Chapter 2
Review of literature
2.1 Bamboo shoot

2.1.1 Nutritional potential

Bamboo belongs to the subfamily Bambusoideae in the family Poaceae and it includes over more than 1250 species, belonging to 75 genera, to which India has contributed more than 125 species belonging to 23 genera. Bamboo shoots are the immature and edible culms arising from the rhizomes. They are harvested generally at the time of June and July when the shoots are of 30 cm in height (Fig. 2.1). The edible part consists of meristematic cell tissue with regions of rapid cell division and differentiation, which is enveloped in protective, non-edible leaf sheaths. Bamboo shoot is a very traditional food for the tribal people and has been a major part of diet in Asian countries like China, Japan, Korea, Taiwan, Thailand and Philippines and its demand is growing worldwide. Bamboo shoots could be considered as an ideal vegetable as it has high nutritional properties. It is a good source of high dietary fiber and low in fat content. Bamboo shoots are also low in cholesterol content and has high amount of potassium which is a heart-healthy mineral. It is rich in many vitamins like tocopherol, vitamin C, Vitamin B₆, thiamin, riboflavin and niacin. Bamboo shoots are rich in many minerals and have 17 different types of amino acids and have excellent antimicrobial qualities. The nutritional potential of various species of bamboo shoots are given in Table 2.1.

Bamboo shoots are also well known for its medicinal values. There are number of literatures showing the medicinal and functional properties of bamboo shoot. Shoots are rich in lignans and also which have anti-inflammatory, anticancer, antibacterial, antifungal, and antiviral properties. It is very effective in reducing the risk of cancer and also prevents any injury to blood vessels. As bamboo shoots being locally available, could be a good source of nutrition for the poor people. Apart from being used as a source of food, bamboo is also used in different other fields like construction, decoration purpose, making furniture etc.
Fig. 2.1. Bamboo shoot (a) & (b) growing on bamboo plant, (c) harvested shoot and (d) peeled shoot
Table 2.1. Nutritional potential of various species of bamboo shoots

<table>
<thead>
<tr>
<th>Name of species</th>
<th>Amino acids (g/100g)</th>
<th>Proteins (g/100g)</th>
<th>Carbohydrates (g/100g)</th>
<th>Starch (g/100g)</th>
<th>Fat (g/100g)</th>
<th>Vitamin C (mg/100g)</th>
<th>Vitamin E (mg/100g)</th>
<th>Ash (g/100g)</th>
<th>Moisture (g/100g)</th>
<th>Dietary fiber (g/100g)</th>
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<tr>
<td>B. bambos</td>
<td>3.98±0.02</td>
<td>3.57±0.03</td>
<td>5.42±0.02</td>
<td>0.25±0.04</td>
<td>0.50±0.02</td>
<td>1.90±0.08</td>
<td>0.61±0.05</td>
<td>1.38±0.03</td>
<td>89.83±0.08</td>
<td>3.54±0.02</td>
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<td>B. kingiana</td>
<td>3.70±0.095</td>
<td>3.57±0.08</td>
<td>5.45±0.12</td>
<td>0.34±0.03</td>
<td>0.35±0.03</td>
<td>2.10±0.12</td>
<td>0.50±0.10</td>
<td>1.38±0.23</td>
<td>90.00±1.02</td>
<td>4.49±0.06</td>
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<tr>
<td>B. nutans</td>
<td>3.89±0.04</td>
<td>2.84±0.12</td>
<td>5.47±0.05</td>
<td>0.21±0.02</td>
<td>0.40±0.02</td>
<td>1.19±0.10</td>
<td>0.47±0.06</td>
<td>0.68±0.11</td>
<td>92.00±0.23</td>
<td>2.28±0.01</td>
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<tr>
<td>B. polymorpha</td>
<td>3.42±0.02</td>
<td>3.64±0.02</td>
<td>5.44±0.05</td>
<td>0.38±0.04</td>
<td>0.46±0.03</td>
<td>2.60±0.13</td>
<td>0.49±0.12</td>
<td>0.76±0.22</td>
<td>90.26±1.68</td>
<td>3.81±0.06</td>
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<td>B. tulda</td>
<td>3.65±0.03</td>
<td>3.69±0.03</td>
<td>6.92±0.04</td>
<td>0.59±0.12</td>
<td>0.48±0.07</td>
<td>1.42±0.06</td>
<td>0.61±0.14</td>
<td>0.85±0.13</td>
<td>83.60±1.26</td>
<td>3.97±0.02</td>
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<td>B. vulgaris</td>
<td>3.57±0.04</td>
<td>3.64±0.03</td>
<td>6.51±0.05</td>
<td>0.27±0.05</td>
<td>0.50±0.01</td>
<td>4.80±0.11</td>
<td>0.52±0.10</td>
<td>1.01±0.21</td>
<td>90.60±0.82</td>
<td>4.24±0.01</td>
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<tr>
<td>D. asper</td>
<td>3.12±0.07</td>
<td>3.59±0.06</td>
<td>4.90±0.11</td>
<td>0.36±0.08</td>
<td>0.40±0.06</td>
<td>3.20±0.06</td>
<td>0.91±0.13</td>
<td>0.95±0.03</td>
<td>89.40±0.98</td>
<td>3.54±0.07</td>
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<td>D. brandisii</td>
<td>3.01±0.11</td>
<td>2.31±0.12</td>
<td>4.90±0.10</td>
<td>0.49±0.04</td>
<td>0.24±0.10</td>
<td>1.59±0.10</td>
<td>0.42±0.10</td>
<td>0.61±0.11</td>
<td>89.80±0.15</td>
<td>4.03±0.09</td>
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<td>D. giganteus</td>
<td>3.86±0.13</td>
<td>3.11±0.17</td>
<td>5.10±0.04</td>
<td>0.51±0.06</td>
<td>0.39±0.03</td>
<td>3.28±0.02</td>
<td>0.69±0.03</td>
<td>0.89±0.13</td>
<td>90.70±0.12</td>
<td>2.65±0.03</td>
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<td>D. hamiltonii</td>
<td>3.18±0.05</td>
<td>3.72±0.12</td>
<td>5.50±0.08</td>
<td>0.47±0.03</td>
<td>0.41±0.02</td>
<td>2.45±0.08</td>
<td>0.71±0.03</td>
<td>0.86±0.20</td>
<td>92.51±0.51</td>
<td>3.90±0.03</td>
</tr>
<tr>
<td>D. membranaceus</td>
<td>3.46±0.02</td>
<td>3.38±0.10</td>
<td>5.40±0.03</td>
<td>0.23±0.04</td>
<td>0.43±0.05</td>
<td>1.58±0.06</td>
<td>0.65±0.10</td>
<td>0.63±0.04</td>
<td>89.30±1.34</td>
<td>2.91±0.06</td>
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<tr>
<td>D. strictus</td>
<td>3.07±0.03</td>
<td>2.60±0.07</td>
<td>6.17±0.02</td>
<td>0.31±0.05</td>
<td>0.33±0.04</td>
<td>2.43±0.11</td>
<td>0.58±0.03</td>
<td>0.71±0.10</td>
<td>90.10±0.93</td>
<td>2.26±0.01</td>
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<tr>
<td>G. albociliata</td>
<td>3.52±0.11</td>
<td>3.05±0.11</td>
<td>4.59±0.09</td>
<td>0.31±0.04</td>
<td>0.51±0.10</td>
<td>1.00±0.08</td>
<td>0.60±0.04</td>
<td>0.73±0.04</td>
<td>89.23±0.30</td>
<td>4.15±0.11</td>
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<td>G. rostrata</td>
<td>3.17±0.08</td>
<td>3.56±0.11</td>
<td>4.32±0.11</td>
<td>0.22±0.03</td>
<td>0.56±0.12</td>
<td>3.20±0.10</td>
<td>0.49±0.05</td>
<td>0.68±0.05</td>
<td>90.56±1.02</td>
<td>4.20±0.09</td>
</tr>
</tbody>
</table>

