agripreneurs and enable them to overcome the barriers related to precision agriculture technology adoption and entrepreneurship in the agriculture sector.

Future research directions on the relationship between precision agriculture technology adoption and empowering women agripreneurs. The future studies can be as follows:

1. Examining the role of social networks and community-based organizations in promoting technology among women agripreneurs.

2. Investigating the impact of precision agriculture technology on the economic empowerment of women agripreneurs, including income generation, job creation, and poverty reduction.

3. Exploring the intersectionality of gender with other factors such as age. education and socio-economic status, and how these factors influence technology adoption and entrepreneurship outcomes.

4. Investigating the barriers and enablers to adopting precision agriculture technology by women agripreneurs, including access to finance, information, and training.

5. Examining the effectiveness of different policy interventions and strategies for promoting precision agriculture technology adoption among women agripreneurs, such as subsidies, tax incentives, and capacity-building programs.

6. Investigating the potential environmental impacts of precision agriculture technology adoption and how this could affect the sustainability of women-led agricultural businesses.

The following table 2. exhibits the theories that can be applied to the study of precision agriculture technology adoption.

Table 2: Theories for accepting technology

Author	Theory	Definition
Davis (1989)	Technology Acceptance Model (TAM)	Users' intention to use technology is determined by their attitude towards the technology, as well as their perceived usefulness and ease of use.
Rodgers (2010)	Diffusion Innovation Theory	The adoption of innovation is influenced by factors such as the innovation's characteristics, the adopter, the communication channels used to promote the innovation, and the social system in which the innovation is being adopted.
Bandura's (1989)	Social Cognitive Theory	The adoption of technology is influenced by social and environmental factors, as well as personal factors such as self-efficacy and outcome expectations, due to the human ability to learn through observing others and adjusting their behaviour accordingly.
Fishbein and Ajzen's (1977)	Theory of Reasoned Action	An individual's behavioural intentions are a result of their attitudes towards the behaviour, as well as their beliefs about how others will perceive their behaviour.
Ajzen's (1991)	Theory of Planned Behaviour	An individual's intention is influenced not only by their attitudes and subjective norms but also by their perceived behaviour control.
Taylor and Todd's (1995)	CTAM-TPB	CTAM-TPB is a combination of the Technology Acceptance Model (TAM) and the Theory of Planned Behaviour (TPB).
Ram and Sheth's (1989)	Innovation Resistance Theory	Factors such as uncertainty, habit, and tradition can cause innovation resistance and propose strategies to overcome such resistance.
Venkatesh et al.'s (2003)	Unified Theory of Technology and Use of Technology	Technology acceptance and use are influenced by factors such as performance expectancy, effort expectancy, social influence, and facilitating conditions.

Source: Authors

These theories can provide a framework for understanding the factors that influence the adoption of precision agriculture technology in the context of women agripreneurs.

5. Discussion

Technology adoption is one of the pathways to sustainable agriculture holding the promise and grip for a sustainable future. The objective of the present study to explore the various factors used in the previous studies, theories, and precision agriculture technologies are mentioned and attained. The review on precision agriculture technology adoption for women found that there were Technology acceptance model (Arun, 2021; Pierpaoli et al., 2013), Unified theory of acceptance use of technology (UTAUT1) (Dehghani, 2018; O'Neill Somers & Stapleton, 2020), Unified theory of acceptance use of technology (UTAUT2) (An et al., 2016; Gansser & Reich, 2021), Internet on things (IoT) (Demestichas et al., 2020; Naresh et al., 2021; Shafi et al., 2019), Geographical information system (Mendes et al., 2020; Shafi et al., 2019), Global positioning system (Demestichas et al., 2020; Grogan, 2012), Remote sensing data acquisition (Naresh et al., 2021; Mendes et al., 2020), Decision support system (Demestichas et al., 2020; Yaseen et al., 2018), Sensor-controlled automation (Mendes et al., 2020; Navarro et al., 2020; Raju & Vijayaraghavan, 2020), and Variable rate technology (VRT) (Naresh et al., 2021), and many more are being used as a technology to improve agriculture.

5.1 Gender Inequalities

Men have greater and more satisfying access to technology than women in agriculture (Peterman, 2014, Achandi et al., 2018). Women have less access to ICT in the agricultural sector and have less information on climate-smart agriculture compared to men (Chuang et al.,2020) Gumucio et al., 2020; Tsige et al., 2020).

5.2 Social Implication:

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1. Promoting technology adoption among women can help to reduce gender inequalities in agriculture. Women mark up a significant proportion of the agricultural workforce in many developing countries, yet they often have limited access to resources, education, and technology. Promoting technology adoption among women agripreneurs can minimize the gender digital gap and promote sustainable agricultural practices (Anyoha et al., 2018; Jarial & Sachan, 2021; Shahraki, 2019; Sinyolo, 2020; Yatribi, 2020).

2. Technology adoption can help improve the livelihoods of women agripreneurs and their families (Chinelo et al., 2022). Precision agricultural technology can increase agricultural productivity, reduce inputs cost, and improve efficiency (Balafoutiset al., 2017), which can help improve the income and food security of women agripreneurs and their households.

3. Promoting technology adoption can help promote sustainable agricultural practices (Li et al., 2022; Takahashi et al., 2019, Muhammad et al. 2020). Precision agriculture technology can help reduce the use of pesticides and fertilizers, promote soil conservation, and reduce water consumption; hence it enhances environmentally friendly farming practices.

5.3 Policy Implications on precision agriculture technology adoption and Women agripreneur

1. Gender-sensitive policies that recognize the specific needs and challenges faced by women agripreneurs and safeguard women's rights and empowerment (Jabeena et al., 2022). This will give equal opportunities for women to access technology and utilize precision agriculture technology and can help to reduce gender inequalities (Singh et al., 2022).

2. Capacity-building programs that provide women agripreneurs with the necessary skills and knowledge to effectively adopt and use precision agriculture technology. The training may include digital literacy, precision agriculture technology, and business management skills.

3. Policymakers need to create mechanisms that provide easy access to finance and credit facilities which in turn expand their business (Abbasi et al., 2017; William et al., 2020).

4. Infrastructure development policies to support precision agriculture technology will enable reliable electricity, internet connectivity, and other necessary infrastructure for effective adoption and utilization (Hundal et al., 2023).

5. Research and development to invest to improve the effectiveness and affordability of precision agriculture technology (DeLay et al., 2022). This can support research institutions and private sector organizations to develop innovative technologies that are tailored to the specific needs of women agripreneurs.

6. Limitations

This study is limited to PA technology adoption concerning women agripreneurs. This study grabbed the articles from databases like Web of Science, Science Direct, Scopus, and Emerald. Only a limited period is being considered based on the availability of the data and for finding the current gap and trends in this research area. The various review methods like Systematic literature review using PRISMA tools, Bibliometric using the R program, Biblioshiny, and VOS viewers, Meta-analysis, and Thematic analysis are suggested for further scientific literature reviews. Future research can test the empirical relationship between precision agriculture technology adoption variables on women agripreneurs specifically on various technologies, and theories used in this study to find the viability. By addressing the gap women agripreneurs will be equipped to adopt precision agriculture technology and digital agriculture, which will ultimately benefit the rural farming women community and achieve sustainability.

7. Conclusion

The present research study concludes that the literature revealed on Precision Agriculture, precision farming, and precision livestock are identified to increase productivity, socio, and economic growth and reduce the risk faced by the women agripreneurs. Most of the developed and developing countries have adopted precision agriculture however digital literacy among women is the major gap found in the review. Age, education, family size, activity experience, ability to collect and interpret information, access to information, perceived profitability with increased use of technology by women farmers, risk aversion, and type of technology adopted on various technologies used separately can be studied further. The three main issues in efficiently monitoring animal welfare are cost, validity, and timing of monitoring findings (from a technological standpoint). In the future, investigations on women's awareness and acceptance of these technologies may be conducted. To reduce the digital divide, the young technically updated agripreneurs should collaborate with the experienced farmers without technical knowledge so that both age groups can be empowered by sharing their knowledge. It is recommended to the policymakers and the government institutions that they should conduct awareness and training sessions with hands-on experience and technical know-how programs for the agripreneurs on technology especially in rural areas so that they can be part of precision agriculture and digital agriculture. By providing these training women agripreneurs can be empowered and self-reliant. This study will be benefit the women agripreneurs, researchers, practitioners, and policymakers.

Conflict of interest

The authors declare no conflict of interest.

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Stakeholder analysis on sustainable food home garden programme (P2l) at sananrejo village, turen district, Malang regency

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The most important human needs are increasing adequacy and improving nutrition through healthy and diverse food consumption patterns. The utilization of the garden is a solution to fulfilling the nutritional needs of the community, especially families. Through the Sustainable Food Home Garden Program (P2L), it is hoped that it will be able to meet the nutritional needs of families from the garden and increase the role of women as economic support for the family. This study aims to identify, explain, and analyse the implementation of the Sustainable Food Home Garden Program (P2L) and identify and analyse stakeholders' roles at each stage of the P2L program. The sampling method is purposive sampling. The research was conducted in Sananrejo Village, Turen District, Malang Regency. To identify and analyse the parties' roles in the sustainability of the P2L Program, Institutional Analysis Design (IAD) (Ostrom, 1990) is used, and mapping the roles of stakeholders in the P2L Program uses the Stakeholder matrix. The results showed that the implementation of the P2L Program was in accordance with existing technical guidelines and could benefit beneficiaries, namely KWT Semi-Lestari. There are nine stakeholders in the P2L program that have key roles or key players, namely the Malang Regency Food Security Service, KWT Semi-Lestari Members and Management, Agricultural Extension, and the Turen District Government, Stakeholders who act as context setters with high influence and low interest are the Village Government, RT Management, and District PKK TP. In contrast, stakeholders who act as crowds with low influence and interest are groceries and Village TP PKK. Recommendations for further research are regarding conflicts and relationships between stakeholders and strategies so that P2L can provide optimal benefits for the community.

1. Introduction

The most essential human need is increasing adequacy and improving nutrition through healthy and diverse food consumption patterns. Availability of good food in terms of sufficient quantity, good quality, and affordable prices. The more advanced a nation is, the greater the demand for and attention to the food quality consumed.

The ideal Nutrition Adequacy Rate (RDA) for Indonesian people, as recommended by the Minister of Health through the National Food and Nutrition Widyakarya (WNPG) is 2100 kcal and 57 grams of protein daily. Based on data from the Central Statistics Agency (BPS) for the Indonesian people, it can be said that they have met the recommended nutritional adequacy standards as in the latest data released in March

2020, it was recorded that the Indonesian people could consume 2112.06 kcal and 61.98 grams of protein in a day. This can be seen from the graphic data from the Central Statistics Agency (BPS), which illustrates the nutritional adequacy of calories and protein per day for the community in March 2020 (Vebronia et al., 2021). According to Statistics obtained from FAOSTAT, South Asia has made significant progress towards reducing hunger, particularly over the last 15 years: The population undernourished in the region was estimated at 14.7 percent in 2018, down from an estimated 21.5 percent in 2005. Although the coronavirus disease 2019 (COVID-19) pandemic may now challenge these outcomes, the trend over the last several decades has been toward improving the region's food and nutrition security (Dizon et al., 2021).

Utilizing the home garden is a solution to fulfilling the nutritional needs of the community, especially families. The quasi-experimental study in Guatemala demonstrated that home garden interventions might have potential benefits when added to other nutrition-specific interventions, particularly in improving child linear growth and household access to various products in rural Guatemala (Guzmán-Abril et al., 2022). Optimizing utilization of the home garden is done by empowering women to optimize the benefits of the home garden as a family food source. Beyond increasing food consumption, home gardens can also improve nutrition. In India, their introduction helped families meet the requirements of a four-member household for beta carotene and vitamins (Chadha et al., 2012). In Bangladesh, such gardens increased the average household supply of plant proteins by 171 percent, iron by 284 percent, vitamin A by 189 percent, and vitamin C by 290 percent (Schreinemachers et al., 2015). These nutrition gains likely occur through increased vegetable consumption and improved dietary diversity (Jana et al., 2015; Birdi and Shah, 2016)

This effort is carried out by cultivating various types of plants according to family food needs, such as tubers, vegetables, and fruit, as well as cultivating small livestock and fish in addition to the availability of Diverse, Nutritious, Balanced, and Safe food. The objective of small-scale production activities is to allow households, and particularly women in those households, to gain control over food security and nutrition (Dizon et al., 2021). The clear advantage of a home garden intervention is its ability to address multiple micronutrient deficiencies, yet data limitations forced to focus on iron, vitamin A, and zinc, which are nevertheless the main micronutrient deficiencies affecting Bangladesh (Schreinemachers et al., 2016).

Another study on the same home garden project in Bangladesh showed that women gained self-esteem by being recognized for their agricultural skills in the community. It suggests that noneconomic motives might be more important and that valuing women's gardening time at the daily wage rate underestimates the true cost-effectiveness of the intervention (Patalagsa et al., 2015). In Ghana, The agricultural sector is the main employer for both rural women and men; nevertheless, rural women also have high employment participation in wholesale retail, marketing, and tourism, as well as in the manufacturing sector. Most rural Ghanaians are self-employed in agriculture or not, and 56 percent of the rural working population has a second job or more. Overall, very few of them engage in paid labour, and when opportunities exist, women are disadvantaged: in rural areas, men take part five times more in wage employment than women. On the contrary, rural women are more likely to be engaged in unpaid family work and non-agricultural self-employment activities than rural men (FAO, 2012). Participation in farmer-based organizations (FBOs) is one pathway that may contribute to the empowerment of rural women (Ferguson & Kepe, 2011).

In Indonesia, one of the steps to empower women in economic development in rural areas is to form a Women's Farming Group. A recent study showed women's membership in dairy producer organizations improved their use of income, ownership, decision-making over land and assets, and control over productive decisions (Mwambi et al., 2021). So that (Abdu et al., 2022) found that In Ghana, the likelihood of household gender equality was higher in households where a woman was participating in a Farmer Based Organization (FBO). However, women's FBO membership was not associated with overall male empowerment.

KWT Semi-Lestari in Sananrejo Village, Turen District, was one of the women's farming groups in Sananrejo Village with 30 members. The formation of women farming groups was based on a common need and goal to empower women according to the potential of existing natural resources, namely in the agri-

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cultural sector so that women can later support rural economic development and improve the welfare and fulfilment of family nutrition through the use of garden around the house.

The Sustainable Food Home Garden Program (P2L) at KWT Semi-Lestari, Sananrejo Village, began to be implemented in 2021, and it can be said that it was successful until it won Third Place in the Home Garden Category at the P2L Competition at the Malang Regency Level in 2022. The Sustainable Food Home Garden at KWT Semi-Lestari, Snanrejo has three components. The first is a seed garden, the second is a demonstration plot and the third is the women farmer's garden that can be planted by the members. The success of the P2L Program cannot be separated from the role of several parties, starting from planning and implementation to evaluation and sustainability of the program.

In Indonesia and several countries, the program to use gardens around the house is also one of the solutions to fulfil family food needs. One of them in Vancouver, Kanada. (Valley & Wittman, 2019) Vancouver has several neighbourhood food networks (NFNs) that have initiated food system programming involving urban food production to promote community food security. NFNs in Vancouver are typically coalitions of residents, community agencies, and municipal staff that share similar objectives and priorities around addressing food system issues specific to the neighbourhood in which they operate.

This study aims to identify, explain, and analyse the implementation of the Sustainable Food Home Garden Program (P2L) and identify and analyse stakeholders' roles at each stage of the P2L program. It will discuss in depth the roles and mapping of the roles of stakeholders in the Sustainable Food Home Garden Program (P2L), starting from the community as actors or recipients of the program, technical officers, and government from the RT, village, sub-district, to district levels so that the program This program can be successful and able to fulfil the food needs of families that are nutritious, diverse, balanced and safe. Stakeholder analysis has become increasingly popular with a wide range of organizations in many different fields, and it is now used by policy-makers, regulators, governmental and non-governmental organizations, businesses, and the media (Friedman & Miles, 2002). As the definition suggests, stakeholders are actors who influence the achievement of a company's objectives and, by inference, their sustainability. Many studies on corporate sustainability consider stakeholders as fundamental, and empirical results for the manufacturing and service industries have shown that building successful relationships with stakeholders enhances corporate sustainability (Ogawa, et al, 2023).

2. Material and Methods

2.1. Location and Respondents

The research was conducted at KWT Semi-Lestari, Sananrejo Village, Turen District, Malang Regency. Subjects or informants in this research were selected by purposive sampling with the representation of the actors to identify the stakeholders involved, starting from the village government, sub-district government, Village TP PKK, and Sub-district TP PKK who played a role in the success and sustainability of the P2L Program.

2.2. Collect data methods

Primary data was collected through observation and direct interviews with informants. The observation take place during 2022. The researcher is directly involved in each stage of the activity so that the observation is carried out by non-participant observation. The research informants are detailed in Table 1 below. Meanwhile, secondary data was obtained through written sources, including reports, books, and records relevant to the problem under study, related regulations, and documents and photographs containing information about the P2L Program.

The validity of research data is checked by triangulation of data sources, which according to Creswell, 2019 is by examining evidence originating from these sources and using them to build justifications for themes based on a number of data sources or perspectives from participants.

2.3. Data Analysis

The data analysis used descriptive qualitative analysis and was carried out by examining all existing data from various data sources obtained by researchers. The data source came from interviews, observation,

Table 1. Informants and Stakeholders involved in the P2L Program

No	Type of Stakeholder	Number of Informants (people)	Information
1	KWT Semi-Lestari	30	direct implementation of P2L
2	RT manager	3	Facilitation of the garden to the member
3	Village government	5	facilitate the infrastructure of P2L
4	TP PKK Village	6	Advisor when the member needs some advice to maintaining sustainability
5	District Government	5	advisor and supervisor
6	TP PKK District	6	motivator, coach
7	Agricultural Extension	6	facilitator
8	Malang Regency Food Security Service	5	Program carrier, evaluation
9	Groceries	3	
	Count	69	

and documentation. The analysis technique used in this study is a data analysis technique with a linear and hierarchical approach built from the ground up to identify the implementation of the P2L Program. Meanwhile, to identify and analyse the roles and map the roles of stakeholders in the P2L Program, the stakeholder matrix is used.

Actor linkage matrices require stakeholders to be listed in a table's rows and columns, creating a grid to describe the interrelations between them. As actor-linkage matrices require no more than pen and paper, they have been particularly valuable in development, where due to resource limitations, research may need to be conducted without the use of computers (Reed et al., 2009).

Stakeholders are key players, context setters, subjects, and crowds. Key players have high interest and power. Context setter has high power but low interest. The subject has high interest but low power, and the crowd is stakeholders with low power and interest.

3. Result

3.1. Activity of Sustainable Food Home Garden Program

3.1.1. KWT Semi-Lestari

KWT Semi-Lestari was formed in 2018 with 30 members, with a secretariat at Jl. Kyai H. Hasyim Asyari RT 031 RW 007. The formation of KWT Semi-Lestari started from the desire of the members of RT 031 to utilize the home garden as a source of family nutrition. The encouragement of women to form KWTs was not only based on the desire to increase family nutrition sources but also to increase income and efforts to preserve the environment and create a beautiful environment around the house.

The location of Sananrejo Village and KWT Semi-Lestari can be seen in the figure 2.

The Organizational Structure of KWT Semi-Lestari is as follows:

a. Protector: Head of Sananarejo Village
b. Supervisor: Head of TP PKK Sananrejo Village
c. Assistant: Sananrejo Village Agriculture Extension
d. Chairman: Sri Setyowati
e. Vice Chairman: Rahmatun Nisa F. W
f. Secretary: Lailatul Fitria
g. Treasurer: Nuzulia Indah Fatma

The organizational structure chart of KWT Semi-Lestari can be seen in the figure 3.

