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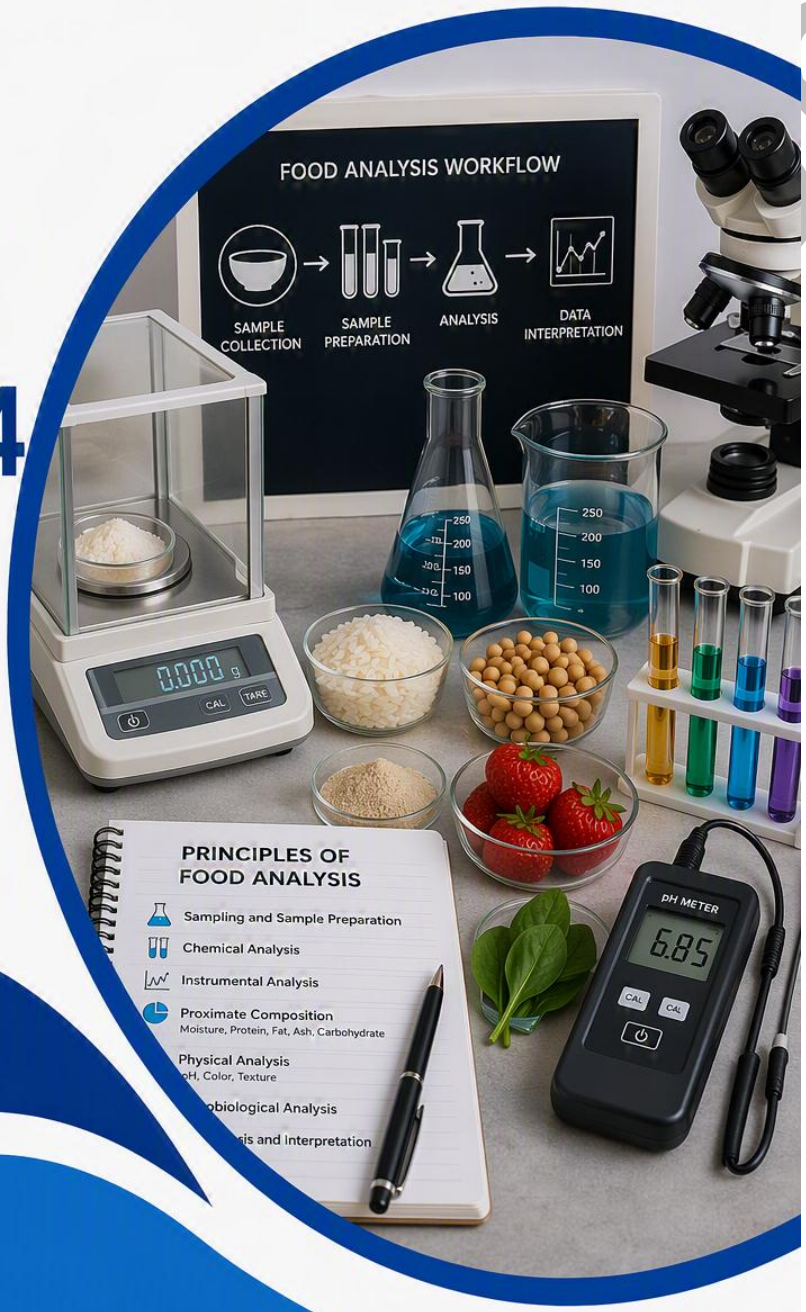
FST304

PRINCIPLES OF FOOD ANALYSIS



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Course code: FST304

Course title: Principles of Food Analysis

Course credit load: 3 units

List of Series:

1. **Physical and Chemical Transformations in Foods**
2. **Lipids and Proteins: Properties, Reactions, and Applications**
3. **Carbohydrates, Hydrocolloids, and Starch Modifications**
4. **Enzyme Systems and Browning Reactions in Food Quality**
5. **Vitamins, Natural Pigments, Flavours, and Additives in Foods**

1. Physical Changes in Foods during Handling and Storage

- 1.1 Moisture in Foods
- 1.2 Free and Bound Water
- 1.3 Hydrogen Bonding and its Role in Food Structure

2. Chemical Changes in Foods during Processing and Storage

- 2.1 Lipid Changes: Auto-oxidation, Pro-oxidants, and Antioxidants
- 2.2 Protein Changes: Denaturation and Gel Formation
- 2.3 Carbohydrate Changes: Gelatinisation and Retrogradation

3. Measurement and Analysis of Food Changes

- 3.1 Methods of Measuring Lipid Changes
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4. Implications of Physical and Chemical Changes on Food Quality

- 4.1 Flavour Changes in Foods
- 4.2 Texture and Structural Modifications
- 4.3 Nutritional and Safety Considerations

Introduction

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Food is never static. From the moment it is harvested or produced, it begins to undergo a variety of **physical changes** such as moisture loss and textural modifications, as well as **chemical changes** including oxidation and enzymatic reactions. These transformations are central to food quality, safety, and shelf life. For anyone studying food science, recognising how these changes occur during handling, processing, and storage is essential, since they directly influence flavour, texture, nutritional value, and consumer acceptance. This Series therefore sets the foundation for understanding the dynamic nature of foods and prepares you to analyse them with precision.

The aim of this Series is to equip you with the knowledge and skills needed to explain, analyse, and evaluate the physical and chemical changes that foods undergo, and to relate these changes to food quality and measurement techniques.

We shall commence this Series by examining the physical changes in foods during handling and storage, with particular attention to moisture, water states, and hydrogen bonding. Next, we will explore chemical changes that occur during processing and storage, focusing on lipids, proteins, and carbohydrates. Following that, we will consider methods of measurement and analysis that help us study these changes in detail. Finally, we will wrap up by discussing the implications of these transformations on food quality, including flavour, texture, nutrition, and safety. This sequential approach will enable you to build a clear and connected understanding of how foods evolve from production to consumption.

Series Learning Outcomes

Upon completing this Series, you should be able to:

SLO 1.1 define the concept of physical changes in foods and explain the roles of moisture, water states, and hydrogen bonding during handling and storage,

SLO 1.2 analyse the chemical changes that occur in lipids, proteins, and carbohydrates during processing and storage,

SLO 1.3 demonstrate methods of measurement and analysis used to assess lipid oxidation, protein denaturation, and carbohydrate modifications,

SLO 1.4 evaluate the implications of physical and chemical changes on food quality, including flavour, texture, nutrition, and safety.

1.1 Physical Changes in Foods During Handling and Storage

Physical changes in foods are alterations that affect the **structure, texture, and appearance** of food without necessarily altering its chemical composition. These changes occur during handling, processing, and storage, and they are critical because they influence consumer acceptance and shelf life. Examples include moisture migration, crystallisation, and changes in firmness. By

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studying these changes, you will be able to explain why foods behave differently under varying storage conditions and how these behaviours can be controlled.

Fill in the blank: Physical changes in foods affect their _____, texture, and appearance without altering chemical composition.

1.1.1 Moisture in foods

Moisture refers to the amount of water present in food. It plays a vital role in determining food quality, safety, and stability. Foods with high moisture content, such as fruits and vegetables, are more prone to microbial spoilage, while low-moisture foods, such as grains, are more stable but can suffer from textural changes. Moisture can be classified into **free water**, which is available for microbial growth and chemical reactions, and **bound water**, which is tightly associated with food molecules and less available for reactions.

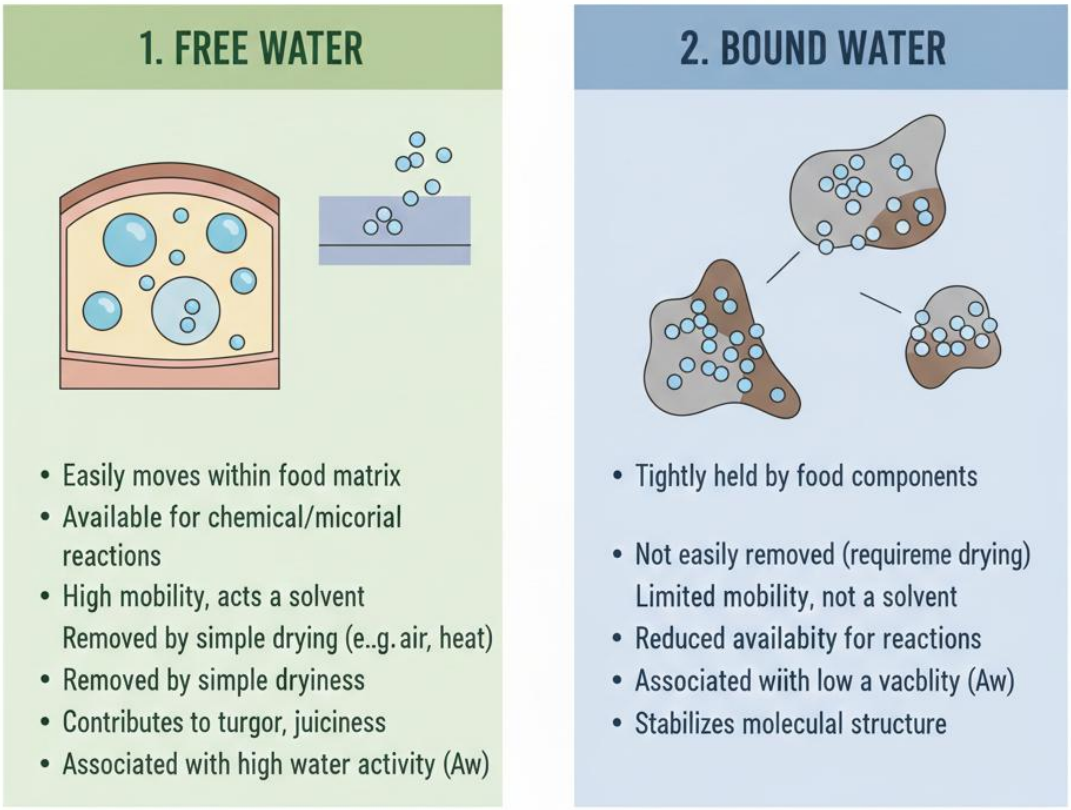

Figure 1.1 Distribution of free and bound water in food.

Fill in the blank: _____ water is available for microbial growth, while _____ water is tightly associated with food molecules.

1.1.2 Free and bound water

Free water is water that is not chemically bound to food components and can move freely within the food matrix. It supports microbial growth and enzymatic activity. **Bound water** is water that

is held tightly by proteins, carbohydrates, or other molecules, making it unavailable for microbial growth. The ratio of free to bound water determines the stability of food during storage.

Table 1.1 Characteristics of free and bound water in foods.

	FREE WATER	BOUND WATER
Definition & Mobility	Easily moves, held loasely in food matrix pores	Tighty associated with food molecules, limited mobility
Energy / Avaiblitt	Low energy, removed by simple drying	High energy, diffcult to remove
Availablite	Available for chemical, enzammic & microribal reactions	Unaavalble.7) supports micbribal growth
Water Activity (Aw)	High Aw (>0.7), supports chemical changes	Low Aw (<0.7), inhbits micirical growth
Impact on Food	Texture (juichesis), spolaige	Structure, glass transition
	Texture (juicness), spolaise, ches	Influecture, glass transition
Examples	Fresh fruits/vegetables, raw meat, milk, juices	Dried fruits, crystlaine sugar, freeze-dried products

Fill in the blank: The ratio of free to bound water determines the _____ of food during storage.

1.1.3 Hydrogen bonding and its role in food structure

Hydrogen bonding is the attraction between a hydrogen atom and an electronegative atom such as oxygen or nitrogen. In foods, hydrogen bonding plays a crucial role in stabilising structures such as proteins and carbohydrates. It influences water retention, texture, and the ability of foods to form gels. For example, hydrogen bonding helps starch granules retain water during gelatinisation, and it stabilises protein structures during processing.

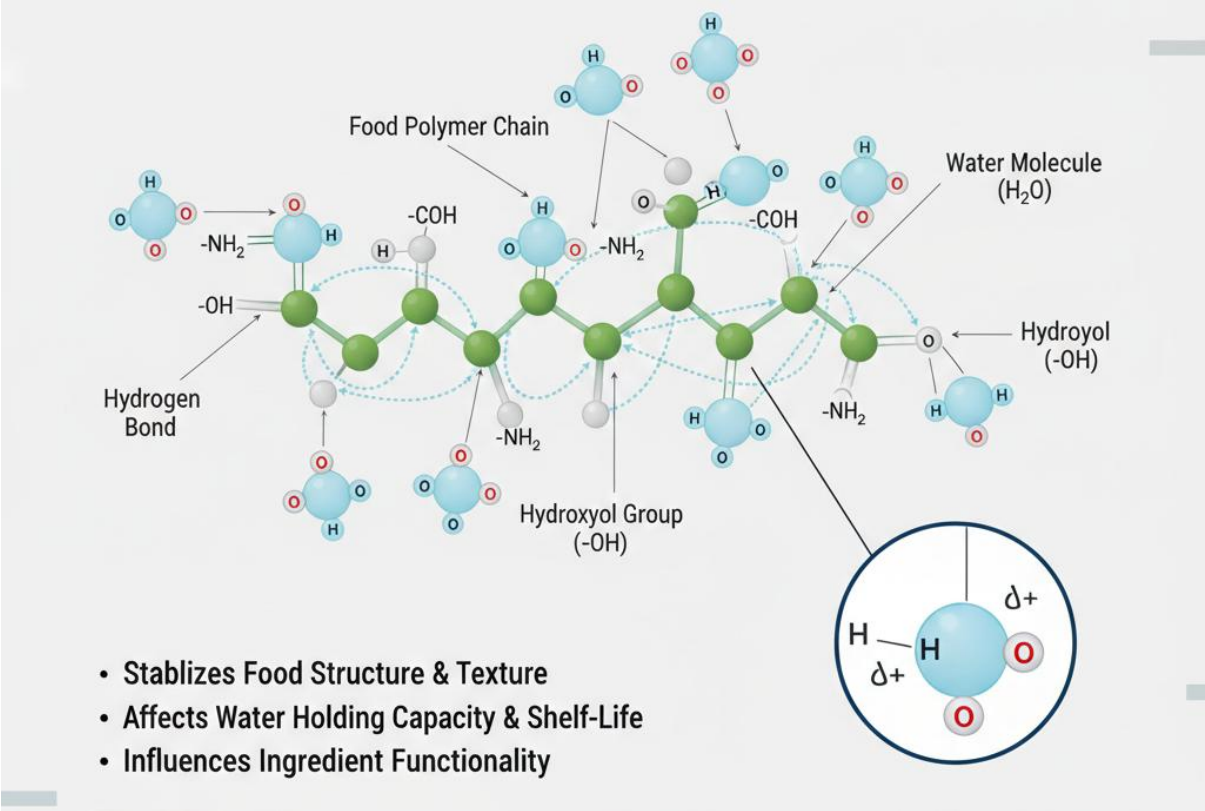

Figure 1.2 Hydrogen bonding interactions in food molecules.

Fill in the blank: Hydrogen bonding stabilises structures such as _____ and carbohydrates in foods.

Pilot questions 1.1

1. Which type of water in foods is available for microbial growth?
2. What is the main difference between free water and bound water?
3. How does moisture content affect food stability?
4. What role does hydrogen bonding play in food texture?
5. Why are high-moisture foods more prone to spoilage than low-moisture foods?

1.2 Chemical Changes in Foods During Processing and Storage

Chemical changes in foods occur when the molecular composition of food components is altered during handling, processing, or storage. These changes are often irreversible and can significantly affect flavour, texture, nutritional value, and safety. By studying chemical changes, you will be able to explain how lipids, proteins, and carbohydrates react under different conditions, and how these reactions influence food quality.

Fill in the blank: Chemical changes in foods involve alterations in their _____ composition, often leading to irreversible effects.

1.2.1 Lipid changes: auto-oxidation, pro-oxidants, and antioxidants

Lipids are fats and oils that serve as important sources of energy and flavour in foods. One major chemical change in lipids is **auto-oxidation**, which is the spontaneous reaction of unsaturated fatty acids with oxygen, leading to rancidity and off-flavours. This process is accelerated by **pro-oxidants**, which are substances such as light, heat, and certain metals that promote oxidation. To counteract this, **antioxidants** are compounds that delay or prevent oxidation by stabilising free radicals.

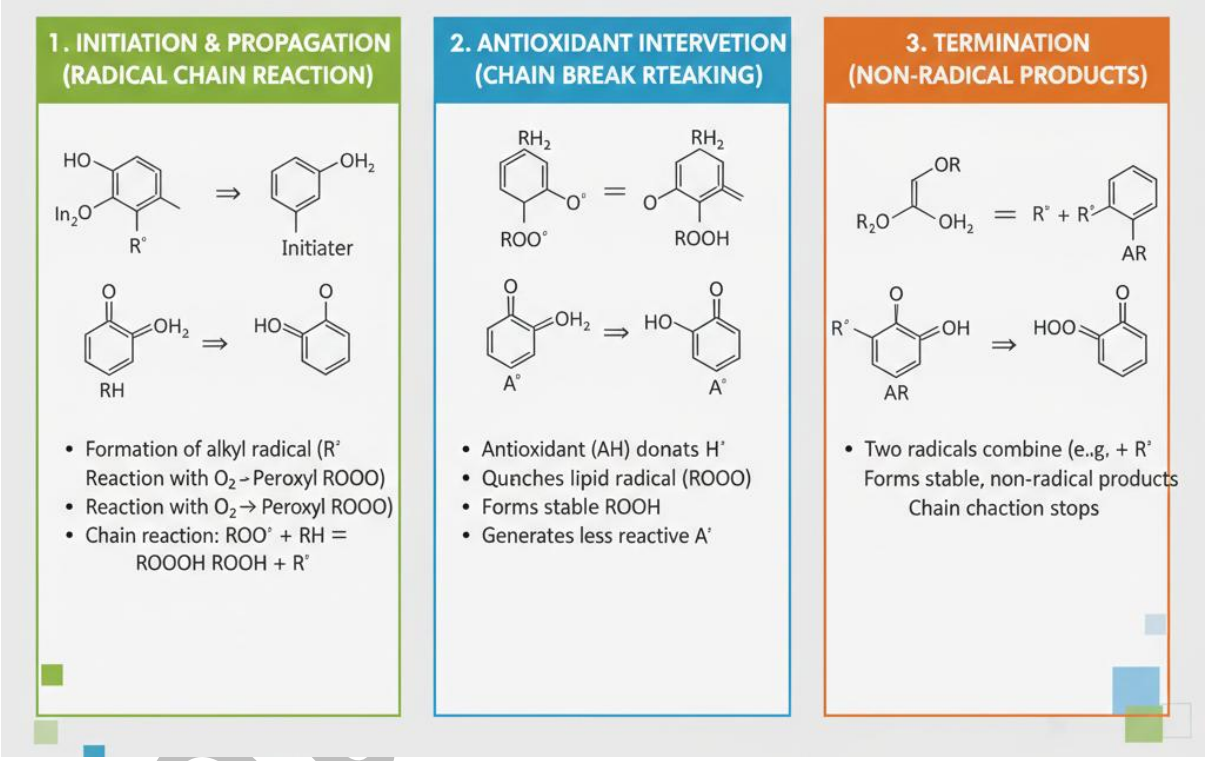

Figure 1.3 Auto-oxidation of lipids and the role of antioxidants.

Fill in the blank: Substances such as light, heat, and metals that accelerate lipid oxidation are called _____.

1.2.2 Protein changes: denaturation and gel formation

Proteins are large molecules made up of amino acids that provide structure and functionality in foods. **Denaturation** is the process by which proteins lose their natural structure due to heat, pH changes, or mechanical action. This change alters their solubility and functionality. One important consequence of denaturation is **gel formation**, where denatured proteins form a three-dimensional network that traps water, giving foods such as yoghurt and custard their characteristic texture.

Plate 1.1 Gel formation in protein-based foods.

Fill in the blank: The process by which proteins lose their natural structure due to heat or pH changes is called _____.

1.2.3 Carbohydrate changes: gelatinisation and retrogradation

Carbohydrates are sugars and starches that provide energy and contribute to texture in foods. **Gelatinisation** is the process where starch granules absorb water and swell upon heating, leading to thickening of foods such as sauces and puddings. **Retrogradation** occurs when gelatinised starch molecules, particularly amylose, reassociate during cooling, resulting in firming or staling of foods like bread. These changes are important in determining the shelf life and textural quality of carbohydrate-rich foods.

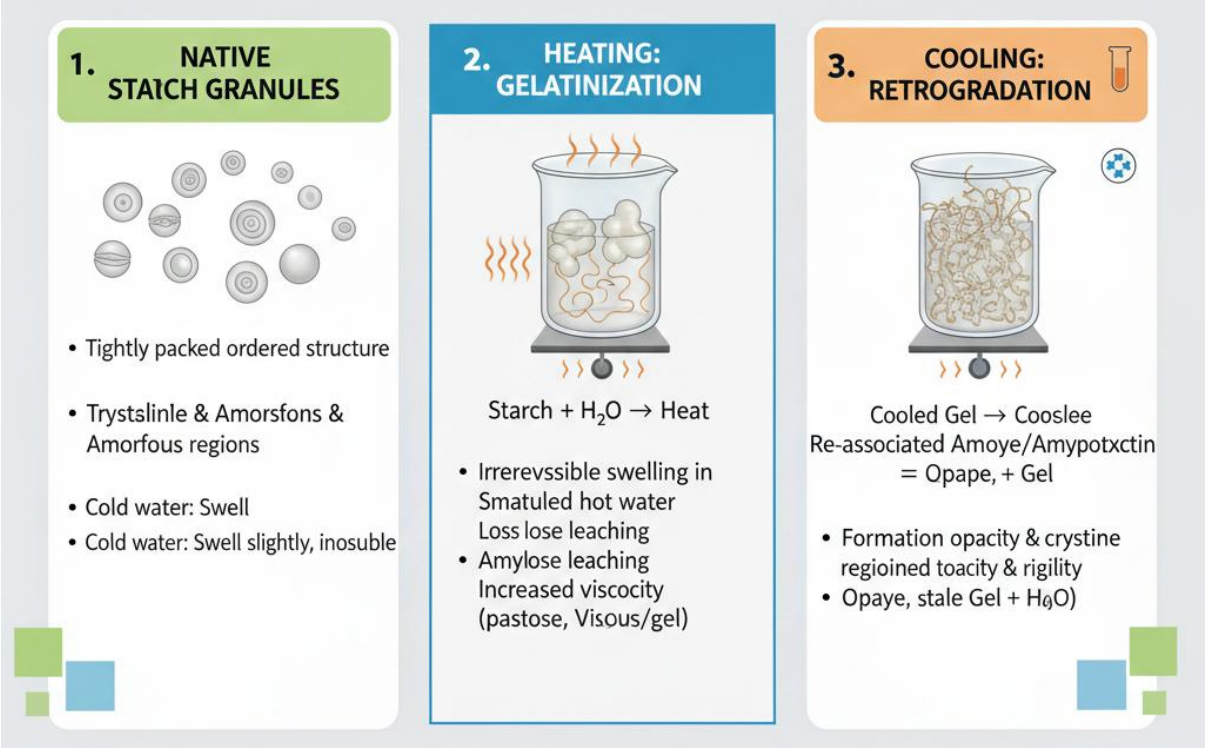

Figure 1.4 Gelatinisation and retrogradation of starch.

Fill in the blank: The firming or staling of bread during storage is mainly due to starch _____.

Pilot questions 1.2

1. What is auto-oxidation in lipids and why is it significant in food storage?
2. Which substances act as pro-oxidants in lipid oxidation?
3. What happens to proteins during denaturation?
4. How does gel formation contribute to the texture of foods?
5. What is the difference between gelatinisation and retrogradation in carbohydrates?

1.3 Measurement and Analysis of Food Changes

Food analysis involves the use of scientific methods to measure and evaluate the physical and chemical changes that occur in foods during handling, processing, and storage. These measurements are essential for ensuring food quality, safety, and shelf life. By learning how to assess changes in lipids, proteins, and carbohydrates, you will be able to apply analytical techniques to monitor deterioration, improve processing methods, and design better food products.

Fill in the blank: Food analysis uses scientific methods to measure and evaluate _____ and chemical changes in foods.

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1.3.1 Methods of measuring lipid changes

Lipid oxidation is one of the most common chemical changes in foods, leading to rancidity and off-flavours. To measure lipid changes, several methods are used:

- **Peroxide value (PV):** This measures the concentration of peroxides formed during the early stages of lipid oxidation.
- **Thiobarbituric acid (TBA) test:** This detects malondialdehyde, a secondary product of lipid oxidation, which correlates with rancidity.
- **Gas chromatography (GC):** This separates and quantifies fatty acids, providing detailed information about lipid composition and oxidation products.

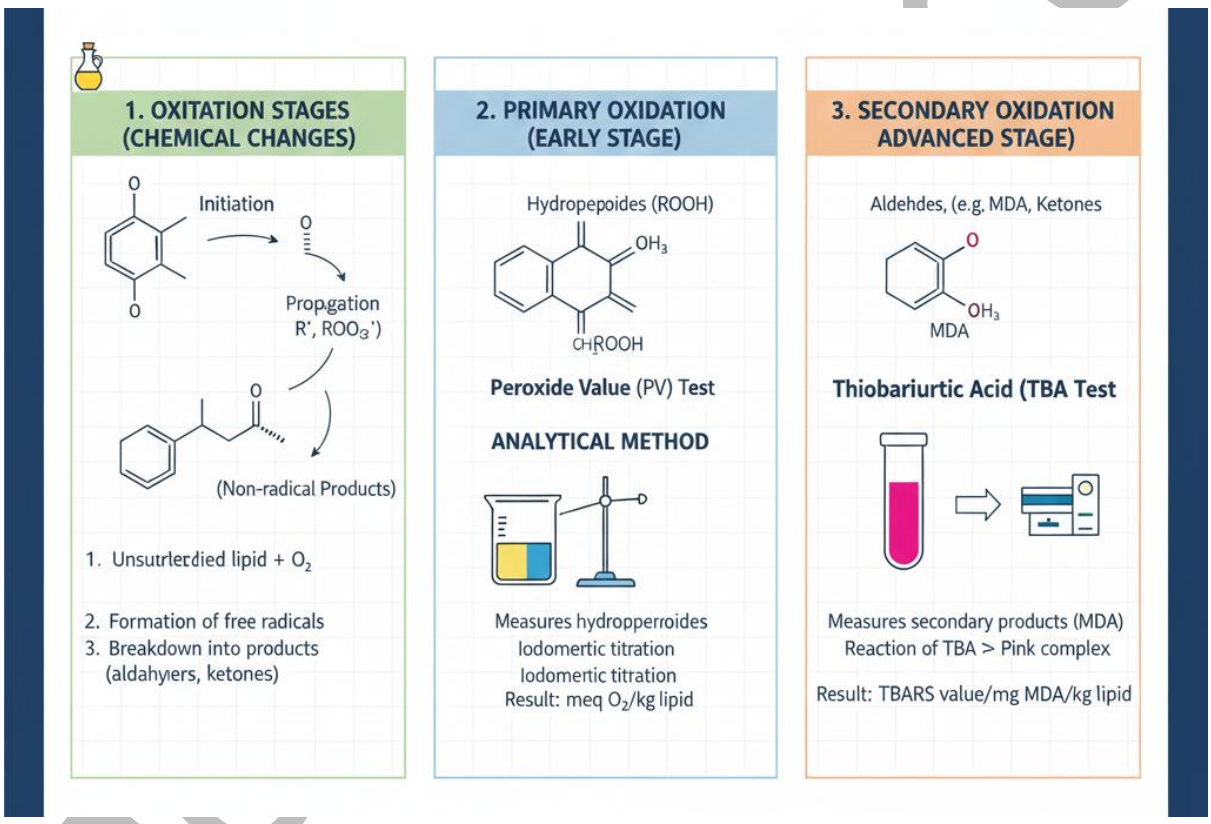


Figure 1.4 Methods of measuring lipid oxidation in foods.

Fill in the blank: The peroxide value measures the concentration of _____ formed during the early stages of lipid oxidation.

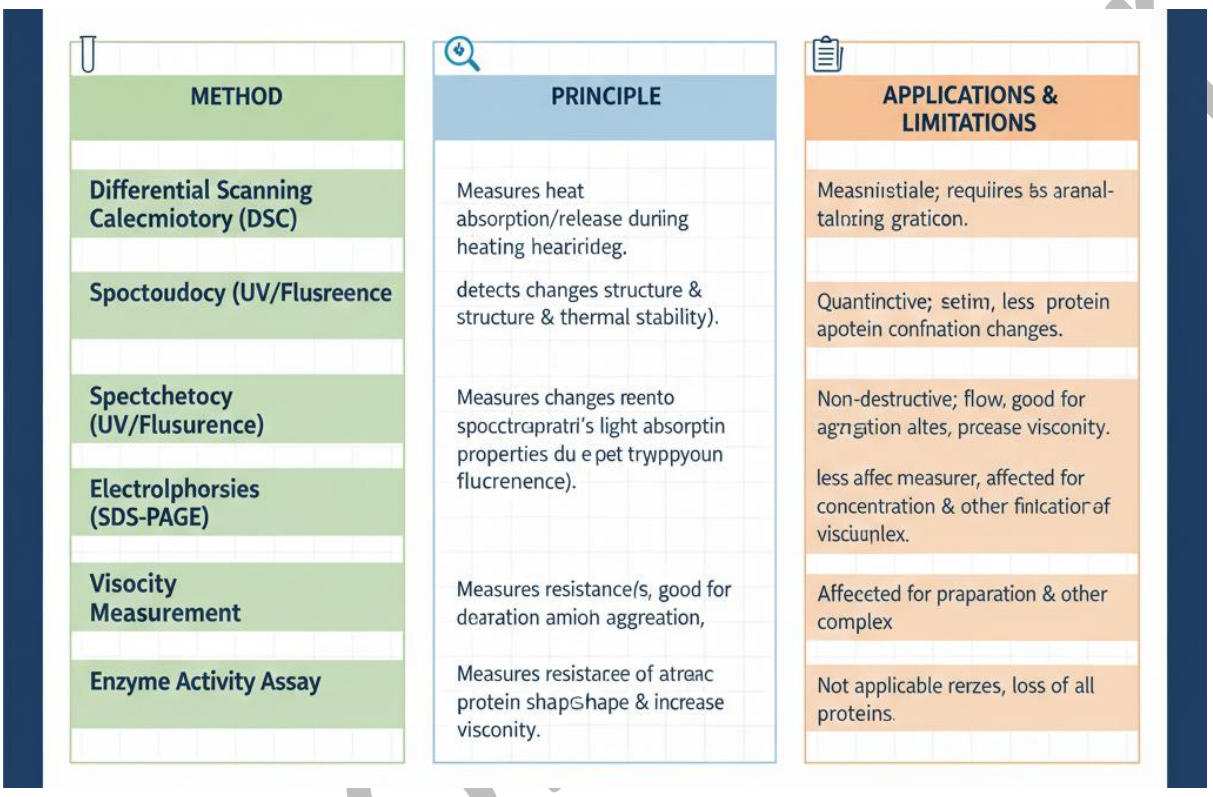
1.3.2 Methods of assessing protein denaturation

Protein denaturation alters the structure and functionality of proteins, affecting solubility, texture, and nutritional quality. Analytical methods include:

- **Spectrophotometry:** Measures changes in protein absorbance, indicating structural alterations.

- **Differential scanning calorimetry (DSC):** Determines the thermal stability of proteins by measuring heat flow during denaturation.
- **Electrophoresis:** Separates proteins based on size and charge, revealing changes in protein structure.

Table 1.2 Methods of assessing protein denaturation.



METHOD	PRINCIPLE	APPLICATIONS & LIMITATIONS
Differential Scanning Calecmiotory (DSC)	Measures heat absorption/release duriing heating heariridеg.	Measniistiale; requiires ɓs aranal-talnring graticon.
Spoctoudocy (UV/Flusreence	detects changes structure & structure & thermal stability).	Quantinctive; setim, less protein apotein confnation changes.
Spectchetocy (UV/Flusurence)	Measures changes reento spocctrapratri's light absorptin properties du e pet trypppyoun flucrenence).	Non-destructive; flow, good for agrngation altes, prcease visconity.
Electrolphorsies (SDS-PAGE)		less affec measurer, affected for concentration & other finicatior of visciuplex.
Visocity Measurement	Measures resistance/s, good for dearation amioh aggreation,	Affeceted for praparation & other complex
Enzyme Activity Assay	Measures resistacee of atreac protein shapshape & increase visconity.	Not applicable rerzes, loss of all proteins.

Fill in the blank: Differential scanning calorimetry measures the _____ stability of proteins during denaturation.

1.3.3 Techniques for studying carbohydrate modifications

Carbohydrate modifications such as gelatinisation and retrogradation affect food texture and shelf life. Techniques for studying these changes include:

- **Viscometry:** Measures the viscosity of starch pastes during gelatinisation.
- **X-ray diffraction (XRD):** Identifies crystalline structures in retrograded starch.
- **Microscopy:** Visualises starch granule swelling and breakdown during cooking.

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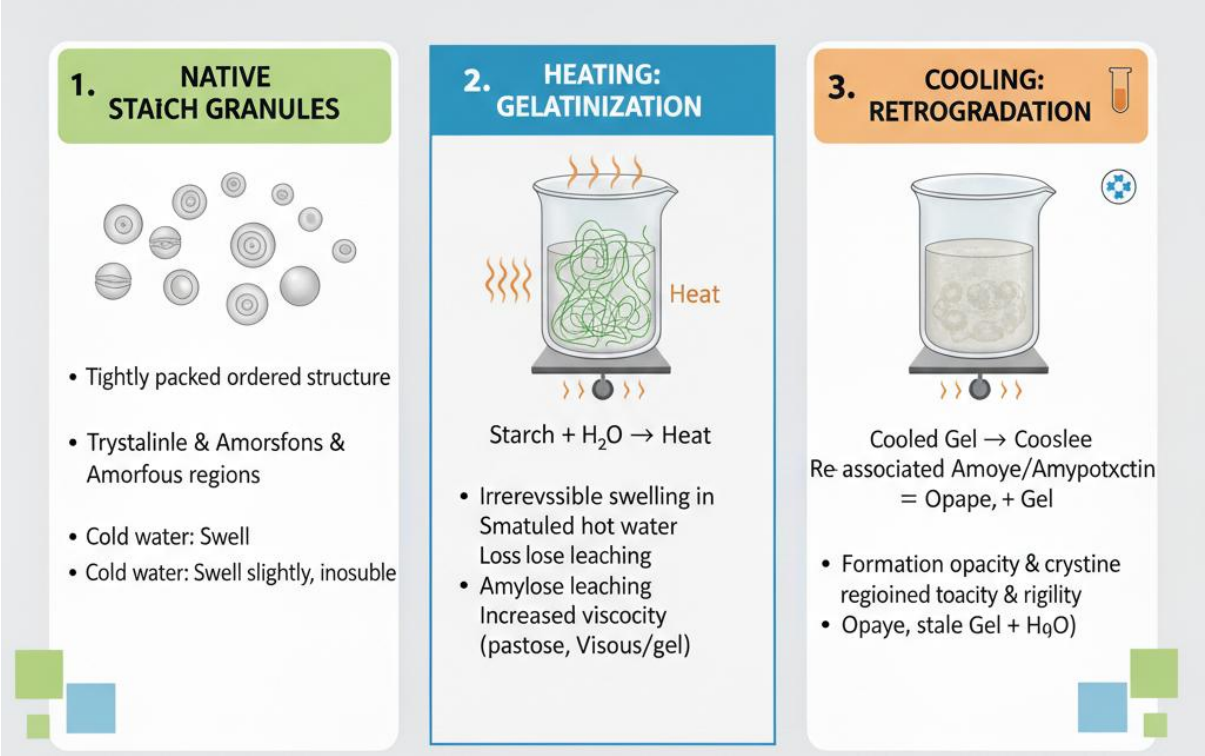

Figure 1.5 Techniques for studying carbohydrate modifications.

Fill in the blank: Viscometry measures the _____ of starch pastes during gelatinisation.

Pilot questions 1.3

1. What does the peroxide value indicate in lipid oxidation?
2. Which test detects malondialdehyde as a marker of rancidity?
3. Name one method used to determine the thermal stability of proteins.
4. How does electrophoresis help in assessing protein denaturation?
5. Which technique is used to measure viscosity changes in starch pastes?

1.4 Implications of Physical and Chemical Changes on Food Quality

Food quality is determined not only by its nutritional value but also by its flavour, texture, and safety. Physical and chemical changes that occur during handling, processing, and storage can either enhance or diminish these qualities. By examining flavour, texture, and nutritional aspects, you will be able to evaluate how these transformations affect consumer acceptance and food stability.

Fill in the blank: Food quality is influenced by nutritional value, flavour, texture, and _____.