B = Bambusa; D = Dendrocalamus; G = Gigantochloa

Source: Chongtham, et al.\textsuperscript{8}
2.1.2 Bamboo shoot processing

Bamboo shoots have high water content and thus are highly perishable. Moreover, since it is a seasonal product so it requires preservation to make the product available throughout the year. Bamboo shoots are tried to be preserved by using different methods like fermentation, canning, pickling, blanching, drying etc. It is consumed in the form of boiled, cooked, fermented and sometime roasted whole shoot. Bamboo shoots are tried to be preserved by using different methods like fermentation, canning, pickling, blanching, drying etc. It is consumed in the form of boiled, cooked, fermented and sometime roasted whole shoot.1 These processing methods are applied basically for the preservation of the shoots so that shoots could be used for a longer time than usual. But many researchers such as Kumbhare and Bhargava,9 Nirmala et al.10 have reported out that all such kind of processing methods lead to the substantial decrease in nutritional values. While decrease in carbohydrate was noticed in case of fermented and canned products, decrease in reducing sugar has been noticed on boiling. The ash content decreased on boiling, fermentation and canning of bamboo shoots. Kumbhare and Bhargava9 reported the decrease in crude protein level on various processing while decrease in amino acids has also been studied. Loss of free amino acids also takes place through leaching or may react with sugars to form complexes.11 Loss of vitamins during processing is also obvious, while loss of trace elements like Cd, Co, Cu, Mg, Mn, Ca, Fe, K, P, Na and Se were also observed.

Bamboo shoots could be dried as it reduces the water content and make it unavailable for the microbes. Study on preservation of bamboo shoots by drying has been done by many researchers. Drying decreases water activity and moisture content which plays important role towards the activity of microorganisms, which is the prime cause of food deterioration. Muchtadi and Adawiyah12 dried bamboo shoot (D. asper) in a cabinet dryer at 60°C for 7-8 h and there was significant decrease in starch and ascorbic acid recorded. However, the colour of shoots dried using superheated steam gets darker than shoots dried using hot air even at same drying temperature.13 Vacuum freeze drying is applied for preserving colour, aroma, taste and shape of foods; and product quality is comparatively good compared to convective hot airflow drying.14 Madamba15 reported a linear relationship between dimensionless volume change and moisture content during hot air drying of bamboo shoot. Shrinkage of bamboo shoot...
parallel to its fibers was different from perpendicular to its fibers. Xu et al.\textsuperscript{16} applied a two-stage hybrid drying techniques i.e. hot airflow drying followed by vacuum freeze drying and reverse of the process i.e. vacuum freeze drying followed by hot airflow drying on bamboo shoot for producing high quality product.