The observations and interviews regarding the members' knowledge showed that as many as 83.3% of

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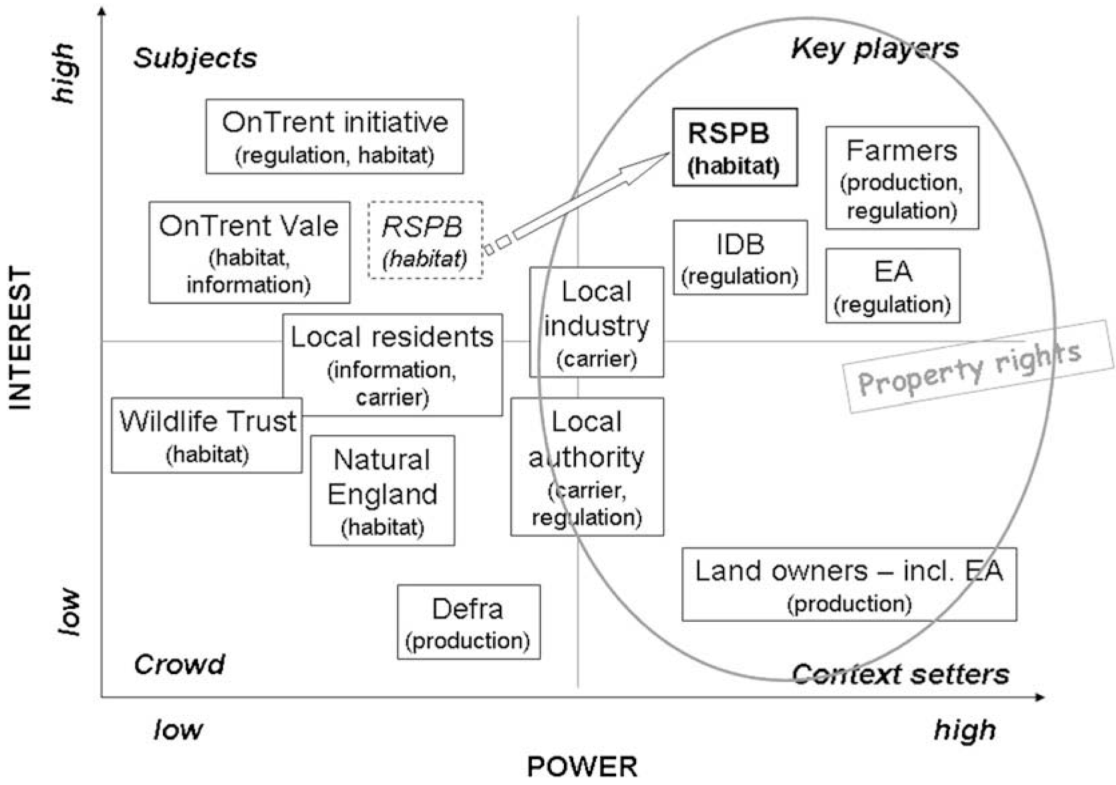
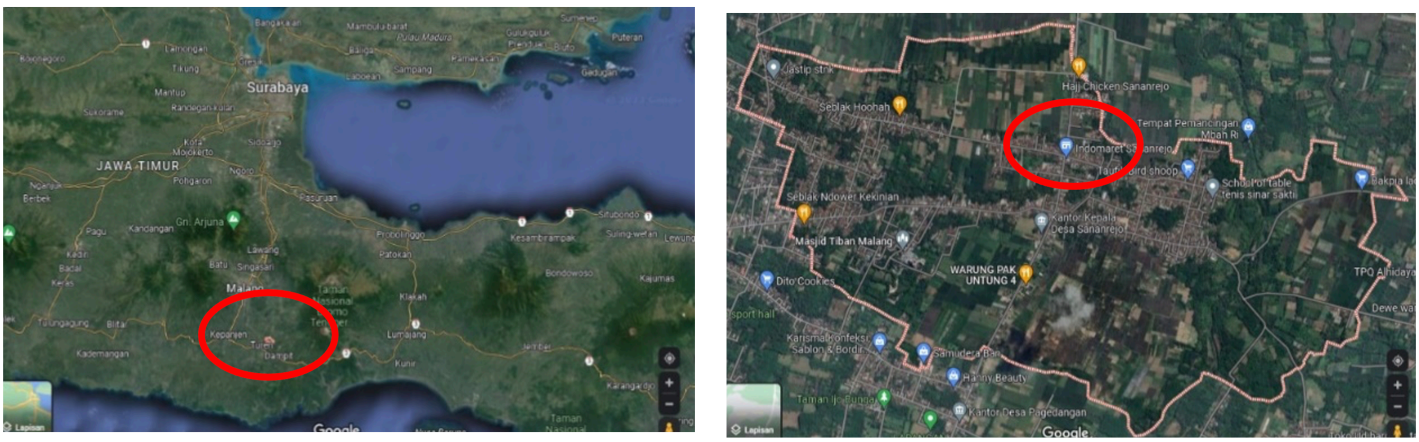


Figure 1. Interest–influence matrix for Integrated Management of Floodplains RELU Project showing stakeholders with property rights. (Reeds et al, 2009)



(a) (b)

Figure 2. (a) Location of Sananrejo Village seen from Java Island, (b) Location of KWT Semi-Lestari seen from Sananrejo Village.

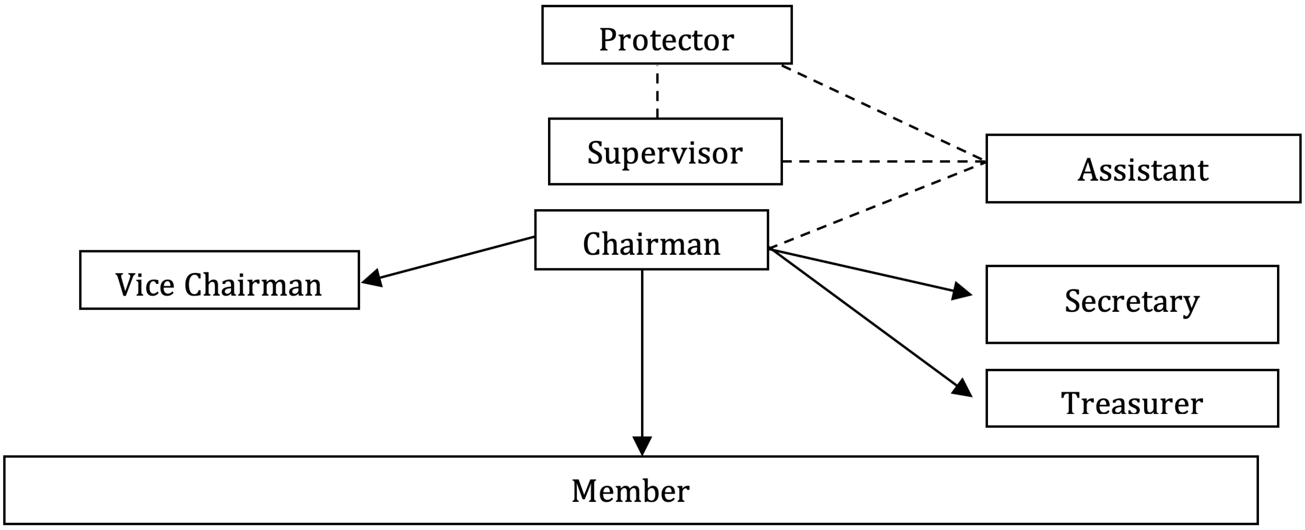


Figure 3. KWT Semi-Lestari Organizational Structure Chart

the members knew about vegetable cultivation in the home garden, and 64.7% of the women farmers knew the market needs of the yard produce. The results of observations and interviews on the psychomotor level or skills of the members show that 72.5% of the members carry out plant maintenance in the members' plantations. Members and administrators harvest or utilize home garden produce once a week.

The next behavioural aspect is attitude or affective. After observing and interviewing members, 74.17% know the importance of planting vegetables in the home garden, and 64.77% are responsible for looking after and caring for plants in the P2L area. When members know the importance of planting vegetables in the home garden, members will try to be responsible for caring for vegetables.

3.1.2. P2L Program Activities

The P2L program is implemented based on the technical instructions of the Head of the Food Security Agency, Ministry of Agriculture Number: 83/KPTS/RC.110/J/10/2020 concerning Technical Guidelines for Sustainable Food Yards in 2021. These technical instructions cover the minimum standards for the P2L Program. Based on the observation results, a comparison of the technical instructions with the realization of P2L in KWT Semi-Lestari can be seen as shown in Table 2.

From these data, it can be seen that the nursery facilities have been built in accordance with the technical instructions, namely greenhouses with a size of 8m x 2.5m or 20m2 with light steel frames, fibre roofs, and insect net walls. The nursery is located at the end of the KWT neighbourhood entrance, making it more attractive. The number of plant seeds has also exceeded the minimum standard in the technical guidelines for the types of seeds planted, namely mustard greens, eggplants, chilies, kale, beets, and cauliflower. The diversity of this type of seed has also exceeded the minimum standard because there are seven types.

The KWT Semi-Lestari Yard Demonstration Plot is located on a member's land with an area of 230m2. This land area is relatively narrow for the size of a demonstration plot in a rural area. It is because KWT Semi-Lestari is located in a relatively densely populated residential area with yards that are, on average less than 100m2. The technical guidelines also require that the demonstration plot land be usable by the group for five years, as evidenced by a land use statement. This requirement caused only one member to allow their plot of land to be used as a KWT demonstration plot. The plants cultivated in the demonstration plots included chilies, mustard greens, mustard greens, cauliflower, kale, red spinach, eggplant, squash, green beans, and bitter gourd. Plants in this demonstration plot were classified as diverse because there were more than 10 types of plants. Activity on the demonstration plots can be seen from the frequency of harvesting ac-

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Table 2. Minimum Amount and Realization of P2L Components based on Technical Instructions

	Description	Minimum amount	Realization amount
	Nursery Area	20m2	20m2
	Number of Seeds	7.500 seeds	8.240 seeds
	Seed Diversity	5 type	7 type
	Demonstration plot area	400-500 m2	230 m2

tivities on the demonstration plots, where the average harvesting activity in one year is 5 harvests, and as much as 80% of the harvest is sold.

In the members' yards, it can be seen that the number of polybags in each member's yard according to the technical instructions is at least 75 polybags. Based on the results of observations, for members who have large yards, some grow vegetables up to 150 polybags, so the average number of polybags for each member is 106 polybags, and this is classified as very good. Vegetables grown in the members' yards include mustard greens, cauliflower, eggplant, kale, red spinach, red sla, chilies, and green onions, with an average of 7 types of plants per house. Activities in the member's plantations can be seen from the utilization of the results of the yard for family food consumption, where 65% of vegetable needs are obtained from the yard. On average, only 40% of the members' vegetables are sold for the marketing of yard vegetables.

Many activities have been carried out by KWT including community service in filling polybags, plant maintenance which is carried out together every afternoon, maintenance of demonstration plots together and carrying out harvesting together. There are 6 types of processed yard produce: beetroot juice, bitter melon chips, spinach chips, mustard chips, crispy eggplant, and spring onion chips. Processing this yard's results involves only 40% of the members. Not all members are involved in processing yard produce because not all members have the skills and willingness in food processing.

The activity of processing yard produce can be seen from the continuity of the production of yard produce which is in the sufficient category because processed yard produce is only produced 2x in one year, namely during Eid al-Fitr and during the school holiday season. Not all processed yard products are marketed, members consume some. For the marketing of processed products outside KWT, only about 60% is sold. Marketing is not 100% out yet because there are still some product deficiencies, including the product's durability and durability as well as the product's taste which is still being tested.

3.1.3. Regulation

Regulations for the implementation of the P2L Program include written norms and rules. The existing norms in society have different binding powers. The norms among women farmer groups include watering the plants daily, picketing on demonstration plots, planting after harvest, pulling weeds on planting each member, and community service twice a month. Most of these norms are carried out by KWT members and administrators.

The Malang Regency Food Security Service made written rules regarding the P2L Program as the executor of activities at the district level. The written rules are in the form of Technical Instructions, which have been issued before the Program was handed down to the women farmer groups as program beneficiaries. The Food Security Service disseminated these technical instructions to the assistant officers or agricultural extension officers and the heads of the women farmer groups before the P2L Program was implemented in the field. The Technical Instructions are then conveyed to other KWT members and administrators by agricultural extension workers or assistant officers, who the members then understand together. These rules or technical instructions are well documented in the secretariat of the women farmer group.

3.2. Stakeholder Role Mapping

Based on the identification results, nine stakeholders are involved in Sustainable Food Yard (P2L) activities at KWT Semi-Lestari, Sananrejo Village, Turen District. The results of interviews with stakeholders show the role of stakeholders along with their strengths and interests listed in Table 3.

A stakeholder analysis was made using the Microsoft Excel tool that processes data from interviews with stakeholders regarding the interests and influence of the P2L program. The stakeholder role mapping analysis results can be seen in Figure 4 below.

From the results of the stakeholder analysis, it can be seen that:

1. Stakeholders who act as key players with strong influence and importance are the Malang Regency Food Security Office, KWT Semi-Lestari members and management, agricultural extension workers, and the Turen District Government.
2. Stakeholders who act as context setters with high influence and low interest are the Village Government, RT Management, and Subdistrict TP PKK.
3. Stakeholders who act as a crowd with low influence and interest are vegetable traders and village TP PKK.

4. Discussion

4.1. Sustainable Food Home Garden Program Activities

Women have a role at every stage of agricultural activity, from farming to food processing served at the dinner table, and their contribution is large or small depending on the amount of time and energy used. Women play a role in food production, processing,

Table 3. Roles, Strengths, and Interests of Stakeholders

NO	STAKEHOLDERS	ROLE	POWER	INTEREST
1.	KWT Semi-Lestari	• Propose P2L activities to the village • Direct implementation of P2L activities • Provide land for demonstration plots and seedling houses • Selling yard produce	+++++	+++++
2	RT manager	• Assist KWT members in implementing P2L • Provide motivation and orders for environmental sustainability	++++	+++
3	Village Government	• Proposing P2L activities to the sub-district Musrenbang • Provide motivation and emphasis so that rules and norms can be implemented • Support activities through the provision of supporting facilities and infrastructure	++++	+++
4	TP PKK Village	· Provide assistance and motivation	+++	+++
5	Turen District Government	• Propose P2L activities through the district musrenbang • Provide assistance and motivation to comply with rules and norms	++++	++++
6	TP PKK District	• Provide assistance and motivation • Teaches how to process crops	++++	+++
7	Agricultural Extension	• Socializing and accompanying each activity to comply with technical instructions • Providing new knowledge related to vegetable cultivation, nurseries to harvest, and post-harvest handling	+++++	+++++
8	Groceries	• Selling crops	++	++
9	Malang Regency Food Security Service	• Develop technical instructions • Provide outreach and funding • Perform monitoring and supervision • Carrying out a P2L Competition	++++++	+++++

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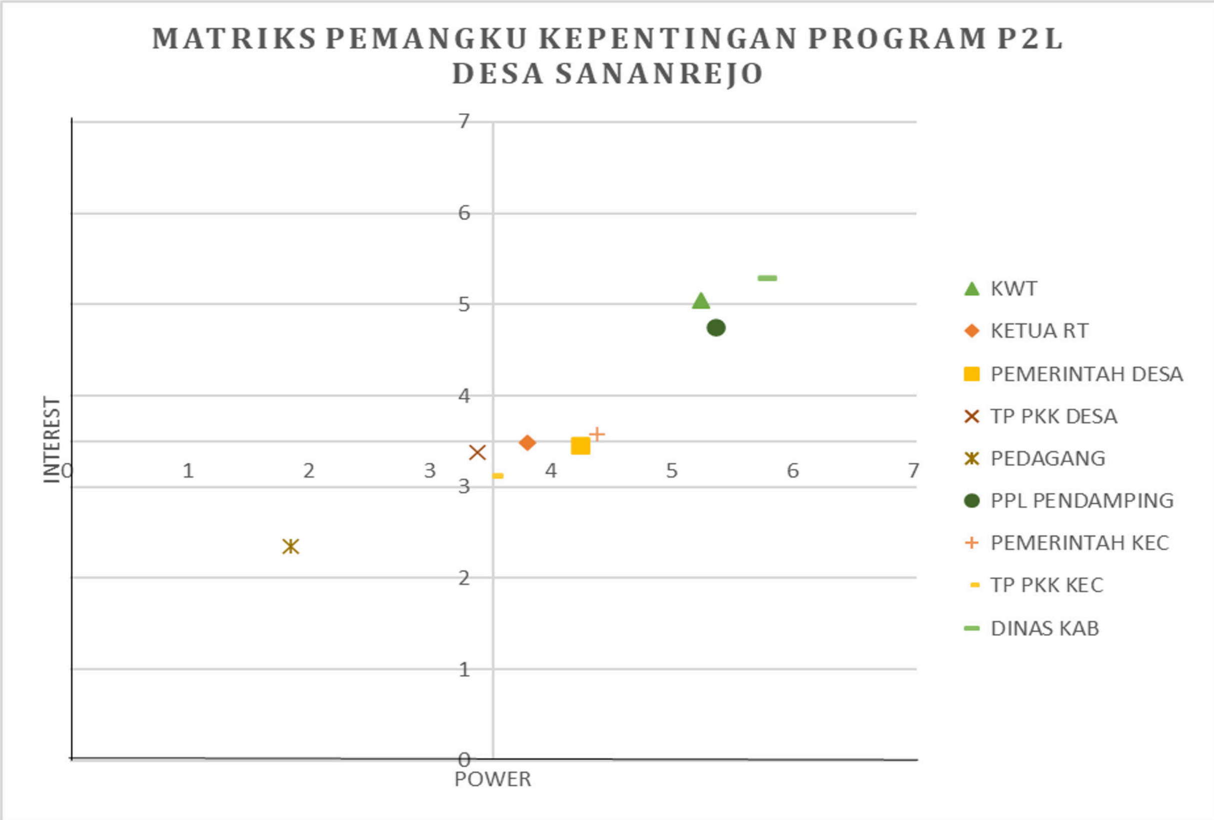

Figure 4. Stakeholder analysis results

and distribution at the household level (Atmadja et al., 2020)

According to (Hutajulu, 2015), the higher involvement of women in agriculture is due to the economic drive to meet the needs of family members, or, on the other hand, it may make women's position stronger in the family. The higher the income of women farmers in contributing income in family income, the higher the position above men, and the role of women in the family. If a woman's income is low in contributing to family income, her role in the family is still under the husband's.

The women who are members of KWT Semi-Lestari in Sananrejo Village strongly desire to have a strong role in the family. Apart from being a determinant of fulfilling family nutrition, KWT Semi-Lestari members also hope to help husbands increase family income without reducing the husband's role as head of the family. This is one of the important aspects to consider in promoting gender equality and empowering women in agricultural activities. So agriculture has an important role in support gender equality.

Research shows that when women are not active participants in decision-making and employment, this imbalance and negligence in addressing gender-based differences often result in disparities in development (Adebayo & Worth, 2022).

KWT Semi-Lestari is located in RT 031 RW 007 Desa Sananrejo. Placement of farmer groups or women farmer groups in an area facilitates coaching, empowerment, and coordination activities in each activity. In addition, the stakeholders of this similarity of location make it easier for social interaction between individuals to occur to achieve the goal of forming a KWT.

According to Jamaludin, 2015, social contact and communication are the conditions for social interaction. Social contact can be direct or primary contact where a person meets another person face to face, and secondary contact is made through an intermediary. Group members in one location allow direct contact so that communication between individuals can occur in two directions directly. It is reflected by Parsons (Ritzer, 2018), which relates the personality system to the social system. First, actors must learn to see themselves in a way appropriate to their place in society. Second, the expected role is attached to each role an individual actor occupies. Then there is learning to discipline oneself, live the value orientation, identify, and so on.