1.4.1 Flavour changes in foods

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Flavour refers to the combined perception of taste and aroma in foods. Chemical changes such as lipid oxidation and enzymatic reactions can lead to off-flavours, while desirable flavour compounds may be formed during processes like roasting or fermentation. For example, the pleasant aroma of baked bread results from Maillard reactions, whereas rancid flavours in oils are due to oxidation.

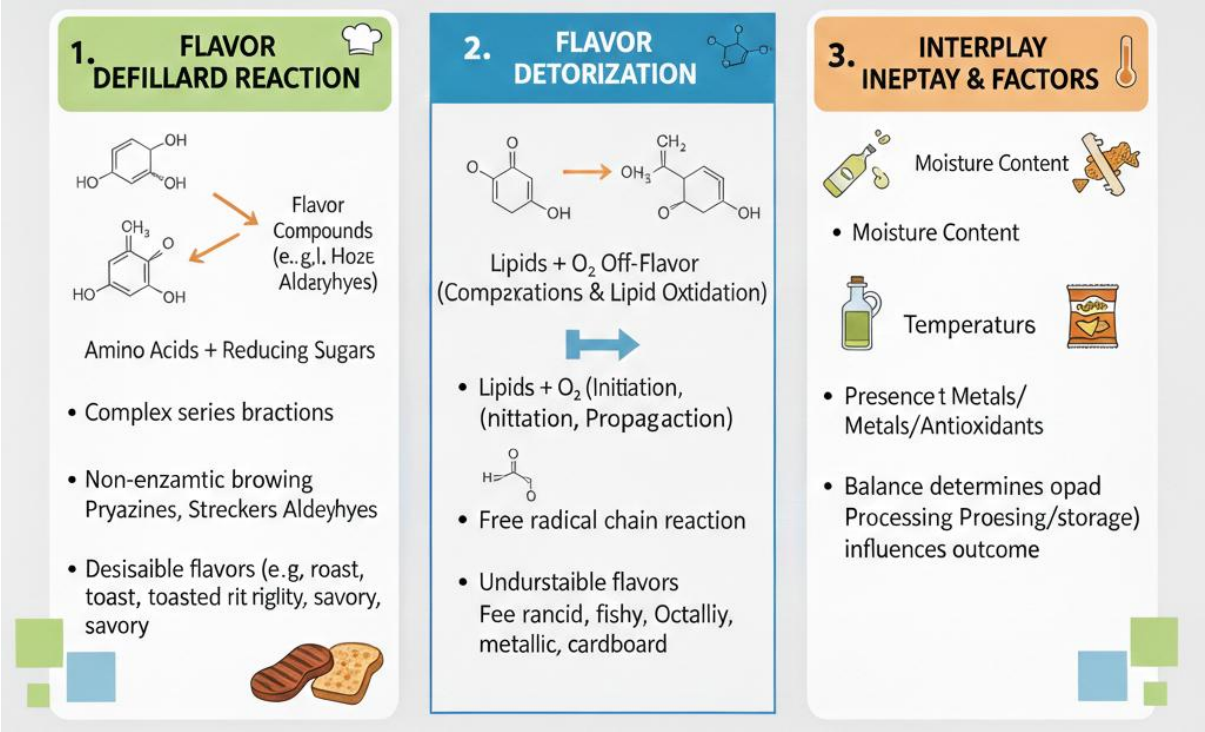

Figure 1.7 Flavour changes in foods due to chemical reactions.

Fill in the blank: The pleasant aroma of baked bread is mainly due to _____ reactions.

1.4.2 Texture and structural modifications

Texture is the sensory perception of food structure, including attributes such as crispness, chewiness, and smoothness. Physical changes like moisture migration and starch retrogradation can alter texture significantly. For instance, bread becomes firm during storage due to starch retrogradation, while biscuits lose crispness when exposed to moisture. Structural modifications also occur when proteins denature and form gels, giving foods like yoghurt and custard their characteristic consistency.

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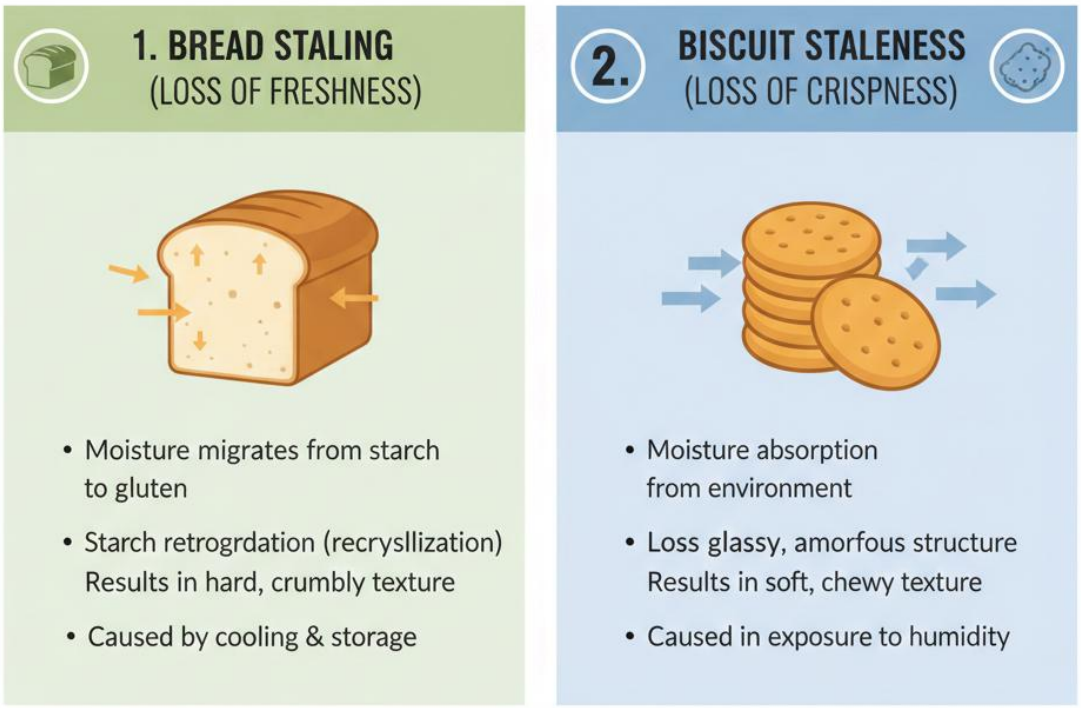

Plate 1.2 Textural modifications in bread and biscuits.

Fill in the blank: Bread becomes firm during storage mainly due to starch _____.

1.4.3 Nutritional and safety considerations

Nutritional quality refers to the retention of essential nutrients such as vitamins, proteins, and carbohydrates in foods. Chemical changes like oxidation can degrade vitamins, while excessive heat can reduce protein digestibility. **Food safety** is also affected, since microbial growth is influenced by moisture content and chemical composition. For example, high-moisture foods are more prone to spoilage, while lipid oxidation can produce harmful compounds if uncontrolled.

Box 1.2 Nutritional and safety implications of food changes.

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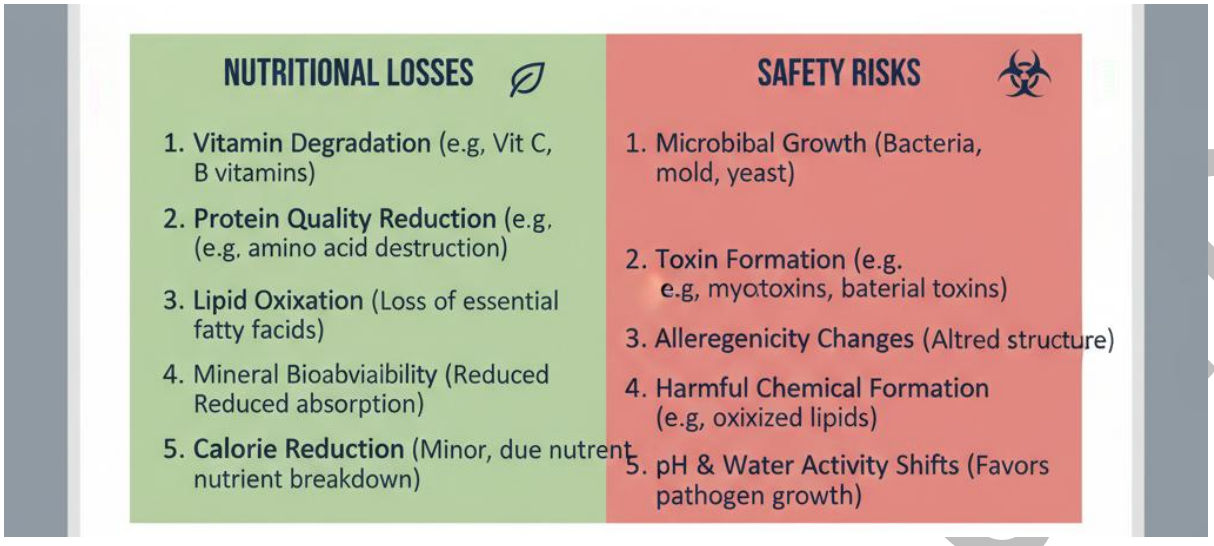

Fill in the blank: High-moisture foods are more prone to _____ growth and spoilage.

Pilot questions 1.4

1. What chemical reaction is responsible for the pleasant aroma of baked bread?
2. How does moisture migration affect the texture of biscuits?
3. Why does bread become firm during storage?
4. Which nutrients are most affected by oxidation during food storage?
5. How does moisture content influence food safety?

Series Summary

This Series has introduced you to the physical and chemical changes that foods undergo during handling, processing, and storage, highlighting their importance for food quality, safety, and consumer acceptance. We began by exploring physical changes such as moisture behaviour, free and bound water, and the role of hydrogen bonding. Then we examined chemical changes in lipids, proteins, and carbohydrates, focusing on processes like oxidation, denaturation, gelatinisation, and retrogradation. Following that, we considered methods of measurement and analysis, including peroxide value, spectrophotometry, and viscometry, which allow us to monitor these transformations. Finally, we discussed the implications of these changes on flavour, texture, nutrition, and safety, linking scientific principles to practical outcomes in food systems.

By completing this Series, you should now be able to define and explain the physical changes in foods, analyse chemical reactions affecting lipids, proteins, and carbohydrates, demonstrate methods of measurement and analysis, and evaluate the implications of these transformations on food quality. These abilities directly reflect the Series Learning Outcomes (SLOs 1.1 to 1.4),

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equipping you with the foundational knowledge and skills to assess food changes critically and apply them in food analysis and industry contexts.

Glossary of Terms

Antioxidants: Compounds that delay or prevent oxidation in foods by stabilising free radicals, helping to preserve flavour and shelf life.

Bound water: Water that is tightly held by food molecules such as proteins and carbohydrates, making it unavailable for microbial growth or chemical reactions.

Carbohydrates: Organic compounds including sugars and starches that provide energy and contribute to texture and sweetness in foods.

Denaturation: The process by which proteins lose their natural structure due to heat, pH changes, or mechanical action, altering their solubility and functionality.

Flavour: The combined perception of taste and aroma in foods, influenced by chemical reactions such as oxidation and Maillard reactions.

Gel formation: The process where denatured proteins or polysaccharides form a three-dimensional network that traps water, creating a semi-solid texture.

Gelatinisation: The process where starch granules absorb water and swell when heated, causing thickening in foods such as sauces and puddings.

Hydrogen bonding: The attraction between a hydrogen atom and an electronegative atom such as oxygen or nitrogen, which stabilises food structures and influences water retention.

Hydrocolloids: Plant-derived polysaccharides, such as guar gum and carrageenan, that thicken, stabilise, or form gels in food systems.

Lipids: Fats and oils that serve as sources of energy and flavour in foods, subject to chemical changes such as oxidation.

Moisture: The amount of water present in food, which affects its stability, texture, and susceptibility to microbial spoilage.

Peroxide value (PV): A measure of the concentration of peroxides formed during the early stages of lipid oxidation, used to assess rancidity.

Pro-oxidants: Substances such as light, heat, and metals that accelerate lipid oxidation, leading to deterioration in food quality.

Proteins: Large molecules made up of amino acids that provide structure and functionality in foods, subject to changes such as denaturation.

Retrogradation: The process where gelatinised starch molecules reassociate during cooling, leading to firming or staling in foods like bread.

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Viscometry: A technique used to measure the viscosity of starch pastes during gelatinisation, providing insights into textural changes.

Free water: Water that is not bound to food molecules and is available for microbial growth and chemical reactions.

Nutritional quality: The retention of essential nutrients such as vitamins, proteins, and carbohydrates in foods, which can be affected by physical and chemical changes.

Food safety: The assurance that food is free from harmful substances or microbial contamination, influenced by moisture content and chemical composition.

Concept Check Questions 1

Objective Questions

1. Which type of water in foods is available for microbial growth? (Linked to SLO 1.1)
2. The peroxide value is used to measure which stage of lipid oxidation? (Linked to SLO 1.2)
3. What process causes bread to become firm during storage? (Linked to SLO 1.2)
4. Which analytical method measures the viscosity of starch pastes during gelatinisation? (Linked to SLO 1.3)
5. Which reaction is responsible for the pleasant aroma of baked bread? (Linked to SLO 1.4)

Short-Answer Questions

6. Define hydrogen bonding and explain its role in food structure. (Linked to SLO 1.1)
7. Describe the difference between free water and bound water in foods. (Linked to SLO 1.1)
8. Explain how protein denaturation leads to gel formation in foods such as yoghurt. (Linked to SLO 1.2)
9. Identify one method used to assess protein denaturation and explain its principle. (Linked to SLO 1.3)
10. Evaluate how moisture migration affects the texture of biscuits during storage. (Linked to SLO 1.4)

Long-Answer Questions

11. Analyse the chemical changes that occur in lipids, proteins, and carbohydrates during food processing and storage, and discuss their implications for food quality. (Linked to SLO 1.2 and SLO 1.4)

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12. Demonstrate how measurement techniques such as peroxide value, spectrophotometry, and viscometry can be applied to monitor food changes, and evaluate their importance in food analysis. (Linked to SLO 1.3)

Answers to Concept Check Questions 1

Objective Questions

1. Free water.
2. Early stage of lipid oxidation.
3. Retrogradation.
4. Viscometry.
5. Maillard reaction.

Short-Answer Questions

6. Hydrogen bonding is the attraction between a hydrogen atom and an electronegative atom such as oxygen or nitrogen. It stabilises food structures and influences water retention.
7. Free water is not bound to food molecules and is available for microbial growth, while bound water is tightly held by food molecules and unavailable for reactions.
8. Protein denaturation unfolds protein structures, allowing them to form a three-dimensional network that traps water, resulting in gel formation.
9. Differential scanning calorimetry measures the thermal stability of proteins by recording heat flow during denaturation.
10. Moisture migration softens biscuits, reducing crispness and altering consumer perception of texture.

Long-Answer Questions

11. *Basic response:* Lipids undergo oxidation leading to rancidity, proteins denature and form gels, and carbohydrates experience gelatinisation and retrogradation. These changes affect flavour, texture, and shelf life. *Value-added response:* Beyond these basics, lipid oxidation can produce harmful compounds, protein denaturation can reduce digestibility, and carbohydrate retrogradation contributes to staling. Understanding these changes allows food scientists to design interventions such as antioxidants, stabilisers, and modified starches to improve food quality.
12. *Basic response:* Peroxide value measures lipid oxidation, spectrophotometry detects protein structural changes, and viscometry assesses starch gelatinisation. These methods help monitor food transformations. *Value-added response:* In addition, combining these techniques with advanced tools like gas chromatography and X-ray diffraction provides

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deeper insights. Their application ensures food safety, optimises processing, and supports product innovation in the food industry.

Answers to Pilot Questions [Series 1]

Part 1: Physical Changes in Foods during Handling and Storage

1. Free water.
2. Free water is available for microbial growth, while bound water is tightly associated with food molecules.
3. Moisture content affects food stability by influencing microbial growth and chemical reactions.
4. Hydrogen bonding stabilises food structures and influences texture.
5. High-moisture foods are more prone to spoilage than low-moisture foods.

Part 2: Chemical Changes in Foods during Processing and Storage

1. Auto-oxidation is the spontaneous reaction of unsaturated fatty acids with oxygen, leading to rancidity.
2. Pro-oxidants include light, heat, and certain metals.
3. Proteins lose their natural structure during denaturation.
4. Gel formation contributes to the semi-solid texture of foods such as yoghurt and custard.
5. Gelatinisation involves starch swelling during heating, while retrogradation involves starch reassociation during cooling.

Part 3: Carbohydrates, Hydrocolloids, and Starch Modifications

1. Pectic substances are polysaccharides found in plant cell walls, especially fruits.
2. Hydrocolloids improve food texture by thickening and stabilising products.
3. Starch granules absorb water and swell during gelatinisation.
4. Retrogradation causes staling in bread by starch reassociation.
5. Pre-gelatinised starch thickens instantly in cold water.

Part 3: Measurement and Analysis of Food Changes

1. The peroxide value indicates the concentration of peroxides formed during early lipid oxidation.
2. The thiobarbituric acid (TBA) test detects malondialdehyde, a marker of rancidity.

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3. Differential scanning calorimetry (DSC) measures the thermal stability of proteins.
4. Electrophoresis separates proteins based on size and charge, showing structural changes.
5. Viscometry measures the viscosity of starch pastes during gelatinisation.

Part 4: Implications of Physical and Chemical Changes on Food Quality

1. Maillard reaction.
2. Moisture migration softens biscuits, reducing crispness.
3. Bread becomes firm during storage due to starch retrogradation.
4. Vitamins, especially water-soluble ones, are most affected by oxidation.
5. Moisture content influences microbial growth and food safety.

References and Attributions [Series 1]

This section compiles all references and attributions for Series 1: *Physical and Chemical Changes in Foods*. It includes suggested open educational resources (OERs) for illustrations, as well as notes on AI-generated prompts. The referencing style applied here follows APA guidelines for clarity and consistency.

General References

- Fellows, P. (2017). *Food Processing Technology: Principles and Practice* (4th ed.). Woodhead Publishing.
- Potter, N. N., & Hotchkiss, J. H. (2012). *Food Science* (5th ed.). Springer.
- Belitz, H. D., Grosch, W., & Schieberle, P. (2009). *Food Chemistry* (4th ed.). Springer.

Illustration References and Attributions

- *Figure 1.1 Distribution of free and bound water in food.* Suggested OER source: "free vs bound water in food diagram OER." AI prompt: "Generate a labelled diagram showing free water and bound water in food structure."
- *Table 1.1 Characteristics of free and bound water in foods.* Suggested OER source: "free and bound water properties food science OER." AI prompt: "Create a table comparing free water and bound water in foods with properties and examples."
- *Figure 1.2 Hydrogen bonding interactions in food molecules.* Suggested OER source: "hydrogen bonding in food molecules diagram OER." AI prompt: "Generate a diagram showing hydrogen bonding between water molecules and food polymers."

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- *Figure 1.3 Auto-oxidation of lipids and the role of antioxidants.* Suggested OER source: “lipid auto-oxidation food science diagram OER.” AI prompt: “Generate a diagram showing lipid auto-oxidation with free radical formation and antioxidant action.”
- *Plate 1.1 Gel formation in protein-based foods.* Suggested OER source: “protein gel formation food science image OER.” AI prompt: “Generate an image showing gel formation in custard or yoghurt due to protein denaturation.”
- *Figure 1.4 Gelatinisation and retrogradation of starch.* Suggested OER source: “starch gelatinisation retrogradation diagram OER.” AI prompt: “Generate a diagram showing starch gelatinisation during heating and retrogradation during cooling.”
- *Box 1.1 Applications of modified starches in food industry.* Suggested OER source: “applications of modified starches food industry OER.” AI prompt: “Create a box listing applications of modified starches in food products.”
- *Figure 1.5 Methods of measuring lipid oxidation in foods.* Suggested OER source: “lipid oxidation measurement methods food science diagram OER.” AI prompt: “Generate a diagram showing lipid oxidation stages and analytical methods such as PV and TBA tests.”
- *Table 1.2 Methods of assessing protein denaturation.* Suggested OER source: “methods of protein denaturation analysis food science OER.” AI prompt: “Create a table comparing methods of assessing protein denaturation in foods.”
- *Figure 1.6 Techniques for studying carbohydrate modifications.* Suggested OER source: “starch gelatinisation retrogradation analysis food science diagram OER.” AI prompt: “Generate a diagram showing starch granule swelling during gelatinisation and crystalline structure during retrogradation.”
- *Figure 1.7 Flavour changes in foods due to chemical reactions.* Suggested OER source: “flavour changes food Maillard reaction lipid oxidation diagram OER.” AI prompt: “Generate a diagram showing flavour development during Maillard reaction and deterioration due to lipid oxidation.”
- *Plate 1.2 Textural modifications in bread and biscuits.* Suggested OER source: “bread staling biscuits moisture textural changes food science image OER.” AI prompt: “Generate an image showing bread staling and biscuits losing crispness due to moisture changes.”
- *Box 1.2 Nutritional and safety implications of food changes.* Suggested OER source: “nutritional losses food oxidation safety risks OER.” AI prompt: “Create a box listing nutritional losses and safety risks caused by physical and chemical changes in foods.”

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Course code: FST304

Course title: Principles of Food Analysis

Course credit load: 3 units

List of Series:

6. **Physical and Chemical Transformations in Foods**
7. **Lipids and Proteins: Properties, Reactions, and Applications**
8. **Carbohydrates, Hydrocolloids, and Starch Modifications**
9. **Enzyme Systems and Browning Reactions in Food Quality**
10. **Vitamins, Natural Pigments, Flavours, and Additives in Foods**

2.1 Lipids in Foods: Types and Properties

- 2.1.1 Classification of lipids: fats, oils, fatty acids, phospholipids, and derived lipids
- 2.1.2 Physical and chemical properties of natural fats and oils
- 2.1.3 Flavour changes in fats and oils

2.2 Lipid Reactions and Modifications

- 2.2.1 Auto-oxidation of unsaturated fatty acids
- 2.2.2 Role of pro-oxidants and antioxidants
- 2.2.3 Hydrogenation and inter-esterification of lipids

2.3 Proteins in Foods: Sources and Properties

- 2.3.1 Physical and chemical properties of proteins
- 2.3.2 Denaturation and gel formation
- 2.3.3 Plant proteins and animal proteins used in foods (e.g., gluten, casein, whey proteins)

2.4 Measurement and Applications of Lipids and Proteins

- 2.4.1 Methods of determination of lipids in foods
- 2.4.2 Methods of assessing protein denaturation
- 2.4.3 Applications of lipids and proteins in food processing and product development

Introduction

Lipids and proteins are two of the most important components of foods, influencing not only their nutritional value but also their flavour, texture, and stability. From the oils used in cooking to the proteins that give bread its structure or milk its functional properties, these biomolecules undergo

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significant changes during processing and storage. Understanding their properties, reactions, and applications is therefore essential for food scientists and technologists, as it provides the basis for analysing food quality and designing products that meet consumer expectations.

The aim of this Series is to equip you with the knowledge and skills to describe the properties of lipids and proteins, analyse their reactions during processing and storage, and apply methods of measurement and utilisation in food systems.

We shall commence this Series by examining the types and properties of lipids in foods, including fats, oils, fatty acids, and phospholipids. Next, we will explore lipid reactions and modifications, focusing on auto-oxidation, the role of pro-oxidants and antioxidants, and processes such as hydrogenation. Following that, we will move on to proteins, considering their physical and chemical properties, denaturation, gel formation, and sources from both plants and animals. Finally, we will wrap up by discussing methods of measurement and practical applications of lipids and proteins in food processing and product development. This progression will enable you to connect scientific principles with real-world applications in food systems.

Series Learning Outcomes

Upon completing this Series, you should be able to:

SLO 2.1 define the major classes of lipids in foods and explain their physical and chemical properties,

SLO 2.2 analyse flavour changes and reactions in fats and oils during processing and storage,

SLO 2.3 explain the processes of lipid auto-oxidation, hydrogenation, and inter-esterification, and evaluate the roles of pro-oxidants and antioxidants,

SLO 2.4 describe the physical and chemical properties of proteins and demonstrate how denaturation leads to gel formation,

SLO 2.5 differentiate between plant proteins and animal proteins used in foods, giving examples of their applications,

SLO 2.6 apply appropriate methods to measure lipid content and assess protein denaturation in food systems,

SLO 2.7 evaluate the practical applications of lipids and proteins in food processing and product development.

2.1 Lipids in Foods: Types and Properties

Lipids are a diverse group of organic compounds that play vital roles in food systems. They contribute to flavour, texture, mouthfeel, and nutritional value. In addition, lipids act as carriers of

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fat-soluble vitamins and essential fatty acids. Their behaviour during processing and storage strongly influences food quality and shelf life. In this Part, we will explore the types of lipids found in foods, their physical and chemical properties, and how these properties affect flavour.

Fill in the blank: Lipids contribute to flavour, texture, mouthfeel, and _____ value in foods.

2.1.1 Classification of lipids: fats, oils, fatty acids, phospholipids, and derived lipids

Fats and oils are triglycerides composed of glycerol and three fatty acids. Fats are solid at room temperature, while oils are liquid. Their physical state depends on the degree of saturation of the fatty acids.

Fatty acids are the building blocks of lipids. They can be saturated (no double bonds), monounsaturated (one double bond), or polyunsaturated (multiple double bonds). The degree of unsaturation influences melting point, stability, and nutritional quality.

Phospholipids are lipids containing phosphate groups. They are important emulsifiers in foods, helping oil and water mix, as seen in mayonnaise.

Derived lipids include compounds such as sterols (e.g., cholesterol) and fat-soluble vitamins. These play structural and nutritional roles in food systems.

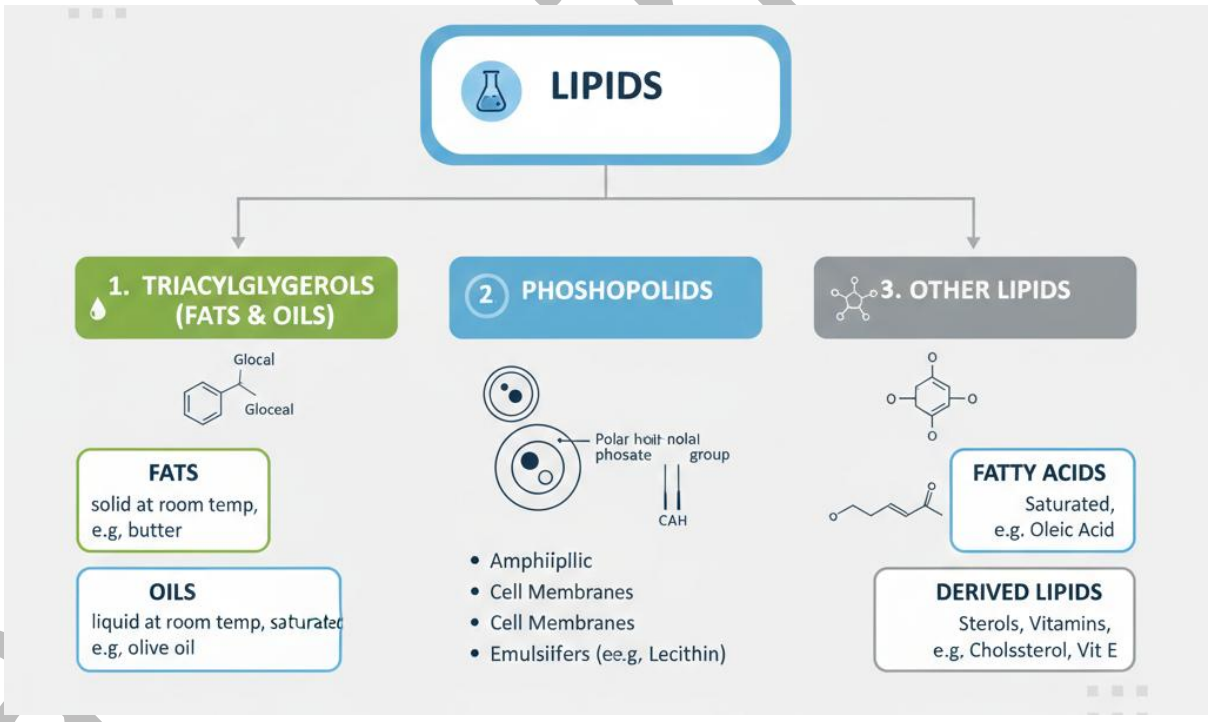

Figure 2.1 Classification of lipids in foods.

Fill in the blank: Phospholipids act as natural _____ in foods, helping oil and water mix.

2.1.2 Physical and chemical properties of natural fats and oils

Lipids exhibit distinctive **physical properties** such as melting point, solubility, and crystallisation behaviour. For example, cocoa butter has a sharp melting point that gives chocolate its desirable snap and melt-in-the-mouth quality.

Their **chemical properties** include susceptibility to oxidation, hydrolysis, and hydrogenation. Unsaturated fatty acids are more prone to oxidation, leading to rancidity. Hydrolysis can release free fatty acids, affecting flavour and stability. Hydrogenation alters unsaturated fats to saturated ones, changing texture and shelf life.

Table 2.1 Physical and chemical properties of fats and oils.

	FATS	OILS
Source	Animal (e.g., butter, lard)	Plant/Fish (e.g., olive, fish)
Physical State (Room Temp)	Solid/Semi-solid	Liquid
Fatty Acid Type (Dominant)	Saturated & Monoususatand	Low (<25°C)
Iodine Value	Low (30-60)	Olivat oil, Sunflower Oil, Fish Oil, Canola Oil
Saturation Level	High	High (80-150)
Examples	Butter, Lard, Cocoa Butter, Margarine	
Key Property	Structure, Flakineiss	Fluidity, Tenderess

Fill in the blank: Unsaturated fatty acids are more prone to _____, leading to rancidity in foods.

2.1.3 Flavour changes in fats and oils

Lipids are closely linked to flavour development and deterioration. Pleasant flavours can arise from lipid breakdown during cooking, such as the nutty aroma of roasted peanuts. However, undesirable flavours occur when lipids oxidise, producing compounds that cause rancidity.

The balance between desirable and undesirable flavour changes depends on storage conditions, processing methods, and the presence of antioxidants. For example, oils stored in clear bottles exposed to light are more likely to develop off-flavours due to photo-oxidation.

Box 2.1 Flavour changes in fats and oils.

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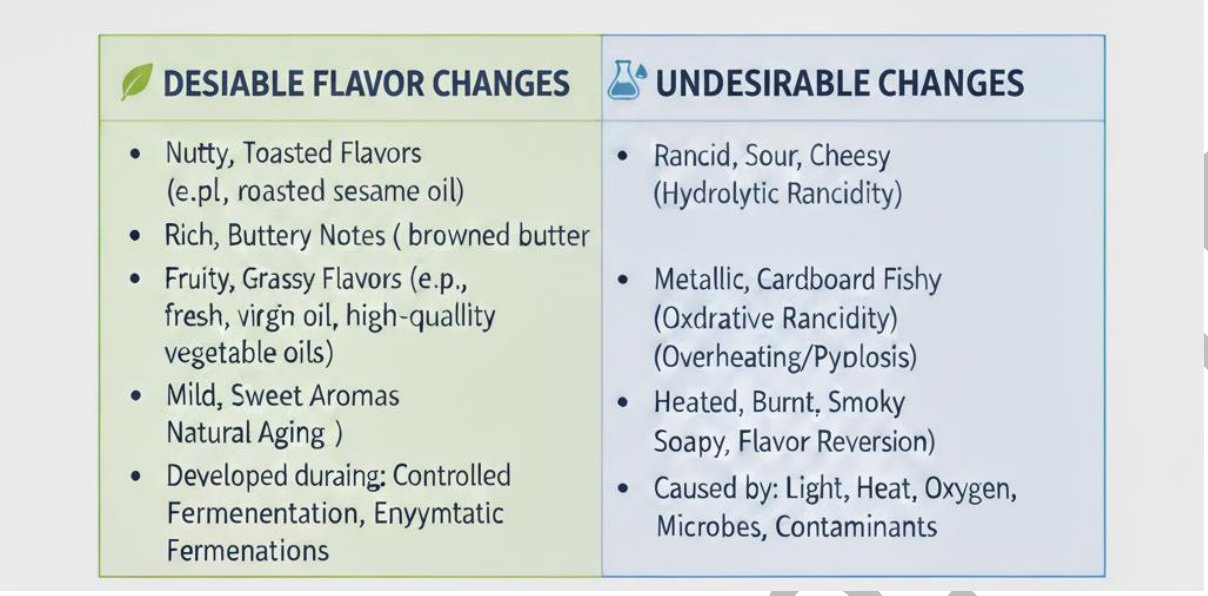

Fill in the blank: Oils stored in clear bottles exposed to _____ are more likely to develop off-flavours.

Pilot questions 2.1

1. What are the main classes of lipids found in foods?
2. How does the degree of saturation affect the properties of fatty acids?
3. Why are phospholipids important in food systems?
4. Which chemical property of lipids is responsible for rancidity?
5. Give one example of a desirable flavour change and one example of an undesirable flavour change in fats and oils.

2.2 Lipid Reactions and Modifications

Lipids undergo several reactions during processing and storage that can either enhance or reduce food quality. These reactions influence flavour, texture, nutritional value, and shelf life. In this Part, we will explore auto-oxidation, the roles of pro-oxidants and antioxidants, and modifications such as hydrogenation and inter-esterification.

Fill in the blank: Lipid reactions influence flavour, texture, nutritional value, and _____ life of foods.

2.2.1 Auto-oxidation of unsaturated fatty acids

Auto-oxidation is the spontaneous reaction of unsaturated fatty acids with oxygen, leading to the formation of free radicals and peroxides. This process results in rancidity, which produces

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undesirable flavours and odours. Auto-oxidation occurs in three stages: initiation, propagation, and termination.

- **Initiation**: Free radicals are formed when oxygen reacts with unsaturated fatty acids.
- **Propagation**: Free radicals react with other fatty acids, producing more radicals and peroxides.
- **Termination**: Stable compounds are formed, but many of these are responsible for off-flavours.

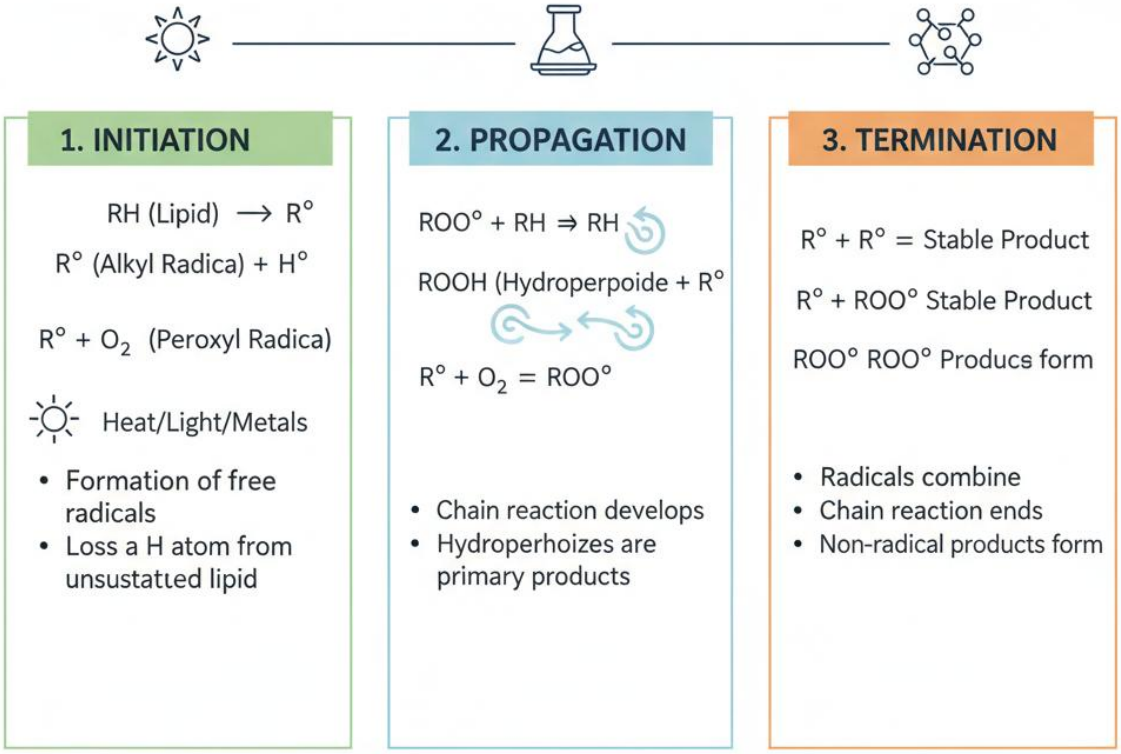

Figure 2.2 Stages of lipid auto-oxidation.

Fill in the blank: The three stages of auto-oxidation are initiation, propagation, and _____.

2.2.2 Role of pro-oxidants and antioxidants

Pro-oxidants are substances that accelerate lipid oxidation. Examples include light, heat, and metals such as iron and copper. Their presence increases the rate of rancidity in foods.