Bal et al.\textsuperscript{3} studied the effect of microwave drying on the colour of bamboo slices. They found that the total colour change (dE) of bamboo shoot slices increased significantly during microwave drying with drying time. Increased in microwave power level the drying rate and the effective moisture diffusivity also increased.\textsuperscript{17} Cheng\textsuperscript{18} found that the combination of vacuum drying, hydro cooling and vacuum cooling have the advantages of lower number of bacteria, a higher stability, longer preservation period and better appearance of bamboo shoot. However, combination of these methods helps to increase the cooling speed and prolong the preservation length in low temperature storage of bamboo shoot. Other kind of preservation techniques viz., modified atmospheric packaging and packaging with other packaging material such as LDPE, PVC also tried on bamboo shoot.\textsuperscript{2,19}

\section*{2.2 Blanching and its effect}

Blanching is a unit operation and a method of preservation used widely in the agro-food sector and particularly important in the processing of vegetables. Its main objective is to inactivate the various enzymes involved in the spoilage of fresh vegetables. Blanching also softens the vegetable tissues to facilitate filling into containers and removes intracellular air which increases the density of food and prevents the oxidation of canned food.\textsuperscript{20} Blanching is a short term heat treatment which serves a variety of function applied to vegetables prior to the processing. It imparts benefits such as to reduce the contaminating microorganism on the surface of vegetables and enhances the colour, texture and keeping quality of product. Despite its preserving advantage, it leads to nutrient degradation, particularly of vitamins and loss of colour. Duration and temperature of blanching inactivate particular enzymes; but over blanching might result in an undesirable loss of colour, flavour, texture and nutrient quality in addition to excessive energy requirement and water disposal.
Blanching at 95±3 °C significantly degrades the ascorbic acid and β-carotene in leafy vegetables. However, controlled blanching could contribute to retention of vitamins and nutrients in processed foods.21

The quality of blanched product depends significantly on the time and temperature of blanching. Industrial blanching process involves temperature ranging from 70°C to 95°C and time usually not higher than 10 min.22 Inactivation of peroxidase was the best indicator to assess the efficiency of blanching of vegetables. It is more resistant to the heat as compared to the other microorganism. Inactivation of enzymes responsible for off-flavor and odour of the vegetables is very important to increase their shelf life. Blanching is done to achieve the stabilization of texture and mixture quality and destruction of microbial load. However, since blanching is a heat treatment that might affect the structural and integrity of the plant tissue as well as the nutritional components.23

The improvement in texture by the changes occurred in cell wall and middle lamella by the increase in enzyme activity (pectin methylesterase) during low temperature and long duration hot water blanching. It also helps in the wilting of leafy vegetables.24 Some researchers have found that the blanching conducted at temperature higher than 80°C catalyze the degradation of pectin due to elimination reaction and their solubilization from the cell wall and the middle lamella between adjacent cell wall.25 The two most widespread and suitable initial operation involve passing food through an atmosphere of saturated steam or hot water bath. Blanching at different time and temperature combinations has different impact on antioxidant, total phenolic content and other nutrients.26 Different studies have showed that steam blanching have advantages over hot water blanching as most of the soluble material leached out into the water during hot water blanching. Higher temperatures for shorter time intervals have minimal loss of nutrients including total solid, vitamin, amino acid etc.27

Green leafy vegetable reduces their antioxidant properties drastically during hot water blanching.28 Gonçalves et al.29 studied the kinetics of peroxidase thermal inactivation, total phenolic content degradation, colour and texture changes during blanching of carrot in a temperature range of 70–90 °C. Most of the changes were
described by a first-order reaction model. Song et al.\textsuperscript{30} recommended that blanching at a high temperature and short time is significant, as they found minimal losses of nutritive components including sugars, vitamins B\textsubscript{1}, B\textsubscript{2}, and C, were minimal at 100 °C for 10 min compared to blanching at 80 °C for 30 min, 90 °C for 20 min. Blanching at 80 and 100 °C caused a significant reduction in firmness and colour of cabbage. However, the temperature effect followed the Arrhenius law, with activation energies for polyphenolic content, antioxidant capacity, colour and texture 9.22–11.5, 9.05–35.05, 15.73 and 33.8 kJ/mol K, respectively.\textsuperscript{22}

\subsection*{2.3 Osmotic dehydration}

\subsubsection*{2.3.1 Mechanism and importance}

Osmotic dehydration is a process that is generally used for the partial removal of water of materials like fruits and vegetables and water diffusion takes place through a semi-permeable membrane. The main phenomenon observed during osmosis is mass transfer between food and surrounding solution.\textsuperscript{31} During osmotic dehydration water is removed from fruits and vegetables with the help of hypertonic solution of sugar, salt or any other osmotic agent. The higher osmotic pressure of the hypertonic solution, force the water to move from the tissue into the solution by creating driving force. The two major counter-current flows occur during osmotic dehydration. In one flow water flow from the tissue into the solution and in another solute is transferred from the solution into the food.\textsuperscript{15} Osmotic dehydration is an energy efficient method of partial dehydration, since there is no need for a phase change.\textsuperscript{32} Osmotic dehydration is useful as a treatment for drying, preventing colour changes due to enzymatic oxidation and the loss of volatile compounds, and reducing the acidity and damage caused by the heat\textsuperscript{33-34}

Osmotic dehydration could also be used as a pre-treatment to many processes like freezing, freeze drying, vacuum drying or air drying and it has been established as one of the most useful pretreatments for drying of fruit and vegetables. It could be carried out at ambient temperature, which helps to improve nutritional, sensorial and functional properties of food and minimum damage to texture, colour and flavour.\textsuperscript{35}
Osmotic dehydration also helps to reduce the water activity of many food materials so that microbial growth will be inhibited. The rate of water loss (WL) and solids gain (SG) during osmotic dehydration is depends on several factors such as solution concentration, temperature, contact time, level of agitation, sample size, solution to sample ratio etc. However, the choice of solutes and its concentration depend on several factors, namely the effect on organoleptic quality properties, solute solubility, cell membrane permeability, its stabilizing effect and cost.

2.3.2 Selection of solutes

The solutes used as osmotic agent affects the final product’s taste, its organoleptic qualities, the preservative effect and the cost. Sugars and salts are two most widely used solute types for osmotic dehydration, with relevance for sucrose and sodium chloride. Sometimes their mixture is also used but the concentrations used depend on the type of food material to be dehydrated. It has been reported earlier that combined solutions of these two substances could be used to enhance water removal with low solids gain by the products. Generally salt is preferred for dehydration of vegetables and meat as sugar gives a candying effect which is not acceptable in case of meat and vegetables. Similarly sugar is used for the dehydration of fruits. Addition of small quantities of sodium chloride to osmotic solutions increased the driving force of the drying process and synergistic effects between sucrose and sodium chloride. Apart from sugar and salt, other agents like corn syrup, glucose and fructose are also used.