Several stakeholders influence the interaction process in rural areas, namely imitation, suggestion, identification, and sympathy. Imitation will encourage someone to always comply with existing rules and values. Stakeholder suggestion is the process of someone following the views expressed by someone. He will follow these views and tend to be emotional, often ignoring rational considerations. Identification is a person's tendency to behave like other people who are liked. This process will shape one's personality. Identification goes deeper than imitation. In the identification process, a person will try to learn to find out the strengths of the person he will emulate (Jamaludin, 2015)

In the process of social interaction at KWT Semi-Lestari, it can be seen that these stakeholders influence social interaction. Each member tries to comply with the rules or norms that have been agreed upon, and the KWT head figure, for example, can give suggestions to members. In the end, the members carry out the identification process so that they can form a personality, especially to love the environment more and try to fulfil family nutrition.

The nursery facility is located near the entrance gate to the KWT Semi-Lestari area making it easy for others to see. The nursery's land is village-owned, so the nursery can be permanent. The provision of irrigation facilities for the seedling houses received support from the Sananrejo Village Government by providing PDAM water and simple irrigation equipment such as pipes and storage tanks.

Provision of irrigation facilities is one of the tasks of the village government, as stated by Jamaludin, 2015 the village head, as part of the village government, is tasked with carrying out government affairs, including regulating community life according to village authority, such as making village regulations and establishing community institutions. The task of the village head in terms of development, namely community empowerment in the provision of public facilities and infrastructure. In rural development, the village government has a vital role, unlike the case in Vancouver, Canada. The recent interest in growing food in the city has been predominantly motivated by individuals and organizations with non-agricultural backgrounds and cultural histories, focused on social justice, environmental justice, food literacy education, and green job creation. Urban farms in Vancouver include both for-profit and social enterprise models, including those operating as part of a network of residential gardens, farms operated in collaboration with a community or city institution such as a school or hospital, indoor production systems, vertical farms, and farms on private agriculturally zoned land. (Valley and Wittman, 2019)

In the development of demonstration plots and planting of members, some obstacles arose, namely bad weather or too much rain, which caused damage to up to 65% of the plants in the members' yards. Apart from that, caterpillar pest attacks, especially for cauliflower plants, cause up to 55% damage. To control this damage, agricultural extension workers provide suggestions for controlling the use of plant-based pesticides and teaching KWT members how to make and spray plant-based pesticides.

Research in other countries also shows that bad weather due to climate change also affects crop damage. With future climate change impacts, crop pest problems in the sub-Saharan region are expected to worsen (Lamichhane et al., 2015). Farmers in Paya commonly recount that crop pest problems have intensified over time, particularly over the past 15–20 years. While generally puzzled about its precise causes, many interviewees connect this to an overall changing climate and an increase in extreme weather events in the region, including prolonged droughts, heavy rainfall, and flooding. Declining soil fertility and the notion that crops are becoming ‘weaker’ and thus more susceptible to pest damage is another factor often mentioned when they speculate about the causes of the mounting crop pest damage. The destructive impacts of pests have not only intensified but also the range of crops being affected. The long rain season, which lasts from around September to December, is depicted as the worst period when “almost all crops are suffering” (Andersson & Isgren, 2021).

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4.2. Stakeholder Behaviour and Role Mapping

As explained by (Leeuwis, 2004), public awareness can be achieved with mass media campaigns, entertainment education, visualization of what is difficult to see, and demonstration experiments. In this P2L activity, female farmers' or members' awareness is achieved after explaining and giving examples by extension workers and after carrying out self-demonstration experiments. Unlike the research that has been conducted by (Kustanti, 2019), the changes to mangrove management started from 1970-1980: the mangrove forest was seen as a green belt along the coast; and continued from 1981-1990: mangroves were converted into traditional prawn ponds, and from 1991-1995: mangrove management was applied as prawn cultivation had been the focus of attention among the actors due to abrasion disaster. By 1996-2005, prawn cultivation by corporations with private ownership was immense. The existence of private corporations in prawn cultivation should be monitored to maintain mangrove forests as a green belt throughout the coast.

Policy analysis has long sought to understand how information, institutions, decisions, and power shape the policy agenda for interest groups in social networks. In policy research, Stakeholder analysis has been seen as a way of generating information about "relevant stakeholders" to understand their behaviour, interests, agendas, and influence on decision-making processes. (Brugha & Varvasovszky, 2000))

The P2L program is a program from the Ministry of Agriculture that, in its implementation, is fully handed over to the regions through the Malang Regency Food Security Service. There are two important policies that encourage community participation, namely devolution and decentralization. Decentralization is the transfer of power from the central government to the regions to maximize development and equality (Evans & Centre for International Forestry Research, 2006)

This P2L program is a women farmer empowerment program that requires the women farmers' active participation. According to (Handono et al., 2020), participation can be seen as a comprehensive process of community empowerment, starting from the roots, stems, branches, and leaves. It means that it is necessary to look at the root of the problem, the targets that have problems, relevant stakeholders or stakeholders, and inhibiting factors or other supports.

Stakeholder analysis identifies individuals, groups, and organizations that are affected or can affect the environment and future generations and prioritize these individuals and groups to be involved in the decision-making process (Reeds et al, 2009).

Stakeholders are grouped into key players, context setters, subjects, and crowds. Key players have high importance and influence. Context setters have high influence but low importance. The subject has high importance but low influence, while the crowd is stakeholders with low interest and influence.

The ecosystems framework was then used to identify and classify stakeholders according to their interest in the goods and services provided by the regulating, production, habitat, carrier, and information functions of agricultural land (de Groot, 2006)

Through the stakeholder matrix, it can be seen that the Malang District Food Security Service has the greatest influence and interest. According to Kustanti, 2019, the interests of local government are framed by their main duties and functions. The interest in the Food Security Service is high because it has the main task of realizing family food security through the consumption of the B2SA menu. The influence of the Food Security Service is also high because it acts as a drafter of technical guidelines for P2L activities where the implementation of activities must be adjusted to these technical instructions.

Research by Kustanti et al, 2014 showed that Involving stakeholders in achieving the common goal of mangrove forest management in accordance with their duties and functions between the three parties' cooperation (local government, community, and University of Lampung).

Another stakeholder who also acts as a key player is KWT Semi-Lestari itself. KWT Semi-Lestari has a role starting from proposing P2L activities to the village government, such as implementing the P2L program, providing land for demonstration plots and seedling houses, and selling home garden produce.

(Bushamuka et al., 2005) quantified the impact of the homestead food production programme of Hellen Keller International using cross-sectional data for 2,160 households. They compared households who received gardening support with a control group of households who did not get support. The study potentially suffers from selection bias as there were clear differences between control and intervention households which were not controlled for in the analysis. The study found a threefold increase in vegetable production (from 46 to 135 kg) and a twofold increase in household vegetable consumption (from 38 to 85 kg) over three months. Furthermore, the study found that more than 3 years after the intervention, these positive effects had been sustained, although the effect on consumption had become less.

Other stakeholders who act as key players are assistant officers or agricultural extension workers. In this P2L program, agricultural extension agents play a role in socializing and assisting KWTs in every process of P2L activities and providing new knowledge and knowledge related to plant cultivation. Socialization can be a positive or negative action. According to research conducted by (Kustanti et al., 2023), Socialization refers to actions to spread the deviated behaviour to the public or between generations so it is accepted as normal behaviour. Socialization is the system that guarantees values and beliefs are transferred well among the people. Socialization consists of three stages: co-optation, incrementalism, and compromise stage. In this P2L activity, agricultural extension workers provide motivation and approach to women farmers so that they can use the land around the house to increase family income. As stated by (Van den Ban and Hawkins, 1999), Extension agents can help farmers understand the magnitude of the influence of economic and social structures to achieve a better life and find ways to change structures or situations that prevent them from achieving these goals.

Stakeholders who act as key players are the sub-district governments. In this study, the sub-district government played a role in proposing P2L activities through Musrenbang and providing motivation to comply with rules and norms. As research conducted by (Nurdin et al., 2014), Biringbulu District, in the implementation of education and training, provides counselling to the community by gathering farmers and community groups in each Village and Kelurahan. To provide an understanding of what activities need to be carried out and how to implement them in the field. The main duties and responsibilities of actors in the key player's quadrant make the level of knowledge possessed by key players deeper than other stakeholders (Mustika et al., 2017).

Stakeholders who act as context setters with high influence and low interest are the Village Government, RT Management, and Sub-district TP PKK. The village government plays a role in proposing P2L activities to the sub-district Musrenbang, providing motivation and emphasis so that rules and norms can be implemented and supporting activities by providing supporting facilities and infrastructure. The Sananrejo Village Government, in this case, acts as a regulator by emphasizing that rules and norms can be implemented properly.

The RT administrator also acts as a context setter. In this P2L Program, the RT administrator plays a role in assisting KWT members in implementing P2L as well as providing motivation and instructions for environmental sustainability. According to research (Zaina, 2018), Rukun Tetangga (RT) and Rukun Warga (RW) are the lowest organizations. They are closest to the community and understand the conditions and problems faced by the community in their environment.
Stakeholders who act as context setters are the District TP PKK. The district TP PKK has the role of providing assistance and motivation as well as teaching how to process the results. In carrying out its activities and programs, the PKK has 10 main programs that form the basis for the programs being implemented to improve the quality of life for families in accordance with the goals of the PKK movement. These programs include food, housing, and household management.

In the food sector, efforts are made to instil awareness of the importance of healthy and nutritious food to shape physically and spiritually to build healthy, intelligent, and strong families. PKK also promotes counselling for the use of yards. The utilization of this yard can also support housing programs and household management. This housing and household management program is directed at the idea of a healthy

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home suitable for families to live in (Kusumastuti & Darsono, 2019).

The next stakeholder is the one who acts as a crowd with low influence and interest. Further consideration is needed to involve this actor because the interests and influence held can usually change over time, so it must be monitored (Wakka, 2014). In this P2L Program, the crowd is Vegetable Traders and Village TP PKK. Vegetable traders play a role in accommodating the harvested vegetables in the P2L program, but in reality, not all harvested vegetables are always sold to vegetable traders. Most of the vegetables grown in the members' yards are used for family consumption and are only sold if there is an excess harvest. Vegetable traders cannot pressure or arrange for KWT members to grow vegetables according to what is needed. This is because vegetable traders are also not too dependent on vegetable yields in the P2L Program. After all, they already have their vegetable suppliers, so the interest of vegetable traders in the vegetable yields in KWT Semi-Lestari is low. It is in accordance with research conducted by (Sheyoputri & Abri, 2021), where the farmer's business scale is relatively small, and farming is not based on market demand, causing the bargaining position of farmers to be very weak, this allows the presence of intermediary traders who are then more dominant in determining the selling price at the farmer level. The share received by farmers from the price paid by consumers for several types of vegetables is, on average smaller than that received by intermediary traders, so the marketing system is considered less efficient for farmers. This is why women farmers are still reluctant to sell their crops to vegetable traders.

Stakeholders who act as the next crowd are TP PKK Sananrejo Village. The TPP PKK in Sananrejo Village has low influence and importance, in contrast to the Kecamatan TPP PKK, which has high influence. In this P2L Program, the Sananrejo Village TP PKK only provides assistance and motivation, in contrast to the District TP PKK, which provides counselling related to product processing.

5. Conclusion

5.1. The implementation of the Sustainable Food

Home Garden Program (P2L) in Sananrejo Village, Turen District, Malang Regency is in accordance with existing technical instructions and can provide benefits to recipients, namely KWT Semi-Lestari, which is a nursery area of 20m2, number of seedlings 8,240 seedlings, there are 7 types of seedlings, an area the demonstration plot area is 230m2, the members' yards average 106 polybags and there are processed agricultural products.

5.2. Nine stakeholders in the P2L program who have key roles or key players, namely the Malang Regency Food Security Office, KWT Semi-Lestari members and management, agricultural extension workers, and the Turen District Government. The Food Security Service has a key role because it has high importance, as a program carrier and high power as a drafter of technical guidelines. KWT members have high interest and influence because they are direct executors of P2L activities. Agricultural extension workers also act as key players because they play a role in overseeing, assisting, and facilitating the P2L Program directly, while the Turen District government also plays a role as a key player because it participates in monitoring and supervising P2L activities. The Village Government, RT Management, and the District PKK TP are stakeholders who act as context setters. It is because the village government, RT administrators, and the Sub-District PKK Mobilization Team are actors who are close to the KWT, so they have influence, namely the power to directly supervise and guide KWTs. Stakeholders who act as a crowd with low influence and interest are vegetable traders and village TP PKK. Recommendations for further research regard efforts to mediate conflicts and relations between stakeholders and strategies so that P2L can provide optimal benefits for the community, especially for the Village TP PKK.

Conflict of Interest

The author declares that there is no conflict of interest between the authors.

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Effect of storage temperatures and modified atmosphere packaging on sprouting and quality attributes of fresh peeled garlic cloves

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Data of the article

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This study was conducted during the 2021 and 2022 seasons to evaluate the influence of active modified atmosphere packaging (MAP) at levels of 3% O_2 + 5% CO_2, 3% O_2 + 10% CO_2, 3% O_2 + 15% CO_2, 3% O_2 + 97% N_2, and 5% N_2 + 95% O_2 compared with passive MAP as a control on sprouting and rooting delay and maintaining quality attributes of freshly peeled garlic cloves during storage at 5 and 10°C and 90 - 95% relative humidity for 20 days. The results indicated that all active MAP treatments were effective in reducing weight loss, colour changes, O_2 consumption, CO_2 production, and polyphenol oxidase activity, retarding sprouting and rooting growth, and maintaining pyruvic acid, total phenolic contents, and the overall appearance of peeled garlic cloves during storage as compared with passive MAP (control). Also, all cloves stored at 5°C were the best in all quality attributes compared to those stored at 10°C. However, peeled garlic cloves packed in active MAP at 3% O_2 + 15% CO_2 and stored at 5°C proved to be the most effective treatment in retarding sprouting growth and preserving all the quality attributes of the cloves. Furthermore, this treatment showed the excellent appearance of cloves without any rooting or discoloration after 20 days of storage at 5°C, while those stored at 10°C gave a good appearance after 16 days of storage. Cloves packed in 3% O_2 + 95% N_2 gave an excellent appearance for 16 days of storage at 5°C and gave a good appearance after 12 days of storage at 10°C. Whereas, passive MAP gave an unsalable appearance at the end of storage at 5°C and 10°C.

1. Introduction

Garlic (*Allium sativum L.*) is widely used as a therapeutic food and a flavouring agent. Owing to rapid urbanisation and more women joining the workforce, the use of ready-to-eat, minimally processed convenience foods is gaining increasing popularity. Because the peeling of garlic is a laborious and time-consuming process, the peeled garlic clove is a popular commodity among minimally processed vegetable products in the market and attracts the interest of retail food stores, restaurants, and consumers because of its convenience and suitability for modern lifestyles (Cantwell & Suslow, 2002). However, the peeling process results in broken and damaged pieces, and damage is the major factor leading to decay and quality loss during storage. Physical damage that occurs during the peeling process contributes to increased respiration rates and spoilage of minimally processed products (Ramirez-Moreno et al., 2000). Like other minimally processed vegetables, the exposed produce surface in peeled garlic cloves accelerates surface discoloration, including enzymatic and non-enzymatic browning, moisture loss, microbial spoilage, and senescence, which results in short shelf life and poor quality. Other important factors contributing to the loss of quality include sprouting and rooting, which result from high humidity in plastic packaging without a modified atmosphere and as a result of storage at temperatures higher than the recommended temperature of 0 - 2 °C (Cantwell & Suslow, 2002). Therefore, it is necessary to use some techniques to reduce sprouting growth, maintain all quality attributes, and extend the shelf life of peeled garlic cloves. The major factors affecting the shelf life of peeled garlic cloves are storage temperatures and modified atmosphere packaging (Tanamati et al., 2016).

Temperature management is one of the most important tools for extending the shelf life of fruits (Lee & Kader, 2000) because it regulates the rate of all associated physiological and biochemical processes. If the storage temperature is lower or higher than the optimum temperature of the product, this will deteriorate the quality and reduce the product's storage life (Khorshidi et al., 2010).

Peeled garlic should be stored at 0-5°C to maintain quality. The storage life is expected to be 2 to 3 weeks if the cloves are stored at 5°C or below, while storage temperatures above 5°C will encourage root and shoot development and cause discoloration of the cloves in damaged areas to turn pink and brown (Kang & Lee, 1999). Furthermore, Cantwell et al. (2003a) found that for peeled garlic cloves stored at 0 and 5°C, excellent visual quality was maintained during >21 and 16 days of storage, respectively. At 10 and 15°C, acceptable quality was maintained for 12 and 8 days, respectively.

Modified atmosphere packaging (MAP) is a preservation technique used to prolong the shelf life of processed or fresh food by changing the composition of the air surrounding the food in the package. The MAP technology works by increasing CO_2 levels and decreasing O_2 levels in the package (Martinez-Romero et al., 2003). MAP may be created as a result of the commodity's own respiration (passive MAP) or by the addition and removal of gases from food packages (active MAP) to manipulate O_2 and CO_2 levels (Daş et al., 2006). Reduced O_2 and/or enriched CO_2 levels can reduce respiration and metabolic activity, prevent water loss, retard textural softening, delay browning, maintain colour, lower microbial populations, and slow down compositional changes associated with ripening, thereby resulting in an extension of shelf life and preserving the quality (Gonzalez-Aguilar et al., 2004). Moreover, the use of MAP has proved useful in maintaining fruit firmness by reducing or inhibiting the activities of enzymes responsible for degrading pectin polysaccharides (Femenia et al., 1998).

MAP (low O_2 and high CO_2) was the most effective treatment for retaining firmness, colour, total soluble solids, total antioxidant activity, total phenols, and pyruvic acid of peeled garlic throughout the storage period at 10°C (Madhav et al., 2016), reducing the colour change, and suppressing the sprouting and rooting of the garlic cloves (Kang & Lee, 1999). Furthermore, high carbon dioxide atmospheres retarded discoloration and decay, reduced sprout development in peeled garlic during storage at 5 and 10°C (Ramirez-Moreno et al., 2000), and preserved an acceptable quality of peeled garlic cloves stored at 10°C without any injuries (Attia & Atress, 2016). Also, fresh-cut red cabbage stored in MAP with 95% N_2 + 5% O_2 delayed microbial growth, decreased weight loss, and discoloration, maintained very good quality and freshness and gave a good visual appearance for 16 days of storage at 0°C (Atress et al., 2011).

A reasonable expected storage life of commercially peeled and modified-atmosphere-packaged garlic is 3-4 weeks at 0°C, 2-3 weeks at 5°C, and 1-2 weeks at 10°C (Tanamati et al., 2016). Therefore, the objective of the present study was to evaluate the effect of storage temperatures and modified atmosphere packaging on sprouting and quality attributes of fresh-peeled garlic cloves during storage at 5oC and 10oC and 90-95% relative humidity for 20 days.

2. Materials and Methods

2.1. Sample Preparation

Garlic bulbs (*Allium sativum L.*) cv. Seds 50 were harvested in the commercial maturity stage of marketing on the 18th and 23rd of May in the 2021 and 2022 seasons, respectively, and field cured on a local farm located in Beni Suef Governorate, Egypt. Garlic bulbs were transported to the laboratory of Handling of Vegetable Crops Department, Agricultural Research Centre, Giza, and manually sorted to select uniform-sized

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bulbs free from blemishes. They were then stored at room temperature for 4 months. The outer cloves of the garlic bulb were peeled and hand-dehulled (the peeled garlic cloves were prepared by breaking the bulbs into individual cloves and removing the husk shell manually without any machine) after breaking the dormancy, and the growth of the sprout reached 50% of full clove length. "Dormancy is a physiological phenomenon in plants, and it is a period where the activity of the plant, such as growth and development, is temporarily stopped. The garlic bulb has a dormancy period of more than 3 months, but as the time of postharvest storage is prolonged, the dormancy of the bulb is broken and sprout growth commences (Woldeyes et al., 2017)".