Antioxidants are compounds that slow or prevent oxidation by stabilising free radicals. Natural antioxidants include vitamin E and vitamin C, while synthetic antioxidants such as BHA (butylated hydroxyanisole) and BHT (butylated hydroxytoluene) are commonly used in food preservation.

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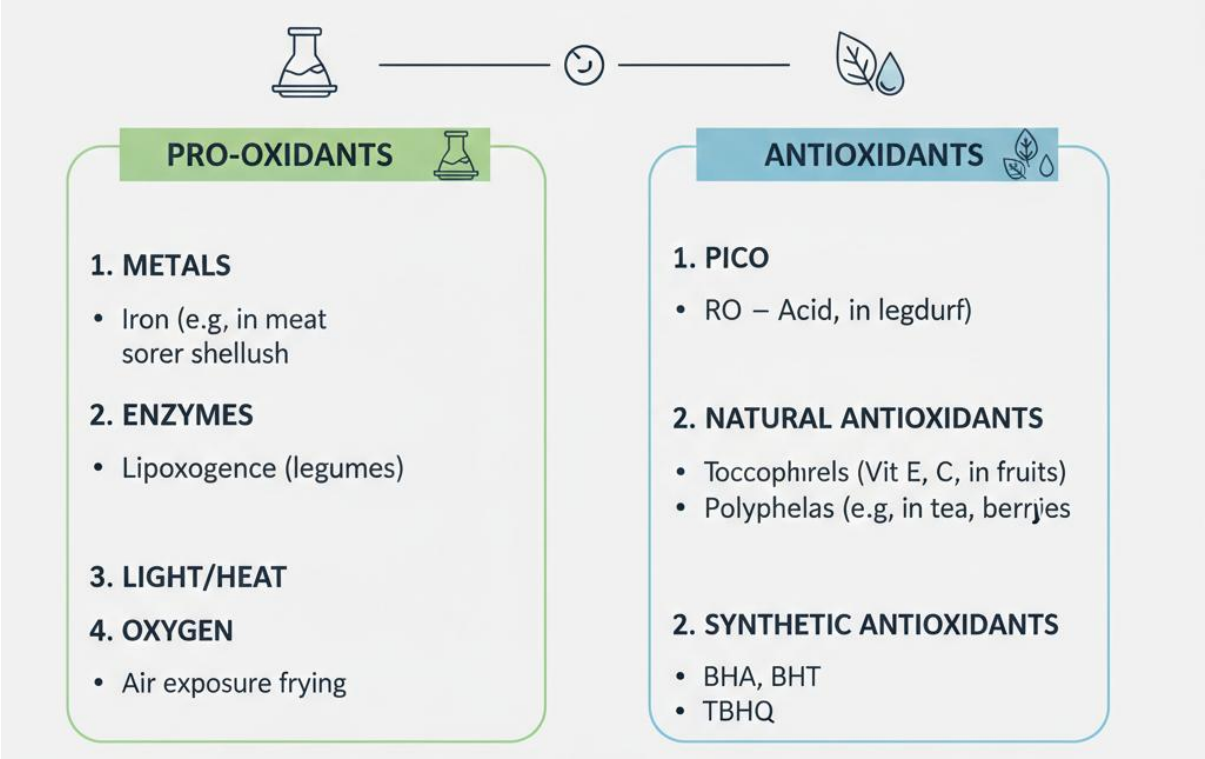
Table 2.2 Examples of pro-oxidants and antioxidants in foods.



Fill in the blank: Substances such as light, heat, and metals that accelerate lipid oxidation are called _____.

2.2.3 Hydrogenation and inter-esterification of lipids

Hydrogenation is the process of adding hydrogen to unsaturated fatty acids, converting them into saturated fats. This increases stability and changes texture, making oils more solid at room temperature. However, partial hydrogenation can produce trans fats, which are associated with health risks.

Inter-esterification is the rearrangement of fatty acids within triglycerides. This process modifies melting points and crystallisation behaviour without producing trans fats. It is used to create fats with desirable properties for baking and confectionery.

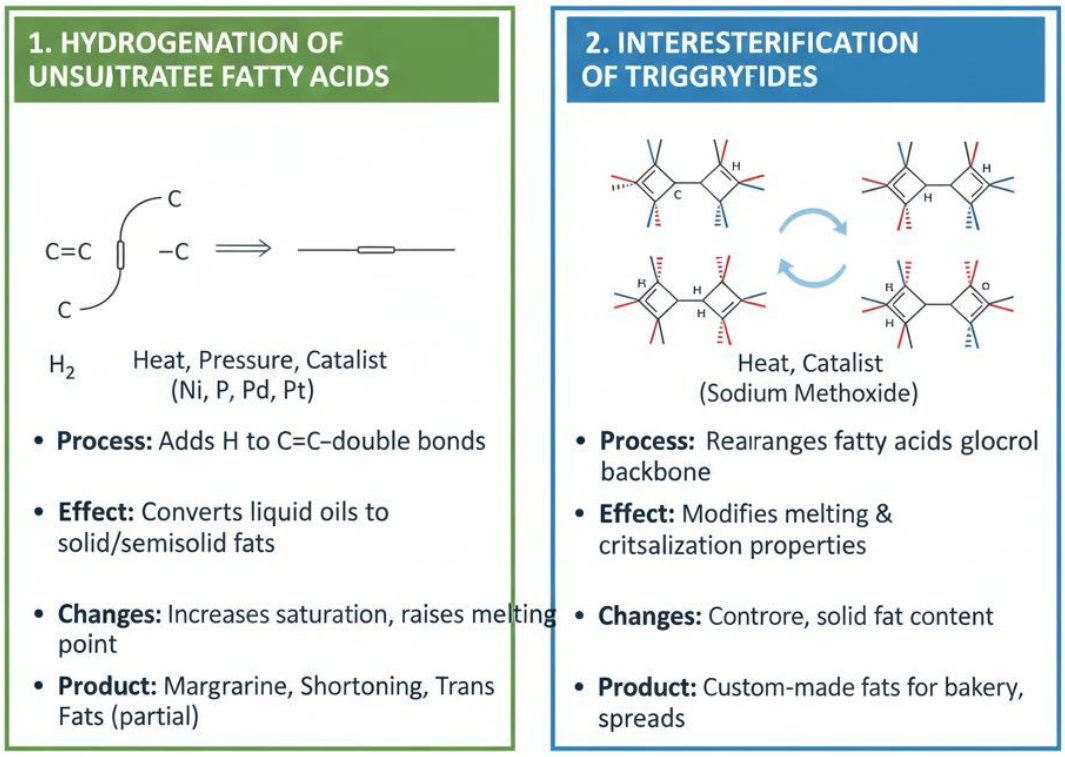


Figure 2.3 Hydrogenation and inter-esterification of lipids.

Fill in the blank: Partial hydrogenation of oils can produce _____ fats, which are linked to health risks.

Pilot questions 2.2

1. What are the three stages of lipid auto-oxidation?
2. Give two examples of pro-oxidants that accelerate lipid oxidation.
3. Name one natural antioxidant and one synthetic antioxidant used in foods.
4. What is the main difference between hydrogenation and inter-esterification?
5. Why are trans fats considered undesirable in food systems?

2.3 Proteins in Foods: Sources and Properties

Proteins are fundamental to both the nutritional and functional qualities of foods. They are macromolecules composed of amino acids linked by **peptide bonds**, and their diverse structures allow them to perform a wide range of roles in food systems. Beyond their importance as a source

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of essential amino acids, proteins contribute to the texture, flavour, and stability of foods. Their behaviour during processing—whether they are soluble, denatured, or cross-linked—determines how they influence the final product. In this Part, we will explore their physical and chemical properties, examine how denaturation leads to gel formation, and distinguish between plant and animal protein sources.

Fill in the blank: Proteins are made up of amino acids linked by _____ bonds.

2.3.1 Physical and chemical properties of proteins

Proteins exhibit a variety of physical properties that make them indispensable in food systems. One of the most important is **solubility**, which determines how proteins interact with water and other food components. Soluble proteins, such as whey proteins, can form clear solutions and are often used in beverages. Insoluble proteins, such as gluten, provide structural integrity in baked goods. Another key property is **water-binding capacity**, which allows proteins to retain moisture and improve juiciness in products like meat analogues. Proteins also have the ability to form foams and gels, which are critical in products ranging from meringues to custards.

Chemically, proteins are defined by their amino acid composition and the distribution of charges along their chains. This influences their reactivity and interactions with other molecules. Proteins can undergo **hydrolysis**, where peptide bonds are broken, leading to smaller peptides and free amino acids that may enhance flavour. They may also experience **oxidation**, which can alter their nutritional quality and functionality. Cross-linking reactions, such as those occurring during heating, can strengthen protein networks, contributing to firmer textures in foods like cheese.

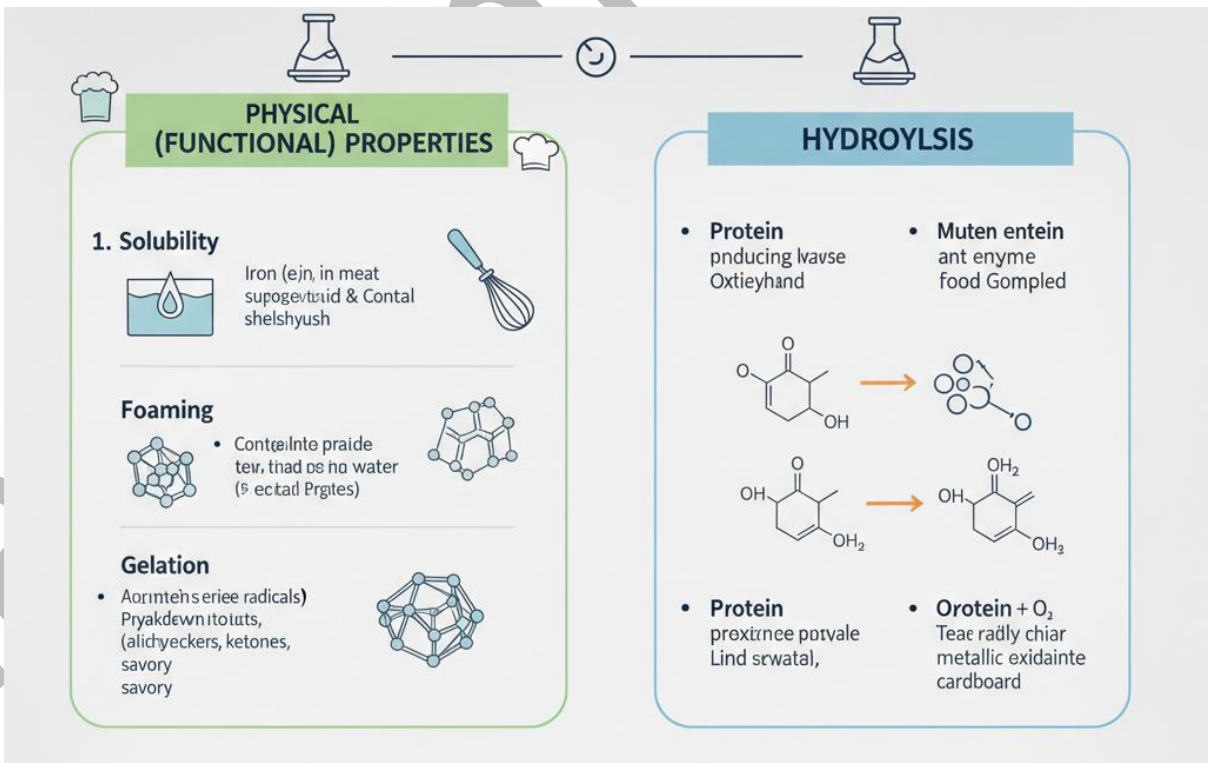


Figure 2.4 Physical and chemical properties of proteins.

Fill in the blank: The ability of proteins to form foams is an example of a _____ property.

2.3.2 Denaturation and gel formation

Denaturation occurs when proteins lose their natural three-dimensional structure due to external factors such as heat, pH changes, or mechanical agitation. This unfolding exposes reactive groups that were previously hidden, altering solubility and functionality. For instance, heating egg whites causes proteins to denature and coagulate, transforming a clear liquid into a firm, opaque mass.

One of the most significant outcomes of denaturation is **gel formation**. When proteins unfold, they can form new bonds with one another, creating a three-dimensional network that traps water and other molecules. This network gives foods their characteristic semi-solid texture. Yoghurt, custard, and cheese are classic examples where gel formation is essential to product identity. The firmness of tofu, for instance, depends on the extent of protein denaturation and the formation of a stable gel. Gel formation is not only important for texture but also for stabilising food systems, preventing separation of components, and improving mouthfeel.

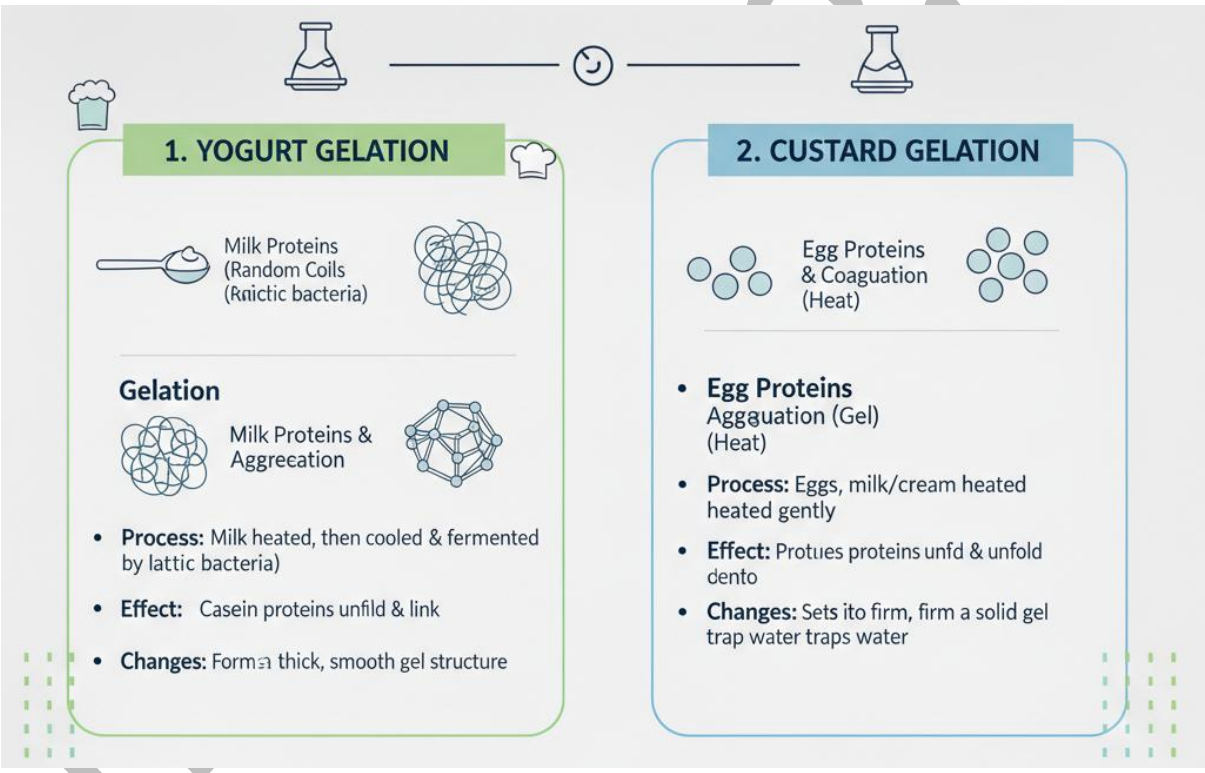


Plate 2.1 Gel formation in protein-based foods.

Fill in the blank: Denatured proteins form a three-dimensional network that traps _____, creating gels.

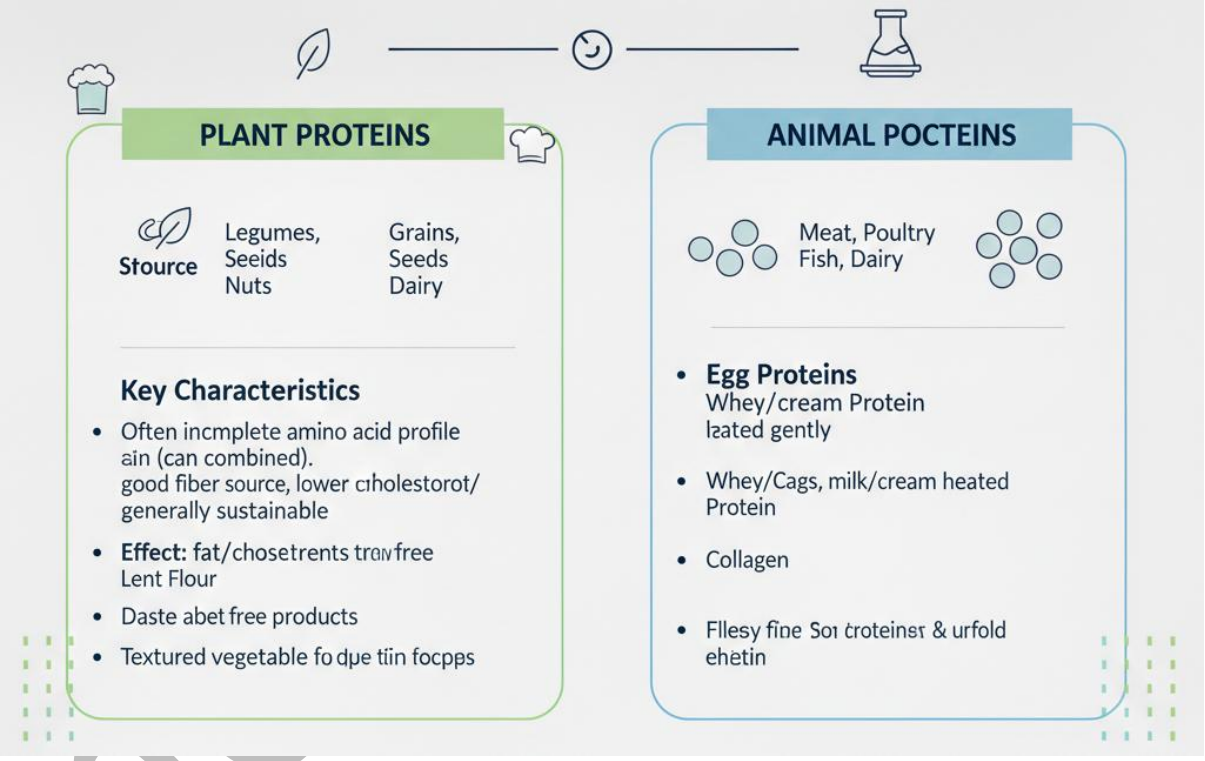
2.3.3 Plant proteins and animal proteins used in foods

Proteins are derived from both plant and animal sources, each offering unique properties and applications. **Plant proteins** such as gluten, soy, and pea proteins are widely used in bakery products, meat substitutes, and beverages. Gluten, found in wheat, provides elasticity and

extensibility in dough, allowing bread to rise and maintain structure. Soy proteins are versatile, used in textured vegetable protein (TVP) for meat alternatives, and in soy milk for beverages. Pea proteins are increasingly popular in plant-based products due to their neutral flavour and good emulsifying properties.

Animal proteins include casein and whey proteins from milk, as well as collagen and gelatin from connective tissues. Casein plays a central role in cheese-making, forming a stable gel when coagulated by enzymes or acids. Whey proteins are highly soluble and functional, making them valuable in sports nutrition and functional foods. Collagen, when hydrolysed, produces gelatin, which is prized for its gelling ability in confectionery and desserts. These proteins not only contribute to texture and stability but also provide high-quality nutrition, as they contain all essential amino acids.

Table 2.3 Examples of plant and animal proteins in foods.



Fill in the blank: Gluten provides elasticity in _____, while casein is important in cheese-making.

Pilot questions 2.3

1. What are the main physical and chemical properties of proteins in foods?
2. How does denaturation affect protein functionality?
3. What role does gel formation play in foods such as yoghurt and custard?
4. Give one example of a plant protein and its application in food systems.

5. Give one example of an animal protein and its application in food systems.

2.4 Measurement and Applications of Lipids and Proteins

Lipids and proteins are not only vital food components but also critical indicators of food quality, safety, and functionality. To ensure that foods meet nutritional and sensory expectations, scientists and technologists employ various methods to measure their content and assess their behaviour during processing. In addition, lipids and proteins are deliberately applied in food systems to achieve desirable textures, flavours, and stability. This Part will guide you through the methods of determining lipids, assessing protein denaturation, and exploring practical applications in food processing and product development.

Fill in the blank: Lipids and proteins are measured and applied in food systems to ensure quality, safety, and _____.

2.4.1 Methods of determination of lipids in foods

Lipids can be measured using several analytical techniques, each suited to different food matrices. One of the most common methods is **solvent extraction**, where lipids are separated from food using organic solvents such as ether or chloroform. This provides a measure of total fat content. Another widely used method is the **Soxhlet extraction**, which involves continuous solvent reflux to extract lipids efficiently.

More advanced techniques include **gas chromatography (GC)**, which separates and quantifies fatty acids, providing detailed information about lipid composition. GC is particularly useful for identifying the proportion of saturated, monounsaturated, and polyunsaturated fatty acids in oils. **Infrared spectroscopy (IR)** can also be used to detect functional groups in lipids, offering rapid and non-destructive analysis.

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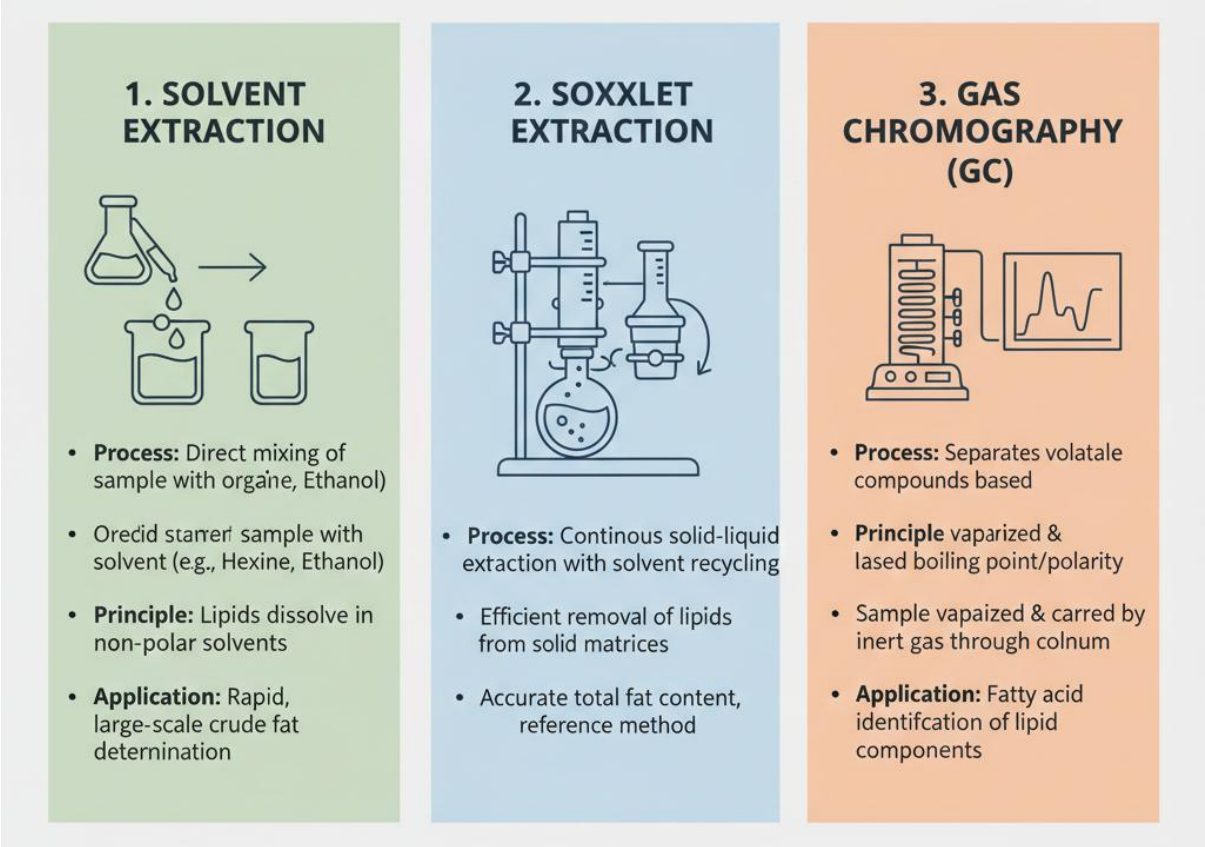

Figure 2.5 Methods of lipid determination in foods.

Fill in the blank: Gas chromatography is particularly useful for identifying the proportion of _____ fatty acids in oils.

2.4.2 Methods of assessing protein denaturation

Protein denaturation alters the structure and functionality of proteins, and measuring this change is essential for understanding food behaviour. **Spectrophotometry** is a common method, where changes in protein absorbance at specific wavelengths indicate structural alterations. For example, aromatic amino acids absorb ultraviolet light, and shifts in absorbance can reveal unfolding.

Another powerful technique is **differential scanning calorimetry (DSC)**, which measures heat flow associated with protein denaturation. DSC provides insights into the thermal stability of proteins, which is important in designing heat-processed foods. **Electrophoresis** is also widely used, separating proteins based on size and charge. Changes in band patterns can reveal denaturation or aggregation.

These methods allow food scientists to monitor protein quality during processing, ensuring that products such as dairy, meat, and plant-based alternatives retain desirable textures and nutritional properties.

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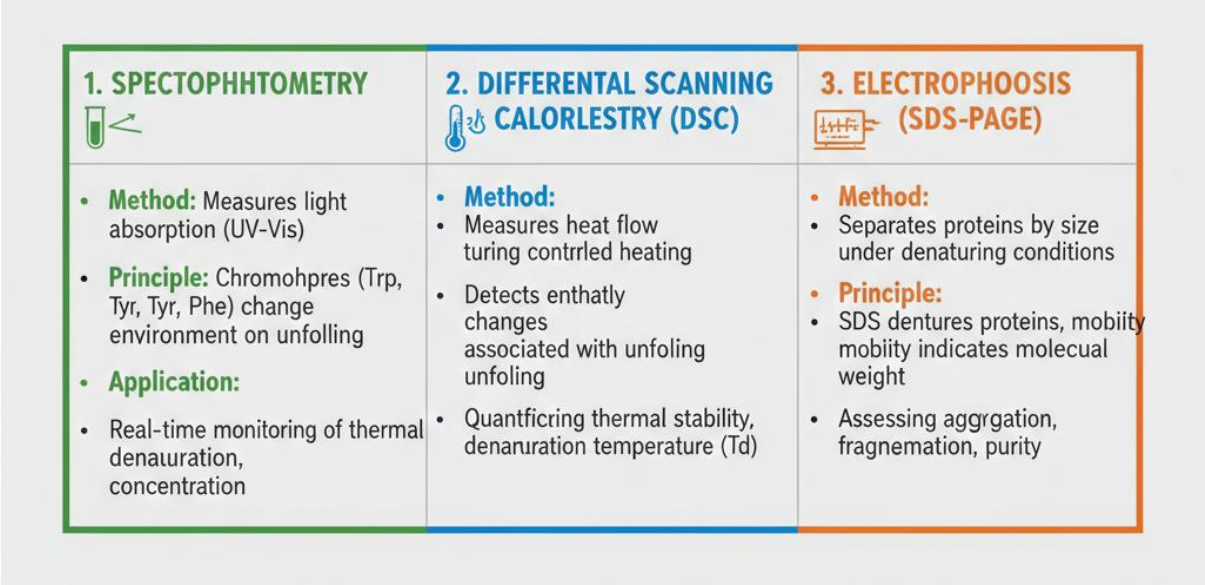
Table 2.4 Methods of assessing protein denaturation.



Fill in the blank: Differential scanning calorimetry measures the _____ stability of proteins during denaturation.

2.4.3 Applications of lipids and proteins in food processing and product development

Lipids and proteins are deliberately applied in food systems to achieve specific functional outcomes. Lipids contribute to mouthfeel, flavour release, and stability. For example, emulsified fats in ice cream provide creaminess, while oils in baked goods enhance tenderness. Modified lipids, such as hydrogenated or inter-esterified fats, are used to control melting behaviour and improve shelf life.

Proteins are equally versatile. Casein and whey proteins are used in dairy products to provide structure and nutritional value. Plant proteins such as soy and pea are incorporated into meat substitutes to mimic texture and improve protein content. Gelatin, derived from collagen, is widely used in confectionery for its gelling properties. Proteins also act as emulsifiers, stabilising mixtures of oil and water in products like mayonnaise.

The deliberate application of lipids and proteins demonstrates how food scientists harness their properties to design products that meet consumer expectations for taste, texture, and nutrition.

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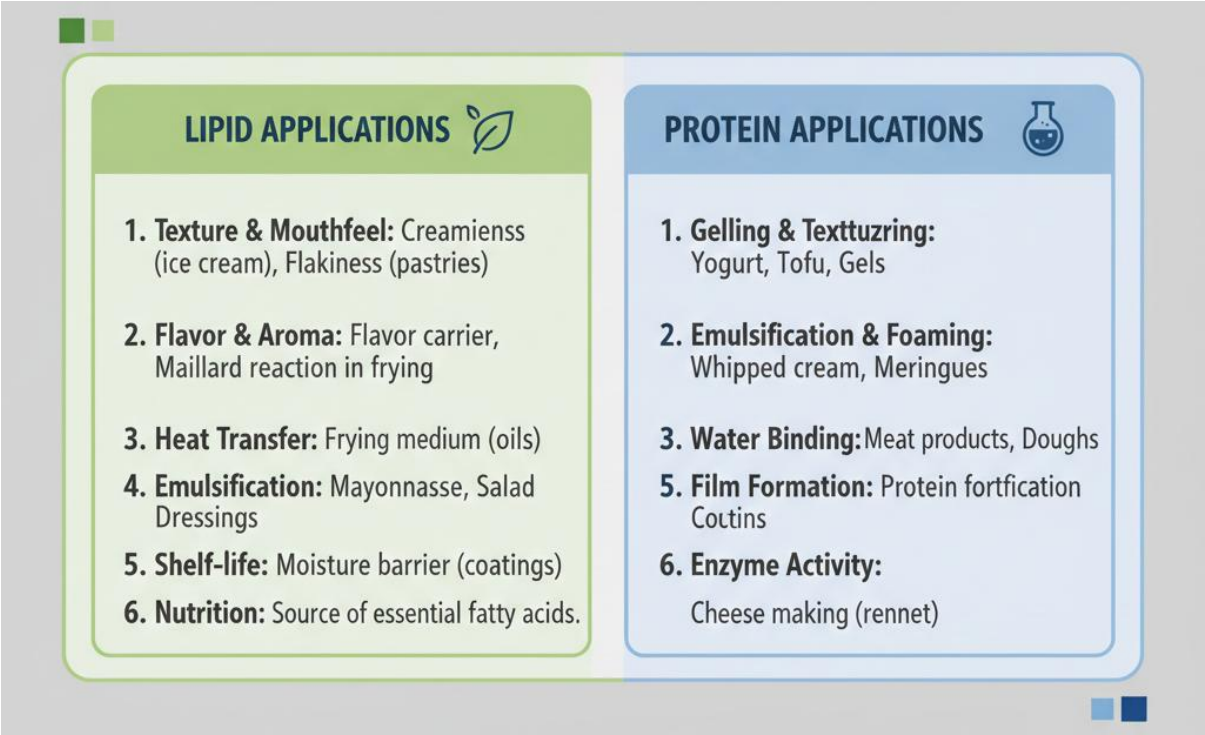
Box 2.2 Applications of lipids and proteins in food processing.



Fill in the blank: Gelatin, derived from collagen, is widely used in _____ for its gelling properties.

Pilot questions 2.4

1. What are the main methods used to determine lipid content in foods?
2. How does gas chromatography provide information about lipid composition?
3. Which analytical method measures heat flow during protein denaturation?
4. How does electrophoresis reveal changes in protein structure?
5. Give one example of how lipids and one example of how proteins are applied in food processing.

Series Summary

This Series has focused on lipids and proteins, two essential food components that influence nutrition, flavour, texture, and stability. Its purpose was to help you understand their properties, the reactions they undergo during processing and storage, and their practical applications in food systems. We began by examining the types and properties of lipids, including fats, oils, fatty acids, and phospholipids. Then we explored lipid reactions such as auto-oxidation, the roles of pro-oxidants and antioxidants, and modifications like hydrogenation and inter-esterification. Following that, we turned to proteins, considering their physical and chemical properties,

denaturation, gel formation, and sources from both plants and animals. Finally, we discussed methods of measurement and highlighted how lipids and proteins are applied in food processing and product development.

By completing this Series, you should now be able to define and describe the major classes of lipids and proteins, analyse their reactions and modifications, explain processes such as denaturation and gel formation, apply methods for measuring lipid content and protein quality, and evaluate their applications in food systems. These abilities directly reflect the Series Learning Outcomes (SLOs 2.1 to 2.7), equipping you with the knowledge and skills to assess, monitor, and utilise lipids and proteins effectively in food analysis and product innovation.

Glossary of Terms

Antioxidants: Compounds that slow or prevent lipid oxidation by stabilising free radicals, helping to preserve flavour and extend shelf life.

Auto-oxidation: A spontaneous reaction of unsaturated fatty acids with oxygen, producing free radicals and peroxides that cause rancidity.

Casein: A milk protein that coagulates to form gels, playing a central role in cheese-making.

Denaturation: The process where proteins lose their natural structure due to heat, pH changes, or mechanical action, altering their solubility and functionality.

Differential scanning calorimetry (DSC): An analytical method that measures heat flow to determine the thermal stability of proteins during denaturation.

Electrophoresis: A technique that separates proteins based on size and charge, used to detect structural changes such as denaturation.

Fatty acids: The building blocks of lipids, classified as saturated, monounsaturated, or polyunsaturated depending on the number of double bonds.

Gel formation: The creation of a three-dimensional protein network that traps water, giving foods such as yoghurt and custard their semi-solid texture.

Gelatin: A protein derived from collagen, valued for its gelling properties in confectionery and desserts.

Gluten: A protein complex found in wheat that provides elasticity and extensibility in dough, allowing bread to rise and maintain structure.

Hydrogenation: A process where hydrogen is added to unsaturated fatty acids, converting them into saturated fats and altering texture and stability.

Inter-esterification: A modification process where fatty acids are rearranged within triglycerides to change melting points and crystallisation behaviour without producing trans fats.

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Lipids: A group of organic compounds including fats, oils, phospholipids, and sterols that contribute to flavour, texture, and nutritional value in foods.

Peptide bonds: Chemical links between amino acids that form the backbone of protein molecules.

Phospholipids: Lipids containing phosphate groups that act as natural emulsifiers, helping oil and water mix in foods such as mayonnaise.

Pro-oxidants: Substances such as light, heat, and metals that accelerate lipid oxidation, leading to rancidity.

Solvent extraction: A method of determining lipid content in foods by separating fats and oils using organic solvents.

Soy proteins: Plant-derived proteins widely used in meat substitutes, beverages, and processed foods for their functional and nutritional properties.

Spectrophotometry: An analytical technique that measures changes in protein absorbance at specific wavelengths to detect structural alterations.

Whey proteins: Soluble milk proteins used in sports nutrition and functional foods, valued for their high nutritional quality and versatility.

Concept Check Questions 2

Objective Questions

1. Which type of lipid acts as a natural emulsifier in foods such as mayonnaise? (Linked to SLO 2.1)
2. What are the three stages of lipid auto-oxidation? (Linked to SLO 2.2)
3. Which process rearranges fatty acids within triglycerides without producing trans fats? (Linked to SLO 2.3)
4. What analytical method measures heat flow to determine the thermal stability of proteins? (Linked to SLO 2.4)
5. Which protein provides elasticity in dough, allowing bread to rise? (Linked to SLO 2.5)

Short-Answer Questions

6. Define fatty acids and explain how their degree of saturation influences food properties. (Linked to SLO 2.1)
7. Describe the role of antioxidants in lipid oxidation. (Linked to SLO 2.2)
8. Explain how protein denaturation leads to gel formation, giving one food example. (Linked to SLO 2.4)

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9. Differentiate between casein and whey proteins in terms of their applications in food systems. (Linked to SLO 2.5)

10. Identify one method used to determine lipid content in foods and explain its principle. (Linked to SLO 2.6)

Long-Answer Questions

11. Analyse the chemical reactions of lipids during processing and storage, and evaluate their implications for food flavour and stability. (Linked to SLO 2.2 and SLO 2.3)

12. Demonstrate how measurement techniques such as solvent extraction, gas chromatography, spectrophotometry, and electrophoresis can be applied to monitor lipids and proteins, and assess their importance in food analysis. (Linked to SLO 2.6)

13. Evaluate the practical applications of lipids and proteins in food processing and product development, giving examples from both plant and animal sources. (Linked to SLO 2.7)

Answers to Concept Check Questions 2

Objective Questions

1. Phospholipids.
2. Initiation, propagation, and termination.
3. Inter-esterification.
4. Differential scanning calorimetry (DSC).
5. Gluten.