2.3.3 Factors affecting osmotic dehydration

Osmotic dehydration is mainly used for the purpose of water removal and so the efficiency of the process depends on the rate and extent of water removed from the material during the process. The rate of diffusion of water from any material made up of such tissues depends upon factors such as: temperature and concentration of the osmotic solution, the size and geometry of the material, the solution-to-material mass ratio and the level of agitation of the solution. These factors determine the extent to which the
different mass transport mechanisms act in the tissue and their influence on the overall mass transfer rate, solids gain, water loss, and also the structural changes.

The size and shape of the food sample also plays a major role in mass transfer due to different surface area or surface to thickness ratio. Agitation has a positive effect on the rate of diffusion also it helps to speed up the water removal process since agitation provides better contact between the sample and the solution. Agitation was used to reduce the mass transfer resistance at the surface of the carrots and to ensure good mixing and close temperature uniformity and control in the osmotic medium. The solute used and its molecular weight also affects the process. The osmotic solute to be used generally should be of low molecular weight and it should have high dissolving property in water. Smaller the size of the osmotic solute, larger will be its penetrating property. Generally salt and sucrose are used. The salt presence promotes a faster osmotic dehydration of tissues than sucrose, due to its greater water activity depression power. On the other hand sugar even though it is considered to be a good agent, because of its bigger size, it has less diffusivity and thus in comparison to salt, its effect is less.

Another factor is the immersion time. It has been seen from many studies that the water loss is linearly affected by immersion time. Time has a significant effect on solids gain (sugar uptake) and moisture loss; while for the mass gain, time has no effect. The sample to solution ratio also has significant effect on the osmotic dehydration process. Higher osmotic solution/fruit ratio favored higher moisture removal. The sample to solution ratio generally varies depending on the sample size. In osmotic dehydration of sugar beet in combined aqueous solutions of sucrose and sodium chloride in order to avoid dilution of osmotic solution and subsequent decrease of driving force for osmotic dehydration, the weight ratio between sample and osmotic solution was 1:10.

2.3.4 Mass transfer during osmotic dehydration

During osmotic dehydration the dominant resistance to the mass transfer is semi-permeable cell membranes of fruits and vegetables. During this process the
material is soaked in different osmotic solution as per requirement. The difference of chemical potential between the components in the solution and the material leads to three mass transfer flows:

- Transfer of water from the material to the osmotic solution.
- Transfer of solutes from the solution into the material.
- Transfer of soluble solids from the material to the osmotic solution.

The last flux is often considered negligible, but can affect the organoleptic and nutritional characteristics of the product.49

Due to the difference of osmotic pressure inside and outside of the cells, part of mass transfer process takes place through the cell membranes. However, other mass transfer phenomena take place during the process is convective movement and diffusion of substances in the soaking solution and in the intercellular spaces filled with liquid in the material, liquid movement through the pores due to capillary forces, symplastic transport between cells, etc.50-51

Modelling of mass transfer process during osmotic dehydration is important for an adequate control of composition of the resulting dehydrated material and to reduce the experimental work. Various authors have used different approaches for modelling the osmotic dehydration process. Panagiotou et al.52 used an empirical approach, in which the mathematical equations fitted to experimental data to obtain mass transfer coefficients. However, by considering only internal resistance to mass transfer, and using Fick’s second law of diffusion, effective diffusion coefficients could be obtained for the diffusing substances.46 The rate of diffusion of water from any material depends upon various factors such as temperature, concentration of the osmotic solution, size and geometry of the material, solution to material ratio and the level of agitation of the solution.53

Sometime during mass transfer modelling different assumptions are considered, like any finite food geometry as infinite flat plate configuration, neglecting the diffusion in the other directions and out of these only a few have considered unsteady state mass transfer during osmotic dehydration. Such assumptions hold good when thickness is
very small as compared to sides indicating negligible peripheral diffusion, but practically it is impossible. Therefore it is important to take the peripheral diffusion by considering food piece as rectangular parallelepiped rather than infinite plate. Such work is done on pineapple and carrot.\textsuperscript{54-56}

The following unsteady state Fickian diffusion model can be applied to describe the osmosis mechanism for infinite flat plate (Eq. 2.1).

\[
\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial Z^2}
\]  

(2.1)

With the following assumptions and boundary conditions,

\[C = C_0 \text{ at } t = 0; \quad -l < x < +l \quad \text{and} \quad C = C_1 \text{ at } t > 0; \quad x = l\]

Where, \(C_0\) and \(C_1\) are the initial and bulk concentrations, respectively.

The solution of Fick’s second law for diffusion from a rectangular parallelepiped of sides \(2a, 2b\) and \(2c\) (cube is a special case when all the sides are equal) results in the following well-known equations for the transfer of water and solute (Eq. 2.2 & 2.3), respectively.\textsuperscript{57}

\[M_r = \frac{(m_t - m_\infty)}{(m_0 - m_\infty)} = \sum_{n=1}^{\infty} C_n^3 \exp \left\{ -D_{ew} t q_n^2 \left[ \frac{1}{a^2} + \frac{1}{b^2} + \frac{1}{c^2} \right] \right\}
\]  

(2.2)

and

\[S_r = \frac{(s_t - s_\infty)}{(s_0 - s_\infty)} = \sum_{n=1}^{\infty} C_n^3 \exp \left\{ -D_{es} t q_n^2 \left[ \frac{1}{a^2} + \frac{1}{b^2} + \frac{1}{c^2} \right] \right\}
\]  

(2.3)

Where, \(M_r\) and \(S_r\) are the moisture and solute ratio; the subscripts \(o, \infty\) and \(t\) represent relevant initial concentrations, at equilibrium, and at any time; \(D_{ew}\) and \(D_{es}\) are the effective diffusivity of water and solute, respectively, and \(C_n\) is equal to \(2\alpha(1+\alpha)/(1+\alpha+\alpha^2 q_n^2)\) where, \(q_n\)’s are the nonzero positive roots of the equation \(\tan q_n = -\alpha q_n\). Here \(\alpha\) is the ratio of volume of solution to that of each piece.