2.2. Modified Atmosphere Packaging (MAP)

Peeled garlic cloves were packed in polyethylene bags (30µm thickness, 10 × 15 cm size) and divided into six treatments. The six treatments were applied as follows: the bags were sealed and flushed with different gas mixtures (active MAP) at 3% O_2 + 5% CO_2, 3% O_2 + 10% CO_2, 3% O_2 + 15% CO_2, 3% O_2 + 97% N_2 and 5% N_2 + 95% O_2, and without flushing (passive MAP) as a control treatment. Each bag contains about 100 gram of cloves as an experimental unit. Thirty experimental units were prepared for each treatment; all samples were stored at 5°C and 10°C and 90 - 95 % relative humidity for 20 days (fifteen samples from each treatment for each storage temperature degree). The design of the experiment was completely randomized design with three replicates; the treatments were assigned to the experimental units completely at random. This allows every experimental unit to have an equal probability of receiving a treatment. Replication refers to the number of distinct experimental units under the same treatment. Replication, with randomization, will provide a basis for calculating the experimental error variance. The greater the number of replications, the greater the precision of the experiment and the lower the experimental error. Three samples were randomly selected from each treatment and were examined immediately after harvest and after 4, 8, 12, 16, and 20 days at 5°C and 10°C for the following properties:

2.3. Data Collection

1. The percentage of weight loss was calculated using the following equation:

$$\text{Weight loss \%} = \frac{\text{Initial weight of bag} - \text{weight of bag at sampling date}}{\text{Initial weight of bag}} \times 100$$

2. The general appearance (score) was evaluated on a scale from 9 to 1, with 9 being excellent, 7 being good, 5 being fair, 3 being poor, and 1 being unsalable; fruits rated (5 or lower) were judged unmarketable. It was recorded for wilting, surface colour discoloration, rooting and sprouting development, and any other visible deterioration, as stated by Attia & Atress (2016).

3. The sprouting ratio was estimated by cutting cloves longitudinally in half and the length of the sprout was measured with a ruler (mm) and the ratio of sprouting was reported as a fraction of the full clove length. A value of sprout length > 1.0 indicates sprout emergence Cantwell et al. (2003b).

4. Rooting (mm) was estimated by visual observation and measuring it with a ruler, as described by Dronachari et al. (2010).

5. Discoloration (score) was evaluated on a scale of 1 to 5, where 1= none, 2= slight, 3= moderate, 4= severe, and 5= extra severe, as described by Cantwell et al. (2009).

6. Colour was measured by using the Minolta CR-400 Chroma Meter (Minolta Co., Ltd., Osaka, Japan) to get readings for the Lightness (L* value) of the colour found on the outside surface of cloves. Lightness was used to express the gloss and skin colour. During the entirety of each data observation, three readings were taken from each garlic clove at different locations (McGuire, 1992).

7. Gas composition in package (%): O_2 and CO_2 concentrations in the package were measured with a Dual Trak Model 902 D gas analyser. It is an oxygen and CO_2 headspace analyser used for the measurement of residual oxygen and carbon dioxide in gas-flushed food packages. This headspace analyser contains an internal pump to draw in samples from the package and display O_2 and CO_2 concentration results by inserting the test probe through a rubber seal attached to the outside of the packaging.

8. Pyruvic acid content (mg/100g F.W.) as determined according to Schwimmer & Weston (1961).

9. Total phenolic content (mg/100g F.W.) as determined according to Singleton et al. (1999).

10. Polyphenol oxidase (PPO) activity (mg/100g F.W.) as determined according to Dogan et al. (2002).

2.4. Statistical Analysis

Statistical analysis was performed on the studied traits for each season, and pooled analysis was carried out when the errors were homogenous. The combined data across the two seasons of the study was analysed. The collected data were submitted for analysis of variance using SPSS. Mean separations were estimated by calculating LSD at the 5% level. The homogeneity of variances for the two seasons was checked by the Levene (1960) test.

3. Results

3.1. Weight loss

Data in Table 1 indicate that there was a significant increase in weight loss % with the prolongation of the storage period. All the active modified atmosphere packaging (MAP) treatments significantly reduced the weight loss % of cloves as compared to the control (passive MAP). Moreover, active MAP at 3% O_2 + 15% CO_2 was the best treatment for significantly reducing the percentage of weight loss (0.43%), followed by 3% O_2 + 95% N_2 (0.56%) and 3% O_2 + 10% CO_2 (0.65%) with no significant difference between them. While passive MAP treatment recorded the greatest percentage of weight loss (1.21%). Concerning the effect of storage temperatures, cloves stored at 5°C reduced the weight loss (0.67%) as compared to those stored at

Table 1. Effect of storage temperatures and modified atmosphere packaging on weight loss (%) of peeled garlic cloves during storage in 2021 and 2022 seasons (combined analysis).

Temperature	Treatment*	Storage period (day)						
		0	4	8	12	16	20	Mean
5ºC	**3% O_2 + 5% CO_2**	0.00	0.52	0.77	1.02	1.28	1.62	**0.87**
	3% O_2 + 10% CO_2	0.00	0.19	0.37	0.60	0.92	1.34	**0.57**
	3% O_2 + 15% CO_2	0.00	0.11	0.24	0.39	0.55	0.78	**0.35**
	3% O_2 + 97% N_2	0.00	0.24	0.54	0.83	1.13	1.47	**0.70**
	3% O_2 + 95% N_2	0.00	0.14	0.31	0.50	0.78	1.11	**0.47**
	Passive MAP	0.00	0.85	1.05	1.29	1.55	1.83	**1.09**
	Mean	**0.00**	**0.34**	**0.54**	**0.77**	**1.04**	**1.36**	**0.67**
10ºC	**3% O_2 + 5% CO_2**	0.00	0.65	0.95	1.30	1.66	2.04	**1.10**
	3% O_2 + 10% CO_2	0.00	0.26	0.49	0.81	1.19	1.64	**0.73**
	3% O_2 + 15% CO_2	0.00	0.20	0.33	0.55	0.86	1.17	**0.52**
	3% O_2 + 97% N_2	0.00	0.34	0.70	0.98	1.40	1.89	**0.89**
	3% O_2 + 95% N_2	0.00	0.26	0.47	0.71	1.06	1.46	**0.66**
	Passive MAP	0.00	0.97	1.26	1.54	1.87	2.30	**1.32**
	Mean	**0.00**	**0.45**	**0.70**	**0.98**	**1.34**	**1.75**	**0.87**
Mean	**3% O_2 + 5% CO_2**	0.00	0.59	0.86	1.16	1.47	1.83	**0.98**
	3% O_2 + 10% CO_2	0.00	0.22	0.43	0.70	1.06	1.49	**0.65**
	3% O_2 + 15% CO_2	0.00	0.15	0.29	0.47	0.71	0.98	**0.43**
	3% O_2 + 97% N_2	0.00	0.29	0.62	0.91	1.26	1.68	**0.79**
	3% O_2 + 95% N_2	0.00	0.20	0.39	0.60	0.92	1.28	**0.56**
	Passive MAP	0.00	0.91	1.15	1.41	1.71	2.06	**1.21**
	Mean	**0.00**	**0.39**	**0.62**	**0.87**	**1.19**	**1.55**	
LSD at 5%	Temperature (TE)=0.05	Treatment (TR)=0.09		Storage period (S)=0.09				
	TExTR=0.13	SxTR=0.22		SxTE=0.13		TExSxTR=0.31		

*MAP: Modified Atmosphere Packaging

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10°C (0.87%) during storage periods with significant differences between them.

The interaction among MAP, storage temperatures, and storage periods was significant. The results show that active MAP of 3% O_2 + 15% CO_2 treatment and storage at 5°C significantly reduced the weight loss % of cloves after 20 days of storage (0.78%), followed by 3% O_2 + 95% N_2 and storage at 5°C (1.11%) and 3% O_2 + 15% CO_2 and storage at 10°C (1.17%) with no significant differences between them, while cloves packed in passive MAP or active MAP of 3% O_2 + 5% CO_2 and stored at 10°C had the highest values of weight loss (2.30 & 2.04%, respectively) with no significant differences between them.

3.2. General appearance (GA)

As shown in Table 2, there was a considerable decrease in the GA score of freshly peeled garlic cloves with increasing storage duration. However, there were significant differences among all active MAP treatments and passive MAP treatment (control) in maintaining GA during storage periods. The active MAP of 3% O_2 + 15% CO_2 was the best treatment for maintaining GA (8.61), followed by 3% O_2 + 95% N_2 treatment (8.14). On the other hand, passive MAP treatment had the lowest score in this concern (6.25). Concerning the effect of storage temperatures, peeled garlic cloves stored at 5°C recorded the highest significant score of GA (7.94) as compared to those stored at 10°C (7.21). The interaction among MAP, storage temperatures, and storage periods on GA was significant. The results reveal that garlic cloves packed in 3% O_2 + 15% CO_2 did not exhibit any changes in their appearance till

Table 2. Effect of storage temperatures and modified atmosphere packaging on general appearance (score) of peeled garlic cloves during storage in 2021 and 2022 seasons (combined analysis).

Temperature	Treatment*	Storage period (day)						
		0	4	8	12	16	20	Mean
5ºC	3% O_2 + 5% CO_2	9.00	9.00	9.00	7.67	6.33	5.00	**7.67**
	3% O_2 + 10% CO_2	9.00	9.00	9.00	8.67	7.00	5.00	**7.94**
	3% O_2 + 15% CO_2	9.00	9.00	9.00	9.00	9.00	8.33	**8.89**
	3% O_2 + 97% N_2	9.00	9.00	9.00	8.33	6.67	5.00	**7.83**
	3% O_2 + 95% N_2	9.00	9.00	9.00	9.00	8.33	7.00	**8.56**
	Passive MAP	9.00	9.00	7.33	6.33	5.00	4.00	**6.78**
	Mean	**9.00**	**9.00**	**8.72**	**8.17**	**7.06**	**5.72**	**7.94**
10ºC	3% O_2 + 5% CO_2	9.00	9.00	7.67	6.67	5.67	3.33	**6.89**
	3% O_2 + 10% CO_2	9.00	9.00	8.67	7.33	6.33	4.33	**7.44**
	3% O_2 + 15% CO_2	9.00	9.00	9.00	9.00	7.67	6.33	**8.33**
	3% O_2 + 97% N_2	9.00	9.00	8.33	7.00	5.67	4.00	**7.17**
	3% O_2 + 95% N_2	9.00	9.00	9.00	7.33	6.33	5.67	**7.72**
	Passive MAP	9.00	8.67	6.00	5.00	3.67	2.00	**5.72**
	Mean	**9.00**	**8.94**	**8.11**	**7.06**	**5.89**	**4.28**	**7.21**
Mean	3% O_2 + 5% CO_2	9.00	9.00	8.33	7.17	6.00	4.17	**7.28**
	3% O_2 + 10% CO_2	9.00	9.00	8.83	8.00	6.67	4.67	**7.69**
	3% O_2 + 15% CO_2	9.00	9.00	9.00	9.00	8.33	7.33	**8.61**
	3% O_2 + 97% N_2	9.00	9.00	8.67	7.67	6.17	4.50	**7.50**
	3% O_2 + 95% N_2	9.00	9.00	9.00	8.17	7.33	6.33	**8.14**
	Passive MAP	9.00	8.83	6.67	5.67	4.33	3.00	**6.25**
	Mean	**9.00**	**8.97**	**8.42**	**7.61**	**6.47**	**5.00**	
LSD at 5%	Temperature (TE)=0.16	Treatment (TR)=0.29			Storage period (S)=0.29			
	TExTR=0.40	SxTR=0.70		SxTE=0.40		TExSxTR=1.00		

*MAP: Modified Atmosphere Packaging

20 days of storage at 5°C (8.33), while those stored at 10°C gave a good appearance after 16 days of storage (7.67). Cloves packed in 3% O_2 + 95% N_2 showed an excellent appearance after 16 days of storage at 5°C (8.33) and rated a good appearance after 12 days at 10°C (7.33). While passive MAP treatment gave the unsalable appearance of cloves at the end of storage at 5°C and 10°C (4.00 & 2.00, respectively).

3.3. Sprouting ratio and Rooting

Data in Tables 3&4 show that the sprouting ratio and rooting of fresh peeled garlic cloves increased with increasing storage durations. All active MAP treatments were much better at reducing sprouting and rooting compared to passive MAP (control). Furthermore, the active MAP at 3% O_2 + 15% CO_2 was the most effective treatment in controlling sprouting and rooting growth (0.71 & 0.14 mm, respectively), followed by 3% O_2 + 95% N_2 (0.79 & 0.29 mm, respectively) and 3% O_2 + 10% CO_2 (0.88 & 0.51 mm, respectively) with a significant difference between them, while the other active MAP treatments were less effective in this regard. The higher value of sprouting and rooting growth was obtained from passive MAP (1.21& 1.50 mm, respectively). Concerning the effect of storage temperatures, cloves stored at 5°C reduce sprouting and rooting (0.87 & 0.45 mm, respectively) more than those stored at 10°C (0.97 & 0.88 mm, respectively) with significant difference between them.

Table 3. Effect of storage temperatures and modified atmosphere packaging on sprouting ratio of peeled garlic cloves during storage in 2021 and 2022 seasons (combined analysis).

Temperature	Treatment*	Storage period (day)						
		0	4	8	12	16	20	Mean
5°C	3% O_2 + 5% CO_2	0.50	0.66	0.82	0.98	1.21	1.46	**0.94**
	3% O_2 + 10% CO_2	0.50	0.63	0.75	0.89	0.99	1.24	**0.83**
	3% O_2 + 15% CO_2	0.50	0.56	0.61	0.70	0.80	0.91	**0.68**
	3% O_2 + 97% N_2	0.50	0.64	0.77	0.93	1.11	1.40	**0.89**
	3% O_2 + 95% N_2	0.50	0.58	0.68	0.77	0.89	0.97	**0.73**
	Passive MAP	0.50	0.73	0.98	1.24	1.51	1.79	**1.13**
	Mean	**0.50**	**0.63**	**0.77**	**0.92**	**1.09**	**1.29**	**0.87**
10°C	3% O_2 + 5% CO_2	0.50	0.69	0.89	1.08	1.37	1.70	**1.04**
	3% O_2 + 10% CO_2	0.50	0.66	0.82	0.97	1.19	1.39	**0.92**
	3% O_2 + 15% CO_2	0.50	0.57	0.65	0.75	0.87	1.11	**0.74**
	3% O_2 + 97% N_2	0.50	0.66	0.83	0.98	1.29	1.60	**0.98**
	3% O_2 + 95% N_2	0.50	0.60	0.70	0.92	1.10	1.24	**0.84**
	Passive MAP	0.50	0.81	1.13	1.45	1.78	2.13	**1.30**
	Mean	**0.50**	**0.66**	**0.84**	**1.03**	**1.27**	**1.53**	**0.97**
Mean	3% O_2 + 5% CO_2	0.50	0.67	0.86	1.03	1.29	1.58	**0.99**
	3% O_2 + 10% CO_2	0.50	0.64	0.78	0.93	1.09	1.32	**0.88**
	3% O_2 + 15% CO_2	0.50	0.56	0.63	0.72	0.84	1.01	**0.71**
	3% O_2 + 97% N_2	0.50	0.65	0.80	0.96	1.20	1.50	**0.94**
	3% O_2 + 95% N_2	0.50	0.59	0.69	0.85	1.00	1.11	**0.79**
	Passive MAP	0.50	0.77	1.05	1.35	1.65	1.96	**1.21**
	Mean	**0.50**	**0.65**	**0.80**	**0.97**	**1.18**	**1.41**	
LSD at 5%	Temperature (TE) =0.02	Treatment (TR)=0.03			Storage period (S)=0.03			
	TExTR=0.05	SxTR=0.08		SxTE=0.05		TExSxTR=0.11		

***MAP:** Modified Atmosphere Packaging

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Table 4. Effect of storage temperatures and modified atmosphere packaging on rooting (mm) of peeled garlic cloves during storage in 2021 and 2022 seasons (combined analysis).

Temperature	Treatment*	Storage period (day)						
		0	4	8	12	16	20	Mean
5ºC	3% O_2 + 5% CO_2	0.00	0.00	0.00	0.00	1.67	2.50	**0.69**
	3% O_2 + 10% CO_2	0.00	0.00	0.00	0.00	0.00	1.83	**0.31**
	3% O_2 + 15% CO_2	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
	3% O_2 + 97% N_2	0.00	0.00	0.00	0.00	0.83	2.17	**0.50**
	3% O_2 + 95% N_2	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
	Passive MAP	0.00	0.00	0.00	1.67	2.50	3.00	**1.19**
	Mean	**0.00**	**0.00**	**0.00**	**0.28**	**0.83**	**1.58**	**0.45**
10ºC	3% O_2 + 5% CO_2	0.00	0.00	0.00	0.83	2.33	3.17	**1.06**
	3% O_2 + 10% CO_2	0.00	0.00	0.00	0.00	2.00	2.33	**0.72**
	3% O_2 + 15% CO_2	0.00	0.00	0.00	0.00	0.00	1.67	**0.28**
	3% O_2 + 97% N_2	0.00	0.00	0.00	0.00	2.00	2.83	**0.81**
	3% O_2 + 95% N_2	0.00	0.00	0.00	0.00	1.50	2.00	**0.58**
	Passive MAP	0.00	0.00	1.83	2.33	2.83	3.83	**1.81**
	Mean	**0.00**	**0.00**	**0.31**	**0.53**	**1.78**	**2.64**	**0.88**
Mean	3% O_2 + 5% CO_2	0.00	0.00	0.00	0.42	2.00	2.83	**0.88**
	3% O_2 + 10% CO_2	0.00	0.00	0.00	0.00	1.00	2.08	**0.51**
	3% O_2 + 15% CO_2	0.00	0.00	0.00	0.00	0.00	0.83	**0.14**
	3% O_2 + 97% N_2	0.00	0.00	0.00	0.00	1.42	2.50	**0.65**
	3% O_2 + 95% N_2	0.00	0.00	0.00	0.00	0.75	1.00	**0.29**
	Passive MAP	0.00	0.00	0.92	2.00	2.67	3.42	**1.50**
	Mean	**0.00**	**0.00**	**0.15**	**0.40**	**1.31**	**2.11**	
LSD at 5%	Temperature (TE)=0.07		Treatment (TR)=0.11			Storage period (S)=0.11		
	TExTR=0.16		SxTR=0.28		SxTE=0.16		TExSxTR=0.39	

***MAP:** Modified Atmosphere Packaging

The interaction among MAP, storage temperatures, and storage periods on sprouting and rooting was significant. After 20 days, peeled garlic cloves exposed to active MAP at 3% O_2 + 15% CO_2 or 3% O_2 + 95% N_2 and stored at 5°C had the lowest values of sprouting and did not show any rooting (0.91 & 0.00 mm) and (0.97 & 0.00 mm), respectively, with no significant difference between them, while the highest value was recorded with cloves packed in passive MAP and stored at 10°C during the same period (2.13 & 3.83 mm, respectively).