Short-Answer Questions

6. Fatty acids are the building blocks of lipids. Saturated fatty acids have no double bonds and are solid at room temperature, while unsaturated fatty acids contain one or more double bonds, making them liquid and more prone to oxidation.
7. Antioxidants stabilise free radicals, slowing or preventing lipid oxidation and helping to preserve flavour and shelf life.
8. Protein denaturation unfolds protein structures, allowing them to form a network that traps water. For example, in yoghurt, denatured proteins form a gel that gives the product its semi-solid texture.
9. Casein is used in cheese-making, forming stable gels when coagulated, while whey proteins are soluble and functional, used in sports nutrition and beverages.
10. Solvent extraction separates lipids from food using organic solvents, providing a measure of total fat content.

Long-Answer Questions

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11. *Basic response:* Lipids undergo auto-oxidation, producing rancid flavours, and may be modified through hydrogenation or inter-esterification to improve stability. These reactions influence flavour and shelf life.
Value-added response: Beyond these basics, lipid oxidation can generate harmful compounds, while hydrogenation may produce trans fats linked to health risks. Inter-esterification provides safer alternatives. Understanding these reactions allows food scientists to design interventions such as antioxidant use and packaging innovations to maintain quality.

12. *Basic response:* Solvent extraction measures total lipid content, gas chromatography identifies fatty acid composition, spectrophotometry detects protein structural changes, and electrophoresis separates proteins to reveal denaturation. These methods help monitor food quality.
Value-added response: In addition, combining these techniques with advanced tools such as infrared spectroscopy and mass spectrometry provides deeper insights. Their application ensures food safety, supports product innovation, and enhances nutritional profiling.

13. *Basic response:* Lipids are applied to improve texture and flavour, while proteins provide structure and stability. Examples include oils in baked goods and casein in cheese.
Value-added response: Outstanding learners will note that lipids also act as carriers of fat-soluble vitamins, while proteins serve as emulsifiers and stabilisers in complex food systems. Applications such as plant proteins in meat substitutes and whey proteins in functional foods demonstrate how these components are harnessed to meet consumer demands for health, sustainability, and innovation.

Answers to Pilot Questions [Series 2]

Part 2.1: Lipids in Foods: Types and Properties

1. Fats, oils, fatty acids, phospholipids, and derived lipids.
2. The degree of saturation affects melting point, stability, and nutritional quality.
3. Phospholipids are important because they act as natural emulsifiers, helping oil and water mix.
4. Oxidation of unsaturated fatty acids.
5. A desirable flavour change is the nutty aroma of roasted peanuts, while an undesirable change is rancidity in oils.

Part 2.2: Lipid Reactions and Modifications

1. Initiation, propagation, and termination.
2. Light and metals such as iron or copper.

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3. Vitamin E (natural) and BHA (synthetic).
4. Hydrogenation adds hydrogen to unsaturated fatty acids, while inter-esterification rearranges fatty acids within triglycerides.
5. Trans fats are undesirable because they are linked to health risks such as cardiovascular disease.

Part 2.3: Proteins in Foods: Sources and Properties

1. Solubility, water-binding capacity, foaming, gelation (physical); amino acid composition, charge distribution, hydrolysis, oxidation, and cross-linking (chemical).
2. Denaturation unfolds proteins, altering solubility and functionality.
3. Gel formation provides semi-solid textures and stabilises food systems, as seen in yoghurt and custard.
4. Gluten, which provides elasticity in dough.
5. Casein, which is important in cheese-making.

Part 2.4: Measurement and Applications of Lipids and Proteins

1. Solvent extraction, Soxhlet extraction, gas chromatography, and infrared spectroscopy.
2. Gas chromatography separates and quantifies fatty acids, showing proportions of saturated and unsaturated types.
3. Differential scanning calorimetry (DSC).
4. Electrophoresis reveals changes in protein structure by separating proteins based on size and charge.
5. Lipids are applied to improve texture and flavour, such as oils in baked goods; proteins are applied to provide structure and stability, such as casein in cheese.

References and Attributions [Series 2]

This section compiles all references and attributions for Series 2: *Lipids and Proteins: Properties, Reactions, and Applications*. It includes suggested open educational resources (OERs) for illustrations, as well as notes on AI-generated prompts. The referencing style applied here follows APA guidelines for clarity and consistency.

General References

- Belitz, H. D., Grosch, W., & Schieberle, P. (2009). *Food Chemistry* (4th ed.). Springer.
- Fellows, P. (2017). *Food Processing Technology: Principles and Practice* (4th ed.). Woodhead Publishing.

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- Potter, N. N., & Hotchkiss, J. H. (2012). *Food Science* (5th ed.). Springer.

Illustration References and Attributions

- *Figure 2.1 Classification of lipids in foods.* Suggested OER source: "classification of lipids food science diagram OER." AI prompt: "Generate a diagram showing classification of lipids: fats, oils, fatty acids, phospholipids, and derived lipids."
- *Table 2.1 Physical and chemical properties of fats and oils.* Suggested OER source: "physical chemical properties fats oils food science OER." AI prompt: "Create a table comparing physical and chemical properties of fats and oils with examples."
- *Box 2.1 Flavour changes in fats and oils.* Suggested OER source: "flavour changes fats oils food science OER." AI prompt: "Create a box listing examples of flavour changes in fats and oils, both desirable and undesirable."
- *Figure 2.2 Stages of lipid auto-oxidation.* Suggested OER source: "lipid auto-oxidation stages food science diagram OER." AI prompt: "Generate a diagram showing initiation, propagation, and termination stages of lipid auto-oxidation."
- *Table 2.2 Examples of pro-oxidants and antioxidants in foods.* Suggested OER source: "pro-oxidants antioxidants food science table OER." AI prompt: "Create a table comparing pro-oxidants and antioxidants in foods with examples."
- *Figure 2.3 Hydrogenation and inter-esterification of lipids.* Suggested OER source: "hydrogenation inter-esterification lipids food science diagram OER." AI prompt: "Generate a diagram showing hydrogenation of unsaturated fatty acids and inter-esterification of triglycerides."
- *Figure 2.4 Physical and chemical properties of proteins.* Suggested OER source: "physical chemical properties proteins food science diagram OER." AI prompt: "Generate a diagram showing physical properties (solubility, foaming, gelation) and chemical properties (hydrolysis, oxidation) of proteins."
- *Plate 2.1 Gel formation in protein-based foods.* Suggested OER source: "protein gel formation food science image OER." AI prompt: "Generate an image showing gel formation in yoghurt or custard due to protein denaturation."
- *Table 2.3 Examples of plant and animal proteins in foods.* Suggested OER source: "plant animal proteins food science table OER." AI prompt: "Create a table comparing plant and animal proteins used in foods with examples and applications."
- *Figure 2.5 Methods of lipid determination in foods.* Suggested OER source: "methods of lipid determination food science diagram OER." AI prompt: "Generate a diagram showing solvent extraction, Soxhlet extraction, and gas chromatography methods for lipid analysis."
- *Table 2.4 Methods of assessing protein denaturation.* Suggested OER source: "methods of protein denaturation analysis food science OER." AI prompt: "Create a table comparing spectrophotometry, DSC, and electrophoresis methods for assessing protein denaturation."

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- *Box 2.2 Applications of lipids and proteins in food processing.* Suggested OER source: "applications of lipids proteins food science OER." AI prompt: "Create a box listing applications of lipids and proteins in food processing and product development."

Course code: FST304

Course title: Principles of Food Analysis

Course credit load: 3 units

List of Series:

11. **Physical and Chemical Transformations in Foods**
12. **Lipids and Proteins: Properties, Reactions, and Applications**
13. **Carbohydrates, Hydrocolloids, and Starch Modifications**
14. **Enzyme Systems and Browning Reactions in Food Quality**
15. **Vitamins, Natural Pigments, Flavours, and Additives in Foods**

3.1 Carbohydrates in Foods: Types and Functions

- 3.1.1 Classification of carbohydrates: monosaccharides, disaccharides, oligosaccharides, polysaccharides
- 3.1.2 Functional roles of carbohydrates in foods (sweetness, bulk, energy source)
- 3.1.3 Carbohydrate interactions with other food components

3.2 Hydrocolloids: Properties and Applications

- 3.2.1 Definition and classification of hydrocolloids
- 3.2.2 Functional properties: thickening, stabilising, emulsifying
- 3.2.3 Applications in food systems (beverages, sauces, bakery, dairy)

3.3 Starch: Gelatinisation, Retrogradation, and Modifications

- 3.3.1 Structure and properties of native starch
- 3.3.2 Gelatinisation and retrogradation processes
- 3.3.3 Modified starches: pre-gelatinised, cross-linked, oxidised, and their applications

3.4 Measurement and Analysis of Carbohydrates and Hydrocolloids

- 3.4.1 Methods of carbohydrate analysis (e.g., chromatography, spectrophotometry)

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- 3.4.2 Techniques for studying starch behaviour (viscometry, microscopy, DSC)
- 3.4.3 Analytical approaches for hydrocolloid functionality

3.5 Implications for Food Quality and Product Development

- 3.5.1 Role of carbohydrates in flavour and texture development
- 3.5.2 Hydrocolloids in shelf-life extension and stability
- 3.5.3 Starch modifications in convenience foods and industrial applications

Introduction

Carbohydrates are among the most abundant biomolecules in foods, providing energy, sweetness, and bulk, while also influencing texture and stability. Alongside them, hydrocolloids and starches play crucial roles in shaping the quality of food products, from thickened sauces and creamy desserts to the structure of bread and convenience foods. Understanding how these components behave, interact, and can be modified is essential for food scientists and technologists, as it directly impacts product development, shelf life, and consumer acceptance.

The aim of this Series is to equip you with the knowledge and skills to describe the properties of carbohydrates and hydrocolloids, explain the processes of starch gelatinisation and retrogradation, apply analytical methods to study their behaviour, and evaluate their implications for food quality and product innovation.

We shall commence this Series by examining carbohydrates in foods, focusing on their types, classification, and functional roles. Next, we will explore hydrocolloids, considering their properties and applications in food systems. Following that, we will study starch, looking closely at its structure, gelatinisation, retrogradation, and modifications. Afterwards, we will continue with methods of measurement and analysis, highlighting techniques used to study carbohydrates, starch, and hydrocolloids. Finally, we will wrap up by discussing their implications for food quality and product development, showing how these components are harnessed to create stable, appealing, and innovative food products.

Series Learning Outcomes

Upon completing this Series, you should be able to:

SLO 3.1 define the major classes of carbohydrates in foods and explain their functional roles,

SLO 3.2 analyse how carbohydrates interact with other food components to influence flavour, texture, and stability,

SLO 3.3 describe the properties of hydrocolloids and demonstrate their applications as thickeners, stabilisers, and emulsifiers in food systems,

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SLO 3.4 explain the processes of starch gelatinisation and retrogradation and evaluate their impact on food texture and shelf life,

SLO 3.5 differentiate between native and modified starches and apply examples of their use in food processing,

SLO 3.6 apply appropriate analytical methods to measure carbohydrate content and assess hydrocolloid and starch behaviour in foods,

SLO 3.7 evaluate the implications of carbohydrates, hydrocolloids, and starch modifications for food quality and product development.

3.1 Carbohydrates in Foods: Types and Functions

Carbohydrates are one of the most abundant biomolecules in foods and serve as a primary source of energy for humans. They also contribute to sweetness, bulk, texture, and stability in food systems. Beyond their nutritional role, carbohydrates interact with other food components to influence flavour, mouthfeel, and shelf life. In this Part, we will examine their classification, functional roles, and interactions with other food constituents.

Fill in the blank: Carbohydrates are the most abundant biomolecules in foods and serve as a primary source of _____.

3.1.1 Classification of carbohydrates: monosaccharides, disaccharides, oligosaccharides, polysaccharides

Carbohydrates can be classified based on the number of sugar units they contain.

Monosaccharides are the simplest carbohydrates, consisting of a single sugar unit. Examples include glucose, fructose, and galactose. They are easily absorbed and provide quick energy.

Disaccharides are formed when two monosaccharides join together. Common examples are sucrose (glucose + fructose), lactose (glucose + galactose), and maltose (glucose + glucose). These sugars must be broken down into monosaccharides before absorption.

Oligosaccharides contain 3–10 sugar units. They are less common in foods but are found in legumes and certain vegetables. Some oligosaccharides act as prebiotics, supporting beneficial gut bacteria.

Polysaccharides are long chains of monosaccharides. Examples include starch, glycogen, and cellulose. Starch is the main storage carbohydrate in plants, while cellulose provides structural support.

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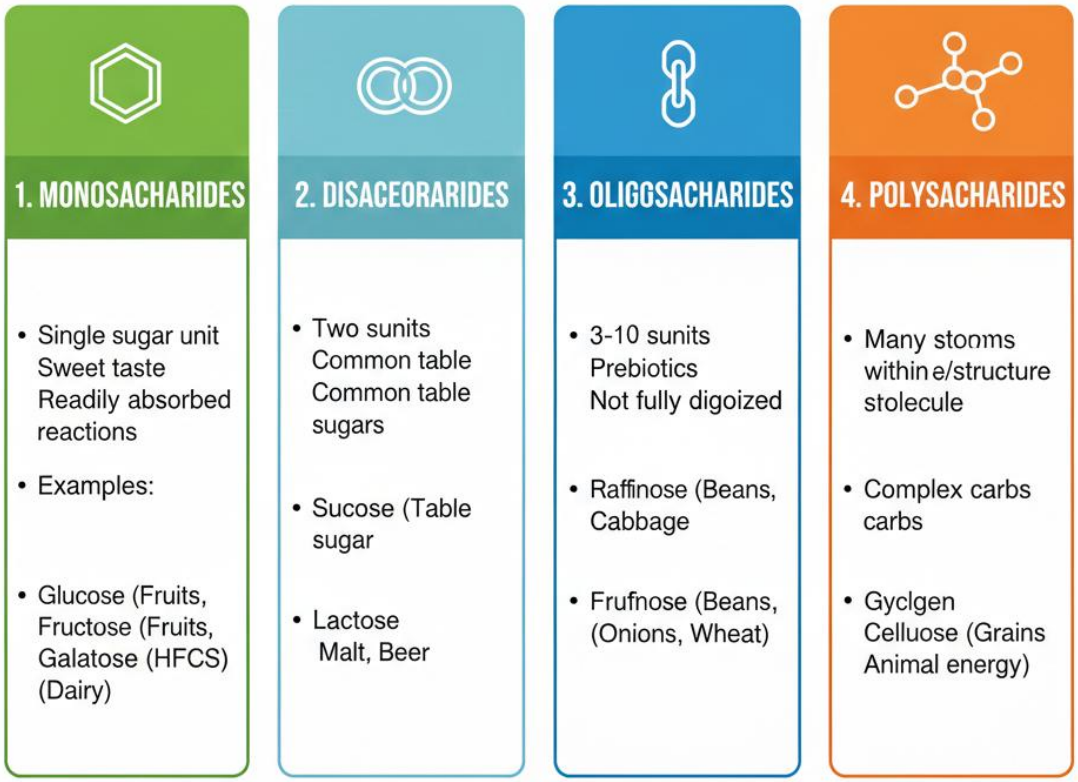

Figure 3.1 Classification of carbohydrates in foods.

Fill in the blank: Sucrose is a disaccharide made up of _____ and fructose.

3.1.2 Functional roles of carbohydrates in foods (sweetness, bulk, energy source)

Carbohydrates perform several important functions in foods.

One of the most obvious roles is **sweetness**, provided by sugars such as sucrose and fructose. Sweetness enhances palatability and consumer acceptance.

Carbohydrates also provide **bulk**, contributing to the body and texture of foods. For example, starch adds thickness to sauces, while cellulose contributes to dietary fibre in vegetables.

As an **energy source**, carbohydrates supply 4 kcal per gram, making them the primary fuel for human metabolism. Glycogen stored in the liver and muscles serves as a readily available energy reserve.

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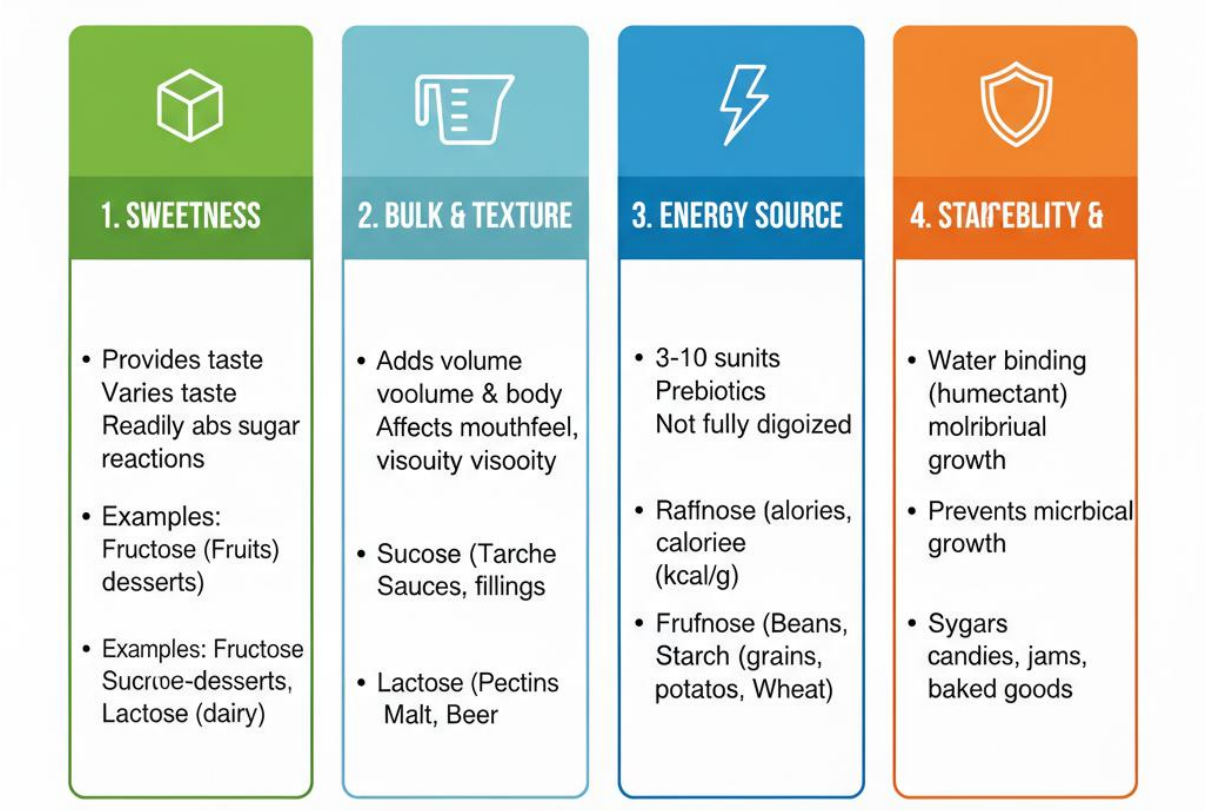
Table 3.1 Functional roles of carbohydrates in foods.



Fill in the blank: Carbohydrates provide _____ kcal per gram as an energy source.

3.1.3 Carbohydrate interactions with other food components

Carbohydrates interact with proteins, lipids, and water to influence food quality.

One important interaction is the **Maillard reaction**, where reducing sugars react with amino acids during heating to produce brown colours and complex flavours. This reaction is responsible for the crust on bread and the flavour of roasted coffee.

Carbohydrates also interact with water, affecting viscosity and texture. Starch granules absorb water and swell during cooking, thickening soups and sauces. Fibre interacts with water to increase bulk and aid digestion.

Interactions with lipids can influence emulsification and stability. For example, polysaccharides such as gums stabilise emulsions in salad dressings.

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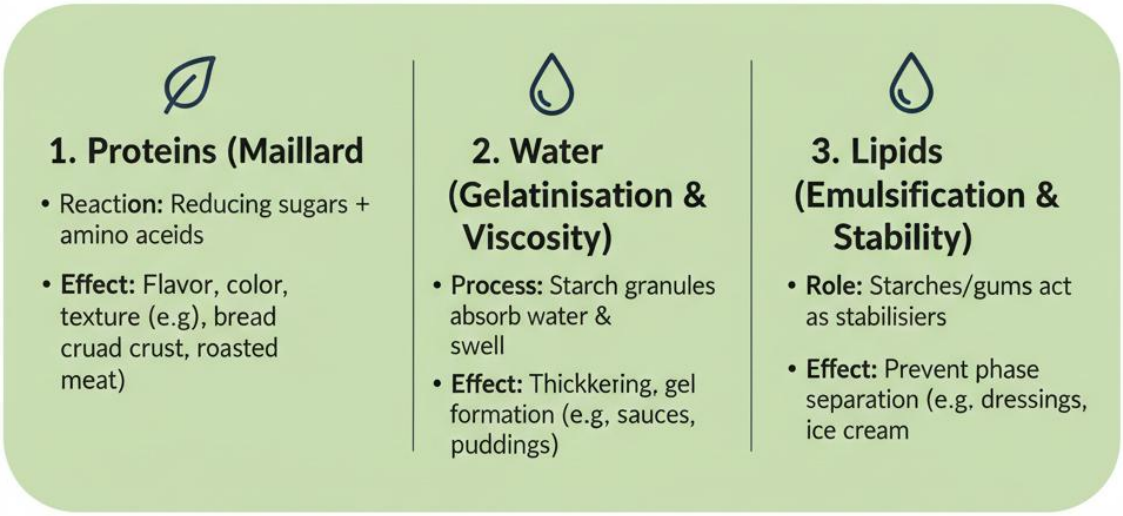
Box 3.1 Carbohydrate interactions in food systems.



Fill in the blank: The Maillard reaction occurs when reducing sugars react with _____ during heating.

Pilot questions 3.1

1. What are the four main classes of carbohydrates found in foods?
2. Give one example each of a monosaccharide, disaccharide, and polysaccharide.
3. What are the three main functional roles of carbohydrates in foods?
4. How many kilocalories per gram do carbohydrates provide as an energy source?
5. What reaction between carbohydrates and proteins produces brown colours and flavours in foods?

3.2 Hydrocolloids: Properties and Applications

Hydrocolloids are a diverse group of substances widely used in food systems to modify texture, stabilise mixtures, and improve shelf life. They are typically polysaccharides or proteins that disperse in water to form viscous solutions or gels. Their ability to interact with water and other food components makes them indispensable in modern food processing. In this Part, we will explore their definition and classification, examine their functional properties, and consider their applications in different food systems.

Fill in the blank: Hydrocolloids are substances that disperse in _____ to form viscous solutions or gels.

3.2.1 Definition and classification of hydrocolloids

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The term **hydrocolloids** refers to water-loving polymers that can thicken or gel aqueous solutions. They are usually derived from plants, seaweeds, microbial fermentation, or animal sources. Hydrocolloids are classified into several groups depending on their origin and chemical structure. Plant-derived hydrocolloids include starch and pectin, while seaweed-derived examples include agar and carrageenan. Microbial hydrocolloids such as xanthan gum are produced through fermentation, and animal-derived hydrocolloids include gelatin.

Each type of hydrocolloid has unique properties. For instance, agar forms firm gels that remain stable at room temperature, while gelatin produces elastic gels that melt in the mouth. Pectin is widely used in jams and jellies because of its ability to form gels in the presence of sugar and acid. Xanthan gum is valued for its ability to stabilise emulsions and maintain viscosity even under varying temperatures.

Figure 3.2 Classification of hydrocolloids in foods.

Fill in the blank: Pectin is widely used in _____ and jellies because of its gelling ability.

3.2.2 Functional properties: thickening, stabilising, emulsifying

Hydrocolloids are valued for their **functional properties**, which make them versatile in food applications. One of the most important functions is **thickening**, where hydrocolloids increase the viscosity of liquids. This property is essential in soups, sauces, and beverages, giving them body and improving mouthfeel.

Another key function is **stabilising**, which prevents separation of components in food systems. For example, hydrocolloids can stabilise suspensions in fruit juices or prevent ice crystal growth in frozen desserts. By binding water, they also help retain moisture, extending shelf life.

Hydrocolloids also act as **emulsifiers**, helping oil and water mix in products such as salad dressings and mayonnaise. Although not all hydrocolloids are strong emulsifiers, many contribute to emulsion stability by increasing viscosity and forming protective films around droplets.

Table 3.2 Functional properties of hydrocolloids in foods.

Fill in the blank: Hydrocolloids prevent separation of components in food systems by acting as _____.

3.2.3 Applications in food systems (beverages, sauces, bakery, dairy)

Hydrocolloids are applied across a wide range of food systems to improve quality and consumer appeal. In **beverages**, they are used to stabilise fruit pulp, prevent sedimentation, and enhance mouthfeel. For example, xanthan gum is often added to fruit juices to maintain uniform texture.

In **sauces and dressings**, hydrocolloids provide thickness and stability. They prevent oil and water from separating in mayonnaise and salad dressings, while also ensuring smooth consistency in tomato sauces.

In **bakery products**, hydrocolloids improve dough handling, moisture retention, and shelf life. Guar gum and carboxymethyl cellulose (CMC) are commonly used to enhance softness and delay staling in bread.

In **dairy products**, hydrocolloids stabilise yoghurt, ice cream, and cheese. They prevent whey separation in yoghurt, reduce ice crystal formation in ice cream, and improve texture in processed cheese.

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Box 3.2 Applications of hydrocolloids in food systems.

Fill in the blank: Hydrocolloids reduce ice crystal formation in _____, improving texture and stability.

Pilot questions 3.2

1. What are hydrocolloids and how are they classified?
2. Give one example each of plant-derived, seaweed-derived, microbial, and animal-derived hydrocolloids.
3. What are the three main functional properties of hydrocolloids in food systems?
4. How do hydrocolloids improve the stability of frozen desserts?
5. Give one example of how hydrocolloids are applied in bakery products.

3.3 Starch: Gelatinisation, Retrogradation, and Modifications

Starch is one of the most important carbohydrates in food systems, serving as a major source of energy and a key functional ingredient. It is found abundantly in cereals, tubers, and legumes, and its behaviour during processing strongly influences the texture, stability, and quality of foods. In this Part, we will explore the structure and properties of native starch, examine the processes of gelatinisation and retrogradation, and consider the modifications applied to starch to enhance its performance in food products.

Fill in the blank: Starch is abundantly found in cereals, tubers, and _____.

3.3.1 Structure and properties of native starch

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Starch is a polysaccharide composed of two molecules: **amylose**, a mostly linear chain of glucose units, and **amylopectin**, a highly branched chain of glucose units. The ratio of amylose to amylopectin varies among starch sources and influences their functional properties. For example, waxy maize starch contains almost no amylose, while potato starch has a relatively high amylose content.

Native starch exists in the form of granules, which differ in size and shape depending on the source. These granules are insoluble in cold water but swell when heated, a property that underpins many food applications. Starch provides thickening, gelling, and stabilising functions in foods such as soups, sauces, and puddings.

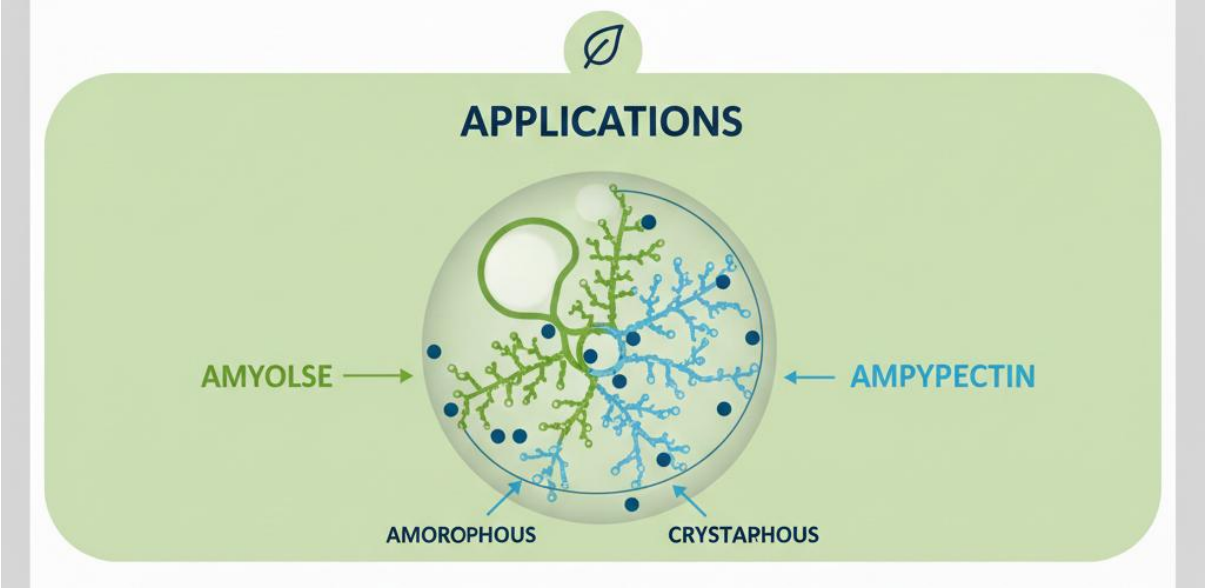

Figure 3.3 Structure of native starch granules.

Fill in the blank: Starch is composed of two molecules, amylose and _____.

3.3.2 Gelatinisation and retrogradation processes

Gelatinisation is the process by which starch granules absorb water and swell upon heating, leading to the disruption of their crystalline structure. As the granules swell, amylose leaches out into the surrounding water, increasing viscosity and forming a thickened paste. This process is fundamental in cooking and baking, as it gives sauces their thickness and custards their creamy texture.

Retrogradation occurs when gelatinised starch cools and the amylose and amylopectin chains reassociate, forming a more ordered structure. This leads to the firming or hardening of foods, such as the staling of bread. Retrogradation can reduce palatability but is sometimes desirable, as in the formation of resistant starch, which has health benefits such as improved gut health.

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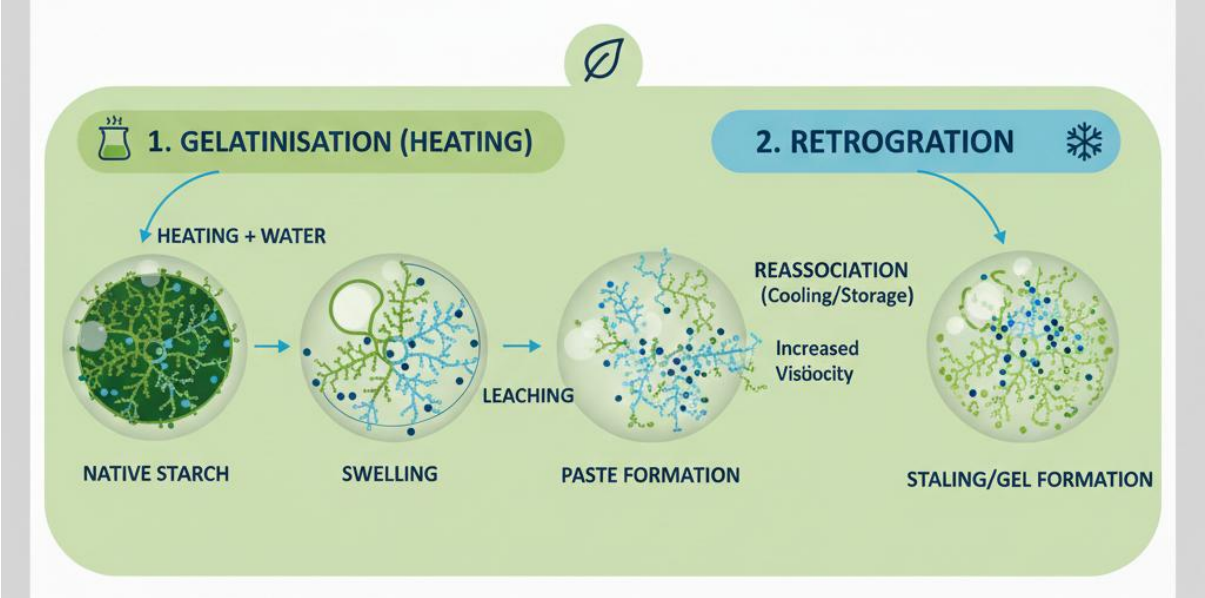

Figure 3.4 Gelatinisation and retrogradation of starch.

Fill in the blank: Retrogradation is responsible for the _____ of bread during storage.

3.3.3 Modified starches: pre-gelatinised, cross-linked, oxidised, and their applications

Native starches often have limitations, such as instability under high heat, shear, or acidic conditions. To overcome these, starches are chemically or physically modified to improve their performance.

Pre-gelatinised starch is starch that has been cooked and dried, allowing it to thicken instantly in cold water. It is widely used in instant puddings and soups.

Cross-linked starch is treated with chemical agents to strengthen the bonds between starch molecules. This modification improves resistance to heat, acid, and mechanical shear, making it suitable for canned foods and sauces.

Oxidised starch is produced by treating starch with oxidising agents, which reduce viscosity and improve film-forming properties. It is often used in confectionery and coatings.

These modifications expand the range of applications for starch, ensuring stability and consistency in processed foods.

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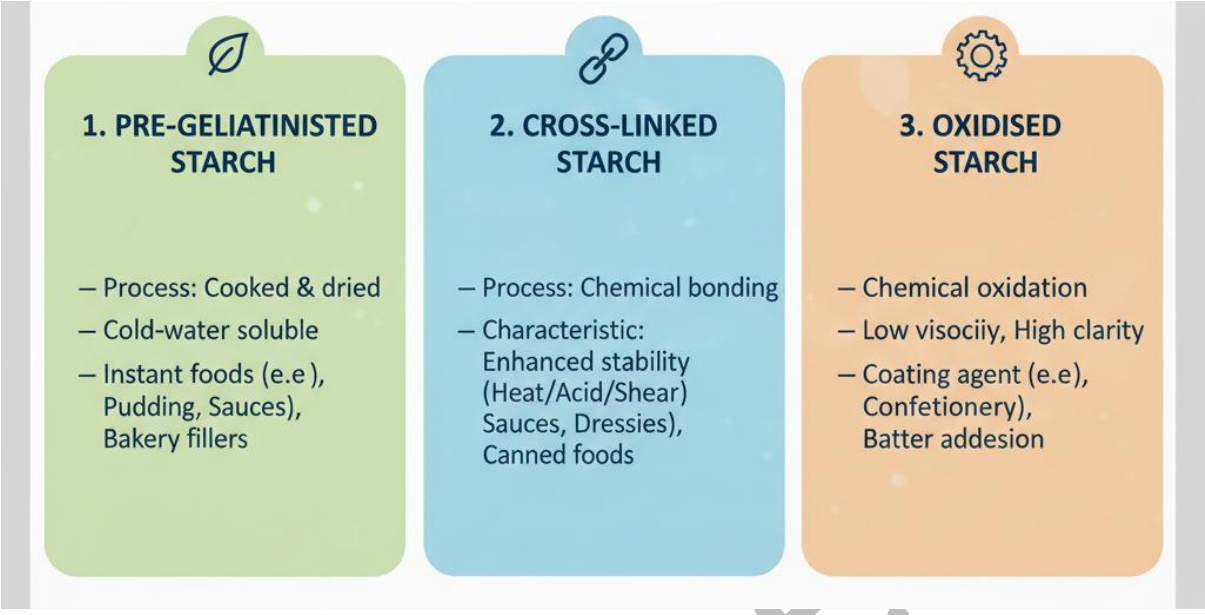
Table 3.3 Types of modified starches and their applications.



Fill in the blank: Pre-gelatinised starch is able to thicken instantly in _____ water.

Pilot questions 3.3

1. What are the two main molecules that make up starch?
2. How does the ratio of amylose to amylopectin influence starch properties?
3. What happens to starch granules during gelatinisation?
4. What process is responsible for bread staling during storage?
5. Give one example of a modified starch and its application in food systems.

3.4 Measurement and Analysis of Carbohydrates and Hydrocolloids

Accurate measurement and analysis of carbohydrates and hydrocolloids are essential in food science, as they determine nutritional value, functional behaviour, and product quality. These analyses allow food technologists to monitor changes during processing, ensure compliance with standards, and design products with desirable textures and stability. In this Part, we will explore methods of carbohydrate analysis, techniques for studying starch behaviour, and approaches for assessing hydrocolloid functionality.

Fill in the blank: Measurement and analysis of carbohydrates and hydrocolloids are essential for determining nutritional value and _____.

3.4.1 Methods of carbohydrate analysis

Carbohydrates can be analysed using several techniques, depending on whether the focus is on total content or specific types. One common method is **chromatography**, which separates

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carbohydrate molecules based on their size or chemical properties. High-performance liquid chromatography (HPLC) is widely used to quantify sugars such as glucose, fructose, and sucrose in beverages and processed foods.