Considering only the first term of the above equations to be significant and other terms to be negligible (which can be done when the Fourier number \(= D_t/A^2\) value is
more than 0.1, and A being defined below), the equations reduces to the following equations (Eq. 2.4 & 2.5).

\[-\ln \left( \frac{M_r}{C_1^3} \right) = q_1 \frac{2}{A^2} \left( \frac{D_{ew}t}{A^2} \right) \]  
(2.4)

\[-\ln \left( \frac{S_r}{C_1^3} \right) = q_1 \frac{2}{A^2} \left( \frac{D_{es}t}{A^2} \right) \]  
(2.5)

Where, \(1/A^2 = \left[ \frac{1}{a^2} + \frac{1}{b^2} + \frac{1}{c^2} \right]\). The values of \(D_{ew}\) and \(D_{es}\) can be calculated from the slopes of the regression lines obtained by plotting \(-\ln \left( \frac{M_r}{C_1^3} \right)\) and \(-\ln \left( \frac{S_r}{C_1^3} \right)\) against t.

Calculated \(D_{ew}\) and \(D_{es}\) values can be fitted to Arrhenius type of equation to calculate activation energy (Eq. 2.6 & 2.7).

\[D_{ew} = D_{ow} \exp \left( -\frac{E_{aw}}{RT} \right) \]  
(2.6)

\[D_{es} = D_{os} \exp \left( -\frac{E_{as}}{RT} \right) \]  
(2.7)

Where, \(D_{ow}\) and \(D_{os}\) is the reference diffusivity of water and solute at infinitely high temperature, R is the ideal gas constant (J/mol K), T is temperature (K), \(E_{aw}\) and \(E_{as}\) are the respective activation energy (J/mol).

Above equations could be represented in a linear form and activation energy could be obtained from the slope of the resulting straight line.

\[\ln D_{ew} = \ln D_{ow} + \left( -\frac{E_{aw}}{RT} \right) \]  
(2.8)

\[\ln D_{es} = \ln D_{os} + \left( -\frac{E_{as}}{RT} \right) \]  
(2.9)

### 2.3.5 Effect of centrifugal force and vacuum pressure on osmotic dehydration

Application of centrifugal force and vacuum pressure to enhance osmotic dehydration process is a new trend in food processing. Azaura et al.\(^{60}\) showed that application of centrifugal force enhances the water loss from potatoes and apples and limits the uptake of solids undergoing osmotic dehydration. Amami et al.\(^{45}\) reported that the centrifugal force permits the better dehydration (higher WL) and limits the solids uptake (smaller SG) compared to general osmotic dehydration. However, centrifugal force, in combination with pulsed electric field and salt addition, significantly enhances
water loss during osmotic dehydration of carrots, but decreases SG, rehydration capacity, and firmness of the rehydrated tissue.

The osmotic process can be performed at atmospheric pressure or with vacuum pulse application for a small period at the beginning of the process. Due to application of vacuum the water loss and solid gain are higher during start of the process. By applying vacuum pressure, an outflow of internal gas or liquid from the tissue and the entrance of external solution are established that promotes water loss and the uptake of external solutes. The kinetics of osmotic dehydration under vacuum are reported to be quicker than at atmospheric pressure. Rastogi and Raghavarao also found the same result and concluded that vacuum affects only the rate at which the equilibrium is attained and not the equilibrium osmotic pressure as such.

Corrêa et al. stated that the effects of pressure conditions on the mass transfer kinetics were clearly observed only with the application of the vacuum pulse during 15 min at the beginning of the process. Several studies have shown that when a vacuum pulse is applied for 5 to 10 min the mass transfer rate can increase when atmospheric conditions are re-established. However, Fermín and Corzo found that a vacuum pulse of less than 300 mbars applied during osmotic dehydration had no significant effect on solid gain (SG) and weight loss (WL) of melon (Cucumis melo L.). Shi et al. performed same kind of experiment to check the diffusivity and porosity of the sample and concluded that Osmotic dehydration under vacuum makes it possible to obtain a higher diffusional rate of water transfer at lower solution temperatures, and that fruits with higher porosity are more suitable for treatment with vacuum treatment.

According to Maneepan and Yuenyongputtakal, the operation is carried out in two steps after product immersion in a container during the liquid phase. In the first step, vacuum pressure is imposed on the system for a short time in the closed container, thus promoting the expansion and outflow of internal gases in the product. In the second step, atmospheric pressure is restored in the container leading to a great volume reduction of the gas remaining in the pores, and thus to the subsequent influx of external liquid into the porous structure. The application of vacuum osmotic dehydration (VOD) can reduce the process time and energy costs. Pulsed-vacuum osmotic dehydration (PVOD),
a variation of VOD, consists of the use of an initial VOD process for different periods followed by the application of osmotic dehydration at atmospheric pressure. Moreover, the application of a vacuum in osmotic dehydration requires an understanding of how the mass transfer, physical properties and cell structure are affected by varying the vacuum pressure level and the vacuum pre-treatment method. A sound understanding of these factors is important for the successful application of the osmotic dehydration process, for efficient treatment and it can be beneficial to the food industry.