3.4. Discoloration

As shown in Table 5, there is a considerable increase in the discoloration (score) of peeled garlic cloves with the extension of the storage duration. However, all active MAP treatments reduce the incidence of discoloration when compared to passive MAP treatment. Furthermore, active MAP at 3% O_2 + 15% CO_2 was the most effective treatment in preventing discoloration in peeled garlic cloves, which showed the lowest score of discoloration (1.10), followed by 3% O_2 + 95% N_2 treatment (1.26). Whereas passive MAP treatment showed the highest score of discoloration (2.47). Significant differences in the discoloration of cloves were found between storage temperatures (5°C and 10°C). Cloves stored at 5°C gave the lowest values of discoloration (1.49), while the highest values were recorded with cloves stored at 10°C (1.89).

The interaction among MAP, storage temperatures, and storage durations was significant. Data reveal that

Table 5. Effect of storage temperatures and modified atmosphere packaging on discoloration (score) of peeled garlic cloves during storage in 2021 and 2022 seasons (combined analysis).

Temperature	Treatment*	Storage period (day)						
		0	4	8	12	16	20	Mean
5°C	3% O_2 + 5% CO_2	1.00	1.00	1.00	1.33	2.50	3.50	**1.72**
	3% O_2 + 10% CO_2	1.00	1.00	1.00	1.00	1.33	2.83	**1.36**
	3% O_2 + 15% CO_2	1.00	1.00	1.00	1.00	1.00	1.00	**1.00**
	3% O_2 + 97% N_2	1.00	1.00	1.00	1.50	2.00	3.17	**1.61**
	3% O_2 + 95% N_2	1.00	1.00	1.00	1.00	1.00	1.33	**1.06**
	Passive MAP	1.00	1.00	1.50	2.17	3.33	4.17	**2.19**
	Mean	**1.00**	**1.00**	**1.08**	**1.33**	**1.86**	**2.67**	**1.49**
10°C	3% O_2 + 5% CO_2	1.00	1.00	1.50	2.00	3.50	4.17	**2.19**
	3% O_2 + 10% CO_2	1.00	1.00	1.17	1.67	2.33	3.50	**1.78**
	3% O_2 + 15% CO_2	1.00	1.00	1.00	1.00	1.00	2.17	**1.19**
	3% O_2 + 97% N_2	1.00	1.00	1.50	1.83	2.83	3.67	**1.97**
	3% O_2 + 95% N_2	1.00	1.00	1.00	1.17	2.17	2.50	**1.47**
	Passive MAP	1.00	1.33	2.17	3.17	4.00	4.83	**2.75**
	Mean	**1.00**	**1.06**	**1.39**	**1.81**	**2.64**	**3.47**	**1.89**
Mean	3% O_2 + 5% CO_2	1.00	1.00	1.25	1.67	3.00	3.83	**1.96**
	3% O_2 + 10% CO_2	1.00	1.00	1.08	1.33	1.83	3.17	**1.57**
	3% O_2 + 15% CO_2	1.00	1.00	1.00	1.00	1.00	1.58	**1.10**
	3% O_2 + 97% N_2	1.00	1.00	1.25	1.67	2.42	3.42	**1.79**
	3% O_2 + 95% N_2	1.00	1.00	1.00	1.08	1.58	1.92	**1.26**
	Passive MAP	1.00	1.17	1.83	2.67	3.67	4.50	**2.47**
	Mean	**1.00**	**1.03**	**1.24**	**1.57**	**2.25**	**3.07**	
LSD at 5%	Temperature (TE)=0.09	Treatment (TR)=0.16		Storage period (S)=0.16				
	TExTR=0.22	SxTR=0.38		SxTE=0.22		TExSxTR=0.54		

***MAP:** Modified Atmosphere Packaging

cloves packed in 3% O_2 + 15% CO_2 and stored at 5°C did not show any changes in their colour till the end of the storage period (1.00), while cloves packed in 3% O_2 + 95% N_2 and stored at 5°C showed from none to a slight score of discoloration after 20 days of storage (1.33). On the other hand, cloves packed in passive MAP and stored at 10°C resulted in severe discoloration with the highest score during the same period (4.83).

3.5. Colour (L* value)

Results in Table 6 reveal that the lightness of cloves significantly decreases with an increased storage period. However, peeled garlic cloves packed in 3% O_2 + 15% CO_2 or 3% O_2 + 95% N_2 were the best treatments for decreasing the loss of L* value (76.33 & 75.78, respectively), indicating that the skin surface colour was lighter (higher L* value) during storage with no significant difference between them, followed by 3% O_2 + 10% CO_2 and 3% O_2 + 97% N_2 treatments (74.80 & 74.51, respectively) with no significant difference between them. On the other hand, 3% O_2 + 5% CO_2 treatment was less effective in this regard (73.67), while a lower L* value was detected in the cloves packed in passive MAP (69.35), which showed darker cloves (lower L* value) during storage. There was a continuous decrease in L* values at all storage temperatures. However, cloves stored at 5°C had significantly the highest L* value (77.79), while the lowest ones were

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Table 6. Effect of storage temperatures and modified atmosphere packaging on L* value of peeled garlic cloves during storage in 2021 and 2022 seasons (combined analysis).

Temperature	Treatment*	Storage period (day)						
		0	4	8	12	16	20	Mean
5°C	3% O_2 + 5% CO_2	84.05	81.86	79.44	76.67	73.49	69.37	**77.48**
	3% O_2 + 10% CO_2	84.05	82.02	79.88	77.50	74.73	71.59	**78.30**
	3% O_2 + 15% CO_2	84.05	82.94	81.50	79.66	77.48	74.88	**80.08**
	3% O_2 + 97% N_2	84.05	81.97	79.70	77.13	74.28	71.19	**78.05**
	3% O_2 + 95% N_2	84.05	82.72	81.08	79.13	76.86	73.58	**79.57**
	Passive MAP	84.05	78.24	74.87	71.73	68.04	62.66	**73.26**
	Mean	**84.05**	**81.62**	**79.41**	**76.97**	**74.14**	**70.54**	**77.79**
10°C	3% O_2 + 5% CO_2	84.05	79.85	74.06	67.80	60.60	52.84	**69.87**
	3% O_2 + 10% CO_2	84.05	80.33	75.33	69.78	62.97	55.32	**71.30**
	3% O_2 + 15% CO_2	84.05	80.80	75.95	70.78	65.20	58.71	**72.58**
	3% O_2 + 97% N_2	84.05	79.98	74.67	69.21	62.73	55.14	**70.96**
	3% O_2 + 95% N_2	84.05	80.68	75.78	70.17	64.05	57.25	**72.00**
	Passive MAP	84.05	74.99	68.91	62.74	55.15	46.82	**65.44**
	Mean	**84.05**	**79.44**	**74.12**	**68.41**	**61.78**	**54.30**	**70.36**
Mean	3% O_2 + 5% CO_2	84.05	80.85	76.75	72.24	67.05	61.10	**73.67**
	3% O_2 + 10% CO_2	84.05	81.20	77.60	73.64	68.85	63.46	**74.80**
	3% O_2 + 15% CO_2	84.05	81.87	78.73	75.22	71.34	66.79	**76.33**
	3% O_2 + 97% N_2	84.05	80.98	77.18	73.17	68.49	63.17	**74.51**
	3% O_2 + 95% N_2	84.05	81.70	78.43	74.65	70.45	65.42	**75.78**
	Passive MAP	84.05	76.61	71.89	67.23	61.59	54.74	**69.35**
	Mean	**84.05**	**80.53**	**76.76**	**72.69**	**67.96**	**62.45**	
LSD at 5%	Temperature (TE)=0.39	Treatment (TR)=0.67		Storage period (S)=0.67				
	TExTR=0.95	SxTR=1.44		SxTE=0.95		TExSxTR=2.32		

*MAP: Modified Atmosphere Packaging

obtained from cloves stored at 10°C (70.36).

In general, the interactions among MAP, storage temperatures, and storage periods were significant. After 20 days of storage, cloves packed in 3% O_2 + 15% CO_2 or 3% O_2 + 95% N_2 and stored at 5°C had the highest L* value (74.88 & 73.58, respectively) with no significant difference between them, while those packed in passive MAP and stored at 10°C had the lowest ones at the same period (46.82).

3.6. Gas composition in the package

Data in Tables 7&8 show that there was a significant decrease in O_2% and an increase in CO_2% in the packages during storage periods. The consumption of O_2 and production of CO_2 in active MAP treatments were significantly lower than those of passive MAP during the storage period. However, the lowest consumption of O_2 and production of CO_2 were recorded with cloves packed in active MAP at 3% O_2 + 15% CO_2. The storage temperature significantly affects the gas composition of the bags. Moreover, the consumption of O_2 or the production of CO_2 in the samples stored at 5°C was lower than those stored at 10°C. The average gas concentrations inside the packages in active MAP at 3% O_2 + 15% CO_2 treatment and storage at 5°C after 20 days of storage were 2.14% O_2 and 19.06% CO_2, whereas in passive MAP treatment and storage at 10°C were 12.21% O_2 and 6.59% CO_2 during the same period.

Table 7. Effect of storage temperatures and modified atmosphere packaging on O_2 % of peeled garlic cloves during storage in 2021 and 2022 seasons (combined analysis).

Temperature	Treatment*	Storage period (day)						
		0	4	8	12	16	20	Mean
5ºC	3% O_2 + 5% CO_2	3.00	2.73	2.43	2.12	1.78	1.41	**2.24**
	3% O_2 + 10% CO_2	3.00	2.77	2.53	2.29	2.00	1.67	**2.38**
	3% O_2 + 15% CO_2	3.00	2.89	2.73	2.54	2.34	2.14	**2.61**
	3% O_2 + 97% N_2	3.00	2.76	2.51	2.26	1.96	1.61	**2.35**
	3% O_2 + 95% N_2	5.00	4.84	4.65	4.44	4.18	3.88	**4.50**
	Passive MAP	20.80	20.23	19.45	18.47	17.31	15.89	**18.69**
	Mean	**6.30**	**6.04**	**5.72**	**5.35**	**4.93**	**4.43**	**5.46**
10ºC	3% O_2 + 5% CO_2	3.00	2.66	2.31	1.95	1.57	1.15	**2.11**
	3% O_2 + 10% CO_2	3.00	2.70	2.40	2.08	1.73	1.33	**2.20**
	3% O_2 + 15% CO_2	3.00	2.86	2.65	2.39	2.13	1.88	**2.48**
	3% O_2 + 97% N_2	3.00	2.71	2.39	2.05	1.71	1.30	**2.19**
	3% O_2 + 95% N_2	5.00	4.77	4.50	4.21	3.89	3.53	**4.32**
	Passive MAP	20.80	19.72	18.36	16.62	14.51	12.21	**17.04**
	Mean	**6.30**	**5.90**	**5.43**	**4.88**	**4.25**	**3.56**	**5.06**
Mean	3% O_2 + 5% CO_2	3.00	2.69	2.37	2.03	1.67	1.28	**2.17**
	3% O_2 + 10% CO_2	3.00	2.74	2.46	2.18	1.86	1.50	**2.29**
	3% O_2 + 15% CO_2	3.00	2.87	2.69	2.47	2.24	2.01	**2.55**
	3% O_2 + 97% N_2	3.00	2.74	2.45	2.15	1.83	1.45	**2.27**
	3% O_2 + 95% N_2	5.00	4.80	4.57	4.33	4.04	3.71	**4.41**
	Passive MAP	20.80	19.98	18.90	17.55	15.91	14.05	**17.86**
	Mean	**6.30**	**5.97**	**5.58**	**5.12**	**4.59**	**4.00**	
LSD at 5%	Temperature (TE)=0.05	Treatment (TR)=0.08		Storage period (S)=0.08				
	TExTR=0.11	SxTR=0.20		SxTE=0.11		TExSxTR=0.28		

*MAP: Modified Atmosphere Packaging

3.7. Pyruvic acid content

The pungency of garlic can be measured by analysing its pyruvic acid content. The data in Table 9 show that the pyruvic acid (pungency) of peeled garlic cloves decreased significantly with increasing storage duration. However, all active MAP treatments had significantly higher pyruvic acid content as compared with passive MAP (control) during the storage period. Cloves packed in active MAP at 3% O_2 + 15% CO_2 or 3% O_2 + 95% N_2 were the most effective treatments in maintaining total pyruvic acid content (139.80 & 138.50 mg/100g F.W., respectively) with no significant differences between them, followed by 3% O_2 + 10% CO_2 and 3% O_2 + 97% N_2 treatments (134.40 & 134.10 mg/100g F.W., respectively) with no significant differences between them. On the other hand, the lowest values were observed with passive MAP treatment (126.60 mg/100g F.W.). Concerning the effect of storage temperatures, cloves stored at 5°C retained more total pyruvic acid content (137.20 mg/100g F.W.) as compared with cloves stored at 10°C (131.30 mg/100g F.W.) with significant differences between them.

The interaction among MAP, storage temperatures, and storage periods was significant. After 20 days, cloves packed in 3% O_2 + 15% CO_2 or 3% O_2 + 95% N_2 and stored at 5°C maintained total pyruvic acid content (130.80 & 128.60 mg/100g F.W., respectively) with no significant differences between them, followed

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Table 8. Effect of storage temperatures and modified atmosphere packaging on CO_2 % of peeled garlic cloves during storage in 2021 and 2022 seasons (combined analysis).

Temperature	Treatment*	Storage period (day)						
		0	4	8	12	16	20	Mean
5°C	3% O_2 + 5% CO_2	5.00	5.67	6.55	7.66	8.99	10.50	**7.40**
	3% O_2 + 10% CO_2	10.00	10.58	11.34	12.34	13.51	14.92	**12.12**
	3% O_2 + 15% CO_2	15.00	15.59	16.26	17.06	17.97	19.06	**16.82**
	3% O_2 + 97% N_2	0.00	0.56	1.34	2.34	3.51	4.97	**2.12**
	3% O_2 + 95% N_2	0.00	0.54	1.18	1.97	2.97	4.37	**1.84**
	Passive MAP	0.03	0.69	1.53	2.68	4.13	6.11	**2.53**
	Mean	**5.01**	**5.60**	**6.37**	**7.34**	**8.51**	**10.00**	**7.14**
10°C	3% O_2 + 5% CO_2	5.00	5.80	6.79	7.99	9.36	11.00	**7.67**
	3% O_2 + 10% CO_2	10.00	10.73	11.65	12.77	14.12	15.65	**12.49**
	3% O_2 + 15% CO_2	15.00	15.64	16.42	17.29	18.25	19.44	**17.01**
	3% O_2 + 97% N_2	0.00	0.76	1.75	2.91	4.27	5.85	**2.59**
	3% O_2 + 95% N_2	0.00	0.68	1.48	2.37	3.43	4.87	**2.14**
	Passive MAP	0.03	0.85	1.90	3.18	4.67	6.59	**2.87**
	Mean	**5.01**	**5.74**	**6.66**	**7.75**	**9.02**	**10.58**	**7.46**
Mean	3% O_2 + 5% CO_2	5.00	5.73	6.67	7.82	9.18	10.80	**7.54**
	3% O_2 + 10% CO_2	10.00	10.65	11.49	12.56	13.82	15.29	**12.30**
	3% O_2 + 15% CO_2	15.00	15.61	16.34	17.17	18.11	19.25	**16.92**
	3% O_2 + 97% N_2	0.00	0.66	1.54	2.62	3.89	5.41	**2.35**
	3% O_2 + 95% N_2	0.00	0.61	1.33	2.17	3.20	4.62	**1.99**
	Passive MAP	0.03	0.77	1.71	2.93	4.40	6.35	**2.70**
	Mean	**5.01**	**5.67**	**6.52**	**7.55**	**8.77**	**10.29**	
LSD at 5%	Temperature (TR) =0.09	Treatment (TR)=0.016			Storage period (S) =0.016			
	TExTR=0.23	SxTR=0.40		SxTE=0.23	TExSxTR=0.56			

***MAP:** Modified Atmosphere Packaging

by 3% O_2 + 10% CO_2 and 3% O_2 + 97% N_2 and stored at 5°C (118.70 &117.90 mg/100g F.W., respectively) or 3% O_2 + 15% CO_2 and 3% O_2 + 95% N_2 and stored at 10°C (119.10 & 115.70 mg/100g F.W., respectively) with no significant differences between them. Cloves packed in passive MAP and stored at 10°C gave the lowest value during the same period (92.24 mg/100g F.W.).

3.8. Total phenolic content

Results in Table 10 indicate that total phenolic content decreased with the prolongation of the storage period. However, active MAP at 3% O_2 + 15% CO_2 was the most effective treatment in reducing the loss of total phenolic content during storage (28.10 mg/100g F.W.), followed by 3% O_2 + 95% N_2 treatment (27.29 mg/100g F.W.). The lowest values of total phenolic content were obtained from passive MAP (20.87 mg/100g F.W.). Concerning the effect of storage temperatures, cloves stored at 5°C gave the highest values of total phenolic content (25.25 mg/100g F.W.), while the lowest values were obtained from cloves stored at 10°C (23.03 mg/100g F.W.) with significant differences between them.

The interaction among MAP, storage temperatures, and storage periods was significant. After 20 days, cloves packed in 3% O_2 + 15% CO_2 or 3% O_2 + 95% N_2 and stored at 5°C maintained their total phenol-

Table 9. Effect of storage temperatures and modified atmosphere packaging on pyruvic acid (mg/100g F.W.) of peeled garlic cloves during storage in 2021 and 2022 seasons (combined analysis).

Temperature	Treatment*	Storage period (day)						
		0	4	8	12	16	20	Mean
5°C	3% O_2 + 5% CO_2	150.10	147.40	142.50	134.90	124.70	111.70	**135.20**
	3% O_2 + 10% CO_2	150.10	147.80	143.10	136.80	128.70	118.70	**137.50**
	3% O_2 + 15% CO_2	150.10	148.80	146.50	142.70	137.60	130.80	**142.70**
	3% O_2 + 97% N_2	150.10	147.80	143.30	136.50	128.00	117.90	**137.30**
	3% O_2 + 95% N_2	150.10	148.40	145.40	141.30	136.20	128.60	**141.70**
	Passive MAP	150.10	143.80	137.20	128.10	115.50	99.54	**129.00**
	Mean	**150.10**	**147.30**	**143.00**	**136.70**	**128.50**	**117.90**	**137.20**
10°C	3% O_2 + 5% CO_2	150.10	144.40	137.10	128.50	115.90	100.50	**129.40**
	3% O_2 + 10% CO_2	150.10	144.60	137.70	129.50	119.30	106.40	**131.30**
	3% O_2 + 15% CO_2	150.10	146.10	141.20	135.70	128.50	119.10	**136.80**
	3% O_2 + 97% N_2	150.10	144.90	137.80	129.20	118.60	104.80	**130.90**
	3% O_2 + 95% N_2	150.10	145.70	140.40	134.00	125.90	115.70	**135.30**
	Passive MAP	150.10	141.50	132.00	120.90	108.00	92.24	**124.10**
	Mean	**150.10**	**144.50**	**137.70**	**129.60**	**119.40**	**106.50**	**131.30**
Mean	3% O_2 + 5% CO_2	150.10	145.90	139.80	131.70	120.30	106.10	**132.30**
	3% O_2 + 10% CO_2	150.10	146.20	140.40	133.10	124.00	112.50	**134.40**
	3% O_2 + 15% CO_2	150.10	147.40	143.90	139.20	133.10	124.90	**139.80**
	3% O_2 + 97% N_2	150.10	146.30	140.50	132.90	123.30	111.40	**134.10**
	3% O_2 + 95% N_2	150.10	147.00	142.90	137.70	131.10	122.10	**138.50**
	Passive MAP	150.10	142.60	134.60	124.50	111.70	95.89	**126.60**
	Mean	**150.10**	**145.90**	**140.30**	**133.20**	**123.90**	**112.20**	
LSD at 5%	Temperature (TE)=0.81	Treatment (TR)=1.40		Storage period (S)=1.40				
	TExTR=1.98	SxTR =3.44		SxTE=1.98		TExSxTR=4.86		

***MAP:** Modified Atmosphere Packaging

ic content (21.59 & 20.34 mg/100g F.W., respectively) with no significant differences between them, followed by the same treatments stored at 10°C (19.58 & 18.28 mg/100g F.W., respectively) with no significant differences between them. Cloves packed in passive MAP and stored at 10°C gave the lowest ones during the same period (7.72 mg/100g F.W.).