Another important technique is **spectrophotometry**, which measures the absorption of light by carbohydrate solutions. The phenol-sulphuric acid method, for example, is a colourimetric test that provides an estimate of total carbohydrate content.

Gravimetric methods, such as **moisture and ash analysis**, can also indirectly provide carbohydrate values by difference, though these are less precise. Modern approaches increasingly combine chromatography with mass spectrometry to achieve detailed carbohydrate profiling.

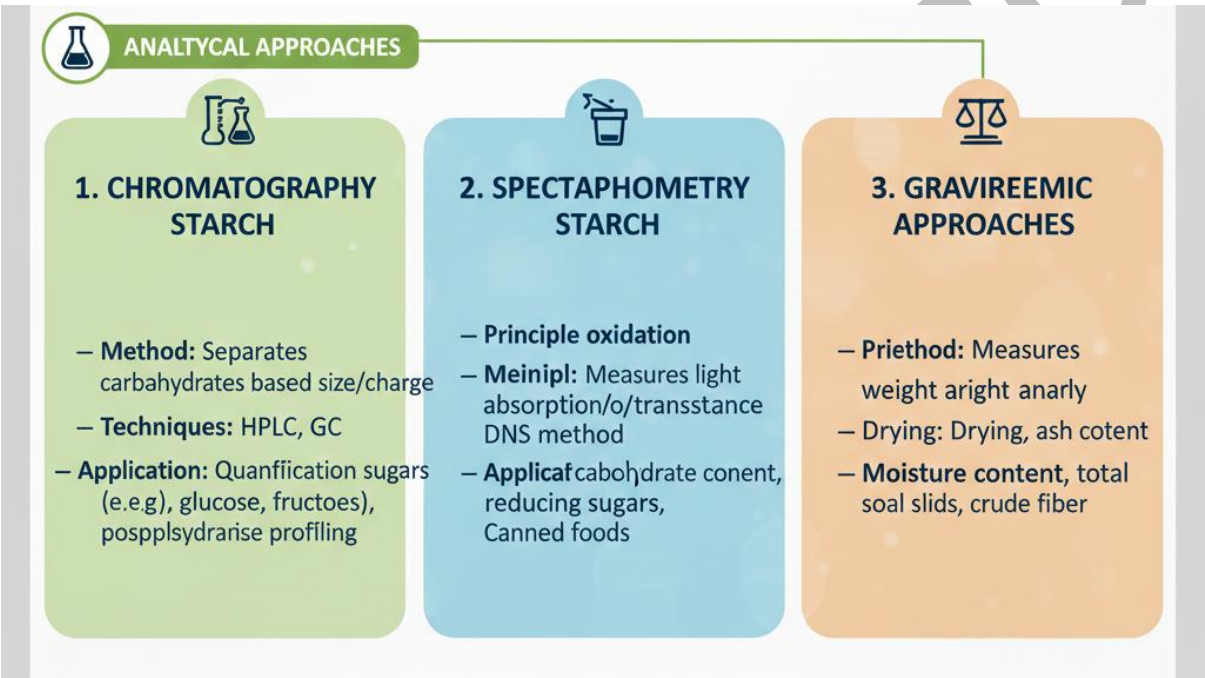


Figure 3.5 Methods of carbohydrate analysis in foods.

Fill in the blank: High-performance liquid chromatography is widely used to quantify _____ in beverages and foods.

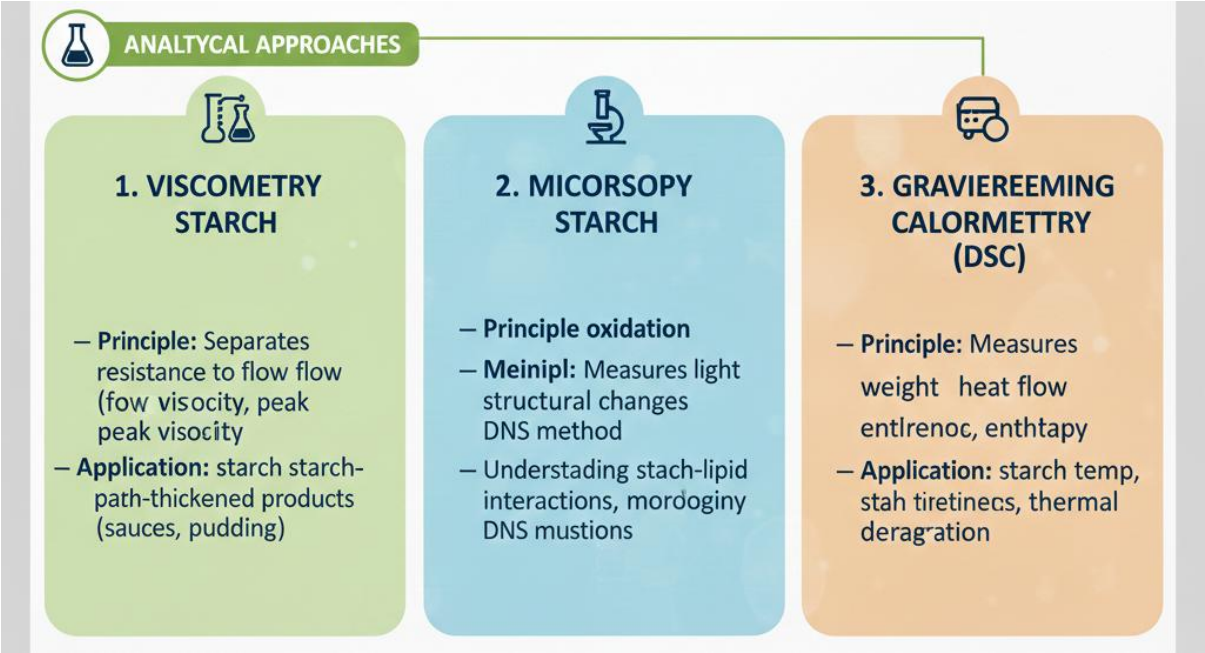
3.4.2 Techniques for studying starch behaviour

Starch behaviour during processing is critical to food texture and stability. One widely used technique is **viscometry**, which measures the viscosity of starch pastes during heating and cooling. This provides information about gelatinisation and retrogradation.

Another technique is **microscopy**, which allows observation of starch granule swelling and rupture. Polarised light microscopy can reveal the loss of birefringence, a key indicator of gelatinisation.

Differential scanning calorimetry (DSC) is also employed to measure the heat flow associated with starch transitions. DSC provides precise data on gelatinisation temperature and enthalpy, which are important for predicting how starch will behave in different food systems.

Table 3.4 Techniques for studying starch behaviour.



Fill in the blank: Loss of birefringence observed under polarised light microscopy is a key indicator of _____.

3.4.3 Analytical approaches for hydrocolloid functionality

Hydrocolloids are analysed to determine their ability to thicken, stabilise, and emulsify food systems. One common method is **rheology**, which measures flow and deformation properties. Rheological tests provide insights into viscosity, elasticity, and gel strength, helping to predict how hydrocolloids will perform in sauces, beverages, and dairy products.

Another approach is **texture analysis**, where instruments measure firmness, cohesiveness, and springiness of hydrocolloid gels. This is particularly useful in bakery and confectionery applications.

Spectroscopic techniques, such as infrared spectroscopy, can also be used to study hydrocolloid interactions with water and other food components. These methods reveal structural changes that influence functionality.

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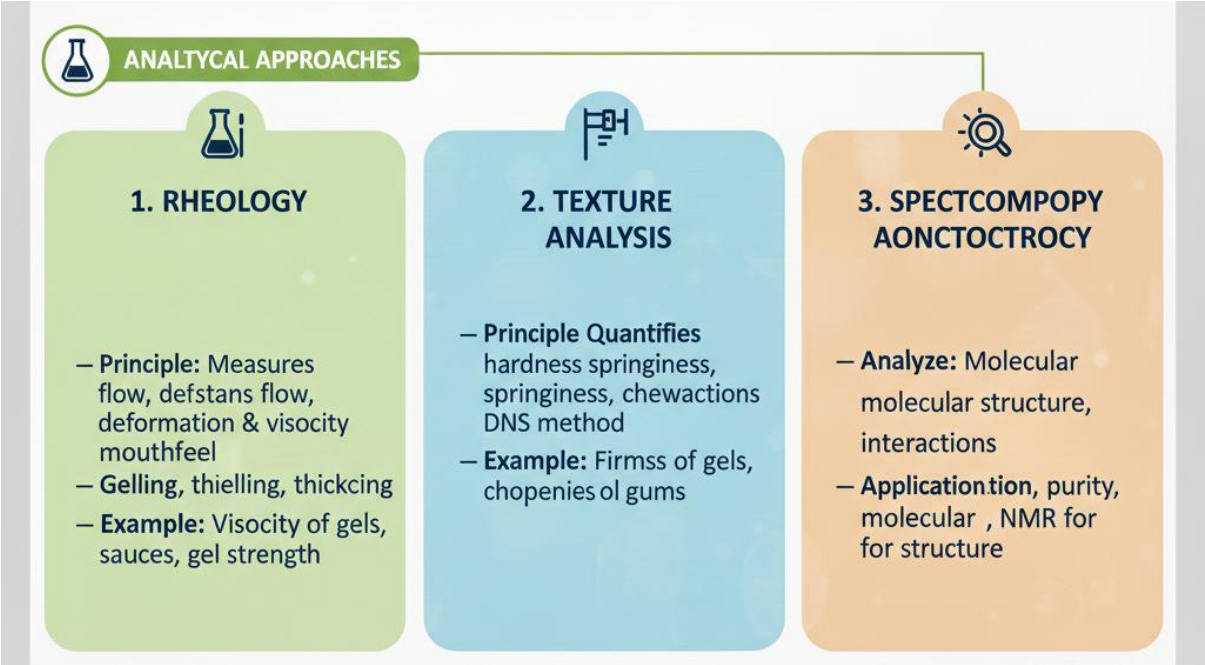
Box 3.3 Analytical approaches for hydrocolloid functionality.



Fill in the blank: Rheology measures the flow and deformation properties of hydrocolloids, including viscosity and _____.

Pilot questions 3.4

1. What are two common methods used to analyse carbohydrates in foods?
2. How does chromatography help in carbohydrate analysis?
3. Which technique measures viscosity changes in starch pastes during heating and cooling?
4. What does polarised light microscopy reveal about starch granules?
5. Name one analytical method used to assess hydrocolloid functionality and explain its purpose.

3.5 Implications for Food Quality and Product Development

Carbohydrates, hydrocolloids, and starches are not only fundamental food components but also powerful tools in shaping product quality and innovation. Their behaviour during processing and storage directly influences flavour, texture, stability, and consumer acceptance. In this Part, we will explore how carbohydrates contribute to flavour and texture development, how hydrocolloids extend shelf life and stability, and how starch modifications support convenience foods and industrial applications.

Fill in the blank: Carbohydrates, hydrocolloids, and starches are powerful tools in shaping product quality and _____.

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3.5.1 Role of carbohydrates in flavour and texture development

Carbohydrates play a central role in flavour and texture. Simple sugars such as glucose and fructose provide sweetness, which enhances palatability and balances acidity or bitterness in foods. Beyond sweetness, carbohydrates contribute to flavour through the **Maillard reaction**, where reducing sugars react with amino acids during heating to produce complex flavours and brown colours. This reaction is responsible for the appealing crust on bread and the roasted notes in coffee.

Carbohydrates also influence texture. Starch, for example, thickens sauces and soups, while cellulose contributes to crispness in vegetables. Dietary fibre, a form of carbohydrate, adds bulk and improves mouthfeel in baked goods. These properties make carbohydrates indispensable in designing foods that are both enjoyable and nutritionally valuable.

Figure 3.6 Role of carbohydrates in flavour and texture development.

Fill in the blank: The Maillard reaction occurs when reducing sugars react with _____ during heating.

3.5.2 Hydrocolloids in shelf-life extension and stability

Hydrocolloids are widely used to improve shelf life and stability in food systems. Their ability to bind water prevents moisture loss, which helps maintain freshness in bakery products and reduces staling. In frozen foods, hydrocolloids inhibit ice crystal growth, ensuring smoother textures in ice cream and frozen desserts.

Hydrocolloids also stabilise emulsions and suspensions, preventing separation in products such as salad dressings, fruit juices, and dairy beverages. By controlling viscosity and forming protective films, they enhance product consistency and consumer satisfaction. Their multifunctional role makes them essential in extending shelf life and maintaining quality across diverse food categories.

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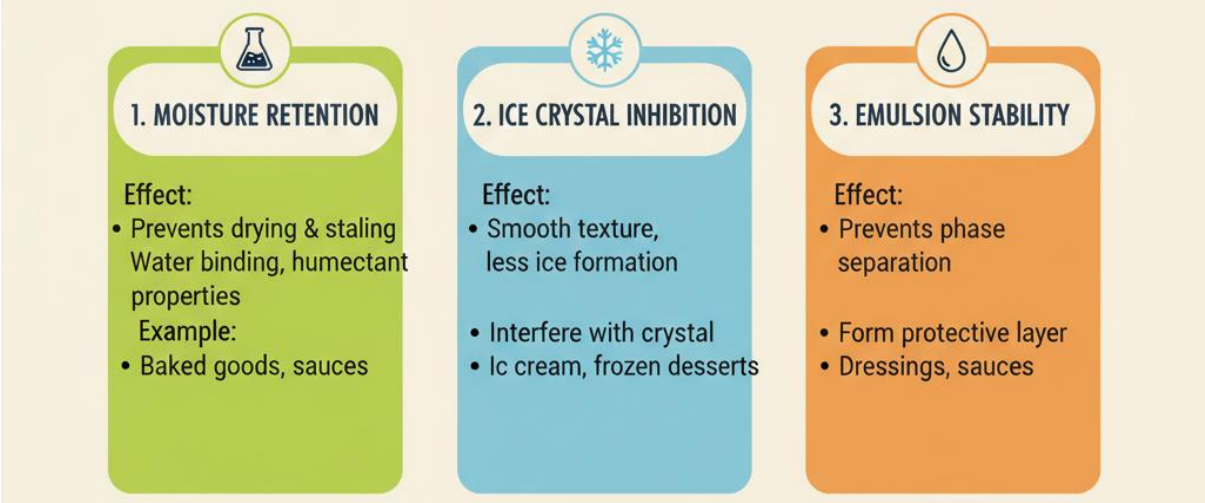
Table 3.5 Hydrocolloids in shelf-life extension and stability.



Fill in the blank: Hydrocolloids inhibit _____ crystal growth in frozen foods, improving texture and stability.

3.5.3 Starch modifications in convenience foods and industrial applications

Modified starches are crucial in modern food processing, particularly in convenience foods and industrial applications. **Pre-gelatinised starch** allows instant thickening in cold water, making it ideal for instant soups and desserts. **Cross-linked starch** provides resistance to heat, acid, and mechanical shear, ensuring stability in canned foods and sauces. **Oxidised starch** improves film-forming properties, which are valuable in confectionery coatings and packaging applications.

These modifications enable starch to meet the demands of large-scale production, where consistency, stability, and ease of preparation are essential. In addition, resistant starch formed during retrogradation offers health benefits, such as improved gut health, making starch modifications relevant not only for industry but also for nutrition.

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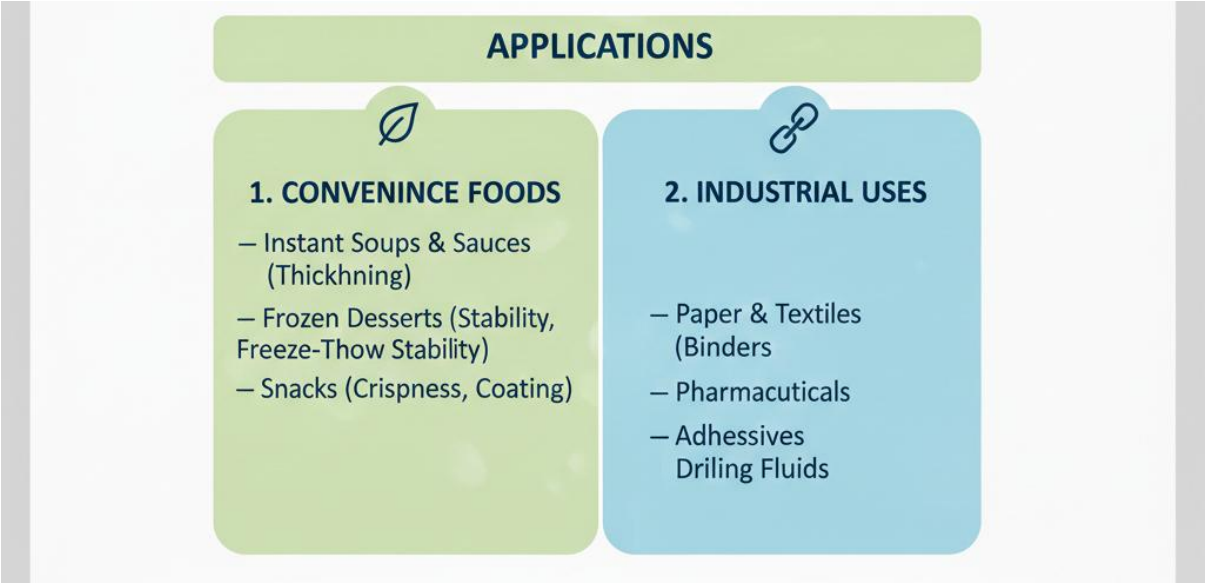
Box 3.4 Applications of modified starches in convenience foods and industry.



Fill in the blank: Pre-gelatinised starch is widely used in instant soups and _____ because it thickens in cold water.

Pilot questions 3.5

1. How do carbohydrates contribute to flavour development in foods?
2. What role does dietary fibre play in food texture?
3. How do hydrocolloids extend shelf life in bakery and frozen products?
4. Give one example of how hydrocolloids stabilise emulsions in food systems.
5. Name one type of modified starch and explain its application in convenience foods.

Series Summary

This Series has highlighted the importance of carbohydrates, hydrocolloids, and starches in food systems, showing how they contribute to nutrition, flavour, texture, and stability. We began by examining carbohydrates, their classification, and their functional roles, before moving on to hydrocolloids, where we considered their properties and wide-ranging applications. Following that, we explored starch in detail, focusing on its structure, the processes of gelatinisation and retrogradation, and the modifications that enhance its performance. We then discussed methods of measurement and analysis, looking at techniques used to study carbohydrates, starch behaviour, and hydrocolloid functionality. Finally, we considered their implications for food quality and product development, emphasising how these components are harnessed to create appealing and innovative products.

By completing this Series, you should now be able to define and describe the major classes of carbohydrates, analyse their interactions with other food components, explain the properties and

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applications of hydrocolloids, and evaluate starch behaviour and modifications. You should also be able to apply analytical methods to measure and assess these components, and critically evaluate their implications for food quality and product innovation. These abilities directly reflect the Series Learning Outcomes (SLOs 3.1 to 3.7), equipping you with practical knowledge and skills to assess, monitor, and utilise carbohydrates, hydrocolloids, and starches effectively in food analysis and product development.

Glossary of Terms

Amylopectin: A highly branched molecule that makes up part of starch, influencing its thickening and gelling properties.

Amylose: A mostly linear molecule found in starch that contributes to gel formation and firmness in foods.

Carbohydrates: Organic compounds made up of sugar units that provide energy, sweetness, bulk, and texture in foods.

Cellulose: A structural carbohydrate found in plant cell walls that contributes to crispness and acts as dietary fibre.

Chromatography: A method used to separate and measure carbohydrates, such as sugars, based on their chemical properties.

Dietary fibre: A type of carbohydrate that is not digested by humans but adds bulk, improves mouthfeel, and supports digestion.

Differential scanning calorimetry (DSC): An analytical technique that measures heat flow to study starch transitions such as gelatinisation.

Gelatinisation: The process where starch granules absorb water and swell when heated, forming a thickened paste.

Gelatin: An animal-derived hydrocolloid obtained from collagen, used for its gelling properties in confectionery and desserts.

Gravimetric methods: Analytical approaches that measure carbohydrate content indirectly by calculating differences in moisture and ash.

Hydrocolloids: Water-loving polymers, often polysaccharides or proteins, that thicken, stabilise, or gel food systems.

Maillard reaction: A chemical reaction between reducing sugars and amino acids during heating that produces brown colours and complex flavours.

Microscopy: A technique used to observe starch granules and their changes, such as swelling and loss of birefringence during gelatinisation.

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Modified starches: Starches that have been chemically or physically altered (e.g., pre-gelatinised, cross-linked, oxidised) to improve stability and functionality.

Oligosaccharides: Carbohydrates containing 3–10 sugar units, some of which act as prebiotics supporting gut health.

Pectin: A plant-derived hydrocolloid used in jams and jellies for its ability to form gels in the presence of sugar and acid.

Polysaccharides: Carbohydrates made up of long chains of sugar units, such as starch, glycogen, and cellulose.

Pre-gelatinised starch: A type of modified starch that has been cooked and dried, allowing it to thicken instantly in cold water.

Retrogradation: The process where gelatinised starch cools and the molecules reassociate, leading to firming or staling in foods.

Rheology: The study of flow and deformation properties of materials, used to assess hydrocolloid performance in foods.

Spectrophotometry: An analytical technique that measures how carbohydrate solutions absorb light, often used to estimate total carbohydrate content.

Starch: A polysaccharide composed of amylose and amylopectin, widely used in foods for thickening, gelling, and stabilising.

Viscometry: A technique that measures changes in viscosity, often used to study starch pastes during heating and cooling.

Xanthan gum: A microbial hydrocolloid produced by fermentation, valued for its ability to stabilise emulsions and maintain viscosity.

Concept Check Questions 3

Objective Questions

1. Which two molecules make up starch? (Linked to SLO 3.4)
2. What type of hydrocolloid is derived from microbial fermentation and commonly used in fruit juices? (Linked to SLO 3.3)
3. Which analytical technique measures heat flow to study starch gelatinisation? (Linked to SLO 3.6)
4. What reaction between reducing sugars and amino acids produces brown colours and flavours in foods? (Linked to SLO 3.1)
5. Which modified starch thickens instantly in cold water? (Linked to SLO 3.5)

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Short-Answer Questions

6. Define carbohydrates and explain their primary nutritional role. (Linked to SLO 3.1)
7. Describe one functional property of hydrocolloids and give a food example. (Linked to SLO 3.3)
8. Explain what happens to starch granules during gelatinisation. (Linked to SLO 3.4)
9. Differentiate between native starch and modified starch in terms of stability and applications. (Linked to SLO 3.5)
10. Identify one method used to analyse hydrocolloid functionality and explain its purpose. (Linked to SLO 3.6)

Long-Answer Questions

11. Analyse how carbohydrates interact with other food components to influence flavour and texture, giving examples. (Linked to SLO 3.2)
12. Demonstrate how analytical techniques such as chromatography, viscometry, and rheology can be applied to study carbohydrates, starch, and hydrocolloids. (Linked to SLO 3.6)
13. Evaluate the implications of carbohydrates, hydrocolloids, and starch modifications for food quality and product development. (Linked to SLO 3.7)

Answers to Concept Check Questions 3

Objective Questions

1. Amylose and amylopectin.
2. Xanthan gum.
3. Differential scanning calorimetry (DSC).
4. The Maillard reaction.
5. Pre-gelatinised starch.

Short-Answer Questions

6. Carbohydrates are organic compounds made up of sugar units. Their primary nutritional role is to provide energy, supplying 4 kcal per gram.
7. Hydrocolloids act as thickeners. For example, starch thickens soups and sauces, improving texture and mouthfeel.
8. During gelatinisation, starch granules absorb water, swell, and lose their crystalline structure, releasing amylose and increasing viscosity.

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9. Native starch is less stable under heat, acid, or shear, while modified starches are altered to improve stability and broaden applications such as instant foods or canned products.

10. Rheology is used to measure flow and deformation properties, providing insights into viscosity and gel strength of hydrocolloids.

Long-Answer Questions

11. *Basic response:* Carbohydrates interact with proteins through the Maillard reaction, producing flavours and brown colours. They also interact with water to thicken foods and with lipids to stabilise emulsions.
Value-added response: Beyond these basics, carbohydrate interactions can be harnessed to design specific textures and flavours. For example, controlled Maillard reactions are used in bakery and coffee roasting, while fibre interactions improve nutritional quality and satiety.

12. *Basic response:* Chromatography separates and quantifies sugars, viscometry measures starch paste viscosity, and rheology assesses hydrocolloid flow and gel strength. Together, these methods provide useful data for food analysis.
Value-added response: Outstanding learners will note that combining these techniques with advanced tools such as mass spectrometry or infrared spectroscopy allows detailed profiling of carbohydrates and hydrocolloids. This supports innovation in functional foods and ensures compliance with nutritional standards.

13. *Basic response:* Carbohydrates provide sweetness and texture, hydrocolloids extend shelf life and stability, and modified starches improve convenience and industrial applications.
Value-added response: In addition, these components are central to meeting consumer demands for healthier, sustainable, and innovative products. Resistant starch contributes to gut health, hydrocolloids reduce fat content while maintaining texture, and carbohydrate interactions are exploited to create appealing flavours in processed foods.

Answers to Pilot Questions [Series 3]

Part 3.1: Carbohydrates in Foods: Types and Functions

1. Monosaccharides, disaccharides, oligosaccharides, and polysaccharides.
2. Glucose (monosaccharide), sucrose (disaccharide), starch (polysaccharide).
3. Sweetness, bulk, and energy source.
4. 4 kilocalories per gram.
5. The Maillard reaction.

Part 3.2: Hydrocolloids: Properties and Applications

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1. Hydrocolloids are water-loving polymers that thicken or gel aqueous solutions. They are classified as plant-derived, seaweed-derived, microbial, or animal-derived.
2. Pectin (plant-derived), agar (seaweed-derived), xanthan gum (microbial), gelatin (animal-derived).
3. Thickening, stabilising, and emulsifying.
4. By binding water and inhibiting ice crystal growth.
5. Guar gum or carboxymethyl cellulose (CMC) used to improve softness and delay staling in bread.

Part 3.3: Starch: Gelatinisation, Retrogradation, and Modifications

1. Amylose and amylopectin.
2. A higher amylose content leads to firmer gels, while higher amylopectin content results in softer, more viscous pastes.
3. They absorb water, swell, lose their crystalline structure, and release amylose, increasing viscosity.
4. Retrogradation.
5. Pre-gelatinised starch used in instant puddings and soups.

Part 3.4: Measurement and Analysis of Carbohydrates and Hydrocolloids

1. Chromatography and spectrophotometry.
2. It separates carbohydrate molecules based on their chemical properties, allowing quantification of specific sugars.
3. Viscometry.
4. It reveals the loss of birefringence, indicating gelatinisation.
5. Rheology, which measures viscosity, elasticity, and gel strength to assess hydrocolloid performance.

Part 3.5: Implications for Food Quality and Product Development

1. By providing sweetness and through the Maillard reaction, which produces complex flavours and brown colours.
2. It adds bulk, improves mouthfeel, and supports digestion.
3. By binding water to retain moisture, preventing staling, and inhibiting ice crystal growth in frozen products.
4. Hydrocolloids stabilise emulsions in products such as salad dressings and fruit juices.

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5. Pre-gelatinised starch, which is used in instant soups and desserts because it thickens in cold water.

References and Attributions [Series 3]

This section compiles all references and attributions for Series 3: *Carbohydrates, Hydrocolloids, and Starch Modifications*. It includes general references, suggested open educational resources (OERs), and notes on AI-generated illustration prompts. The referencing style applied here follows APA guidelines for clarity and consistency.

General References

- Belitz, H. D., Grosch, W., & Schieberle, P. (2009). *Food Chemistry* (4th ed.). Springer.
- Fellows, P. (2017). *Food Processing Technology: Principles and Practice* (4th ed.). Woodhead Publishing.
- Potter, N. N., & Hotchkiss, J. H. (2012). *Food Science* (5th ed.). Springer.

Illustration References and Attributions

- *Figure 3.1 Classification of carbohydrates in foods.* Suggested OER source: "classification of carbohydrates food science diagram OER." AI prompt: "Generate a diagram showing classification of carbohydrates: monosaccharides, disaccharides, oligosaccharides, polysaccharides with examples."
- *Table 3.1 Functional roles of carbohydrates in foods.* Suggested OER source: "functional roles carbohydrates food science table OER." AI prompt: "Create a table showing functional roles of carbohydrates: sweetness, bulk, energy source with food examples."
- *Box 3.1 Carbohydrate interactions in food systems.* Suggested OER source: "carbohydrate interactions food science OER." AI prompt: "Create a box listing carbohydrate interactions with proteins (Maillard reaction), water (gelatinisation), and lipids (emulsification)."
- *Figure 3.2 Classification of hydrocolloids in foods.* Suggested OER source: "classification of hydrocolloids food science diagram OER." AI prompt: "Generate a diagram showing classification of hydrocolloids: plant (starch, pectin), seaweed (agar, carrageenan), microbial (xanthan gum), animal (gelatin)."
- *Table 3.2 Functional properties of hydrocolloids in foods.* Suggested OER source: "functional properties hydrocolloids food science table OER." AI prompt: "Create a table showing functional properties of hydrocolloids: thickening, stabilising, emulsifying with examples."
- *Box 3.2 Applications of hydrocolloids in food systems.* Suggested OER source: "applications of hydrocolloids food science OER."

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AI prompt: “Create a box listing applications of hydrocolloids in beverages, sauces, bakery, and dairy products.”

- *Figure 3.3 Structure of native starch granules.* Suggested OER source: “structure of starch granules amylose amylopectin diagram OER.” AI prompt: “Generate a diagram showing starch granule structure with amylose and amylopectin chains.”
- *Figure 3.4 Gelatinisation and retrogradation of starch.* Suggested OER source: “starch gelatinisation retrogradation food science diagram OER.” AI prompt: “Generate a diagram showing starch gelatinisation (swelling and leaching) and retrogradation (reassociation of chains).”
- *Table 3.3 Types of modified starches and their applications.* Suggested OER source: “types of modified starches food science table OER.” AI prompt: “Create a table showing types of modified starches (pre-gelatinised, cross-linked, oxidised) and their applications.”
- *Figure 3.5 Methods of carbohydrate analysis in foods.* Suggested OER source: “methods of carbohydrate analysis food science diagram OER.” AI prompt: “Generate a diagram showing carbohydrate analysis methods: chromatography, spectrophotometry, and gravimetric approaches.”
- *Table 3.4 Techniques for studying starch behaviour.* Suggested OER source: “techniques starch behaviour analysis food science table OER.” AI prompt: “Create a table comparing viscometry, microscopy, and DSC techniques for studying starch behaviour.”
- *Box 3.3 Analytical approaches for hydrocolloid functionality.* Suggested OER source: “hydrocolloid functionality analysis food science OER.” AI prompt: “Create a box listing analytical approaches for hydrocolloid functionality: rheology, texture analysis, spectroscopy.”
- *Figure 3.6 Role of carbohydrates in flavour and texture development.* Suggested OER source: “carbohydrates flavour texture food science diagram OER.” AI prompt: “Generate a diagram showing carbohydrate roles in flavour (sweetness, Maillard reaction) and texture (thickening, crispness).”
- *Table 3.5 Hydrocolloids in shelf-life extension and stability.* Suggested OER source: “hydrocolloids shelf life stability food science table OER.” AI prompt: “Create a table showing hydrocolloid roles in shelf-life extension: moisture retention, ice crystal inhibition, emulsion stability.”
- *Box 3.4 Applications of modified starches in convenience foods and industry.* Suggested OER source: “applications modified starches convenience foods industry OER.” AI prompt: “Create a box listing applications of modified starches in convenience foods and industrial uses.”

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Course code: FST304

Course title: Principles of Food Analysis

Course credit load: 3 units

List of Series:

16. **Physical and Chemical Transformations in Foods**
17. **Lipids and Proteins: Properties, Reactions, and Applications**
18. **Carbohydrates, Hydrocolloids, and Starch Modifications**
19. **Enzyme Systems and Browning Reactions in Food Quality**
20. **Vitamins, Natural Pigments, Flavours, and Additives in Foods**

4.1 Enzyme systems in foods: types and functions

- 4.1.1 Definition and classification of enzymes
- 4.1.2 Enzyme activity and specificity in food systems
- 4.1.3 Beneficial roles of enzymes in food processing (e.g., fermentation, tenderisation, flavour development)

4.2 Enzymatic browning reactions

- 4.2.1 Mechanism of enzymatic browning (polyphenol oxidase activity)
- 4.2.2 Factors influencing enzymatic browning (pH, temperature, oxygen, inhibitors)
- 4.2.3 Control and prevention strategies in food processing

4.3 Non-enzymatic browning reactions

- 4.3.1 Maillard reaction: stages and flavour development
- 4.3.2 Caramelisation: process and applications
- 4.3.3 Implications of non-enzymatic browning for nutrition and safety

4.4 Measurement and analysis of enzyme activity and browning

- 4.4.1 Methods for measuring enzyme activity (spectrophotometry, titration, enzyme assays)
- 4.4.2 Techniques for assessing browning intensity (colourimetry, sensory evaluation)
- 4.4.3 Analytical approaches for monitoring quality changes during storage and processing

4.5 Implications for food quality and product development

- 4.5.1 Positive contributions of enzymes and browning to flavour, colour, and texture

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- 4.5.2 Negative impacts on shelf life, safety, and consumer acceptance
- 4.5.3 Applications in product innovation and industrial food processing

Introduction

When you slice an apple and leave it exposed to air, it quickly turns brown, while bread develops a golden crust during baking. These everyday changes are not random but are driven by enzyme activity and browning reactions that shape the colour, flavour, and texture of foods. Understanding these processes is vital in food science, as they can enhance product appeal or, if uncontrolled, reduce quality and consumer acceptance. This Series will help you explore how enzyme systems and browning reactions influence food quality and how they can be managed in food processing.

The aim of this Series is to equip you with the knowledge and skills to describe enzyme systems in foods, explain enzymatic and non-enzymatic browning reactions, apply methods for measuring enzyme activity and browning intensity, and evaluate their implications for food quality and product development.

We shall commence this Series by examining enzyme systems in foods, focusing on their types, functions, and beneficial roles in processing. Next, we will explore enzymatic browning reactions, considering their mechanisms, influencing factors, and control strategies. Following that, we will study non-enzymatic browning, including the Maillard reaction and caramelisation, and their nutritional and sensory implications. Afterwards, we will continue with measurement and analysis, highlighting techniques used to assess enzyme activity and browning intensity. Finally, we will wrap up by discussing the broader implications for food quality and product development, showing how these reactions can be harnessed or controlled to create safe, appealing, and innovative food products.

Series Learning Outcomes

Upon completing this Series, you should be able to:

SLO 4.1 define enzyme systems in foods and describe their functional roles in processing,

SLO 4.2 explain the mechanism of enzymatic browning and analyse the factors that influence its occurrence,

SLO 4.3 demonstrate strategies for controlling and preventing enzymatic browning in food systems,

SLO 4.4 describe the stages of the Maillard reaction and evaluate its contribution to flavour and colour development,

SLO 4.5 explain the process of caramelisation and apply examples of its use in food products,

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SLO 4.6 apply appropriate analytical methods to measure enzyme activity and assess browning intensity in foods,

SLO 4.7 evaluate the implications of enzyme systems and browning reactions for food quality, shelf life, and product development.

4.1.1 Definition and classification of enzymes

Enzymes are proteins that act as catalysts, lowering the activation energy required for chemical reactions. They are highly specific, meaning each enzyme acts on a particular substrate. Enzymes in foods are classified based on the type of reaction they catalyse.

The major classes include:

- **Oxidoreductases**, which catalyse oxidation-reduction reactions.
- **Hydrolases**, which break down molecules using water, such as amylases breaking down starch.
- **Transferases**, which transfer functional groups between molecules.
- **Isomerases**, which rearrange molecules into different forms.

In food systems, enzymes may originate naturally from raw materials (such as fruits and cereals) or be added during processing to achieve desired effects.