2.4 Fermentation of bamboo shoots

2.4.1 Methods of fermentation and its microbiology

Fermented foods are not only attractive and palatable in terms of flavour, aroma, texture, and appearance but are also rich in nutrients and good for digestion. Fermented bamboo shoots are popularly consumed by ethnic people living in Himalayan regions, Nepal and Bhutan. In India, the fermentation of bamboo shoots has extensively been carried out in the states of Manipur, Meghalaya, Sikkim, Mizoram, etc. since ancient times. Traditionally bamboo shoots are fermented by grating the shoot and keeping in earthen pot for few days. At the end of fermentation, shoot becomes brown in colour and develops characteristics flavour and taste. In Manipur sliced shoots are dried in sunlight for 10 to 15 min and kept in earthen pot for 2 to 3 months for fermentation by adding small amount of water and salt. Then shoots are taken out and dried in sunlight to about 50% moisture content. In Arunachal Pradesh shoots are chopped and put in bamboo basket, covered tightly with banana leaves for 6-8 days fermentation. In another process, sliced shoots are kept in bamboo basket containing ekkam leaves at bottom. The slices covered tightly with ekkam leaves and basket is kept for 5-6 days in summer and 8-10 days in winter for fermentation. However, method and length of fermentation depends on native communities, tribes, country and product desired. In Nepal, bamboo shoots are fermented with oil and turmeric and then cooked with potato. Jiang-sun is fermented bamboo shoots product, which is a widely used traditional food in Taiwan. Some popular ethnic fermented bamboo shoots products of India are given in Table 2.2.
Lactic acid bacteria are mainly responsible for fermentation of bamboo shoots. Tamang and Sarkar\textsuperscript{81} investigated the dominant microorganism viz. \textit{Lactobacillus plantarum}, \textit{L. brevis} and \textit{Pediococcus pentosaceus} in mesu. The mesu fermentation is initiated by \textit{P. pentosaceus}, followed by \textit{L. brevis}, and finally succeeded by \textit{L. plantarum} species. \textit{L. plantarum} is the main LAB present during the fermentation of jiang-sun.\textsuperscript{82} The population distribution of dominant species in Soidon were \textit{Bacillus subtilis} 29.3\%, \textit{Bacillus cereus} 35.7\%, \textit{Bacillus pumilus} 2.6\%, \textit{Lactobacillus brevis} 9.6\%, \textit{Lactobacillus plantarum} 5.1\%, \textit{Carnobacterium sp.} 11.9\%, \textit{Enterococcus faecium} 1.2\% and \textit{Pseudomonas}.\textsuperscript{83} However, predominant functional LAB strains associated with the fermented bamboo shoot products of Northeast India (viz. mesu, soidon, soibum and soijim) were identified as \textit{Lactobacillus brevis}, \textit{L. plantarum}, \textit{L. curvatus}, \textit{Pediococcus pentosaceus}, \textit{Leuconostoc mesenteroides}, \textit{Leuc. fallax}, \textit{Leuc. lactis}, \textit{Leuc. citreum} and \textit{Enterococcus durans}.\textsuperscript{84} \textit{Ekung, eup} and \textit{hirring} are some common indigenous fermented bamboo products of Arunacla Pradesh, Northeast India. Tamang and Tamang\textsuperscript{85} isolated \textit{Lactobacillus plantarum}, \textit{L. brevis}, \textit{L. casei}, \textit{L. fermentum}, \textit{Lactococcus lactis}, and \textit{Tetragenococcus halophilus} for these products and studied their functionality.

Some film yeast viz., \textit{Saccharomyces cerevisiae} J1, \textit{Candida krusei} J2 and \textit{Candida krusei} J3 etc. were isolated from fermented bamboo shoots of Thailand. All the species tolerated 2.5\% NaCl concentration and clove extract (3\% w/v) inhibited all yeast strains within 12 h. At low concentration of 0.75\% (w/v) clove extract could inhibit film yeast in fermented bamboo shoot.\textsuperscript{86} Lactic acid bacteria strain \textit{Enterococcus faecalis} N1-33, isolated from edible fermented bamboo shoot, displayed inhibitory activity against other lactic acid bacteria and other Gram-positive food spoilage and pathogenic bacteria. The bacteriocin-activity and ability of metabolizing low cost carbohydrates of strain N1-33 is having great potential for use in food biopreservation.\textsuperscript{87}
Table 2.2. Fermented bamboo shoot product of India

<table>
<thead>
<tr>
<th>Regions</th>
<th>Local Name of Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sikkim</td>
<td>Mesu</td>
</tr>
<tr>
<td>Manipur</td>
<td>Soidon, Soibum and Soijim</td>
</tr>
<tr>
<td>Arunachal Pradesh</td>
<td>Ekung, Eup, Hikhu, Hiring and Hithyi</td>
</tr>
<tr>
<td>Meghalaya</td>
<td>Lung-siej or Syrwa</td>
</tr>
<tr>
<td>Orissa</td>
<td>Kardi, Handua</td>
</tr>
<tr>
<td>Tripura</td>
<td>Godhak</td>
</tr>
<tr>
<td>Assam</td>
<td>Khorisa, Miyamikhri</td>
</tr>
</tbody>
</table>


2.4.2 Influence of fermentation on bamboo shoots

Nirmala et al. studied the changes in nutrient components in shoots (*Dendrocalamus giganteus*) after fermentation and canning. The freshly harvested shoots were richer in nutrient components as compared to canned and fermented shoots. Fresh shoots have higher quantities of macronutrients such as amino acids, proteins, carbohydrates, fat and fibre than the fermented and canned shoots except vitamins (C and E) and mineral elements like calcium, iron, potassium and phosphorous. Nutritional profiles for fresh and fermented shoot are given in Table 2.3.