3.9. Polyphenol oxidase (PPO) activity

Data in Table 11 show that the PPO activity of peeled garlic cloves increased with the prolongation of the storage period. The results show that all active MAP treatments reduced PPO activity during storage when compared to passive MAP treatment. Peeled garlic cloves packed in active MAP at 3% O_2 + 15% CO_2 were found to be the most effective treatment for reducing PPO activity (48.75 mg/100g F.W.), followed by 3% O_2 + 95% N_2 treatment (49.97 mg/100g F.W.). While passive MAP treatment had a higher increase in the activity of the PPO enzyme (62.36 mg/100g F.W.). Concerning the effect of storage temperatures, significant differences in PPO activity were found between storage temperatures (5°C and 10°C) during the storage period. Cloves stored at 5°C gave the lowest values of PPO activity (52.82 mg/100g F.W.), while the highest values were found in cloves stored at 10°C (57.15 mg/100g F.W.).

In general, the interaction among MAP, storage tem-

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Table 10. Effect of storage temperatures and modified atmosphere packaging on total phenolic (mg/100g F.W.) of peeled garlic cloves during storage in 2021 and 2022 seasons (combined analysis).

Temperature	Treatment*	Storage period (day)						
		0	4	8	12	16	20	Mean
5ºC	**3% O_2 + 5% CO_2**	33.48	30.03	26.25	21.69	16.67	11.02	**23.19**
	3% O_2 + 10% CO_2	33.48	31.18	27.70	23.45	18.84	13.75	**24.73**
	3% O_2 + 15% CO_2	33.48	32.71	31.13	28.90	25.66	21.59	**28.91**
	3% O_2 + 97% N_2	33.48	31.03	27.67	23.11	18.19	12.64	**24.35**
	3% O_2 + 95% N_2	33.48	32.37	30.56	28.01	24.65	20.34	**28.23**
	Passive MAP	33.48	29.53	24.89	19.96	14.86	9.58	**22.05**
	Mean	**33.48**	**31.14**	**28.03**	**24.19**	**19.81**	**14.82**	**25.25**
10ºC	**3% O_2 + 5% CO_2**	33.48	28.37	23.62	18.47	13.03	7.61	**20.76**
	3% O_2 + 10% CO_2	33.48	28.93	24.65	20.48	15.59	10.60	**22.29**
	3% O_2 + 15% CO_2	33.48	31.14	29.26	26.89	23.40	19.58	**27.29**
	3% O_2 + 97% N_2	33.48	28.38	24.15	19.79	15.10	10.09	**21.83**
	3% O_2 + 95% N_2	33.48	30.67	28.17	25.34	22.12	18.28	**26.34**
	Passive MAP	33.48	27.17	21.70	16.53	11.51	7.72	**19.69**
	Mean	**33.48**	**29.11**	**25.26**	**21.25**	**16.79**	**12.31**	**23.03**
Mean	**3% O_2 + 5% CO_2**	33.48	29.20	24.93	20.08	14.85	9.31	**21.98**
	3% O_2 + 10% CO_2	33.48	30.06	26.17	21.96	17.21	12.18	**23.51**
	3% O_2 + 15% CO_2	33.48	31.92	30.19	27.89	24.53	20.59	**28.10**
	3% O_2 + 97% N_2	33.48	29.71	25.91	21.45	16.65	11.36	**23.09**
	3% O_2 + 95% N_2	33.48	31.52	29.36	26.67	23.39	19.31	**27.29**
	Passive MAP	33.48	28.35	23.29	18.25	13.19	8.65	**20.87**
	Mean	**33.48**	**30.13**	**26.64**	**22.72**	**18.30**	**13.57**	
LSD at 5%	Temperature (TE) =0.25	Treatment (TR)=0.43		Storage period (S) =0.43				
	TExTR=0.61	SxTR =1.06		SxTE=0.61		TExSxTR=1.50		

*__MAP:__ Modified Atmosphere Packaging

peratures, and storage durations was significant. After 20 days of storage, data show that cloves packed in 3% O_2 + 15% CO_2 and stored at 5°C had the lowest values of PPO activity (49.91 mg/100g F.W.), followed by those packed in 3% O_2 + 95% N_2 and stored at 5°C or 3% O_2 + 15% CO_2 and stored at 10°C (52.65 & 57.79 mg/100g F.W., respectively) with significant differences between them. On the other hand, the highest value of PPO activity was obtained from cloves packed in passive MAP and stored at 10°C (91.81 mg/100g F.W.).

4. Discussion

Recently, consumer demand for high-quality foods requiring only a minimum amount of effort and time for preparation has increased. The peeled garlic clove is a popular commodity among minimally processed vegetable products on the market and attracts the interest of retail food stores, restaurants, and consumers because of its convenience. However, the peeling process accelerates weight loss, surface discoloration, sprouting and rooting development, microbial spoilage, and senescence, which results in quality deterioration and reduced shelf life (Cantwell & Suslow, 2002). Therefore, the aim of this study is to determine the best storage temperature and modified atmosphere packaging to slow down the sprouting and rooting, maintain quality properties, and extend the shelf life of peeled garlic cloves. The results of this study

Table 11. Effect of storage temperatures and modified atmosphere packaging on polyphenol oxidase activity (mg/100g F.W.) of peeled garlic cloves during storage in 2021 and 2022 seasons (combined analysis).

Temperature	Treatment*	Storage period (day)						
		0	4	8	12	16	20	Mean
5°C	$3\% O_2 + 5\% CO_2$	44.71	47.32	50.98	56.94	65.83	77.21	**57.17**
	$3\% O_2 + 10\% CO_2$	44.71	46.22	48.30	51.60	57.20	64.28	**52.05**
	$3\% O_2 + 15\% CO_2$	44.71	45.36	46.10	46.97	48.23	49.91	**46.88**
	$3\% O_2 + 97\% N_2$	44.71	46.40	48.46	51.93	58.05	66.43	**52.66**
	$3\% O_2 + 95\% N_2$	44.71	45.61	46.77	48.33	50.25	52.65	**48.05**
	Passive MAP	44.71	48.17	52.56	59.74	70.00	85.32	**60.08**
	Mean	**44.71**	**46.51**	**48.86**	**52.58**	**58.26**	**65.97**	**52.82**
10°C	$3\% O_2 + 5\% CO_2$	44.71	49.67	55.72	62.98	71.85	83.24	**61.36**
	$3\% O_2 + 10\% CO_2$	44.71	48.56	52.89	57.68	64.14	72.08	**56.67**
	$3\% O_2 + 15\% CO_2$	44.71	46.71	48.88	51.35	54.29	57.79	**50.62**
	$3\% O_2 + 97\% N_2$	44.71	48.90	53.67	59.11	65.74	74.32	**57.74**
	$3\% O_2 + 95\% N_2$	44.71	46.89	49.57	52.78	56.52	60.91	**51.90**
	Passive MAP	44.71	50.58	57.35	66.20	77.13	91.81	**64.63**
	Mean	**44.71**	**48.55**	**53.01**	**58.35**	**64.94**	**73.36**	**57.15**
Mean	$3\% O_2 + 5\% CO_2$	44.71	48.49	53.35	59.96	68.84	80.23	**59.26**
	$3\% O_2 + 10\% CO_2$	44.71	47.39	50.59	54.64	60.67	68.18	**54.36**
	$3\% O_2 + 15\% CO_2$	44.71	46.04	47.49	49.16	51.26	53.85	**48.75**
	$3\% O_2 + 97\% N_2$	44.71	47.65	51.06	55.52	61.89	70.38	**55.20**
	$3\% O_2 + 95\% N_2$	44.71	46.25	48.17	50.55	53.38	56.78	**49.97**
	Passive MAP	44.71	49.37	54.96	62.97	73.57	88.57	**62.36**
	Mean	**44.71**	**47.53**	**50.94**	**55.47**	**61.60**	**69.66**	
LSD at 5%	Temperature (TE)=0.45	Treatment (TR)=0.78		Storage period(S)=0.78				
	TExTR=1.10	SxTR =1.91		SxTE=1.10		TExSxTR=2.70		

***MAP:** Modified Atmosphere Packaging

revealed that all active MAP treatments significantly enhanced the storability and maintained all quality properties of cloves compared to the passive MAP (control treatment). Also, all cloves stored at 5°C were the best in all quality attributes compared to those stored at 10°C. Furthermore, peeled garlic cloves exposed to active MAP at 3% O_2 + 15% CO_2 and storage at 5°C was the best treatment for reducing weight loss, sprouting, and polyphenol oxidase activity, modifying the atmosphere inside the package, maintaining pyruvic acid and total phenolic contents, and giving the excellent appearance of cloves without any rooting or discoloration for 20 days of storage, while those stored at 10°C gave a good appearance after 16 days of storage, followed by cloves packed in 3% O_2 + 95% N_2, which gave an excellent appearance for 16 days of storage at 5°C and gave a good appearance after 12 days of storage at 10°C. Whereas passive MAP gave an unsalable appearance at the end of storage at 5°C and 10°C. These results were similar to those confirmed by previous studies (Attia & Atress, 2016, Madhav et al., 2016 and Tanamati et al., 2016).

4.1. Weight loss

The rate of weight loss in peeled garlic cloves increased with prolonged storage, and these results are consistent with Attia & Atress (2016). This may be due to moisture loss through transpiration and respiration, as well as other senescence factors associated

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with metabolic activities during storage (Madhav et al., 2016). However, all active modified atmosphere packaging (MAP) treatments and storage at 5°C significantly reduced the weight loss of cloves compared to the passive MAP treatment (control) and storage at 10°C; these results are consistent with Madhav et al. (2016) and Tanamati et al. (2016). This may be due to the active MAP reducing the respiration rate (Sethi et al., 2014), which provides a decrease in metabolic activities, transpiration, and suppression of the enzyme activities of the product during storage (Rojas-Graü et al., 2009). Furthermore, when moisture is trapped around the product, the relative humidity increases, and the water vapour pressure deficit and transpiration decrease, reducing the weight loss during storage (Gorrepati & Bhogat 2018). Also, the slowdown of physiological processes such as respiration and transpiration that occur during storage at low temperatures (Kays, 1991). In general, the higher the storage temperature, the greater the vapour pressure deficit and the greater the weight loss of fruits (Ibrahim et al., 2018).

4.2. General appearance

The visual appearance of fresh produce is one of the most important quality factors for marketing and is affected by the prolonged storage period. According to the findings in this study, there was a considerable decrease in the general appearance (GA) score of freshly peeled garlic cloves with increasing storage duration. These results were similar to those reported by Tanamati et al. (2016), and this might be due to wilting, surface discoloration, decay, and rooting and sprouting development (Attia & Atress, 2016). However, the active MAP of 3% O_2 + 15% CO_2 and storage at 5°C was the best treatment for maintaining GA. On the other hand, passive MAP treatment and storage at 10°C had the lowest score in this concern; these results are consistent with Tanamati et al. (2016). Active MAP (high CO_2) enables significant improvements in shelf life by reducing physiological changes, respiration rate, transpiration, oxidative deterioration, and colour and pigment changes in peeled garlic cloves (Madhav et al., 2016), reducing microbial growth, and delaying softening (Singh et al., 2019). All these effects can help extend the storage time and maintain the quality of peeled garlic cloves (Madhav et al., 2016).

Also, storage at low temperatures leads to a slowdown of transpiration and respiration rates, thus reducing the speed of quality deterioration and maintaining overall quality (Chen et al., 2019).

Cantwell et al. (2003a) indicated that although a lower temperature is important to maintain the quality of peeled garlic, modified atmospheres containing CO_2 are also essential. Thus, controlling storage temperature and gas composition in the package are important methods to control respiration rate and water loss to prolong the postharvest life of garlic cloves (Chen et al., 2019). Furthermore, Cantwell et al. (2003a) showed that fresh peeled garlic exposed to MAP at CO_2 (5-15%) and O_2 (1-3%) was effective in retarding discoloration and decay during storage at 5 and 10°C for 3 weeks.

4.3. Sprouting ratio and rooting

Our findings demonstrated that the sprouting ratio and rooting of freshly peeled garlic cloves increased with increasing storage durations. These results are similar to those of Tanamati et al. (2016). Mechanical injuries in minimally processed garlic accelerate the respiration rate and deterioration rate of cloves by disrupting membranes and increasing enzymatic activity, which causes undesirable reactions. This may cause sprouting and rooting growth, which can reduce the shelf life and the marketing quality of peeled garlic cloves (Dronachari et al., 2010). However, all active MAP treatments and storage at 5°C were much better at reducing sprouting and rooting compared to passive MAP and storage at 10°C. Furthermore, the active MAP at 3% O_2 + 15% CO_2 and storage at 5°C was the most effective treatment in controlling sprouting and rooting growth. These results are consistent with Tanamati et al. (2016), who showed that lower sprouting and rooting of garlic cloves were observed with lower O_2 and higher CO_2 concentrations inside the packages, as the low oxygen content effectively inhibits its respiration rates and mechanical injuries in minimally processed garlic. Growth phenomena such as sprouting and rooting development of peeled garlic cloves are inhibited by low O_2 and/or high CO_2 (Kang & Lee, 1999), and this may be attributed to an active MAP reducing respiratory rate, thus limiting the energy supply for growth-related events; in addition, it can inhibit some enzymatic steps in the growth process

(Kader, 1986). Additionally, low temperature is one of the factors that primarily controls the emergence of the sprout (Dufoo-Hurtado et al., 2015), due to the non-activation of γ-glutamyl peptidase in garlic during storage at low temperatures (Ichikawa et al., 2006). Therefore, as the storage temperatures decreased, the sprouting and rooting decreased.

4.4. Discoloration

As indicated in the current study, the discoloration of peeled garlic cloves significantly increased with the extension of the storage duration; these results were similar to those of Tanamati et al. (2016). This may be due to the oxidation of phenolic compounds to o-quinones, a reaction catalysed by the polyphenol oxidase (PPO) enzyme. Quinones polymerize into a dark brown polymer, causing browning of the tissue (Singh et al., 2019). However, all active MAP treatments and storage at 5°C reduce the incidence of discoloration when compared to passive MAP treatment and storage at 10°C. These results are similar to those reported by Tanamati et al. (2016) and Singh et al. (2019).

This could be because of low oxygen concentrations around the clove tissues, which slow down browning reactions by reducing enzyme activity (Madhav et al., 2016). The decrease in discoloration during storage at a low temperature may be due to the temperature affecting the metabolic activity of the product and thus reaching the required rate of modified atmosphere (Kader, 1986) and a lower oxygen content in the package, which delays enzymatic browning and reduces the discoloration of the product (Singh et al., 2019). Also, storage temperatures above 5°C will result in pink and brown discoloration on the damaged areas (Kang & Lee, 1999).

4.5. Colour (L* value)

The lightness (L* value) of peeled garlic cloves was affected by the advancement of the storage period; these results are consistent with Tanamati et al. (2016). The surface colour of the peeled garlic cloves was found to be white and changed towards a lighter, redder, or more yellow colour with the prolongation of the storage period (Kang & Lee, 1999). L* value changes generally corresponded to visual appearance quality scores (Tanamati et al., 2016). From our findings, active MAP treatments and storage at 5°C were the best treatments for maintaining the L* value compared with passive MAP treatment and storage at 10°C. These results are in agreement with Tanamati et al. (2016); this may be due to the fact that active MAP reduces enzyme activity, metabolic activity, moisture loss, colour loss, browning of the flesh, and the rate of degradation of organic acids and pigments in fruits and vegetables (Alam & Goyal, 2006). The faster increase in the yellow and reddish colour of peeled garlic cloves in the control package is caused by too much oxygen, which results in enzymatic browning (Singh et al., 2019).

Additionally, the enzyme activity decreases due to the lower storage temperature (Banda et al., 2015). The low storage temperature and high CO_2 concentration inside the package reduce metabolic activity and the rate of organic acid degradation, resulting in the evolution of physicochemical and quality properties such as colour (Alam & Goyal, 2006).

4.6. Gas composition in the package

Garlic cloves are still alive and continue to respire after harvest (Madhav et al., 2016). Studying the gas changes inside the package is extremely crucial in order to achieve the proper gas composition in the packages for all treatments used. The results of this study showed that there was a significant decrease in O_2 and an increase in CO_2 in the packages during storage periods. These results are consistent with Tanamati et al. (2016) and may be due to the consumption of O_2 and the production of CO_2 by cloves during the respiration process (Madhav et al., 2016). However, the consumption of O_2 and production of CO_2 in active MAP treatments and storage at 5°C were significantly lower than those in passive MAP treatment and storage at 10 °C during the storage period. Furthermore, the lowest consumption of O_2 and production of CO_2 were recorded with cloves packed in active MAP at 3% O_2 + 15% CO_2 and stored at 5°C. These results are consistent with Tanamati et al. (2016) and Chen et al. (2019), who showed that the respiration rates of fresh-cut garlic may be reduced by reducing O_2 concentration and increasing CO_2 concentration; this is the premise for the mechanism of MAP. This was also confirmed by the variations in O_2 and CO_2 concentrations over the storage period compared to the initial

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concentrations of O_2 and CO_2 on day 0. These variations could be attributed to the respiration of garlic cloves, which also affects their metabolism (Singh et al., 2019; Chen et al., 2019). In addition, storage temperature had a clear impact on respiration rates; high temperatures accelerated the respiration rates of fresh-cut garlic. The values of the O_2 consumption and the CO_2 production of fresh-cut garlic stored at the same gas concentration increased by 2.5-3.5 times as the temperature increased from 5 to 20°C (Chen et al., 2019).

4.7. Pyruvic acid content

The pyruvic acid (pungency) of peeled garlic cloves decreased significantly with increasing storage duration; these results are consistent with Madhav et al. (2016), and this may be attributed to the hydrolysis of polysaccharides and non-reducing sugars, where acid is utilised for converting them to hexose sugars, and the degradation of pungency constituents, as well as cell disruption caused by volatilization and leaching of substances (Berno et al., 2014). All active MAP treatments and storage at 5°C had significantly higher pyruvic acid content as compared with passive MAP (control) and storage at 10°C during the storage period. These results are consistent with Tanamati et al. (2016) and Gorrepati & Bhagat (2018). This may be due to MAP with a low O_2 concentration, which could substantially reduce the physiological loss in weight and respiration rate, thus maintaining the pyruvic acid content of garlic (Medhav et al., 2016). Also, Singh et al. (2019) found that storage at a low temperature decreased the respiration rate and weight loss with little change in the cell structure of peeled garlic cloves.

4.8. Total phenolic content

The reduction in phenolic content in peeled garlic cloves with the prolongation of the storage period is most likely due to the PPO enzyme, which oxidises phenolic compounds in the presence of oxygen and gives the coloured quinones, which explains the parallel consumption of phenols with the development of darkening throughout the storage period (Queiroz et al., 2008). Cloves packed in active MAP treatments and stored at 5°C maintained their total phenolic content compared with those packed in passive MAP treatment and stored at 10°C. Similar results were obtained by Medhav et al. (2016), who showed that garlic stored at low O_2 concentrations maintained a higher total phenolic content because of the retardation of oxidation processes. Modified atmospheric packaging with low O_2 and high CO_2 was the most effective for retaining total antioxidant activity and total phenols throughout the storage period (Sethi et al., 2014), and modified atmospheres had a positive effect on phenolic-related quality since high CO_2 treatment is a type of abiotic stress that promotes the synthesis and accumulation of phenols as a physiological response (Tomás-Barberán & Espín, 2001). Also, high CO_2 may allow for the removal of free radicals, which are associated with an increase in antioxidant capacity (Wang et al., 2003). Additionally, this is possibly due to the effects of low temperatures on enzyme activity (He & Luo, 2007).