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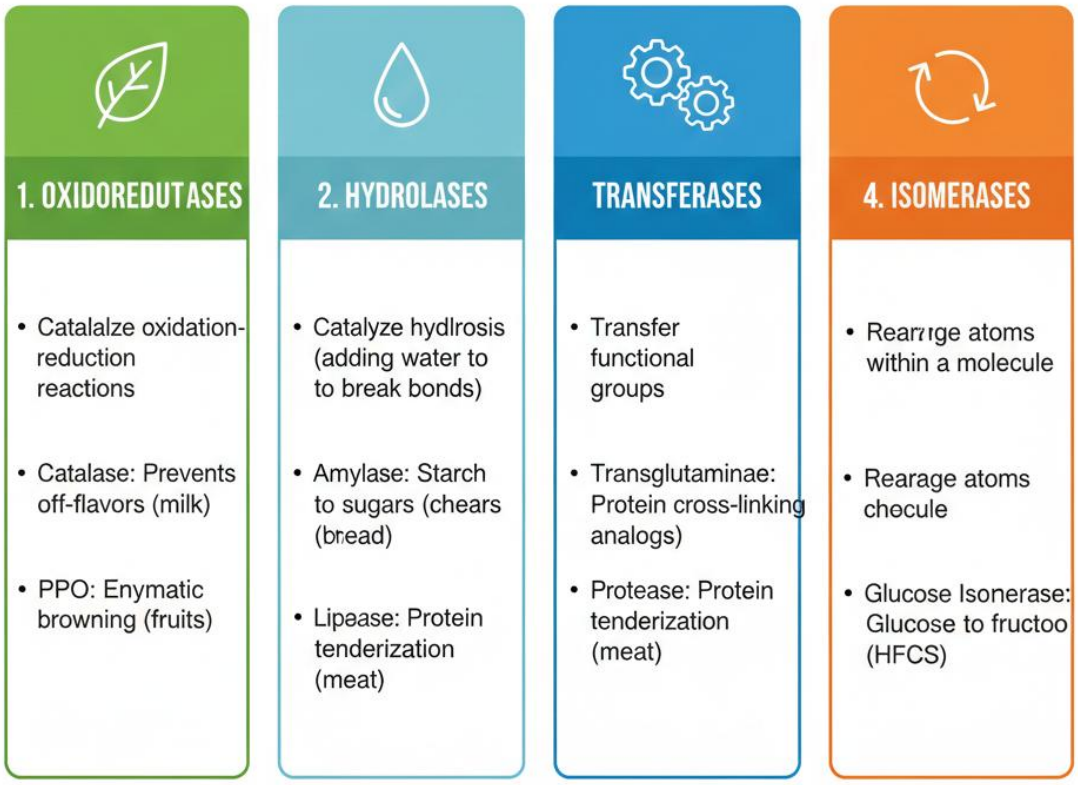

Figure 4.1 Classification of enzymes in foods.

Fill in the blank: Amylases are enzymes that break down _____ into simpler sugars.

4.1.2 Enzyme activity and specificity in food systems

Enzyme activity refers to the rate at which an enzyme catalyses a reaction, influenced by factors such as temperature, pH, and substrate concentration. Enzymes are sensitive to environmental conditions, which can either enhance or inhibit their function. For example, most enzymes in foods are active at moderate temperatures but may denature at high heat.

Specificity is the property that allows enzymes to act only on particular substrates. For instance, lactase specifically breaks down lactose into glucose and galactose, while proteases act on proteins. This specificity ensures that enzymes perform targeted roles in food systems, making them predictable and controllable in processing.

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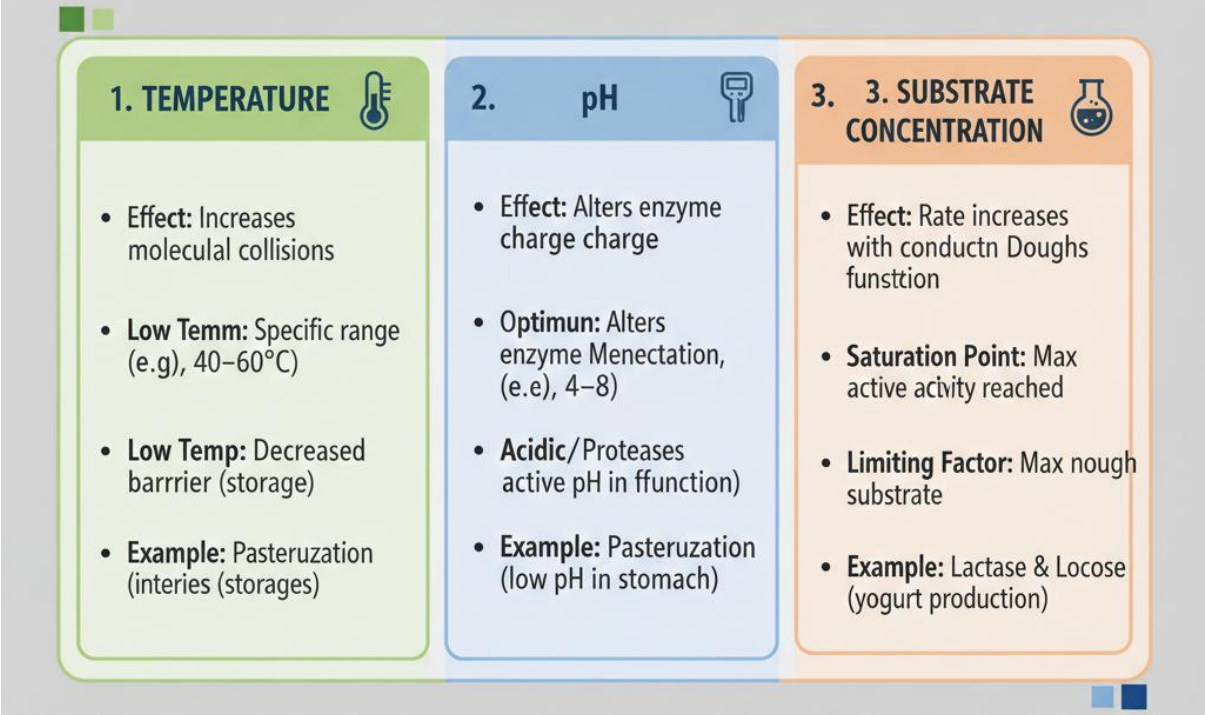
Table 4.1 Factors influencing enzyme activity in foods.



Fill in the blank: Lactase specifically breaks down the sugar _____ into glucose and galactose.

4.1.3 Beneficial roles of enzymes in food processing

Enzymes are widely used in food processing to improve quality and efficiency. In **fermentation**, enzymes such as amylases and proteases break down starches and proteins, providing substrates for microorganisms that produce bread, beer, and yoghurt. In **tenderisation**, proteases such as papain and bromelain soften meat by breaking down muscle proteins.

Enzymes also contribute to **flavour development**. Lipases release fatty acids that enhance cheese flavour, while proteases generate peptides that improve savoury notes. In fruit juice production, pectinases break down pectin, increasing yield and clarity. These applications demonstrate how enzymes are harnessed to create desirable textures, flavours, and appearances in foods.

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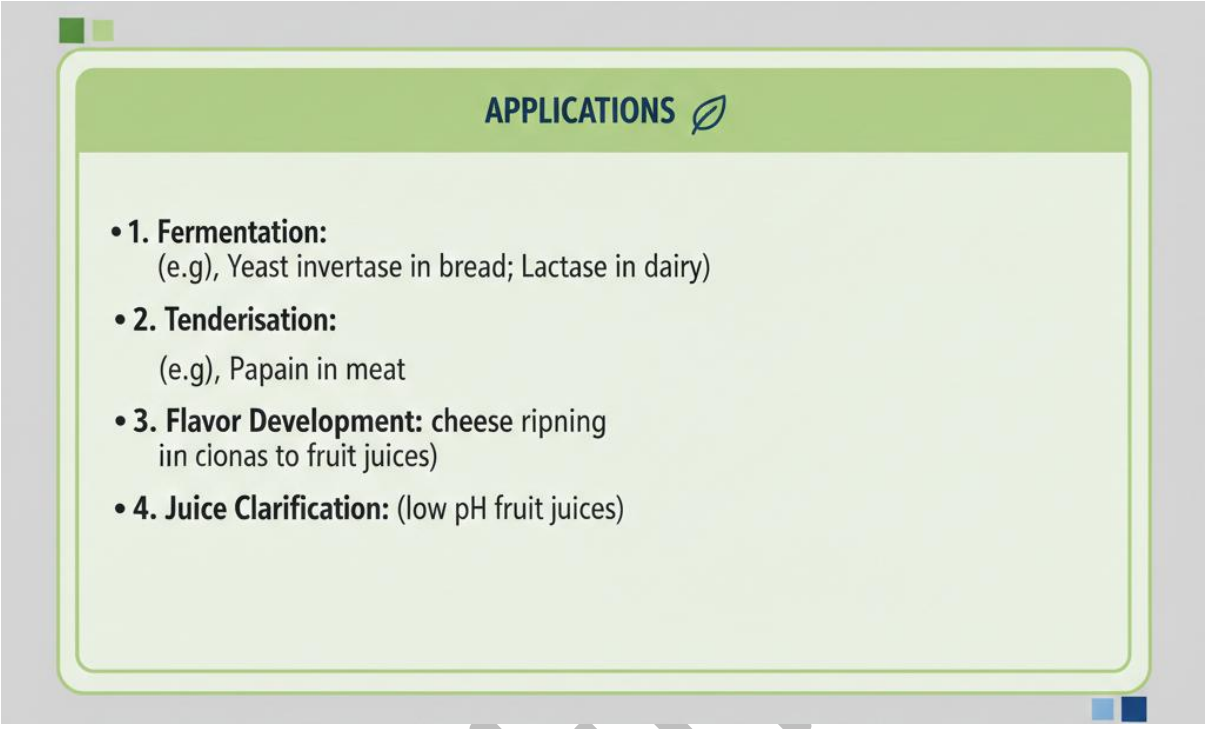
Box 4.1 Examples of beneficial enzyme applications in food processing.



Fill in the blank: Proteases such as papain and bromelain are used in meat _____ to soften muscle proteins.

Pilot questions 4.1

1. What are enzymes and why are they important in food systems?
2. Name the four major classes of enzymes relevant to food science.
3. What factors influence enzyme activity in foods?
4. Give one example of enzyme specificity in food systems.
5. Mention two beneficial roles of enzymes in food processing.

4.2 Enzymatic Browning Reactions

Enzymatic browning is a common phenomenon in foods, often observed when fruits such as apples, bananas, or pears are cut and exposed to air. While it can sometimes add desirable colour and flavour, it is more often considered undesirable because it reduces visual appeal and consumer acceptance. In this Part, we will explore the mechanism of enzymatic browning, the factors that influence its occurrence, and the strategies used to control or prevent it in food systems.

Fill in the blank: Enzymatic browning is commonly observed when fruits such as apples or _____ are cut and exposed to air.

4.2.1 Mechanism of enzymatic browning (polyphenol oxidase activity)

The key enzyme responsible for enzymatic browning is **polyphenol oxidase (PPO)**, also known as tyrosinase. **Polyphenol oxidase** is an enzyme that catalyses the oxidation of phenolic compounds present in plant tissues into quinones. These quinones then polymerise to form brown pigments called melanins.

The process begins when plant tissue is damaged, allowing oxygen to come into contact with phenolic substrates and PPO. This reaction is rapid and visible, leading to the browning of cut or bruised fruits and vegetables. While enzymatic browning can negatively affect appearance, it may also contribute to flavour development in products such as tea and dried fruits.

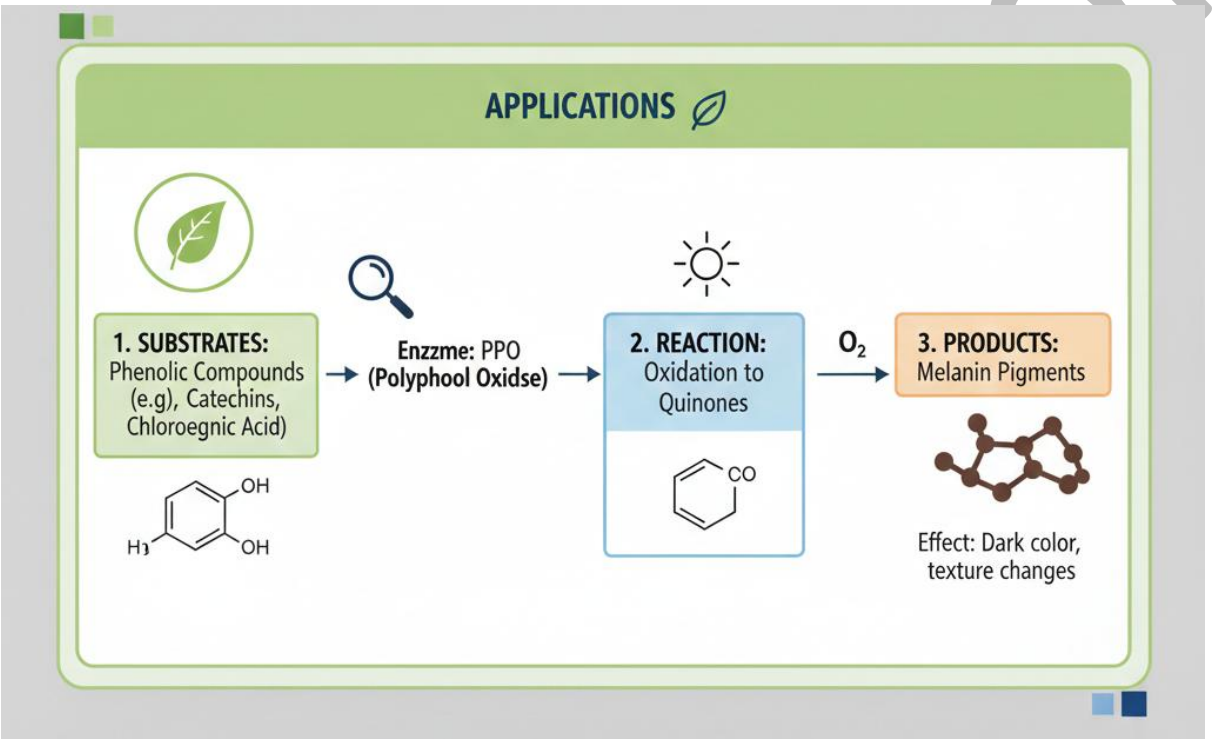


Figure 4.2 Mechanism of enzymatic browning in plant tissues.

Fill in the blank: The enzyme responsible for enzymatic browning in fruits is called _____.

4.2.2 Factors influencing enzymatic browning (pH, temperature, oxygen, inhibitors)

Several factors influence the rate and extent of enzymatic browning.

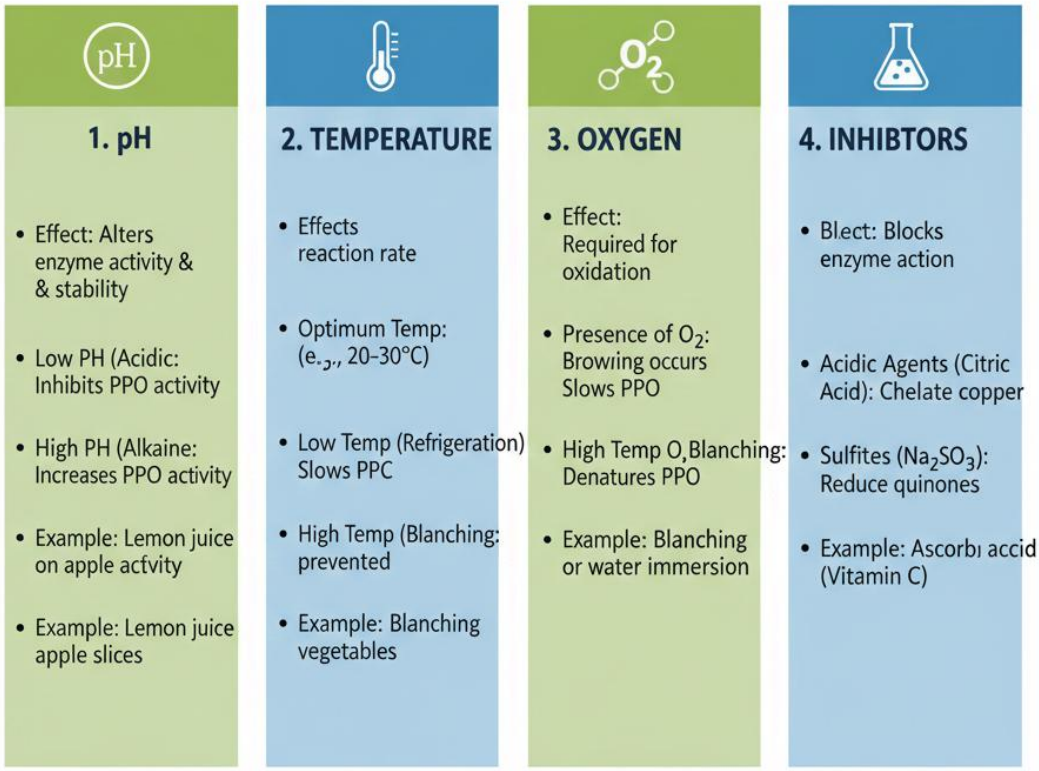
pH plays a critical role, as PPO activity is optimal at neutral to slightly acidic conditions. Lowering the pH with acids such as lemon juice reduces browning.

Temperature affects enzyme activity, with moderate temperatures promoting browning and high heat inactivating PPO. This is why blanching is often used to prevent browning in vegetables before freezing.

Oxygen availability is essential for PPO activity. Limiting oxygen exposure, for example by vacuum packaging, slows down browning.

Inhibitors such as sulphites, ascorbic acid, or citric acid can reduce browning by either inactivating PPO or reacting with quinones before they form pigments.

Table 4.2 Factors influencing enzymatic browning.



Fill in the blank: Blanching prevents enzymatic browning by inactivating the enzyme _____.

4.2.3 Control and prevention strategies in food processing

Food technologists employ several strategies to control enzymatic browning. **Blanching**, which involves briefly heating food, inactivates PPO and slows down browning. **Acidification**, such as adding lemon juice, lowers pH and reduces enzyme activity. **Use of antioxidants**, including ascorbic acid, prevents quinone formation by reducing them back to phenolic compounds.

Another strategy is **oxygen exclusion**, achieved through modified atmosphere packaging or vacuum sealing, which limits the oxygen needed for PPO activity. Chemical inhibitors such as sulphites are also effective, though their use is restricted in some products due to health concerns.

These strategies are chosen based on the type of food, desired shelf life, and consumer safety considerations.

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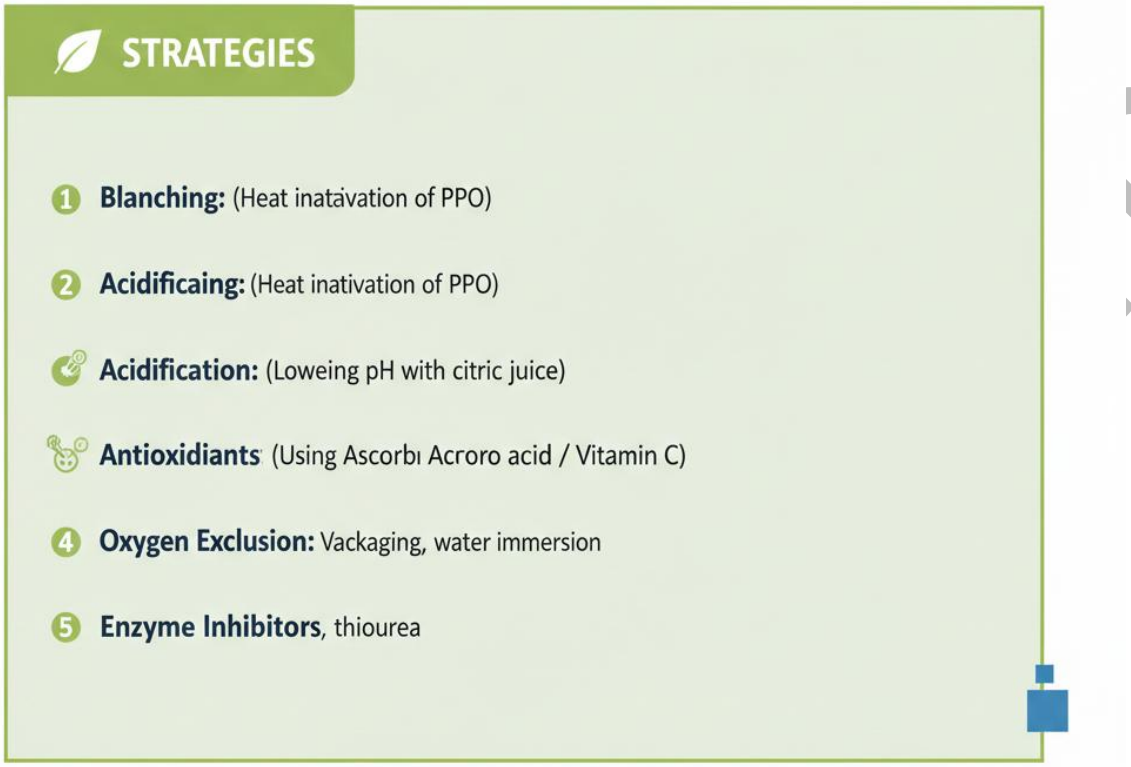
Box 4.2 Strategies for controlling enzymatic browning in foods.



Fill in the blank: Adding lemon juice to cut fruits reduces enzymatic browning by lowering the _____.

Pilot questions 4.2

1. What enzyme is primarily responsible for enzymatic browning in fruits and vegetables?
2. What pigments are formed during enzymatic browning?
3. How does pH influence PPO activity?
4. Why is blanching used to prevent browning in vegetables?
5. Mention two strategies used to control enzymatic browning in food processing.

4.3 Non-Enzymatic Browning Reactions

Non-enzymatic browning refers to chemical reactions that produce brown colours in foods without the involvement of enzymes. These reactions are important in food processing because they contribute to flavour, aroma, and colour development, but they can also reduce nutritional value or create undesirable compounds if not properly controlled. In this Part, we will explore the Maillard reaction, caramelisation, and the broader implications of non-enzymatic browning for nutrition and safety.

Fill in the blank: Non-enzymatic browning produces brown colours in foods without the involvement of _____.

4.3.1 Maillard reaction: stages and flavour development

The **Maillard reaction** is a chemical reaction between reducing sugars and amino acids that occurs during heating. It is responsible for the browning of baked bread, roasted coffee, and grilled meat. The reaction proceeds in several stages: initially, reducing sugars react with amino acids to form glycosylamines, which then undergo rearrangements and further reactions to produce a wide range of flavour and colour compounds.

The Maillard reaction is highly valued in food processing because it generates complex flavours and appealing aromas. However, it must be carefully controlled, as excessive browning can lead to bitterness or the formation of potentially harmful compounds such as acrylamide.

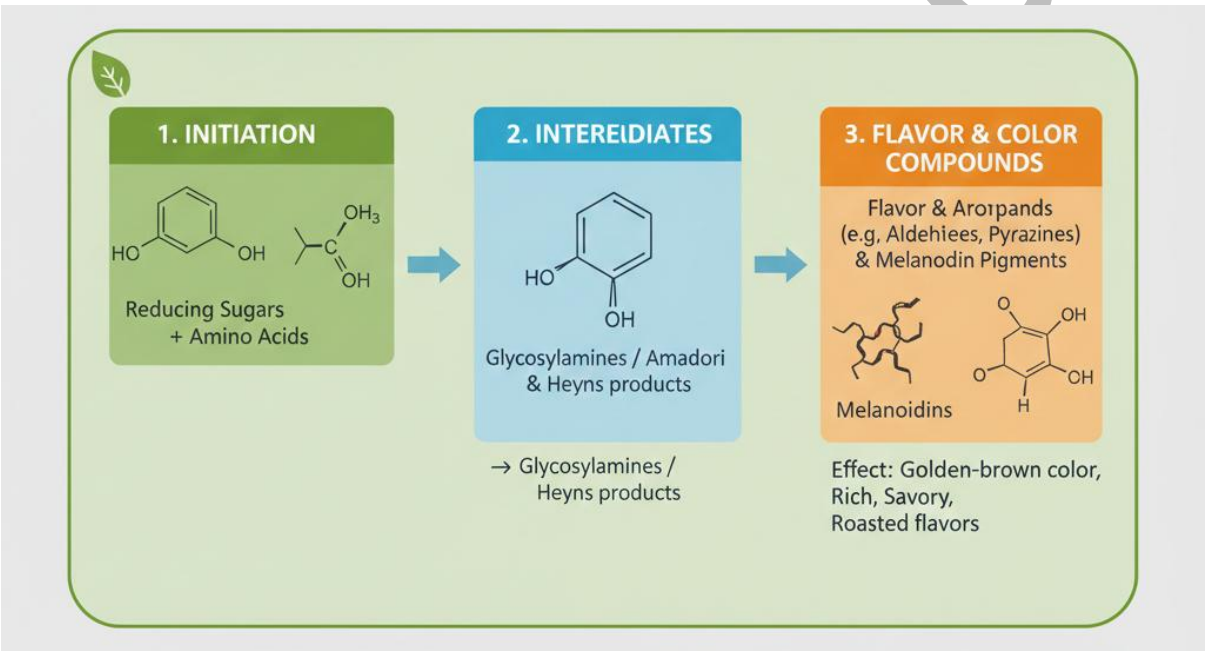


Figure 4.3 Stages of the Maillard reaction in foods.

Fill in the blank: The Maillard reaction occurs between reducing sugars and _____ during heating.

4.3.2 Caramelisation: process and applications

Caramelisation is the thermal decomposition of sugars when heated to high temperatures, typically above 150°C. Unlike the Maillard reaction, caramelisation does not involve amino acids. Instead, sugars break down into smaller molecules, producing brown colours and characteristic flavours.

Caramelisation is widely used in food products such as caramel sweets, toffee, and sauces. It contributes to the golden colour of baked goods and the rich flavour of caramelised onions. The

process is influenced by temperature and sugar type, with sucrose being the most common sugar used.

Plate 4.1 Caramelisation of sugar during heating.

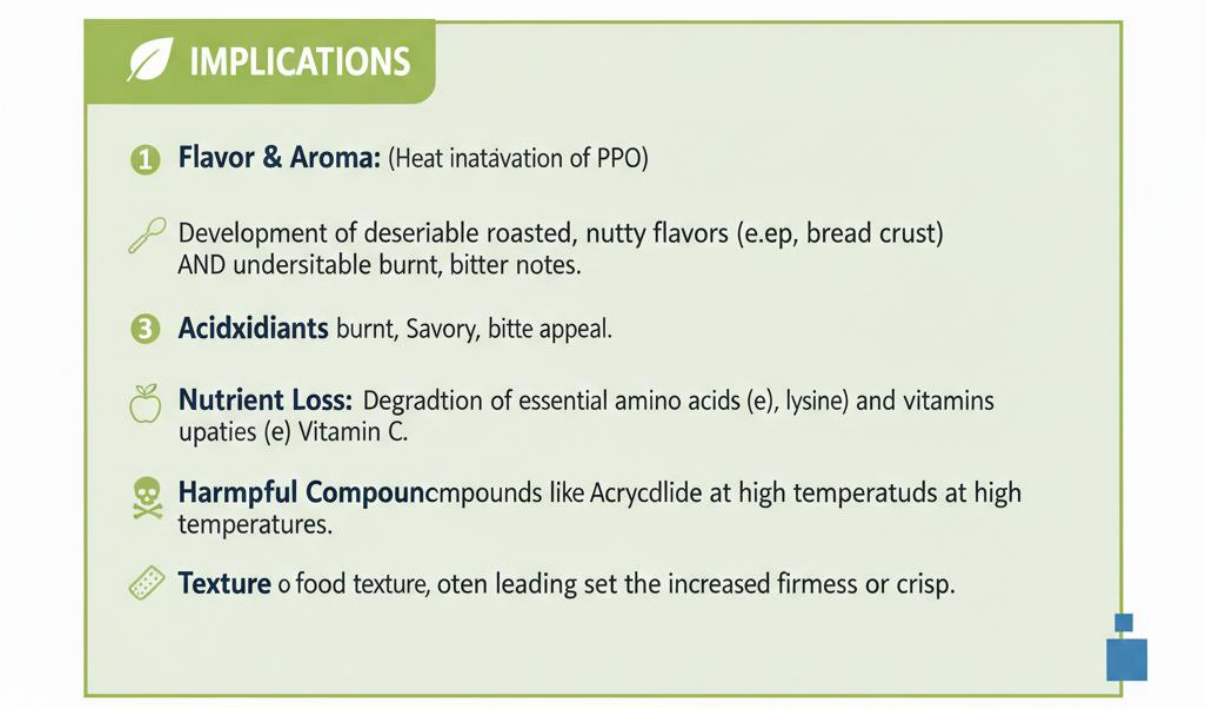
Fill in the blank: Caramelisation is the thermal decomposition of _____ when heated to high temperatures.

4.3.3 Implications of non-enzymatic browning for nutrition and safety

Non-enzymatic browning has both positive and negative implications. On the positive side, it enhances flavour, aroma, and colour, making foods more appealing to consumers. It is essential in products such as bread, coffee, chocolate, and roasted nuts.

On the negative side, non-enzymatic browning can reduce the nutritional value of foods by destroying essential amino acids, particularly lysine. Additionally, some by-products of the Maillard reaction, such as acrylamide, have raised safety concerns due to their potential health risks. Food technologists must therefore balance the desirable sensory qualities with the need to minimise harmful compounds.

Box 4.3 Implications of non-enzymatic browning in food systems.



Fill in the blank: The Maillard reaction can reduce nutritional value by destroying essential amino acids such as _____.

Pilot questions 4.3

1. What is the Maillard reaction and why is it important in food processing?
2. Which two types of molecules react in the Maillard reaction?
3. What is caramelisation and how does it differ from the Maillard reaction?
4. Give two examples of foods where caramelisation is desirable.
5. Mention one positive and one negative implication of non-enzymatic browning in foods.

4.4 Measurement and Analysis of Enzyme Activity and Browning

Accurate measurement and analysis of enzyme activity and browning reactions are essential in food science. These assessments help food technologists monitor quality changes, ensure safety, and design products with desirable sensory attributes. In this Part, we will explore methods for measuring enzyme activity, techniques for assessing browning intensity, and analytical approaches for monitoring quality changes during storage and processing.

Fill in the blank: Measurement and analysis of enzyme activity and browning are essential for monitoring food _____.

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4.4.1 Methods for measuring enzyme activity (spectrophotometry, titration, enzyme assays)

Enzyme activity refers to the rate at which an enzyme catalyses a reaction. It can be measured using several techniques.

Spectrophotometry is widely used to monitor enzyme activity by measuring changes in absorbance of light. For example, polyphenol oxidase activity can be tracked by observing the increase in absorbance as phenolic compounds are oxidised.

Titration methods involve measuring the consumption or release of specific reactants or products. For instance, lipase activity can be determined by titrating the fatty acids released during hydrolysis.

Enzyme assays are specific tests designed to quantify enzyme activity under controlled conditions. These assays often use substrates that produce measurable colour changes or other detectable signals when acted upon by enzymes.

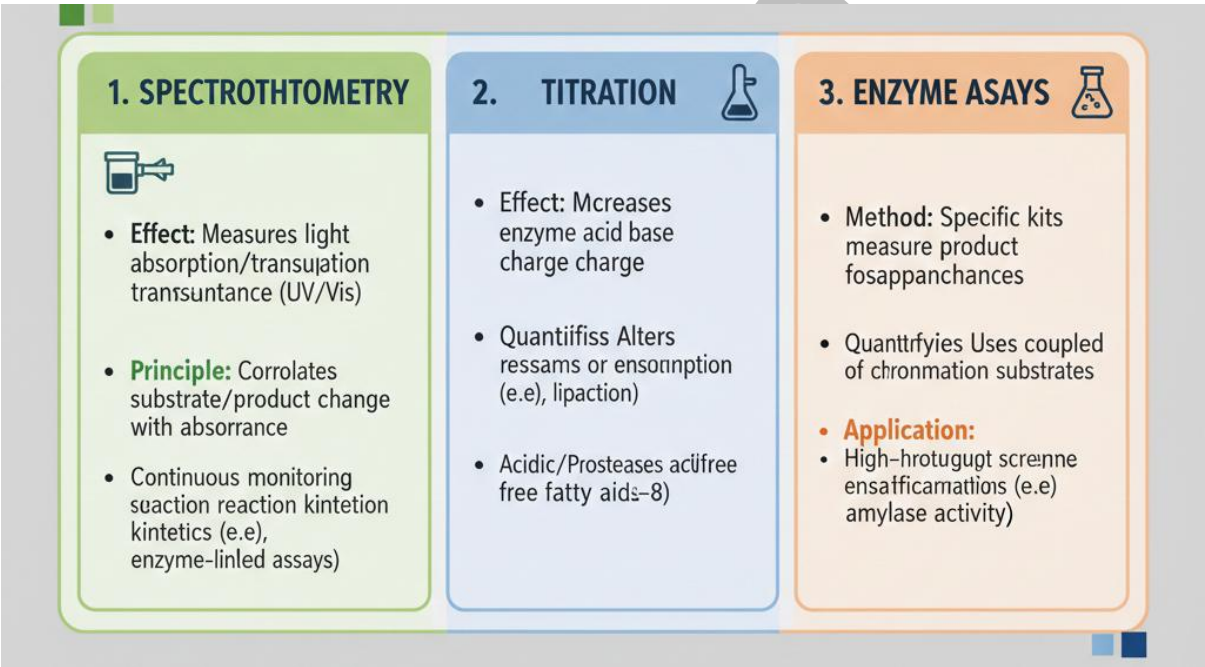


Figure 4.4 Methods for measuring enzyme activity in foods.

Fill in the blank: Spectrophotometry measures enzyme activity by monitoring changes in light _____.

4.4.2 Techniques for assessing browning intensity (colourimetry, sensory evaluation)

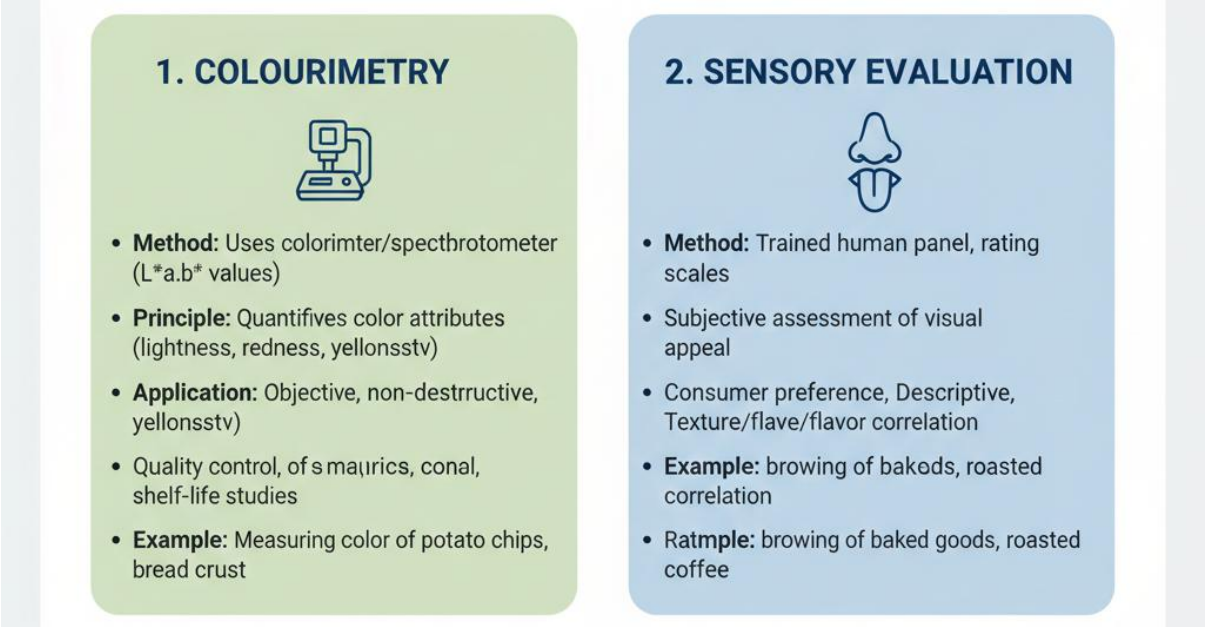
Browning intensity in foods can be assessed using both instrumental and sensory methods.

Colourimetry is an instrumental technique that measures the colour of food samples using a colourimeter or spectrophotometer. It provides objective data on lightness, redness, and yellowness, which can be used to quantify browning.

Sensory evaluation involves trained panels or consumers assessing the appearance, flavour, and acceptability of browned foods. While subjective, sensory evaluation is critical because consumer perception ultimately determines product success.

These techniques are often used together, with colourimetry providing quantitative data and sensory evaluation offering qualitative insights.

Table 4.4 Techniques for assessing browning intensity.



Fill in the blank: Colourimetry provides objective data on food colour, while _____ evaluation reflects consumer perception.

4.4.3 Analytical approaches for monitoring quality changes during storage and processing

Monitoring quality changes during storage and processing is vital to ensure food safety and consumer satisfaction.

Rheological analysis can be used to study changes in viscosity and texture caused by enzymatic or browning reactions. For example, starch retrogradation during storage can be tracked using rheology.

Spectroscopic techniques, such as infrared spectroscopy, provide information on structural changes in carbohydrates and proteins during browning. These methods help identify chemical compounds formed in Maillard reactions.