Carbohydrate, an ideal source of energy was found to be decrease by 70% after fermentation of shoot. Ash content slightly decreased during fermentation. The crude fibre content increased significantly during fermentation. However, fermented shoots contained more amount of acid detergent fibre (3.28 g/100 g fresh wt) and lignin compared to the raw shoots. The fermented shoots have higher amounts of cellulose (18.5%) than the raw shoots. Fermentation also leads to decrease in crude protein, amino acid and fat. Vitamin C and E content in fermented shoot reported as 1.090 and 0.210 mg/100g which was significantly less compared to fresh shoot. However, fermented shoots showed same amount of Cd, Co, Mn, Ni, P and Se content as in the raw shoots.
Table 2.3. Comparisons of fresh and fermented shoot of *D. giganteus* (g/100g)

<table>
<thead>
<tr>
<th>Nutrients</th>
<th>Fresh shoots</th>
<th>Fermented shoots</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amino acids</td>
<td>3.863</td>
<td>2.005</td>
</tr>
<tr>
<td>Proteins</td>
<td>3.108</td>
<td>2.570</td>
</tr>
<tr>
<td>Carbohydrates</td>
<td>5.103</td>
<td>1.504</td>
</tr>
<tr>
<td>Moisture</td>
<td>90.70</td>
<td>88.83</td>
</tr>
<tr>
<td>Fat</td>
<td>0.387</td>
<td>0.315</td>
</tr>
<tr>
<td>Ash</td>
<td>0.890</td>
<td>0.780</td>
</tr>
<tr>
<td>Starch</td>
<td>0.506</td>
<td>0.455</td>
</tr>
<tr>
<td>Nutrient dietary fibre</td>
<td>2.645</td>
<td>4.180</td>
</tr>
<tr>
<td>Acid Detergent Fibre</td>
<td>2.150</td>
<td>3.280</td>
</tr>
<tr>
<td>Lignin</td>
<td>0.560</td>
<td>1.398</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>0.495</td>
<td>0.900</td>
</tr>
<tr>
<td>Vitamin C (mg/100g)</td>
<td>3.280</td>
<td>1.090</td>
</tr>
<tr>
<td>Vitamin E (mg/100g)</td>
<td>0.690</td>
<td>0.210</td>
</tr>
</tbody>
</table>

Source: Nirmala et al. 2008

Changes in nutritional value of fermented bamboo shoot (*soibum*) of Manipur from raw shoots (*Bambusa tulda, Dendrocalamus giganteus* and *Melocanna bambusoides*) were studied by Giri & Janmejay. The process caused depletion of several amino acids, formation of diacetyl, acetoin, volatile phenols and esters, liberation of free phenols, and complete disappearance of ascorbic and aspartic acids. *Soibum* is also rich in dietary fibre, low content of lipid and absence of trans fatty acid indicated its health promoting nature. Fermentation also showed to reduce the amount of reducing sugar to a great extent by converting them to acid and leads to rises in acidity. Significant amount of K, Na, Cl, Mn, Cu etc. were present in *Soibum*.

Effect of pickling process on amino acid contents, texture, pectin and microstructure of bamboo shoots were studied by Zheng et al. The amino acid content of fresh bamboo shoots decreased from 16.35 g/100 g of dry weight to 6.89 g/100 g and
7.91 g/100 g of dry weight with pickling of bamboo shoots with different salt concentrations (8% and 20%) respectively. The texture of bamboo shoot decreased by 60% and 47% after 90 days of pickling process for both salt concentrations and protopectin contents of such shoot decreased by 64% and 49%, respectively.

Fermented bamboo shoots are an enriched source of phytosterol. Sarangthem & Singh\(^9^4\) isolated microorganisms from the fermented bamboo shoot (soibum exudates) which involved in microbial bioconversion of phytosterol during fermentation. Those microorganisms were *Bacillus subtilis, B. licheniformis, B. oagulans* and *Micrococcus luteus*. Concentration of phytosterol was reported to increase from 0.18 to 0.61 % dry wt during fermentation of *Bambusa balcooa* shoots. However, all the isolated microorganisms were responsible for bioconversion of metabolites from fermented bamboo shoots into phytosterols.

Fu et al.\(^9^5\) analyzed volatile aroma active components in fermented bamboo shoots using gas chromatography and mass spectrometry. Static and dynamic headspace extractions of volatile compounds were conducted by solid phase microextraction (SPME) and by cryogenic focusing purge and trap extraction. The gas chromatography detected a total of 29 aroma-active peaks were in bamboo headspace. The 10 most important components were p-cresol, methional, 2-heptanol, acetic acid, (E,Z)-2,6-nonadienal, linalool, phenyl acetaldehyde, and three unknowns. Also SPME and purge and trap extraction method identified 70 various volatile compounds, which includes acetaldehyde, 4-ethylbenzaldehyde and several others.

Bamboo shoot contains cyanide in varying proportions. It contain up to 0.16% total cyanide in the tip and 0.01% in the base.\(^9^6\) However, cyanide content is reported to decrease substantially following harvesting. Different modern and traditional bamboo shoot fermentation methods help to decrease the cyanide contents. Adi women of Arunachal Pradesh use banana leaves for semi-fermentation of shoots and pressed under stones near water stream for 3-4 months to reduce bitterness.\(^6\)

Fermented bamboo shoots also use as preservative in nuggets prepared from desi spent hen for extending its shelf life. Lean meat of desi spent hen was minced and blended along with other non-meat ingredients and fermented bamboo shoot (10%). The
emulsion stability, cooking yield, moisture, crude protein, total ash and sensory score of nuggets added with fermented bamboo shoots were reported significantly high (p<0.01) compared to the normal (control) nuggets. However, storage studies of nuggets showed lower value of pH and thiobarbituric acid as well as total plate count, psychrophillic count and yeast and moulds counts were reported less in fermented bamboo shoots treated nuggets in comparison to control products.97