4.9. Polyphenol oxidase activity

The polyphenol oxidase (PPO) activity of peeled garlic cloves increased with the prolongation of the storage period. These results are consistent with Liu et al. (2021), and this may be attributed to mechanical damage from the peeling process, which led to the intracellular phenols of garlic being released and contacting polyphenol oxidase, thus increasing PPO activity. According to our findings, all active MAP treatments and storage at 5°C reduced PPO activity when compared to passive MAP treatment and storage at 10°C. Active MAP reduces enzyme activity due to a decrease in O_2 and an increase in CO_2 concentration in the headspace surrounding the garlic cloves (Madhav et al., 2016), and low temperatures reduce enzyme activity (He & Luo, 2007).

5. Conclusion

From the previous results, it could be concluded that peeled garlic cloves packed in active MAP at 3% O_2 + 15% CO_2 and stored at 5°C was the most effective treatment for retarded sprouting growth, maintained all quality attributes, and gave cloves an excellent appearance for 20 days of storage without any rooting or discoloration.

Conflict of Interest

The authors declare that they have no conflicts of in-

terest. Furthermore, the funders had no involvement in the study's design, data collection, analysis, or interpretation, manuscript preparation, or decision to publish the results.

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The potency of robusta coffee pulp as a vinegar product

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Coffee processing produces 40-50 % of by-products that can damage coffee plants and cause environmental pollution. The coffee pulp as waste can be used for producing acetic acid solution as a preservative and hand-washing agent to prevent infection. The fermentation process can affect the quality of the acetic acid solution. This study aims to analyse the effect of yeast types and time fermentation as well as to determine the characteristics of acetic acid solution from Robusta coffee pulp. The experiment consists of two types of yeast: bread-fermented yeast, cassava-fermented yeast, and a combination of both yeasts. The second factor is time fermentation which consists of 13 and 16 days of fermentation. The study found that interaction between both yeasts significantly affected the acetic acid solution's moisture content and total soluble solids. Meanwhile, the factor of bread-fermented yeast and cassava-fermented yeast had a significant effect on the pH, acetic acid content, and reduced sugar. The study showed that the treatment of cassava-fermented yeast fermented for 13 days at room temperature can be used as an alternative to produce an acetic acid solution. The physicochemical quality of the acetic acid solution is acetic acid content is 1.983 ± 0.04 %, pH of 4.104 ± 0.04, reducing sugar of 1.505 ± 0.03 %, moisture content of 90.61 ± 0.294 %, and total soluble solid is 15.57 ± 0.153 %. However, the quality of the acetic acid solution from coffee pulp needs to increase, especially the lower acetic acid content and the light brown colour.

1. Introduction

Coffee is one of the most popular beverages and the largest trade commodities worldwide (Lachenmeier et al., 2020; Klingel et al., 2020). Orrego et al. (2018) reported that coffee is one of the most traded commodities, along with crude oils, consumed by millions daily. Indonesia is the fourth largest coffee producer in the world after Brazil, Colombia, and Vietnam which also play major roles in the global coffee trade, developments, and the country's economy (Orrego et al., 2018).

According to Berecha, (2011); Ameca et al., (2018); Klingel et al., (2020), there are two methods of coffee processing which are dry and wet methods that are most useful for coffee processing by farmers and producers. Both processes will produce green beans and by-products. Meanwhile, Mangku et al. (2022) found that there are three methods of coffee processing namely natural, honey, and full wash (wet processing). In the wet process, the coffee pulp is the main by-product and represents 55 % of the whole berry

(Murthy & Naidu, 2012; Ameca et al., 2018). Most of the coffee pulp generated during wet processing is deposited directly into huge waste disposal sites or river streams without undergoing any treatment (Geremu et al., 2016). Navia et al. (2011) stated that coffee processing creates problems (1) organic waste products, such as mucilage and pulp, (2) residue of coffee processing, which represents a major source of environmental pollution, and their disposal is usually done in the water resources closest to the processing sites, such as rivers and lakes. Pulp and mucilage consume the oxygen in water, resulting in the death of plants and animals due to the lack of oxygen or the increased acidity, (3) This fact can later result in a proliferation of undesirable microorganisms, bringing foul odours, attracting flies and other insects and rendering the water undrinkable as well as many other things which make the water useless.

As the production of coffee has increased, the resulting by-products of coffee generated during wet or dry processing also increased (Orrego et al., 2018). Orrego et al. (2018) also reported that wet coffee processing will produce coffee residuals such as 43.2 % (w/w) of skin and pulp, 11.8 % (w/w) mucilage and soluble sugars, and 6.1 % (w/w) silver skin or parchment. Meanwhile, Saisa & Maliya Syabriana. (2018) reported that fresh coffee cherries content of coffee pulp is 45 %, mucilage 10 %, parchment, and silver skin 5 %, and coffee beans 40 %. This means that 60 % of waste is produced when coffee is processed. According to Arpi et al. (2018), coffee processing produces coffee pulp around 43-50 % of coffee cherries. Coffee mucilage, rich in carbohydrates and nitrogen, is considered to be a potential substrate in the bio-based industry to produce value-added molecules and commodities, such as ethanol and lactic acids.

Vinegar is an aqueous solution of acetic acid and other constituents and is known and consumed worldwide as a food condiment and preservative. Furthermore, in folk medicine, it is used in wound treatment, as well as a hand-washing agent to prevent infection (Gomes et al., 2018). Ouattara et al. (2019) reported that vinegar is defined as a 4 % acetic acid solution that is obtained from double-stage fermentation, alcoholic and acetic, performed, respectively, by yeasts and acetic acid bacteria. Vinegar is widely acknowledged for its functional features possessing antimicrobial properties, antioxidant activity, dietary, antidiabetic, and antitumor effects, as well as preventing cardiovascular diseases (Budak et al., 2014; Coelho et al., 2017). The quality of vinegar depends on fermentation, production methods, raw materials, and additives used. In addition, the acetic acid content, odour component, and organic acid and free amino acid composition affect the quality of vinegar (Kang et al., 2020).

Based on data in 2018, it is stated that 527.80 thousand tons of Robusta coffee were processed to produce coffee beans. From the total, 50 % of the processing results are coffee beans and the remaining 50 % (263.9 tons) are by-products (waste). The projection of Indonesian coffee production until 2023 is estimated to reach 777.12 thousand tons of ground coffee. Coffee production growth from 2019 - 2023 is expected to continue to rise, with an average increase of 1.43 % per year (Anonymous, 2019). This means that the more coffee production, the more coffee waste will be generated. The simple impact is a foul smell that quickly appears. This is due to coffee husks still have a high water content, which is 75 - 80 % therefore are very easily overgrown by spoilage microbes, this will disturb the surrounding environment if in large quantities it can pollute the air (Juwita et al., 2017).

Several researchers found that coffee pulp can be used for many products such as silage, molasses, alcohol, soft drinks, jam, pectin, and other products. However, there are only a few who produce vinegar. In light of these environmental concerns need to mitigate the negative environmental impacts of coffee waste from the coffee processing. The study aims to evaluate and analyse the type of yeast and fermentation time effects on quality and to determine the best processing method to produce vinegar. However, this study will increase the utilization of coffee waste to be an innovative product that has economic value and provide benefit for the farmers or producers.

2. Materials and Methods

The material used in this study was the Robusta coffee cherry pulp that grows 1200 m above sea level. The coffee cherries were harvested from a farmer managed by Bumdes Eka Giri Karya Utama located in Wanagiri Village, Sukasada District, Buleleng Regency. Robusta coffee is better grown in elevation ranges 200-700 m above sea level, meanwhile, in this location around 1200 m above sea level, the coffee plants slightly grow

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well. These conditions will affect the chemical composition, taste, and flavour of the coffee beans as well as the waste characteristics. The maturity of coffee cherries is optimally ripe and has a red skin colour of 95 %. The type of yeast used is bread-fermented yeast with the brand "Fermipan" with the composition of Saccharomyces cerevisiae (produced by S.I.L. France, imported by PT. Sangra Ratu Boga, Indonesia) and cassava fermented yeast with the brand "NKL" (Na Kok Liong produced by Ragi Tape NKL, Surakarta, Indonesia). Both yeasts were bought in a Cake Shop in Denpasar, Bali Indonesia. The equipment used in coffee processing includes pulper machine Type Horja (PD. Karya Mitra Usaha, Indonesia), huller MPK 2500 (PT. Bahagia Jayaindo, Indonesia), refrigerator model G236AH-BK (Merk Sanken), rotavapor R-300 BUCHI (Flawil, Switzerland), etc. The pulper machine is used to remove the pulp of coffee cherries from the beans and the huller machine is used to separate the outer skin and green beans. Instruments for chemical and physical analysis consist of Colorimeter CS-280 (Dongguan, Cina), oven, Soxhlet HM250C (Stuart, UK), desiccator, analytical scale, steak thermometer, Hygrometer, condenser, Memmert incubator N-15 (Germany), Centrifuge HC1120T, Autoclave Model HVE-50 (HIRAYAMA, JAPAN), UV-Vis Double beam spectrophotometer Libra S 60 (Biochrom Ltd, UK) and hand refractometer ATAGO (Master-53M JAPAN).

This research used a complete randomized design that consists of two factors, namely: the first factor is the type of yeast including bread-fermented yeast, cassava-fermented yeast, and mixed bread-fermented yeast and cassava-fermented yeast. The second factor is the time of fermentation, which consists of 13 days and 16 days. This research was replicated three times, therefore there are eighteen sample units.

2.1 Sample preparation

The pulp of Robusta coffee was used as a sample to process before being analysed. The coffee pulp was cleaned and sorted to obtain good quality materials as used for a sample. 1500 mL of water was added to 1500 g of cleaned pulp and then blanched before it was extracted for 30 minutes. The filtrate continued to strain to get clear of filtrate then it was pasteurized at 80oC for 10 minutes. After pasteurization, the filtrate was cooled until the temperature was 27oC (room temperature). The 1500 mL of the filtrate was divided into six parts with a volume consisting of 250 mL for each treatment. Two samples were added with 5 g of bread-fermented yeast, two samples were added with 5 g of cassava-fermented yeast, and the last two samples were added by mixing 2.5 g of bread yeast and 2.5 g of cassava-fermented yeast (mixing yeast). All the samples were added with sugar (sucrose) of 50 g. The samples then were centrifuged at 100 rpm for 5 minutes to make a homogenous sample. All the samples were fermented for 2 days with the anaerobic condition and then continued to ferment for 13 days and 16 days at room temperature (30oC) with the aerobic condition. After fermentation was finished, the sample continued to distillate using rotavapor R-300 BUCHI for 1 hour for each treatment, then the filtrate was collected to analyse the chemical characteristics.

2.2 Chemical analysis procedure of acetic acid solution.

The chemical characteristics of the acetic acid solution were evaluated through moisture content, total soluble solids (TSS), pH, acetic acid content, and reducing sugar.

Moisture content

The moisture content of the sample (acetic acid solution) was analysed using the Gravimetric method (Kyaw et al., 2020). Firstly, the dish and its lid were dried in the oven at 105 °C for 3 h and then transferred to the desiccator to be cold. The dish and lid were weighed after cooling. Secondly, 3 g of the coffee sample was weighed and placed in the dish. The dishes with the samples were placed in the oven and dried at 105 ˚C for 3 h. After drying, the dish partially covered with a lid was transferred to the desiccator to be cold. The dish and sample were re-weighted after cooling, and the moisture content of the samples was calculated by Equation 1.

$$\% \text{ Moisture} = \frac{W1-W2}{W1} \times 100\% \quad (1)$$

Where, W1 = weight of the sample before drying (g)
W2 = weight of the sample after drying (g)

Total Soluble Solid (TSS)

Total dissolved solids were measured using a hand refractometer. A sample of the acetic acid solution was placed on a refractometer prism, then readings were taken. Before and after readings, the refractometer prism was cleaned with alcohol. The refractometer number showed the total dissolved solids content (oBrix). A precipitate is formed or not in a reaction depending on the solubility of the solute. Precipitation can occur when the concentration of a compound exceeds its solubility. Testing of Total Soluble Solids of acetic acid solution was carried out using a Hand-Refractometer. First Refractometer was rinsed with distilled water and wiped with a soft cloth. The sample was dropped into the refractometer prism and measured with its o Brix (Wahyudi & Dewi, 2017). Testing the total soluble solids content began with a hand-refractometer calibration using distilled water, then 1-2 drops of the sample were dripped on the refractometer prism at 25 °C, then the Brix degree was measured. The degree of o Brix measured indicated the content of soluble solids in the solution (Ismawati, 2016).

pH

pH measurements were conducted using a digital pH meter (HI 8424 HANNA); a 10 mL homogenized sample (acetic acid solution) and 90 mL of distilled water were added, and the pH was read directly from the pH meter. The instrument was calibrated with standard buffer solutions of pH 7 and 4 before measuring the pH of the samples (Ezemba et al., 2021).

Acetic acid content

Samples of each treatment as much as 10 mL were homogenized with distilled water up to 100 mL in a volumetric flask. Ten millilitres of the solution was added with phenolphthalein indicator (± 2-3 drops) and then titrated with 0.01 N NaOH solution until the pink colour was stable and then the amount of NaOH solution needed was calculated (Nurhasanah & Zona, 2021). (BM of Acetic Acid = 60.05 g/mol).

$$\%\text{ Acetic acid} = \frac{\text{Volume NaOH (ml)} \times \text{N NaOH} \times \text{MW Acetic acid} \times \text{df}}{\text{Volume of Sample (ml)} \times 1000} \times 100\% \quad (2)$$

Where, N = normality of NaOH
MW = molecular weight of acetic acid
df = dilution factor

Reducing sugar

Analysis of reducing sugars using the Nelson-Somogyi method (Romadhoni et al., 2017). 1 mL sample was added with distilled water until the final volume was 10 mL. The mixture was taken at 1 mL and added 9 mL of distilled water. Samples were taken at 1 mL and mixed with 1 mL of Nelson's solution (a mixture of Nelson A & B; 25:1 v/v), then heated at 100°C for 20 minutes. The sample was cooled to room temperature. The sample was added with 1 mL of arsenomolybdate solution and 7 mL of distilled water and then shaken. The mixture was put into a cuvette and the absorption of visible light was measured at a wavelength of 510 nm. The absorbance value obtained was reduced by the absorbance value of the blank so that the absorbance value of the sample was obtained. The absorbance value of the sample was converted to reducing sugar content (mg/mL) based on the standard solution regression equation. The reducing sugar content of the sample was calculated by the following formula.

$$X = \frac{y - a}{b} \quad (3)$$

Where, x = reducing sugar concentration
y = absorbance of a sample
a and b = constants of a standard curve

$$\%\text{ Reducing sugar} = \frac{(x\frac{mg}{mL} \times df \times 100\%)}{\frac{mg}{mL}\,sample} \quad (4)$$

Where, x = reducing sugar (mg/mL)
df = dilution factor

2.3 Statistical analysis

The experiments were replicated three times and the data obtained in the physical-chemicals analysis will be submitted to the Analysis of Variance (ANOVA) with a confidence level of 95 %. The analysis will be continued to Duncan's multiple range test (DMRT) while the effects of the processing methods were significantly different, using Minitab Version 16 (Nakpatchimsakun et al., 2023).

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3. Results

The acetic acid solution produced from coffee by-products was affected by the kind of yeast types used and the fermentation process. The interaction of yeast types and fermentation times had a significant effect ($P < 0.05$) on the moisture content and the total soluble solids (TSS) of the acetic acid solution. The characteristics of the acetic acid solution that was produced are shown in Table 1.

Total Soluble solids (TSS) consist of many compounds such as sugar, pigment, vitamins, and minerals. Sugar is the most abundant content of TSS in vinegar (Zubaidah, 2010). This research found that the yeast types and fermentation times had a significant effect ($P < 0.05$) on the total soluble solid of the acetic acid solution. The TSS content of the acetic acid solution ranged from 13.37 ± 0.153 % to 15.57 ± 0.153 % and the higher TSS of 15.57 ± 0.153 % result was given by cassava fermented yeast with fermentation for 13 days. Meanwhile, the lower TSS is 13.37 ± 0.153 % was produced by mixing yeast, and 13 days of Fermentation (Table 1).

Based on this study the treatments of bread-fermented yeast and cassava-fermented yeast had a significant effect ($P > 0.05$) on pH, acetic acid content, and reducing sugar as well. The average value of pH, acetic acid, and reducing sugar of the acetic acid solution was presented in Table 2.

The interaction of both treatments of fermentation time and yeast types, in which the fermentation time gave no significant effect ($P > 0.05$) on the pH of the acetic acid solution, meanwhile, the yeast types gave a significant effect ($P < 0.05$) on the pH. The pH of the acetic acid solution ranges from 4.104 ± 0.04 to 4.889 ± 0.12. This pH is higher than the pH of grave vinegar ranging from 2.59-2.98 found by Kang et al. (2020). In this study, the highest pH 4.889 ± 0.12 was produced by bread-fermented yeast and showed significantly different with both treatments namely cassava fermented yeast and mixing of both yeasts. Otherwise, the lowest pH 4.104 ± 0.04 was produced by cassava fermented yeast.

Acetic acid content became a parameter that determined the quality of the vinegar. The Increasing acetic acid content in vinegar will increase the quality level. Based on statistical analyses the type of yeast had a significant effect ($P < 0.05$) on the acetic acid con-

Table 1. Physicochemical characteristics of the acetic acid solution in various types of fermentation

Treatments	Moisture content (%)	Total Soluble Solid (%)
Bread Fermented Yeast; 13 days Fermentation	95.75 ± 0.116 a	14.17 ± 0.153 ^{b}
Bread Fermented Yeast; 16 days Fermentation	92.50 ± 0.116 b	13.57 ± 0.321 ^{c}
Cassava Fermented Yeast, 13 days Fermentation	90.61 ± 0.294 ^{c}	15.57 ± 0.153 ^{a}
Cassava Fermented Yeast, 16 days Fermentation	92.65 ± 0.222 ^{b}	15.37 ± 0.153 ^{a}
Mixing yeast, 13 days Fermentation	91.42 ± 0.281 ^{c}	13.37 ± 0.153 ^{c}
Mixing yeast, 16 days Fermentation	88.36 ± 0.126 d	14.07 ± 0.231 ^{b}

Means ± standard deviation with different superscript letters in the same column were significantly different ($P < 0.05$)

Table 2. The chemical characteristics of the acetic acid solution in various types of yeasts and fermentation times

Treatments	pH	Acetic acid (%)	Reducing Sugar (%)
Type of Yeast			
Bread Fermented Yeast	4.889 ± 0.12 a	0.738 ± 0.20 c	1.440 ± 0.24 ^{a}
Cassava Fermented Yeast	4.104 ± 0.04 ^{c}	1.983 ± 0.04 ^{a}	1.505 ± 0.03 ^{a}
Mixing Yeast	4.707 ± 0.02 ^{b}	1.625 ± 0.06 ^{b}	1.385 ± 0.18 ^{a}
Times of Fermentation			
13 days Fermentation	4.610 ± 0.43 ^{a}	1.397 ± 0.72 ^{a}	1.550 ± 0.05 ^{a}
16 days Fermentation	4.523 ± 0.39 ^{a}	1.500 ± 1.40 ^{a}	1.337 ± 0.13 ^{b}

Means ± standard deviation with different superscript letters in the same column were significantly different ($P < 0.05$)

centration of the acetic acid solution. Otherwise, the fermentation time and the interaction of both treatments did not significantly affect ($P > 0.05$) the acetic acid concentration. Table 2 shows that the acetic acid concentration ranges from 0.738 ± 0.20 % to 1.983 ± 0.04 %. The highest acetic acid content of 1.983 ± 0.04 % was found in fermented using cassava fermented yeast. Meanwhile, the lowest acetic acid concentration of 0.738 ± 0.20 % was given by fermentation with bread-fermented yeast, and between both yeasts indicated significant differences.