Shelf-life studies combine analytical measurements with sensory evaluation to determine how enzyme activity and browning affect product stability over time. This holistic approach ensures that foods remain safe, appealing, and nutritionally valuable throughout their intended storage period.

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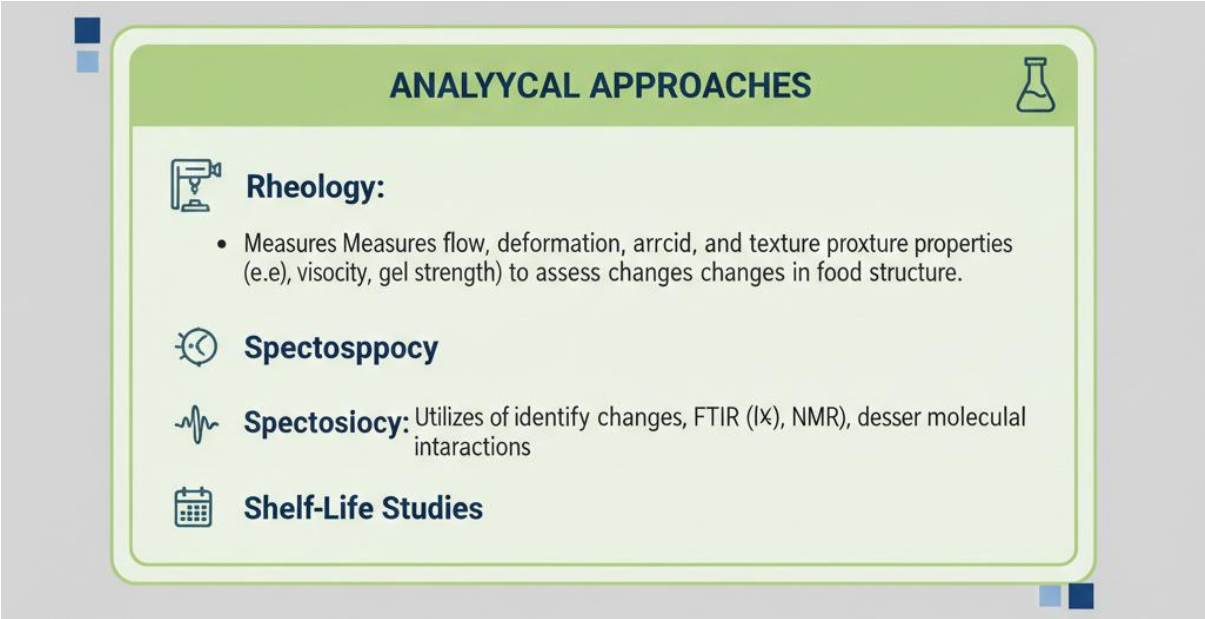
Box 4.4 Analytical approaches for monitoring quality changes in foods.



Fill in the blank: Infrared spectroscopy can be used to study structural changes during the _____ reaction.

Pilot questions 4.4

1. What are three common methods used to measure enzyme activity in foods?
2. How does spectrophotometry help in monitoring enzyme activity?
3. What are two techniques used to assess browning intensity?
4. Why is sensory evaluation important in assessing browning?
5. Mention one analytical approach used to monitor quality changes during storage and explain its purpose.

4.5 Implications for Food Quality and Product Development

Enzyme systems and browning reactions are not merely chemical processes; they are central to the sensory qualities, shelf life, and consumer acceptance of foods. Their effects can be positive, enhancing flavour, colour, and texture, or negative, leading to nutrient loss, off-flavours, and reduced marketability. In this Part, we will examine the positive contributions of enzymes and browning, the negative impacts on food quality, and their applications in product innovation and industrial food processing.

Fill in the blank: Enzyme systems and browning reactions can have both positive and _____ effects on food quality.

4.5.1 Positive contributions of enzymes and browning to flavour, colour, and texture

Enzymes and browning reactions often enhance the sensory appeal of foods. The **Maillard reaction**, for example, produces complex flavours and attractive brown colours in baked bread, roasted coffee, and grilled meat. Similarly, **caramelisation** contributes to the golden colour and sweet flavour of caramelised onions and confectionery.

Enzymes also play beneficial roles. Proteases tenderise meat, amylases improve bread texture, and lipases contribute to flavour development in cheese. These processes are deliberately harnessed in food production to create desirable qualities that consumers expect.

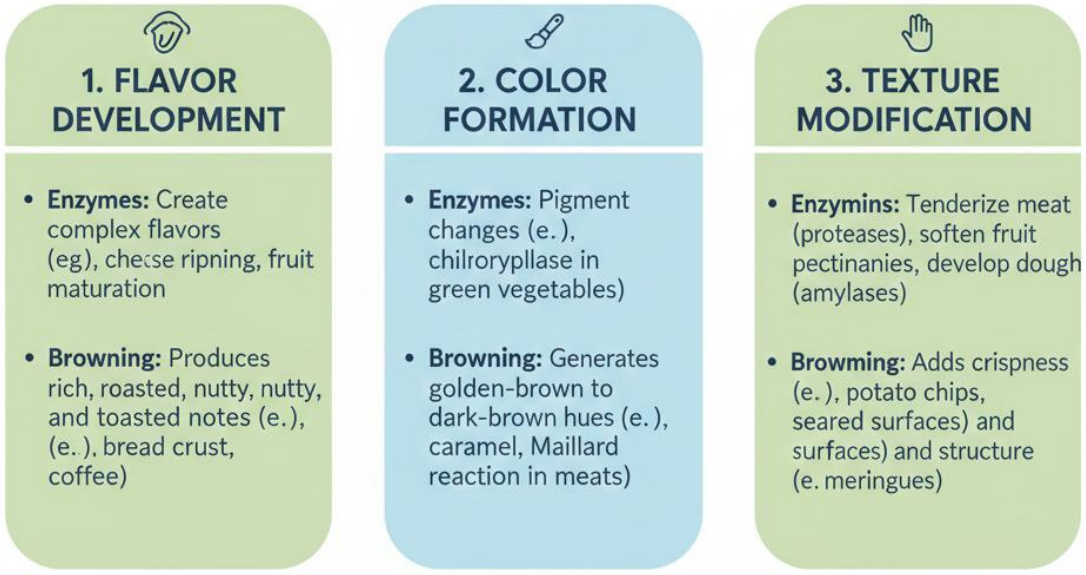


Figure 4.5 Positive contributions of enzymes and browning in foods.

Fill in the blank: The Maillard reaction is responsible for the appealing brown crust on baked _____.

4.5.2 Negative impacts on shelf life, safety, and consumer acceptance

While enzymes and browning can be beneficial, they may also reduce food quality. **Enzymatic browning**, caused by polyphenol oxidase, leads to unattractive discolouration in fruits and vegetables, lowering consumer acceptance.

Non-enzymatic browning can reduce nutritional value by destroying essential amino acids such as lysine. In addition, some by-products of the Maillard reaction, such as **acrylamide**, have raised safety concerns due to their potential health risks. Enzymes may also accelerate spoilage, for example lipases causing rancidity in fats.

Food technologists must therefore balance the desirable sensory qualities with the need to minimise negative impacts on safety and shelf life.

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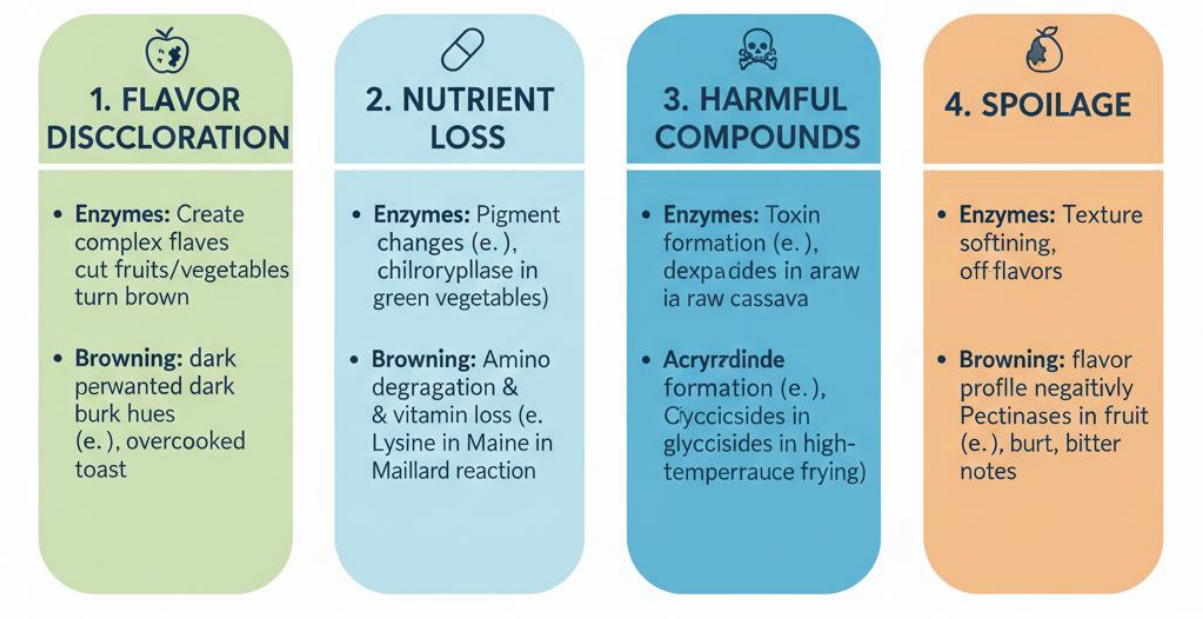
Table 4.5 Negative impacts of enzymes and browning on food quality.



Fill in the blank: Acrylamide, a by-product of the Maillard reaction, has raised concerns about food _____.

4.5.3 Applications in product innovation and industrial food processing

Food industries harness enzyme systems and browning reactions to develop innovative products. Enzymes are used in brewing, baking, dairy processing, and juice clarification, improving efficiency and product quality. Browning reactions are exploited to create appealing colours and flavours in roasted, baked, and fried foods.

In industrial contexts, enzymes are applied to reduce processing costs and improve sustainability. For example, cellulases are used to break down plant materials, increasing yield in juice production. Controlled browning reactions are also used to design new flavour profiles in ready-to-eat meals and snacks.

These applications highlight how food technologists can transform potential challenges into opportunities for product development and innovation.

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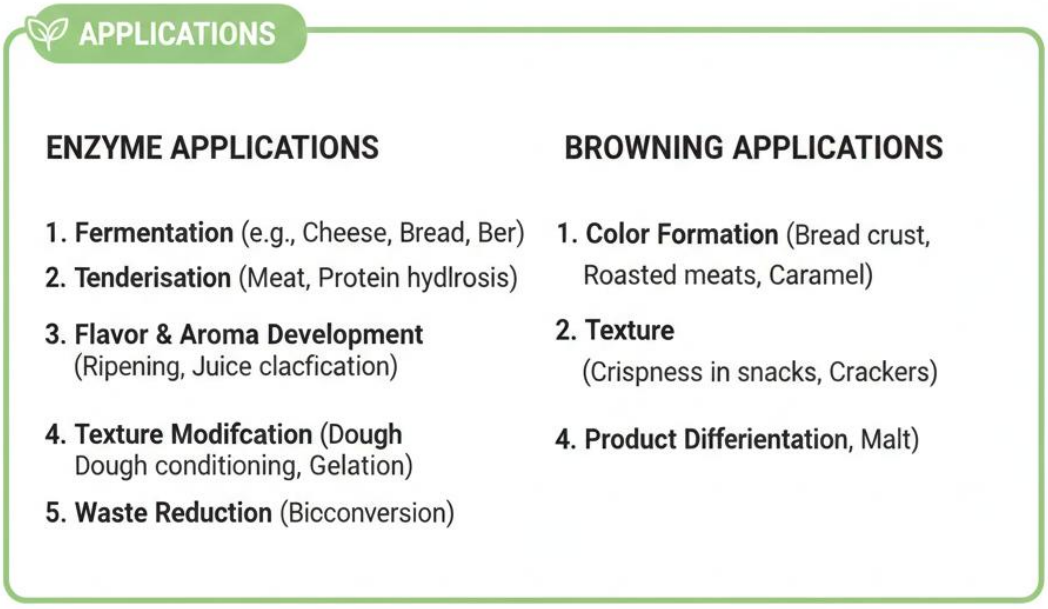
Box 4.5 Applications of enzymes and browning in product innovation.



Fill in the blank: Cellulases are used in juice production to break down plant materials and increase _____.

Pilot questions 4.5

1. How do enzymes and browning reactions positively contribute to flavour and texture in foods?
2. What negative impact does enzymatic browning have on fruits and vegetables?
3. Which essential amino acid is destroyed during non-enzymatic browning, reducing nutritional value?
4. Why is acrylamide considered a safety concern in food processing?
5. Give one example of how enzymes are applied in industrial food processing for product innovation.

Series Summary

This Series has focused on enzyme systems and browning reactions, highlighting their importance in shaping food quality, safety, and consumer acceptance. We began by examining enzyme systems in foods, their types, activity, and beneficial roles in processing. Then we explored enzymatic browning, looking at its mechanism, influencing factors, and control strategies. Following that, we studied non-enzymatic browning, including the Maillard reaction and caramelisation, and considered their nutritional and sensory implications. We continued with methods of measurement and analysis, covering techniques for assessing enzyme activity and

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browning intensity. Finally, we discussed the broader implications for food quality and product development, showing how these processes can be harnessed or controlled to create appealing and innovative products.

By completing this Series, you should now be able to define enzyme systems and describe their functions, explain enzymatic and non-enzymatic browning reactions, apply methods for measuring enzyme activity and browning, and evaluate their implications for food quality and product innovation. These abilities directly reflect the Series Learning Outcomes (SLOs 4.1 to 4.7), equipping you with practical knowledge and skills to assess, monitor, and utilise enzyme systems and browning reactions effectively in food analysis and product development.

Glossary of Terms

Acrylamide: A chemical compound formed as a by-product of the Maillard reaction during high-temperature cooking, considered a potential health risk.

Activation energy: The minimum amount of energy required for a chemical reaction to occur; enzymes lower this energy to speed up reactions.

Caramelisation: The thermal decomposition of sugars at high temperatures, producing brown colours and sweet flavours without involving amino acids.

Colourimetry: An instrumental technique used to measure the colour of food samples, providing objective data on browning intensity.

Enzyme activity: The rate at which an enzyme catalyses a reaction, influenced by factors such as temperature, pH, and substrate concentration.

Enzyme assay: A specific test designed to measure enzyme activity under controlled conditions, often using substrates that produce measurable signals.

Enzymatic browning: A process where enzymes such as polyphenol oxidase oxidise phenolic compounds, leading to brown pigments in fruits and vegetables.

Maillard reaction: A non-enzymatic browning reaction between reducing sugars and amino acids during heating, responsible for flavour and colour development in foods.

Melanin pigments: Brown-coloured compounds formed during enzymatic browning when quinones polymerise.

Non-enzymatic browning: Browning reactions in foods that occur without enzymes, including the Maillard reaction and caramelisation.

Polyphenol oxidase (PPO): An enzyme found in plant tissues that catalyses the oxidation of phenolic compounds, leading to enzymatic browning.

Proteases: Enzymes that break down proteins into smaller peptides or amino acids, often used in meat tenderisation and flavour development.

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Rheology: The study of flow and deformation properties of materials, used to assess changes in viscosity and texture in foods.

Sensory evaluation: A method of assessing food quality based on human perception of appearance, flavour, texture, and overall acceptability.

Spectrophotometry: An analytical technique that measures how much light a sample absorbs, often used to monitor enzyme activity or browning reactions.

Substrate specificity: The property of enzymes that allows them to act only on particular molecules, ensuring targeted reactions in food systems.

Titration: A laboratory method used to measure enzyme activity by quantifying reactants or products, such as fatty acids released during lipase activity.

Concept Check Questions 4

Objective Questions

1. Which enzyme is primarily responsible for enzymatic browning in fruits and vegetables? (Linked to SLO 4.2)
2. What two molecules react in the Maillard reaction? (Linked to SLO 4.4)
3. At what approximate temperature does caramelisation typically occur? (Linked to SLO 4.5)
4. Which analytical technique measures changes in light absorbance to monitor enzyme activity? (Linked to SLO 4.6)
5. Which essential amino acid is destroyed during non-enzymatic browning, reducing nutritional value? (Linked to SLO 4.4)

Short-Answer Questions

6. Define enzymes and explain their role in food systems. (Linked to SLO 4.1)
7. Describe one factor that influences enzymatic browning and explain its effect. (Linked to SLO 4.2)
8. Explain how blanching helps to control enzymatic browning in vegetables. (Linked to SLO 4.3)
9. Differentiate between enzymatic and non-enzymatic browning in terms of mechanism. (Linked to SLO 4.2 and 4.4)
10. Identify one analytical approach used to monitor quality changes during storage and explain its purpose. (Linked to SLO 4.6)

Long-Answer Questions

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11. Analyse the positive contributions of enzymes and browning reactions to flavour, colour, and texture in foods. (Linked to SLO 4.7)
12. Demonstrate how measurement techniques such as spectrophotometry, colourimetry, and sensory evaluation can be applied to study enzyme activity and browning intensity. (Linked to SLO 4.6)
13. Evaluate the implications of enzyme systems and browning reactions for food quality, shelf life, and product development. (Linked to SLO 4.7)

Answers to Concept Check Questions [Series 4]

Objective Questions

1. Polyphenol oxidase (PPO).
2. Reducing sugars and amino acids.
3. Around 150°C or higher.
4. Spectrophotometry.
5. Lysine.

Short-Answer Questions

6. Enzymes are proteins that act as biological catalysts, speeding up reactions in food systems. They influence flavour, texture, and nutritional quality.
7. pH influences enzymatic browning. Lowering pH with acids such as lemon juice reduces PPO activity and slows browning.
8. Blanching briefly heats vegetables, inactivating PPO and preventing enzymatic browning during storage.
9. Enzymatic browning involves PPO oxidising phenolic compounds, while non-enzymatic browning involves chemical reactions such as the Maillard reaction and caramelisation.
10. Rheology is used to monitor changes in viscosity and texture during storage, helping to assess quality changes caused by enzymatic or browning reactions.

Long-Answer Questions

11. *Basic response:* Enzymes and browning reactions enhance flavour, colour, and texture. The Maillard reaction produces appealing flavours and brown colours, while proteases tenderise meat and amylases improve bread texture. *Value-added response:* Beyond these basics, food technologists deliberately harness these processes to design specific sensory profiles. For example, controlled Maillard reactions

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are used in coffee roasting, while enzymatic tenderisation improves meat quality for consumer satisfaction.

12. *Basic response:* Spectrophotometry measures enzyme activity by tracking absorbance changes, colourimetry quantifies browning intensity, and sensory evaluation assesses consumer perception.
Value-added response: Outstanding learners will note that combining these methods provides both objective and subjective insights. For instance, spectrophotometry can quantify PPO activity, while sensory panels confirm whether browning is acceptable to consumers, ensuring comprehensive quality assessment.

13. *Basic response:* Enzyme systems and browning reactions contribute positively to flavour and colour but can also reduce shelf life and nutritional value.
Value-added response: In addition, these processes are central to product innovation. Controlled browning reactions create new flavour profiles in ready-to-eat meals, while enzyme applications improve sustainability and efficiency in industrial food processing. This balance between benefits and risks is key to modern food development.

Answers to Pilot Questions [Series 4]

Part 4.1: Enzyme Systems in Foods: Types and Functions

1. Enzymes are biological catalysts that speed up chemical reactions in food systems.
2. Oxidoreductases, hydrolases, transferases, and isomerases.
3. Temperature, pH, and substrate concentration.
4. Lactase specifically breaks down lactose into glucose and galactose.
5. Fermentation, tenderisation, flavour development, and juice clarification.

Part 4.2: Enzymatic Browning Reactions

1. Polyphenol oxidase (PPO).
2. Melanin pigments.
3. PPO activity is optimal at neutral to slightly acidic pH; lowering pH reduces browning.
4. Blanching inactivates PPO, preventing enzymatic browning.
5. Blanching, acidification, antioxidants, oxygen exclusion, and inhibitors.

Part 4.3: Non-Enzymatic Browning Reactions

1. The Maillard reaction is a chemical reaction between reducing sugars and amino acids during heating, important for flavour and colour development.
2. Reducing sugars and amino acids.

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3. Caramelisation is the thermal decomposition of sugars at high temperatures, while the Maillard reaction involves amino acids and sugars.
4. Caramel sweets and caramelised onions.
5. Positive: flavour and colour development. Negative: nutrient loss and formation of harmful compounds such as acrylamide.

Part 4.4: Measurement and Analysis of Enzyme Activity and Browning

1. Spectrophotometry, titration, and enzyme assays.
2. By monitoring changes in light absorbance as substrates are converted to products.
3. Colourimetry and sensory evaluation.
4. Because consumer perception ultimately determines product acceptance.
5. Rheology, which measures changes in viscosity and texture during storage and processing.

Part 4.5: Implications for Food Quality and Product Development

1. They enhance flavour, colour, and texture, for example through the Maillard reaction and protease activity.
2. It causes unattractive discolouration, reducing consumer acceptance.
3. Lysine.
4. Because it is a potentially harmful compound formed during high-temperature cooking.
5. Enzymes are applied in brewing, baking, dairy processing, and juice clarification to improve efficiency and product quality.

References and Attributions [Series 4]

This section compiles all references and attributions for Series 4: *Enzymes and Browning in Food Quality*. It includes general references, suggested open educational resources (OERs), and notes on AI-generated illustration prompts. The referencing style applied here follows APA guidelines for clarity and consistency.

General References

- Belitz, H. D., Grosch, W., & Schieberle, P. (2009). *Food Chemistry* (4th ed.). Springer.
- Fellows, P. (2017). *Food Processing Technology: Principles and Practice* (4th ed.). Woodhead Publishing.
- Potter, N. N., & Hotchkiss, J. H. (2012). *Food Science* (5th ed.). Springer.

Illustration References and Attributions

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- *Figure 4.1 Classification of enzymes in foods*
  Suggested OER source: "classification of enzymes food science diagram OER."
  AI-generated prompt: "Generate a diagram showing enzyme classes: oxidoreductases, hydrolases, transferases, isomerases with food examples."
- *Table 4.1 Factors influencing enzyme activity in foods*
  Suggested OER source: "enzyme activity factors food science table OER."
  AI-generated prompt: "Create a table showing factors influencing enzyme activity: temperature, pH, substrate concentration."
- *Box 4.1 Examples of beneficial enzyme applications in food processing*
  Suggested OER source: "enzyme applications food processing OER."
  AI-generated prompt: "Create a box listing beneficial enzyme applications in food processing: fermentation, tenderisation, flavour development, juice clarification."
- *Figure 4.2 Mechanism of enzymatic browning in plant tissues*
  Suggested OER source: "enzymatic browning mechanism PPO food science diagram OER."
  AI-generated prompt: "Generate a diagram showing enzymatic browning: PPO oxidises phenolic compounds to quinones, which form melanins."
- *Table 4.2 Factors influencing enzymatic browning*
  Suggested OER source: "factors influencing enzymatic browning food science table OER."
  AI-generated prompt: "Create a table showing factors influencing enzymatic browning: pH, temperature, oxygen, inhibitors."
- *Box 4.2 Strategies for controlling enzymatic browning in foods*
  Suggested OER source: "control strategies enzymatic browning food science OER."
  AI-generated prompt: "Create a box listing strategies for controlling enzymatic browning: blanching, acidification, antioxidants, oxygen exclusion, inhibitors."
- *Figure 4.3 Stages of the Maillard reaction in foods*
  Suggested OER source: "Maillard reaction stages food science diagram OER."
  AI-generated prompt: "Generate a diagram showing the Maillard reaction stages: reducing sugars + amino acids → glycosylamines → flavour and colour compounds."
- *Plate 4.1 Caramelisation of sugar during heating*
  Suggested OER source: "caramelisation sugar cooking food science image OER."
  AI-generated prompt: "Generate an image showing caramelised sugar in a pan with golden-brown colour."
- *Box 4.3 Implications of non-enzymatic browning in food systems*
  Suggested OER source: "implications non-enzymatic browning food science OER."
  AI-generated prompt: "Create a box listing implications of non-enzymatic browning: flavour, aroma, colour, nutrient loss, harmful compounds."

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- *Figure 4.4 Methods for measuring enzyme activity in foods*
  Suggested OER source: "methods measuring enzyme activity food science diagram OER."
  AI-generated prompt: "Generate a diagram showing enzyme activity measurement methods: spectrophotometry, titration, enzyme assays."
- *Table 4.4 Techniques for assessing browning intensity*
  Suggested OER source: "techniques assessing browning intensity food science table OER."
  AI-generated prompt: "Create a table comparing colourimetry and sensory evaluation for assessing browning intensity in foods."
- *Box 4.4 Analytical approaches for monitoring quality changes in foods*
  Suggested OER source: "analytical approaches monitoring food quality enzyme browning OER."
  AI-generated prompt: "Create a box listing analytical approaches for monitoring quality changes: rheology, spectroscopy, shelf-life studies."
- *Figure 4.5 Positive contributions of enzymes and browning in foods*
  Suggested OER source: "positive contributions enzymes browning food science diagram OER."
  AI-generated prompt: "Generate a diagram showing positive contributions of enzymes and browning: flavour, colour, texture."
- *Table 4.5 Negative impacts of enzymes and browning on food quality*
  Suggested OER source: "negative impacts enzymes browning food science table OER."
  AI-generated prompt: "Create a table showing negative impacts of enzymes and browning: discolouration, nutrient loss, harmful compounds, spoilage."
- *Box 4.5 Applications of enzymes and browning in product innovation*
  Suggested OER source: "applications enzymes browning food innovation OER."
  AI-generated prompt: "Create a box listing applications of enzymes and browning in product innovation and industrial food processing."

Course code: FST304

Course title: Principles of Food Analysis

Course credit load: 3 units

List of Series:

21. **Physical and Chemical Transformations in Foods**
22. **Lipids and Proteins: Properties, Reactions, and Applications**

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23. **Carbohydrates, Hydrocolloids, and Starch Modifications**
24. **Enzyme Systems and Browning Reactions in Food Quality**
25. **Vitamins, Natural Pigments, Flavours, and Additives in Foods**

5.1 Vitamins in foods: types, functions, and analysis

- 5.1.1 Classification of vitamins (fat-soluble and water-soluble)
- 5.1.2 Roles of vitamins in nutrition and food systems
- 5.1.3 Methods of vitamin analysis in foods

5.2 Natural pigments in foods: occurrence and significance

- 5.2.1 Major classes of pigments (chlorophylls, carotenoids, anthocyanins, betalains)
- 5.2.2 Functions of pigments in food quality and nutrition
- 5.2.3 Analytical techniques for pigment determination

5.3 Flavours in foods: sources and development

- 5.3.1 Natural flavour compounds (essential oils, aldehydes, esters)
- 5.3.2 Flavour formation during processing (Maillard reaction, enzymatic activity)
- 5.3.3 Methods for flavour analysis and sensory evaluation

5.4 Food additives: types, roles, and safety considerations

- 5.4.1 Classification of food additives (preservatives, colourants, flavour enhancers, stabilisers)
- 5.4.2 Functional roles of additives in food processing and preservation
- 5.4.3 Safety, regulation, and consumer concerns regarding additives

5.5 Implications for food quality and product development

- 5.5.1 Contribution of vitamins, pigments, flavours, and additives to sensory appeal and nutrition
- 5.5.2 Challenges and controversies in additive use
- 5.5.3 Applications in product innovation and industrial food processing

Introduction

From the vibrant colours of fresh vegetables to the distinctive flavours of spices and the preservation of packaged foods, vitamins, pigments, flavours, and additives all play crucial roles in shaping the quality and acceptability of what we eat. These components not only influence

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sensory appeal but also contribute to nutritional value, safety, and innovation in food processing. Understanding them is therefore essential for food scientists and technologists, as they form the foundation of modern food analysis and product development.

The aim of this Series is to equip you with the knowledge and skills to describe the types and functions of vitamins, pigments, flavours, and additives in foods, explain their roles in nutrition and sensory quality, apply methods for their analysis, and evaluate their implications for food safety and product innovation.

We shall commence this Series by examining vitamins in foods, focusing on their classification, nutritional roles, and methods of analysis. Next, we will explore natural pigments, considering their occurrence, functions, and analytical techniques. Following that, we will move on to flavours, studying their sources, development during processing, and methods of evaluation. Afterwards, we will continue with food additives, looking at their classification, functional roles, and safety considerations. Finally, we will wrap up by discussing the broader implications of vitamins, pigments, flavours, and additives for food quality and product development, highlighting both opportunities and challenges in modern food systems.

Series Learning Outcomes

Upon completing this Series, you should be able to:

SLO 5.1 define vitamins and classify them into fat-soluble and water-soluble groups,

SLO 5.2 explain the nutritional roles of vitamins and describe methods used for their analysis in foods,

SLO 5.3 identify major classes of natural pigments in foods and explain their functions in food quality and nutrition,

SLO 5.4 apply appropriate analytical techniques to determine pigment content in food samples,

SLO 5.5 describe natural flavour compounds and explain how flavours develop during food processing,

SLO 5.6 demonstrate methods for flavour analysis and sensory evaluation in food systems,

SLO 5.7 classify food additives according to their types and functional roles in processing and preservation,

SLO 5.8 evaluate safety considerations and regulatory issues related to the use of food additives, and

SLO 5.9 analyse the overall implications of vitamins, pigments, flavours, and additives for food quality, shelf life, and product innovation.

5.1 Vitamins in Foods: Types, Functions, and Analysis

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Vitamins are essential organic compounds required in small amounts to support growth, metabolism, and overall health. Unlike macronutrients such as carbohydrates, proteins, and fats, vitamins do not provide energy but act as regulators of biochemical processes. In food systems, they contribute to nutritional value, stability, and sometimes sensory qualities. Their presence or absence can significantly influence food quality and consumer health.

Fill in the blank: Vitamins are essential organic compounds required in _____ amounts to support growth and metabolism.

5.1.1 Classification of vitamins (fat-soluble and water-soluble)

Fat-soluble vitamins are vitamins that dissolve in fats and oils and are stored in the liver and fatty tissues. Examples include vitamins A, D, E, and K. They are absorbed along with dietary fat and can accumulate in the body, which means excessive intake may lead to toxicity.

Water-soluble vitamins dissolve in water and are not stored in large amounts in the body. Examples include the B-complex vitamins (such as thiamine, riboflavin, niacin, folate, and vitamin B12) and vitamin C. Since they are excreted in urine, they need to be consumed regularly in the diet.

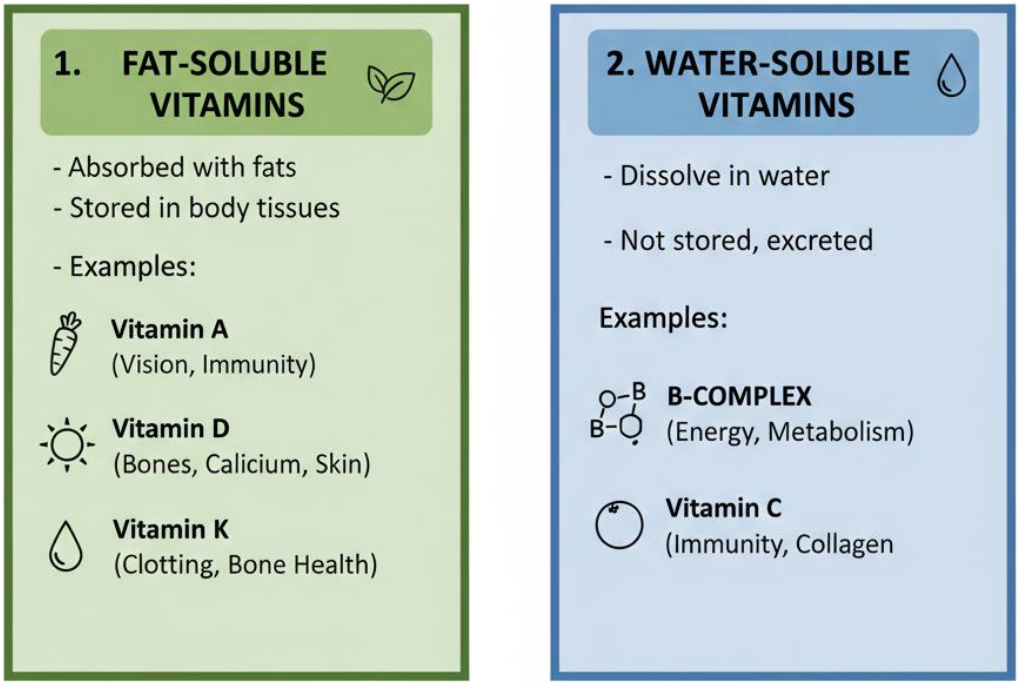

Figure 5.1 Classification of vitamins in foods.

Fill in the blank: Vitamins A, D, E, and K are classified as _____-soluble vitamins.

5.1.2 Roles of vitamins in nutrition and food systems

Vitamins play diverse roles in maintaining health and supporting food quality. For example, **vitamin A** supports vision and immune function, **vitamin D** regulates calcium absorption and

bone health, **vitamin E** acts as an antioxidant protecting cell membranes, and **vitamin K** is essential for blood clotting.

Water-soluble vitamins also have critical functions. **Vitamin C** enhances iron absorption and supports collagen synthesis, while B-complex vitamins are involved in energy metabolism and enzyme function. In food systems, vitamins can also act as natural antioxidants, helping to preserve freshness and prevent spoilage.

Fill in the blank: Vitamin C enhances the absorption of the mineral _____ in the human body.

5.1.3 Methods of vitamin analysis in foods

Analysing vitamins in foods is important for nutritional labelling, quality control, and research. Several methods are commonly used:

Spectrophotometry measures the absorbance of light by vitamin compounds, providing quantitative data. For example, vitamin C can be measured by its ability to reduce certain dyes.

Chromatography (such as high-performance liquid chromatography, HPLC) separates and quantifies vitamins with high accuracy. It is widely used for complex mixtures like B-complex vitamins.

Titration methods are simple chemical techniques, often used for vitamin C determination, where the endpoint is indicated by a colour change.

These methods ensure that food products meet nutritional standards and regulatory requirements.

Fill in the blank: High-performance liquid _____ (HPLC) is widely used for accurate vitamin analysis in foods.

Pilot questions 5.1

1. What are vitamins and why are they important in food systems?
2. Name the fat-soluble and water-soluble groups of vitamins.
3. Give one example of the role of vitamin A in nutrition.
4. Which vitamin enhances iron absorption in the body?
5. Mention two methods used for vitamin analysis in foods.

5.2 Natural Pigments in Foods: Occurrence and Significance

Natural pigments are compounds that give foods their characteristic colours, ranging from the green of leafy vegetables to the red of tomatoes and the purple of berries. These pigments are not only important for visual appeal but also contribute to nutritional value and consumer perception of freshness and quality. In food science, pigments are studied for their roles in health, their stability during processing, and their influence on product development.

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Fill in the blank: Natural pigments are compounds that give foods their characteristic _____.

5.2.1 Major classes of pigments (chlorophylls, carotenoids, anthocyanins, betalains)

Chlorophylls are green pigments found in plants that are essential for photosynthesis. In foods, they provide the green colour of vegetables such as spinach and broccoli. Chlorophylls are sensitive to heat and acidic conditions, which can cause colour changes during cooking.

Carotenoids are yellow, orange, or red pigments found in foods such as carrots, tomatoes, and mangoes. They include compounds like beta-carotene, lycopene, and lutein. Carotenoids are important antioxidants and some, like beta-carotene, serve as precursors to vitamin A.

Anthocyanins are water-soluble pigments responsible for red, purple, and blue colours in fruits such as grapes, berries, and plums. Their colour is highly dependent on pH, appearing red in acidic conditions and blue in alkaline environments.

Betalains are pigments found in beetroots and certain cactus fruits. They are divided into betacyanins (red-violet) and betaxanthins (yellow-orange). Betalains are valued for their antioxidant properties and are used as natural colourants in food products.

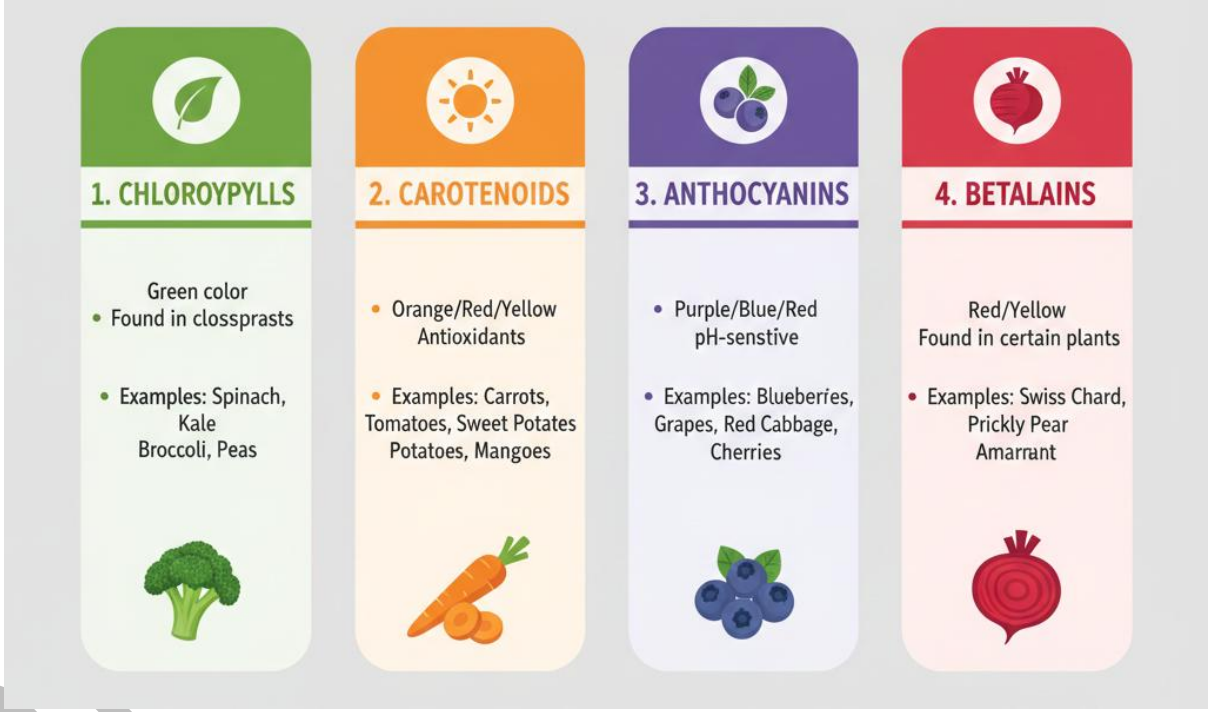

Figure 5.2 Major classes of natural pigments in foods.

Fill in the blank: Anthocyanins appear red in acidic conditions and _____ in alkaline environments.

5.2.2 Functions of pigments in food quality and nutrition

Natural pigments serve multiple functions in foods. They enhance **sensory quality** by providing appealing colours that influence consumer acceptance. For example, the bright red of ripe tomatoes

signals freshness and ripeness. Pigments also contribute to **nutritional value**. Carotenoids act as antioxidants, protecting cells from oxidative damage, while anthocyanins and betalains have been linked to reduced risk of chronic diseases.

In addition, pigments can act as indicators of food quality. Loss of colour during storage or processing often signals nutrient degradation or spoilage. For instance, fading of chlorophyll in vegetables may indicate overcooking or poor storage conditions.

Fill in the blank: Carotenoids act as antioxidants and some serve as precursors to vitamin _____.

5.2.3 Analytical techniques for pigment determination

Analysing pigments in foods is important for quality control, nutritional labelling, and product development.

Spectrophotometry is commonly used to measure pigment concentration by recording absorbance at specific wavelengths. For example, chlorophyll content can be determined by measuring absorbance in the green spectrum.

Chromatography, particularly high-performance liquid chromatography (HPLC), separates and quantifies individual pigments with high precision. This method is widely used for carotenoids and anthocyanins.

Colourimetry provides objective measurements of food colour, which indirectly reflects pigment content. It is often used in industry to monitor consistency in processed foods.

These techniques ensure that food products maintain desirable colour, nutritional value, and consumer appeal.

Fill in the blank: High-performance liquid chromatography (HPLC) is widely used to separate and quantify individual _____.

Pilot questions 5.2

1. Name the four major classes of natural pigments in foods.
2. Which pigment group is responsible for the green colour of vegetables?
3. How does pH affect the colour of anthocyanins?
4. Give one nutritional function of carotenoids.
5. Mention two analytical techniques used to determine pigment content in foods.

5.3 Flavours in Foods: Sources and Development

Flavour is one of the most important attributes of food, influencing consumer preference and acceptance. It is a complex sensation that arises from the interaction of taste, aroma, and mouthfeel.

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While flavour can originate naturally from food components, it can also develop during processing or be enhanced through additives. In food science, understanding flavour is critical not only for sensory appeal but also for product innovation and quality assurance.

Fill in the blank: Flavour is a complex sensation that arises from the interaction of taste, _____, and mouthfeel.

5.3.1 Natural flavour compounds (essential oils, aldehydes, esters)

Natural flavour compounds are chemical substances present in foods that contribute to their characteristic taste and aroma. **Essential oils** are volatile compounds extracted from plants such as citrus fruits, herbs, and spices. They provide distinctive aromas and are widely used in flavouring beverages and confectionery.

Aldehydes are compounds that contribute to fruity and floral notes. For example, benzaldehyde gives almonds their characteristic flavour, while vanillin provides the familiar aroma of vanilla.

Esters are another group of flavour compounds, often responsible for sweet and fruity aromas. Isoamyl acetate, for instance, gives bananas their distinctive flavour. These compounds are naturally present in fruits and are also used in flavour formulations.

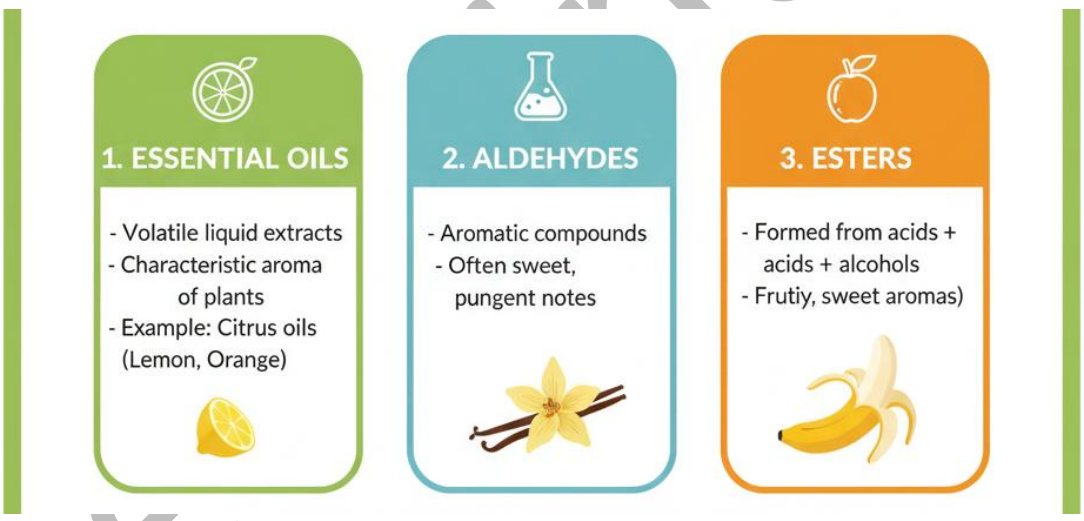

Figure 5.3 Natural flavour compounds in foods.

Fill in the blank: Isoamyl acetate is an ester responsible for the flavour of _____.

5.3.2 Flavour formation during processing (Maillard reaction, enzymatic activity)

Flavour is not only inherent in raw foods but also develops during processing. The **Maillard reaction**, a chemical reaction between reducing sugars and amino acids, produces complex flavour compounds in baked bread, roasted coffee, and grilled meat. This reaction is highly valued for the depth of flavour it imparts.

Enzymatic activity also contributes to flavour development. Enzymes such as lipases release fatty acids that enhance cheese flavour, while proteases generate peptides that contribute to savoury

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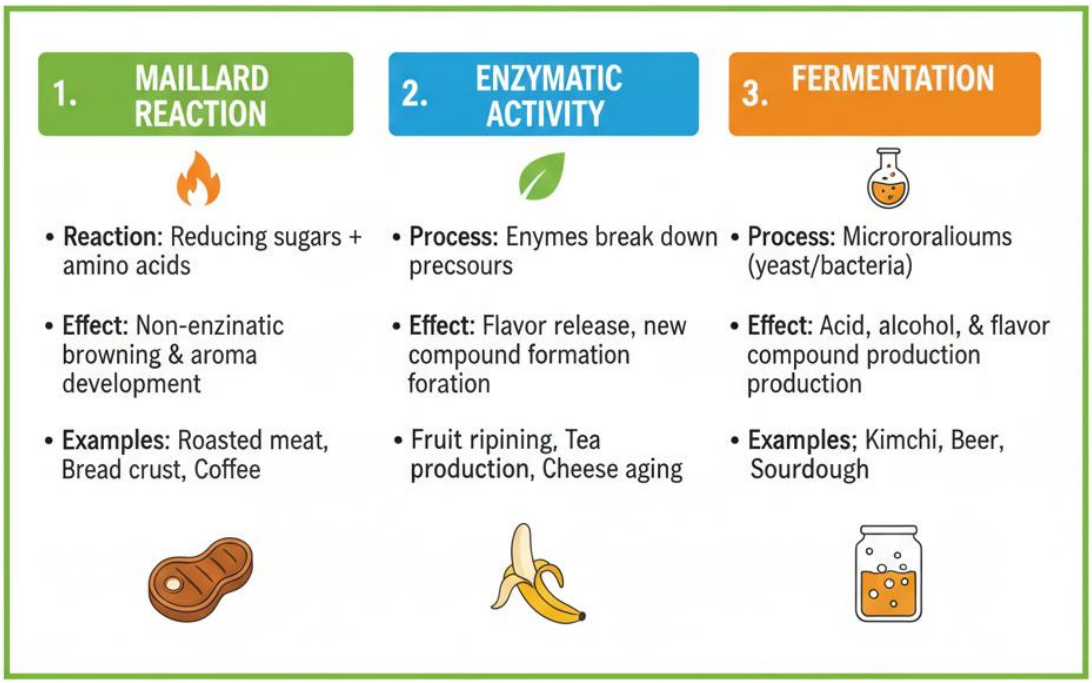
notes. Fermentation processes, driven by enzymes and microorganisms, produce characteristic flavours in products such as yoghurt, beer, and soy sauce.

Processing conditions such as temperature, pH, and time influence the extent and type of flavour compounds formed. Food technologists carefully control these factors to achieve desirable flavour profiles while avoiding off-flavours.

Table 5.1 Flavour formation during food processing.



Fill in the blank: The Maillard reaction occurs between reducing sugars and _____ during heating.

5.3.3 Methods for flavour analysis and sensory evaluation

Analysing flavour is essential for ensuring product consistency and consumer satisfaction. **Gas chromatography (GC)** is widely used to separate and identify volatile flavour compounds. When combined with mass spectrometry (GC-MS), it provides detailed information about the chemical composition of flavours.

Sensory evaluation involves trained panels or consumers assessing flavour attributes such as sweetness, bitterness, aroma intensity, and overall acceptability. While subjective, sensory evaluation is critical because consumer perception ultimately determines product success.

Electronic noses are modern analytical tools that mimic human olfactory systems. They use sensor arrays to detect volatile compounds and provide rapid assessments of flavour quality. These instruments are increasingly used in industry for quality control.

By combining instrumental methods with sensory evaluation, food scientists can obtain both objective and subjective insights into flavour, ensuring products meet consumer expectations.

Fill in the blank: Gas chromatography is widely used to separate and identify _____ flavour compounds.

Pilot questions 5.3

1. What are natural flavour compounds and give one example?
2. Which compound is responsible for the flavour of vanilla?
3. How does the Maillard reaction contribute to flavour development in foods?
4. Name one enzyme that contributes to flavour formation in cheese.
5. Mention two methods used for flavour analysis in food systems.

5.4 Food Additives: Types, Roles, and Safety Considerations

Food additives are substances intentionally added to foods to improve their quality, safety, or shelf life. They may enhance flavour, colour, texture, or preservation. While additives are often essential in modern food systems, they must be carefully regulated to ensure consumer safety and maintain trust. Understanding their types, roles, and safety considerations is crucial for food scientists and technologists.

Fill in the blank: Food additives are substances intentionally added to foods to improve their _____, safety, or shelf life.

5.4.1 Classification of food additives (preservatives, colourants, flavour enhancers, stabilisers)

Food additives can be classified into several groups based on their functions. **Preservatives** are substances that inhibit microbial growth or chemical changes, thereby extending shelf life. Examples include sodium benzoate and sorbic acid.

Colourants are additives that enhance or restore the colour of foods. They may be natural, such as carotenoids, or synthetic, such as tartrazine. Colourants are important for consumer appeal and product consistency.

Flavour enhancers are compounds that intensify the existing taste of foods without adding a flavour of their own. Monosodium glutamate (MSG) is a well-known example, used to enhance savoury notes.

Stabilisers help maintain the uniform dispersion of ingredients in foods, preventing separation. For instance, lecithin is used in chocolate to stabilise fat and water mixtures.

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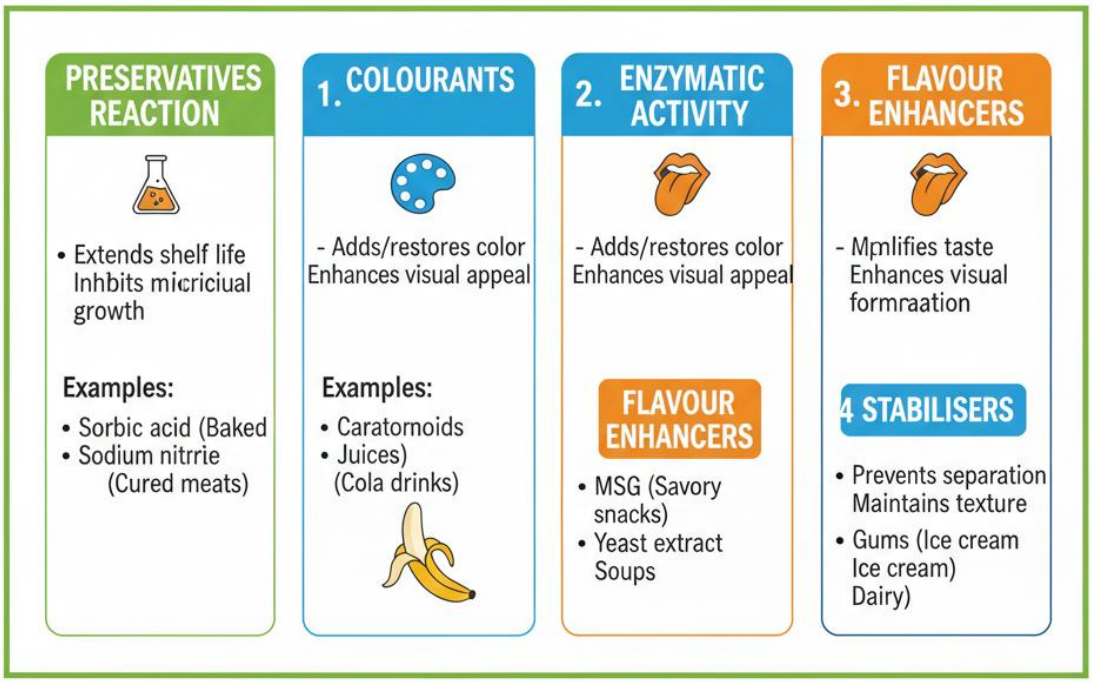

Figure 5.4 Classification of food additives

Fill in the blank: Monosodium glutamate (MSG) is an example of a flavour _____.

5.4.2 Functional roles of additives in food processing and preservation

Food additives serve important roles in ensuring product quality and safety. Preservatives prevent spoilage and extend shelf life, which is vital for reducing food waste. Colourants maintain visual appeal, ensuring that products look fresh and consistent. Flavour enhancers improve taste, making foods more enjoyable and acceptable to consumers. Stabilisers and emulsifiers maintain texture and prevent separation, which is particularly important in products such as sauces, ice cream, and baked goods.

In addition, additives can improve nutritional quality. For example, fortification with vitamins and minerals is considered a functional use of additives, helping to address deficiencies in populations.

Fill in the blank: Preservatives are used to inhibit microbial growth and extend food _____.

5.4.3 Safety, regulation, and consumer concerns regarding additives

The use of food additives is strictly regulated by national and international agencies to ensure safety. Regulatory bodies such as the Food and Agriculture Organization (FAO), World Health Organization (WHO), and national food safety authorities establish acceptable daily intakes (ADIs) and approve additives for use.

Safety considerations involve assessing potential toxicity, allergenicity, and long-term health effects. For example, while MSG is widely considered safe, some consumers report sensitivity to it. Synthetic colourants have also raised concerns, leading to increased demand for natural alternatives.

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Consumer concerns often revolve around perceptions of artificial additives. Many consumers prefer "clean label" products with fewer synthetic ingredients. Food industries are responding by using natural additives and improving transparency in labelling.

Fill in the blank: Regulatory bodies establish acceptable daily _____ (ADIs) to ensure safe use of food additives.

Pilot questions 5.4

1. What are food additives and why are they used in foods?
2. Name four classes of food additives with examples.
3. What role do preservatives play in food processing?
4. Which regulatory bodies oversee the safety of food additives?
5. Why are consumers increasingly concerned about synthetic additives?

5.5 Implications for Food Quality and Product Development

The presence and manipulation of vitamins, pigments, flavours, and additives in foods have far-reaching implications for both food quality and product development. These components influence sensory appeal, nutritional value, shelf life, and consumer acceptance. They can be harnessed to create innovative products, but they also present challenges such as stability, safety, and regulatory compliance. In this Part, we will explore their contributions to food quality, the challenges and controversies surrounding their use, and their applications in product innovation.

Fill in the blank: Vitamins, pigments, flavours, and additives influence sensory appeal, nutritional value, shelf life, and consumer _____.

5.5.1 Contribution of vitamins, pigments, flavours, and additives to sensory appeal and nutrition

Vitamins, pigments, flavours, and additives all contribute positively to food quality. **Vitamins** enhance nutritional value, ensuring foods support health and wellbeing. **Pigments** provide attractive colours that signal freshness and ripeness, such as the red of tomatoes or the green of leafy vegetables. **Flavours** determine the taste and aroma profile of foods, making them enjoyable and distinctive. **Additives** help maintain consistency, extend shelf life, and improve sensory qualities such as texture and mouthfeel.

Together, these components ensure that foods are not only nutritious but also appealing to consumers. For example, fortification with vitamin D improves nutritional quality, carotenoids add vibrant colour, natural flavour compounds enhance taste, and stabilisers maintain desirable texture.

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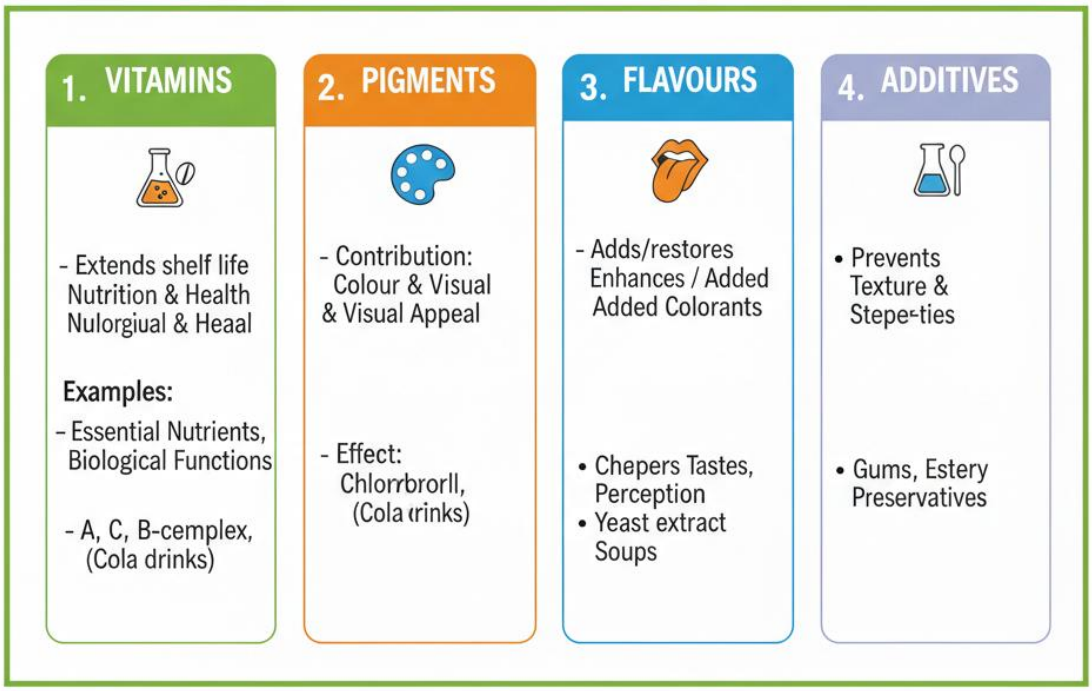

Figure 5.5 Contributions of vitamins, pigments, flavours, and additives to food quality.

Fill in the blank: Carotenoids contribute to food quality by providing attractive _____ colours.

5.5.2 Challenges and controversies in additive use

While additives and other food components provide many benefits, they also raise challenges and controversies. **Additive safety** is a major concern, as some synthetic additives have been linked to potential health risks. Regulatory bodies establish acceptable daily intakes (ADIs), but consumer perception often influences acceptance more strongly than scientific evidence.

Another challenge is **nutrient stability**. Vitamins and pigments can degrade during processing and storage, reducing nutritional value and altering colour. For example, vitamin C is highly sensitive to heat and oxygen, while chlorophyll loses its green colour when exposed to acidic conditions.

Consumer concerns about artificial additives have led to a growing demand for "clean label" products, which emphasise natural ingredients and transparency. This trend challenges food industries to balance functionality with consumer expectations.

Fill in the blank: Regulatory bodies establish acceptable daily _____ (ADIs) to ensure safe levels of additive use.

5.5.3 Applications in product innovation and industrial food processing

Food industries actively harness vitamins, pigments, flavours, and additives to develop innovative products. Fortification with vitamins addresses nutritional deficiencies, while natural pigments are used to create visually appealing products without synthetic colourants. Flavour development

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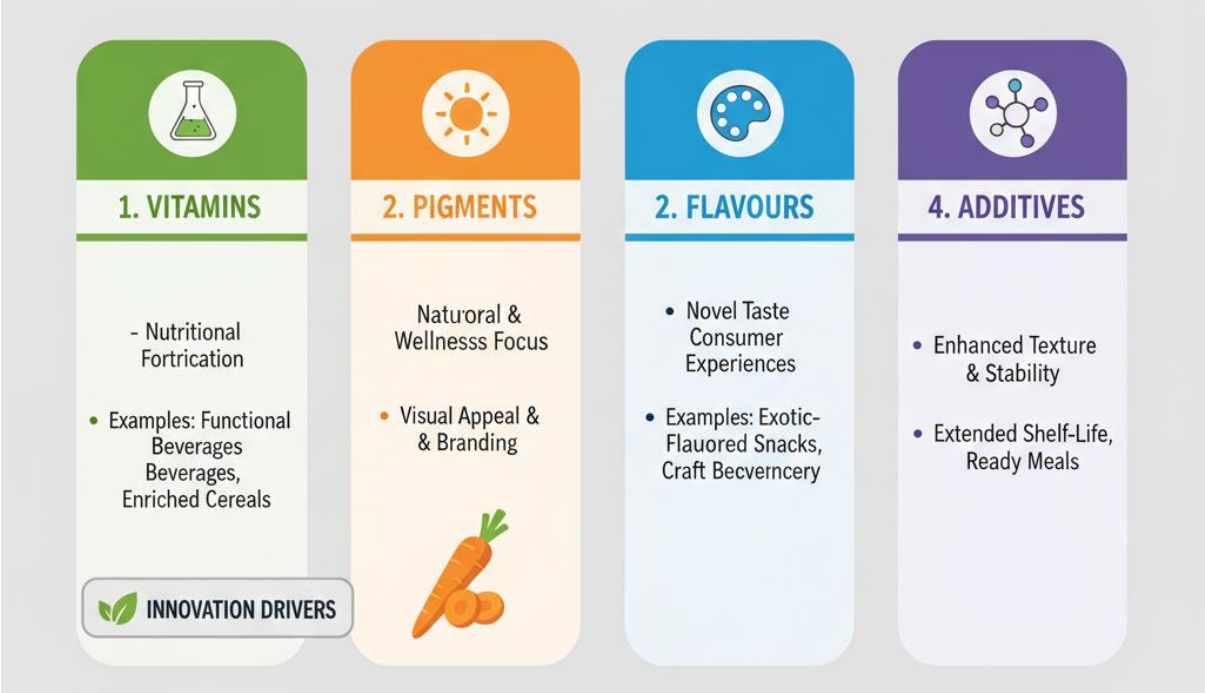
through controlled Maillard reactions or fermentation allows for unique taste profiles in baked goods, beverages, and dairy products.

Additives such as stabilisers and emulsifiers are critical in industrial processing, ensuring product consistency and extending shelf life. For example, lecithin in chocolate prevents fat separation, while preservatives in packaged foods reduce spoilage. These applications highlight how food technologists transform potential challenges into opportunities for innovation.

Box 5.1 Applications of vitamins, pigments, flavours, and additives in product innovation.



Fill in the blank: Fortification with vitamins is used to address nutritional _____ in populations.

Pilot questions 5.5

1. How do vitamins, pigments, flavours, and additives contribute to food quality?
2. What is one challenge associated with nutrient stability in foods?
3. Why are consumers increasingly concerned about artificial additives?
4. Give one example of how additives are used in industrial food processing.
5. Mention one way food industries use pigments or flavours in product innovation.

Series Summary

This Series has explored the essential roles of vitamins, natural pigments, flavours, and additives in foods, highlighting their importance for nutrition, sensory appeal, safety, and product innovation. We began by examining vitamins, their classification, nutritional functions, and

methods of analysis. Then we moved on to natural pigments, considering their occurrence, functions in food quality, and analytical techniques. Following that, we studied flavours, looking at natural compounds, flavour formation during processing, and methods of evaluation. We continued with food additives, discussing their classification, functional roles, and safety considerations. Finally, we concluded with the broader implications of these components for food quality and product development, including both opportunities and challenges.

By completing this Series, you should now be able to define and classify vitamins, explain their nutritional roles, identify and analyse natural pigments, describe flavour compounds and their development, demonstrate methods for flavour and pigment analysis, classify food additives and evaluate their safety, and analyse the overall implications of these components for food quality and innovation. These abilities directly reflect the Series Learning Outcomes (SLOs 5.1 to 5.9), equipping you with practical knowledge and skills to assess, monitor, and apply vitamins, pigments, flavours, and additives effectively in food systems.

Glossary of Terms

Acceptable daily intake (ADI): The maximum amount of a food additive that can be consumed daily over a lifetime without posing health risks, as established by regulatory bodies.

Additives: Substances intentionally added to foods to improve quality, safety, shelf life, flavour, colour, or texture.

Aldehydes: Organic compounds that contribute to fruity and floral flavours in foods, such as vanillin in vanilla.

Anthocyanins: Water-soluble pigments responsible for red, purple, and blue colours in fruits and vegetables, with colour changes influenced by pH.

Betalains: Natural pigments found in beetroot and cactus fruits, divided into betacyanins (red-violet) and betaxanthins (yellow-orange).

Carotenoids: Yellow, orange, or red pigments in foods such as carrots and tomatoes, some of which act as antioxidants and precursors to vitamin A.

Chlorophylls: Green pigments in plants essential for photosynthesis, responsible for the colour of leafy vegetables.

Colourants: Additives used to enhance or restore the colour of foods, which may be natural or synthetic.

Electronic noses: Instruments that mimic the human sense of smell using sensor arrays to detect volatile flavour compounds.

Essential oils: Volatile compounds extracted from plants such as citrus fruits and herbs, contributing distinctive aromas to foods.

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Esters: Organic compounds responsible for sweet and fruity flavours, such as isoamyl acetate in bananas.

Flavour enhancers: Additives that intensify the taste of foods without adding a flavour of their own, such as monosodium glutamate (MSG).

Fortification: The process of adding vitamins or minerals to foods to improve their nutritional value and address deficiencies.

Gas chromatography (GC): An analytical technique used to separate and identify volatile flavour compounds in foods.

High-performance liquid chromatography (HPLC): A precise analytical method used to separate and quantify individual vitamins and pigments in foods.

Monosodium glutamate (MSG): A flavour enhancer commonly used to intensify savoury notes in foods.

Natural flavour compounds: Chemical substances naturally present in foods that contribute to taste and aroma, including essential oils, aldehydes, and esters.

Pigments: Natural compounds that give foods their characteristic colours, such as chlorophylls, carotenoids, anthocyanins, and betalains.

Preservatives: Additives that inhibit microbial growth or chemical changes, extending the shelf life of foods.

Sensory evaluation: A method of assessing food quality based on human perception of taste, aroma, texture, and overall acceptability.

Spectrophotometry: An analytical technique that measures how much light a sample absorbs, often used to determine vitamin or pigment concentration.

Stabilisers: Additives that maintain the uniform dispersion of ingredients in foods, preventing separation and ensuring consistent texture.

Vanillin: An aldehyde compound that provides the characteristic flavour and aroma of vanilla.

Concept Check Questions [Series 5]

Objective Questions

1. Which vitamins are classified as fat-soluble? (Linked to SLO 5.1)
2. What pigment group is responsible for the green colour of leafy vegetables? (Linked to SLO 5.3)
3. Isoamyl acetate is an ester responsible for the flavour of which fruit? (Linked to SLO 5.5)
4. Monosodium glutamate (MSG) is an example of which class of food additives? (Linked to SLO 5.7)

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5. Which analytical technique is widely used to separate and quantify individual vitamins and pigments? (Linked to SLO 5.4)

Short-Answer Questions

6. Define vitamins and explain their importance in food systems. (Linked to SLO 5.1)
7. Describe one nutritional function of carotenoids. (Linked to SLO 5.3)
8. Explain how the Maillard reaction contributes to flavour development in foods. (Linked to SLO 5.5)
9. Identify one functional role of preservatives in food processing. (Linked to SLO 5.7)
10. Mention two consumer concerns about synthetic additives. (Linked to SLO 5.8)

Long-Answer Questions

11. Analyse the contributions of vitamins, pigments, flavours, and additives to food quality and consumer appeal. (Linked to SLO 5.9)
12. Demonstrate how analytical techniques such as spectrophotometry, chromatography, and sensory evaluation can be applied to study vitamins, pigments, and flavours in foods. (Linked to SLO 5.2, 5.4, 5.6)
13. Evaluate the challenges and opportunities associated with the use of food additives in modern food systems. (Linked to SLO 5.8, 5.9)

Answers to Concept Check Questions [Series 5]

Objective Questions

1. Vitamins A, D, E, and K.
2. Chlorophylls.
3. Banana.
4. Flavour enhancer.
5. High-performance liquid chromatography (HPLC).

Short-Answer Questions

6. Vitamins are essential organic compounds required in small amounts to regulate biochemical processes and maintain health. They are important in food systems for nutrition, stability, and sometimes sensory qualities.
7. Carotenoids act as antioxidants, protecting cells from oxidative damage, and some serve as precursors to vitamin A.

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8. The Maillard reaction produces complex flavour compounds during heating, giving baked bread, roasted coffee, and grilled meat their characteristic taste.

9. Preservatives inhibit microbial growth and chemical changes, extending shelf life and reducing food waste.

10. Consumers worry about potential health risks and prefer "clean label" products with fewer synthetic additives.

Long-Answer Questions

11. *Basic response:* Vitamins enhance nutrition, pigments provide colour, flavours create taste and aroma, and additives improve texture and shelf life. Together, they contribute to food quality and consumer appeal.
Value-added response: Beyond these basics, industries use fortification to address deficiencies, natural pigments to replace synthetic colourants, controlled flavour development to create unique profiles, and additives to ensure consistency in industrial processing. These applications highlight innovation in food systems.

12. *Basic response:* Spectrophotometry measures vitamin and pigment concentration, chromatography separates and quantifies compounds, and sensory evaluation assesses flavour perception.
Value-added response: Outstanding learners will note that combining these methods provides both objective and subjective insights. For example, HPLC can quantify carotenoids, while sensory panels confirm whether colour and flavour are acceptable to consumers, ensuring comprehensive quality assessment.

13. *Basic response:* Additives improve shelf life, flavour, and texture but raise safety and consumer perception concerns.
Value-added response: In addition, the demand for natural and "clean label" products creates opportunities for innovation. Food industries are developing natural alternatives, improving transparency in labelling, and balancing functionality with consumer expectations, which shapes the future of product development.

Answers to Pilot Questions [Series 5]

Part 5.1: Vitamins in foods: types, functions, and analysis

1. Vitamins are essential organic compounds required in small amounts to regulate biochemical processes and maintain health.

2. Fat-soluble: A, D, E, K; Water-soluble: B-complex and C.

3. Vitamin A supports vision and immune function.

4. Vitamin C.

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5. Spectrophotometry and titration.

Part 5.2: Natural pigments in foods: occurrence and significance

1. Chlorophylls, carotenoids, anthocyanins, and betalains.
2. Chlorophylls.
3. They appear red in acidic conditions and blue in alkaline environments.
4. Carotenoids act as antioxidants and some serve as precursors to vitamin A.
5. Spectrophotometry and chromatography.

Part 5.3: Flavours in foods: sources and development

1. Natural flavour compounds are chemical substances that contribute to taste and aroma; example: essential oils.
2. Vanillin.
3. It produces complex flavour compounds during heating, giving foods like bread and coffee their characteristic taste.
4. Lipases.
5. Gas chromatography and sensory evaluation.

Part 5.4: Food additives: types, roles, and safety considerations

1. Food additives are substances intentionally added to foods to improve quality, safety, shelf life, flavour, colour, or texture.
2. Preservatives (sodium benzoate), colourants (carotenoids), flavour enhancers (MSG), stabilisers (lecithin).
3. They inhibit microbial growth and extend shelf life.
4. FAO, WHO, and national food safety authorities.
5. Concerns about health risks and preference for clean label products.

Part 5.5: Implications for food quality and product development

1. Vitamins enhance nutrition, pigments provide colour, flavours create taste and aroma, additives improve texture and shelf life.
2. Vitamin C is highly sensitive to heat and oxygen, leading to nutrient loss.
3. They worry about artificial additives and prefer natural alternatives.
4. Lecithin in chocolate prevents fat separation.

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5. Natural pigments are used to replace synthetic colourants, and controlled flavour development creates unique taste profiles.

References and Attributions [Series 5]

This section compiles all references and attributions for Series 5: *Vitamins, Pigments, Flavours, and Additives in Foods*. It includes general references, suggested open educational resources (OERs), and notes on AI-generated illustration prompts. The referencing style applied here follows APA guidelines for clarity and consistency.

General References

- Belitz, H. D., Grosch, W., & Schieberle, P. (2009). *Food Chemistry* (4th ed.). Springer.
- Fellows, P. (2017). *Food Processing Technology: Principles and Practice* (4th ed.). Woodhead Publishing.
- Potter, N. N., & Hotchkiss, J. H. (2012). *Food Science* (5th ed.). Springer.
- World Health Organization (WHO) & Food and Agriculture Organization (FAO). (2019). *Food additives and contaminants*. FAO/WHO Codex Alimentarius Commission.

Illustration References and Attributions

- *Figure 5.1 Classification of vitamins in foods*
  Suggested OER source: "classification of vitamins food science diagram OER."
  AI-generated prompt: "Generate a diagram showing fat-soluble vitamins (A, D, E, K) and water-soluble vitamins (B-complex, C)."
- *Figure 5.2 Major classes of natural pigments in foods*
  Suggested OER source: "major classes of natural pigments food science diagram OER."
  AI-generated prompt: "Generate a diagram showing chlorophylls (green), carotenoids (orange/red), anthocyanins (purple/blue), betalains (red/yellow) with food examples."
- *Figure 5.3 Natural flavour compounds in foods*
  Suggested OER source: "natural flavour compounds food science diagram OER."
  AI-generated prompt: "Generate a diagram showing natural flavour compounds: essential oils (citrus), aldehydes (vanilla), esters (banana)."
- *Table 5.1 Flavour formation during food processing*
  Suggested OER source: "flavour formation food processing table OER."
  AI-generated prompt: "Create a table summarising flavour formation during processing: Maillard reaction, enzymatic activity, fermentation."
- *Figure 5.4 Classification of food additives*
  Suggested OER source: "classification of food additives food science diagram OER."

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AI-generated prompt: “Generate a diagram showing food additive classes: preservatives, colourants, flavour enhancers, stabilisers with examples.”

- *Figure 5.5 Contributions of vitamins, pigments, flavours, and additives to food quality*
  Suggested OER source: “contributions vitamins pigments flavours additives food quality diagram OER.”
  AI-generated prompt: “Generate a diagram showing contributions of vitamins (nutrition), pigments (colour), flavours (taste), additives (texture/shelf life).”
- *Box 5.1 Applications of vitamins, pigments, flavours, and additives in product innovation*
  Suggested OER source: “applications vitamins pigments flavours additives food innovation OER.”
  AI-generated prompt: “Create a box listing applications of vitamins, pigments, flavours, and additives in product innovation.”

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