Reducing the sugar content of the coffee pulp can contribute to acetic acid formation during the fermentation process. The increase of reducing sugar in raw material will increase the acetic acid content of the acetic acid solution. The reduced sugar content of the acetic acid solution ranged from 1.337 to 1.550 % (Table 2). These values were lower than that of 25.13 to 39.09 % obtained by Ouattara et al. (2019). Table 2 showed that the types of yeast were not significantly affected ($P > 0.05$) by reducing the sugar content of the acetic acid solution. Meanwhile, the times' fermentation had a significant effect ($P < 0.05$) on reducing sugar content. The reduced sugar of fermentation for 13 days 1.550 ± 0.05 % is higher than the acetic acid solution that fermentation for 16 days is 1.337 ± 0.13 % and both fermentation times showed significantly different.

4. Discussion

Moisture content can affect the quality of the acetic acid solution. The moisture content of the acetic acid solution is influenced by the water content of raw material, the addition of water in the extraction step, and the evaporating time used during the processing of the acetic acid solution. Based on the statistical analysis, the interaction of both treatments from the types of yeast and fermentation times significantly affected the moisture content of the acetic acid solution. Table 1 shows that the moisture content of the acetic acid solution from all combination treatments ranges from 88.36 ± 0.126 % to 95.75 ± 0.116 % indicating that the acetic acid solution still has a higher moisture content that causes decreasing quality, especially acetic acid content. This moisture content is slightly higher than those obtained from the vinegar by Ouattara et al. (2019) of 80.03 % to 88,67 %. Increasing in time fermentation tends to decrease moisture content. Using cassava-fermented yeast gave a lower moisture content of 90.61 ± 0.294 % than bread-fermented yeast except with combination of both yeasts showed a significant difference ($P < 0.05$) due to slightly higher moisture content. Probably due to cassava fermented yeast (NKL) consisting of many microorganisms that used the substrate of coffee pulp for growth and therefore, it increased the moisture in the acetic acid solution. According to Triani et al. (2019) & Ester et al. (2021), acetic acid in vinegar is oxidized by acetic acid bac-

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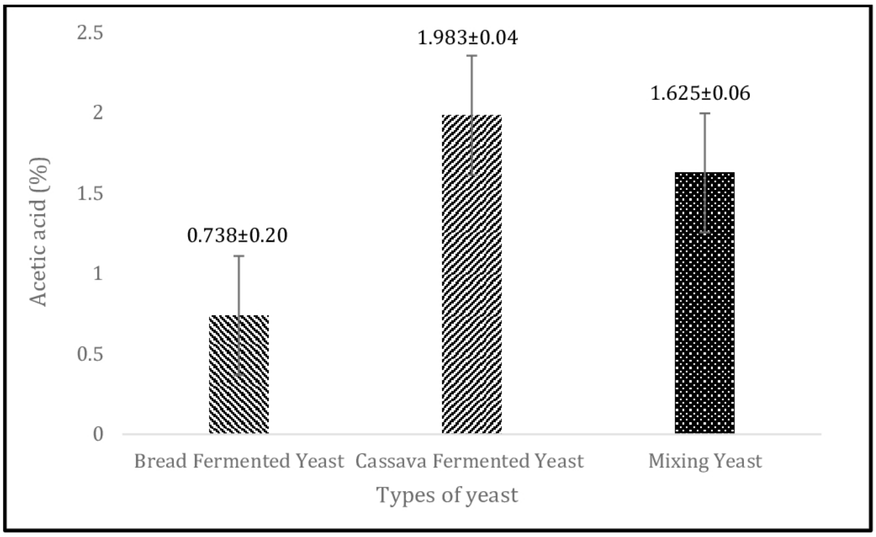

Figure 1. Acetic acid concentration (%) in the acetic acid solution in various types of fermentation

teria to produce H2O and CO2 therefore decreasing acetic acid concentration. Navia et al. (2011) reported that the decomposition is related to soluble solids, pH, and microorganisms present in the raw materials. However, while the moisture content is higher 92.50 ± 0.116 %, therefore, the acetic acid concentration in vinegar is lower.

The lower TSS content will make the acetic acid solution look clearer than the higher TSS content. However, this TSS content of 13.37-15.57 % is higher than was studied by Kang et al. (2020) who found the TSS content of grave vinegar ranges from 8.30-9.53 % o Brix. This is probably due to cassava fermented yeast containing many microorganisms that cause the breakdown of large compounds, thus increasing simple compounds. The cassava fermented yeast (NKL) consists of many types of microorganisms such as Amylomyces sp. Aspergillius sp, Mucor sp, Saccharomyces sp, Candida sp, and Acetobacter aceti (Ninsix, 2013). Wicklund et al. (2020) reported that yeast strains of Saccharomyces cerevisiae, S. bayanus or S. bayanus var. uvarum produce ciders of good quality. In addition, during fermentation, the total soluble solid (TSS) decreases due to the increase in fermentation time. Zubaidah, (2010) reported the decrease in total soluble solids during fermentation was due to the hydrolysed of sugar into alcohol and CO2 which is then used by acetic acid bacteria as a carbon resource. Increasing the TSS content in the coffee pulp will increase the formation of acetic acid concentration in the acetic acid solution.

The pH of the acetic acid solution shown is in line with that of vinegar from mango juice is 4.25 studied by Adebayo-Oyetoro et al. (2017). The highest pH of 4.889 ± 0.12 produced by bread-fermented yeast is probably due to yeast containing only Saccharomyces cerevisiae which can break down the carbohydrate to alcohol and therefore can increase the pH. The highest pH was also due to the lowest content of acetic acids is 0.738 ± 0.20 % (Table 2). This is in line with what was stated by Cempaka et al. (2023) under anaerobic conditions, yeast produce ethanol that can increase the pH. Meanwhile, cassava fermented yeast contains many microorganisms such as yeast, mould, and bacteria that can convert carbohydrates to alcohol and then oxidation alcohol to acid compound decreasing the pH. According to Fauziah et al. (2020), cassava fermented yeast contains many microorganisms such as mould, yeast, and bacteria. The longer fermentation for 16 days gave a lower pH of 4.523 ± 0.39 than the fermentation for 13 days of 4.610 ± 0.43. However, both fermentation time does not show a significant difference in the pH of the acetic acid solution (Table 2). Fauziah et al. (2020) reported that longer fermentation can increase the alcohol and acid content and then decrease of pH. Probably, this range of pH of

4.104 ± 0.04 to 4.889 ± 0.12 is favourable for growing Saccharomyces cerevisiae. Triani et al. (2019) & Ester et al. (2021) reported that the optimum pH for Saccharomyces cerevisiae is around 3.5-6.5.

This acetic acid content is lower than that of 1.08 to 4.26 % obtained by Ouattara et al. (2019) due to the vinegar from mango juice having higher reducing sugar and lower moisture content than Robusta coffee pulp. In this study, there is a tendency that the use of bread-fermented yeast will decrease acetic acid content (Figure 1). The highest content of acetic acid was given by cassava fermented yeast probably due to acetic acid bacteria contained in the yeast oxidation of the alcohol to acetic acid in aerobic conditions. This is related to the research found by Fauziah et al. (2020) that alcohol will oxidize to acetic acid by acetic acid bacteria in aerobic conditions. In line with what was studied by Nurhasanah & Octarya, (2018) it was found that cassava-fermented yeast is better used for vinegar production from banana peel. Luzón-Quintana et al. (2021) reported the different microorganisms responsible for each process along with the physicochemical properties of the final products. The raw material employed for vinegar production plays an important role in the final characteristics of the developed product. Based on this study, acetic acid concentration in acetic acid solution is still low due to higher water content. Reducing moisture content can be done by increasing the time of the evaporating process. According to Indonesia National Standard, (2020) (SNI 01-3711-1995) & FDA (Adebayo-Oyetoro et al., 2017), the vinegar product contains a minimum of 4 % of acetic acid. Meanwhile, vinegar in this study contains less than the standard namely ranging from 0.738 ± 0.20 % to 1.983 ± 0.04 % which means that it does not fulfil the standard yet. However, it needs to increase evaporating time and sugar concentration to increase the acetic acid concentration.

The increasing fermentation time can decrease the sugar content in acetic acid solution due to being hydrolysed into alcohol and CO2. Shamsudin et al. (2019) & Kong et al. (2018) stated that the increase in reducing sugar content is due to the hydrolysis of polysaccharides present in the vinegar, such as pectin, cellulose, and starch, into reducing sugars. In addition, the increase in reducing sugar is also caused by converting sucrose sugar into glucose and fructose (reducing sugar) by an invertase enzyme that is produced by Saccharomyces cerevisiae (Triani et al., 2019) & (Ester et al., 2021).

Conclusion

The characteristics of the acetic acid solution were affected by the types of yeast and fermentation time. The use of cassava fermented yeast (NKL) can produce better characteristics of the acetic acid solution than bread-fermented yeast and mixing both yeasts. Increasing fermentation time tends to increase acetic acid content but decreases pH and reduces sugar. Production of acetic acid solution from Robusta coffee pulp can use cassava fermented yeast with fermentation for 13 days at room temperature. The characteristic of the acetic acid solution that was produced has a moisture content of 90.61 ± 0.294 %, a total soluble solid is 15.57 ± 0.153 %, reducing sugar of 1.505 ± 0.03 %, the acetic acid content of 1.983 ± 0.04 %, and pH of 4.104 ± 0.04. However, the quality of the acetic acid solution is still low, therefore it needs to improve especially for the acetic acid content that doesn't fulfil the standard quality yet, and also the colour of the acetic acid solution still looks light brown.

Conflicts of interest

The authors declare no conflicts of interest.

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Consumer Priorities: Welfare Trumps Climate in Pork Preferences

Pork production is facing multifaceted societal concerns, spanning antibiotic usage, infectious diseases, animal welfare, and environmental impacts. Despite industries like beef, coffee, and chocolate being recognized as major contributors to climate change, the global consumption of pork results in hundreds of millions of tons of CO2 emissions annually.

A recent study led by researchers from the University of Copenhagen delved into consumer attitudes towards climate-friendly pork in Denmark, Germany, the UK, and Shanghai, China. The survey revealed that approximately 75% of respondents in Denmark, Germany, and China, along with 60% in the UK, expressed a willingness to pay more for pork that demonstrated improvements in animal welfare, reduced climate impact, decreased antibiotic use, ensured freedom from harmful bacteria, and excluded soy-fed practices linked to rainforest clearing.

Notably, among European consumers, the paramount concern was improved animal welfare. Climate considerations ranked lower in importance compared to other factors, with respondents believing that they could make a more tangible difference to individual pig welfare than to the broader climate impact through their pork purchases. The study's lead author, Professor Peter Sandøe, emphasized that while climate-friendly pork is important, it should not come at the expense of compromising animal welfare. He further advocated for higher minimum welfare standards and a reduction in overall meat consumption.

1. Sigrid Denver, Tove Christensen, Thomas Bøker Lund, Jakob Vesterlund Olsen, Peter Sandøe. **Willingness-to-pay for reduced carbon footprint and other sustainability concerns relating to pork production – A comparison of consumers in China, Denmark, Germany and the UK**. Livestock Science, 2023; 276: 105337 DOI: 10.1016/j.livsci.2023.105337

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New method to keep the blueberry fresh

Sunflowers, widely cultivated for their seeds and oil, often leave their flower stems, known as receptacles, as a disregarded byproduct. However, a team led by Xiao-Dong Luo and Yun Zhao recognized the potential value of these receptacles. Given the crop's robust resistance to various plant diseases, they embarked on an investigation to uncover potential chemical constituents within the receptacles responsible for this protective trait. Their aim was to explore if these compounds could serve as an eco-friendly alternative to chemical fungicides in safeguarding fruit against fungal pathogens, thereby circumventing issues of toxicity and resistance associated with conventional methods.

Using methanol and ethyl acetate, the researchers extracted compounds from sunflower stems. They then meticulously identified and isolated the components, with a special focus on diterpenoids known for their biological activity. In their findings, the team uncovered 17 diterpenoids, including four previously unidentified compounds. Significantly, most of these diterpenoids displayed remarkable efficacy against gray mold. Among them, four compounds, including two of the newly discovered ones, demonstrated the ability to disrupt the plasma membrane of the fungus, inducing cell leakage and inhibiting biofilm formation. Additionally, in an experimental trial, blueberries briefly treated with receptacle extracts before exposure to mold spores exhibited nearly 50% protection against mold growth over a six-day period. This study suggests that extracts from sunflower stems hold promise as a natural biocontrol agent for preventing postharvest fruit diseases.

1. Yun Zhao, Zi-Jiao Wang, Chang-Bin Wang, Bang-Yin Tan, Xiao-Dong Luo. **New and Antifungal Diterpenoids of Sunflower against Gray Mold.** Journal of Agricultural and Food Chemistry, 2023; DOI: 10.1021/acs.jafc.3c05553

Unlocking the Health Benefits of Bioactives in Plant-Based Fiber Sources

Recognizing the pivotal role of fiber in gut health, a recent study underscores the importance of acknowledging the broader spectrum of health benefits provided by bioactives found in plant-based sources of insoluble dietary fiber. Joanne Slavin, a professor at the University of Minnesota, emphasizes that while fiber is a recognized health marker, it's imperative to also highlight the valuable bioactive components present in these sources. The study consolidates existing literature on the health advantages of bioactives in plant-derived insoluble dietary fiber, revealing that various plant foods such as fruits, vegetables, legumes, nuts, seeds, and whole grains contain unique bioactives that support health in distinct ways. Noteworthy bioactives like Quercetin, Resveratrol, Catechins, Anthocyanins, Lutein, Lycopene, and Beta-Carotene were identified in a range of plant foods rich in insoluble dietary fiber. Additionally, plant sources rich in both bioactives and insoluble dietary fiber offer opportunities to enhance the nutritional value of processed foods, utilizing byproducts like peel, hulls, pulp, or pomace.

Jan-Willem Van Klinken, co-author and senior vice president of medical, scientific, and regulatory affairs for Brightseed, notes that though the advice to increase fruit and vegetable intake is not new, many individuals still find it challenging. Introducing widely available, fiber-fortified products with enhanced bioactive content could be a transformative solution. The study underscores the need for collaborative efforts between industry, academia, and government to promote awareness and education about bioactives in both food and health systems. This research marks a potential paradigm shift in how insoluble dietary fiber and bioactives are perceived, emphasizing their significant impact on human health. While further research is necessary to identify optimal extraction and processing methods for preserving bioactive compounds, this study paves the way for a more comprehensive approach to nutrition and health.

1. Madeline Timm, Lisa C. Offringa, B. Jan-Willem Van Klinken, Joanne Slavin. **Beyond Insoluble Dietary Fiber: Bioactive Compounds in Plant Foods.** Nutrients, 2023; 15 (19): 4138 DOI: 10.3390/nu15194138

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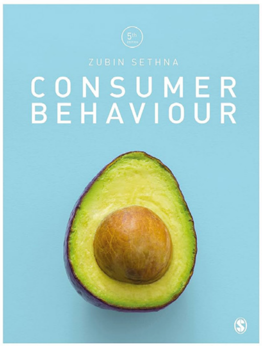

Consumer Behaviour

A review by Diana Ismael

Edited by Zubin Sethna
Publisher: SAGE Publications
Published year: Fifth Edition - April 14, 2023
Language: English
ISBN: 9781529784244, 1529784247
Length: 616 pages

"Consumer Behaviour" emerges as a original work in the study of consumer Behaviour, *blending academic issues with an engaging and accessible style.* This book serves as a comprehensive introduction to the field, targeting a broad audience that includes both students and practitioners. Authored by Professor Zubin Sethna of Regent's University London, a renowned figure in entrepreneurial marketing and consumer Behaviour, the book stands as a testament to his expertise and depth of knowledge.

The book is characterized by its engaging layout, which employs a group of learning features and real-world examples to explain complex concepts in consumer behaviour. This approach makes the textbook not just informative but also highly engaging. Sethna's ability to present the material in a manner that is both in-depth and accessible is particularly commendable, making it suitable for a wide range of readers, from novices to experienced professionals in the field.

The book includes balanced overview of both psychological and sociological aspects of consumer behaviour. By drawing examples from global contexts and encompassing a variety of consumer brands and B2B companies, the book offers a comprehensive perspective on the subject. This broad view is essential for understanding how consumers behave in different contexts and industries.

The text is structured into three thematic areas, each delving into different dimensions of consumer behaviour. The first part, 'Consumer Behaviour in Context,' the book sets the stage for a profound exploration of consumer behaviour. It begins by establishing the foundational concepts that are crucial for understanding the dynamics of consumer interactions in the marketplace. This section is particularly insightful in how it contrasts consumer behaviour in Business-to-Consumer (B2C) and Business-to-Business (B2B) settings, offering a perspective often overlooked in consumer behaviour studies. This section also addresses the role of consumer technology and innovation, highlighting how these factors reshape the landscape of consumer choices and behaviours. This part of the book is instrumental in providing readers with the context needed to appreciate the complexities and differences of consumer behaviour in various settings.

The second section, "Consumers as Individuals," dives into the psychological aspects of consumer behaviour. The section explores a range of topics including drive, motivation, and the concept of self-satisfaction in consumer choices. This section is key to understanding the internal processes that influence consumer decisions. The exploration of the self and personality offers insights into how individual identities and traits impact purchasing behaviours. Furthermore, This section discusses perception, learning, and knowledge, and how these cognitive processes shape the way consumers interact with products and brands. The section on attitude formation and change is particularly relevant, shedding light on how consumer attitudes are developed and how they can evolve over time. This part of the book is essential for readers seeking to understand the individual psychological factors that drive consumer behaviour.

In the final section, "Consumers as Social Actors," the focus shifts to the sociological aspects of consumer behaviour. The section examines how social factors such as reference groups, age, gender, and familial roles influence consumer choices and behaviours. It explore the impact of culture and social mobility, providing a thorough look at how societal contexts affect consumer actions. The chapters on ethical and sustainable consumption are particularly timely, reflecting the growing consumer awareness and concern about these issues. This section effectively illustrates how consumers do not make decisions in isolation but are influenced by a myriad of social factors and group dynamics. The sociological perspective offered in this part of the book is crucial for understanding consumer behaviour in a broader social context.

In sum, each section of this book contributes significantly to the overall understanding of the field. The book is not only a testament to Sethna's expertise but also a reflection of the dynamic and evolving nature of consumer behaviour studies. Throughout the book, Sethna employs a range of engaging features such as 'critical reflection', 'consumer behaviour in action', and 'brand experiences'. These elements not only illustrate theoretical concepts with real-world examples but also encourage readers to engage critically with the material, enhancing the book's practical relevance.

In conclusion, "Consumer Behaviour" is a must-read for anyone interested in gaining a in-depth knowledge of consumer behaviour. Its depth, clarity, and practical applicability make it a worthy addition to any academic or professional library. The book stands out for its complete coverage, contemporary relevance, and effective bridge between theory and practice. Whether you are a student new to the subject or a seasoned practitioner, this book offers valuable insights and a thorough understanding of consumer behaviour in the modern context.

About the author:

Diana Ismael is a sensory specialist with a PhD in Food and Sensory Science/Consumer Behaviour from Kassel University, Germany. Her research focuses on understanding the intention-behaviour gap in organic food consumption. Currently, she works as the Managing Editor at the Future of Food Journal: Journal on Food, Agriculture & Society.

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