2.4.3 Traditional fermented bamboo shoot products of Assam

Microbial preservation of bamboo shoots refers to extend in storage life and enhanced safety of foods using the natural micro flora and their antibacterial compounds. The people of Assam have been using Lactic acid fermentation of bamboo shoots to enhance their shelflife without the aid of modern amenities like refrigeration, canning and vacuum packaging. Fermentation of bamboo shoots extends their shelflife for over a year or even sometimes more. The fermented shoots are used in local cuisines, as medicine and in pickle making. These techniques of bamboo shoot fermentation have been perfected over hundreds of years based on trial and error. The local people might not be able to explain the scientific side of these processes like the biochemistry or the microbiology, but, they know how to provide favourable conditions for the fermentation and thereby promote beneficial microbial growth for getting the desired fermented product. These products include Khorisa, Poka Khorisa, Khorisa Pani, Kahudi and Miyamikhri. Traditionally bamboo shoot fermentation is done in earthen pots as shown in Fig. 2.2. Bamboo has been a very significant resource plant in the life of the ethnic populace, its usage extending and visible in every aspect of their existence in this region. Such usage is also observed at every place wherever bamboo is available as a natural resource.
2.4.3.1 Khorisa

*Khorisa* is an ethnic fermented bamboo shoot of Assam. It is produced during the monsoons, when bamboo shoots are available. The process of making *khorisa* is quite similar to some of the other bamboo shoot fermentation techniques of the Northeastern regions. The bamboo shoots are harvested and then the outer surface is peeled off and the white inner part is used for making *khorisa*. The bamboo shoots are then washed and hammer-milled in a traditional wooden husking pedal called as *dheki*. It breaks down the bamboo shoots into mash of pulp. This is then packed inside earthen pots. The pots are smoked prior to packing. In some regions small dried pieces of *Garcinia pedunculata* Roxb., locally known as *borthekera* are mixed along with the bamboo shoot pulp as an acidifier. Additionally, dried chillies are also placed inside the earthen pots along with small amount of water. All the ingredients are mixed and
mildly pressed into the earthen pots and then mouth is tied with banana leaves (Fig. 2.3(a)). The entire system is made facultatively anaerobic. It is then allowed to ferment naturally for a period of 4-12 days depending upon shoot species, regions and locality. A mild acidic taste and sour smell indicate the completion of fermentation, and the entire pulp is removed from the pots. The excess water is removed by pressing and is sun dried for 2-3 days. When the moisture content reduces substantially and the product becomes crispy, it is stored in jars for further use. It is used in the traditional cuisines like fish, meat, and sweets. The cuisines cooked with *khorisa* are a good appetizer for the indigenous population (Figure 3a). The method of *khorisa* preparation is somewhat similar to *soidon*, a fermented bamboo shoot product of Manipur and group of Lactobacillus species are mainly responsible for fermentation of bamboo shoot.  

### 2.4.3.2 Poka khorisa

*Poka khorisa (khorisa tenga)* is also an ethnic fermented bamboo shoot of Assam. It is whitish in colour with a faint aroma and sour taste. However, it is not dry and crispy like *khorisa* and moist in nature. The smell and taste of *poka khorisa* is a real appetizer for the indigenous population of Assam. Locally grown young edible bamboo shoots of Bhaluka baah (*Bambusa balcooa*), Kako baah (*Dendrocalamus hamiltonii*) are defoliated, hammer-milled in a traditional wooden husking pedal called as *Dheki*. The bamboo shoots are then mixed with dried *Garcinia pedunculata* Roxb. (*Borthekera*) and dried chillies, and are packed inside pre-roasted earthen pots and pressed mildly. The mouth of the earthen pot is tied with banana leaves, and is left to ferment anaerobically for 4-12 days. Completion of fermentation is indicated by the typical *poka khorisa* smell. The pulp is taken out and the excess water is soaked out by pressing, and then the solid fermented product is stored in jars. It is used in cuisines, pickle making and as medicine. *Poka khorisa* is also mixed with edible oils, chillies and salt (pickled) and can be kept in closed containers for up to two years. The non-pickled fermented *poka khorisa* can also be kept in closed jars for more than a year. Like *khorisa*, group of Lactobacillus species are mainly responsible for *poka khorisa* preparation (Fig. 2.3(b)).
2.4.3.3 Khorisa pani

*Khorisa pani* is another ethnic fermentation product of Assam. However, it is not solid in nature like *khorisa* or *poka khorisa*. It is liquid in nature and has a sour acidic taste, similar to *poka khorisa* (Fig. 2.3(c)). It is produced during the fermentation of bamboo shoots. When bamboo shoots are fermented in earthen pots, a sour liquid is produced. When the fermentation process is stopped the produced liquid is collected in bottles and is used in making curry, meat, sour fish curry, etc. The liquid however, does not stay good for more than 7 days. The liquid is usually used up within a week, and any remaining liquid is discarded. The *khorisa pani* is also thought to possess medicinal properties. This liquid is fed to children who suffer from measles or chicken pox. It is believed that, the liquid helps in quick de-pigmentation of pox marks.

2.4.3.4 Kahudi

*Kahudi* is one of the traditional fermented bamboo shoot products mainly consumed by people of the river island Majuli of Assam. Mustard seeds are kept submerged in *khorisa pani*, the sour liquid that is collected after fermentation of *poka khorisa*. The seeds are kept submerged for 3-4 days in the liquid. Then it is taken out and sun dried for a day and then mixed with *khorisa pani* again and then blended into a paste (Fig. 2.3(d)). The paste is then transferred to a vessel and can be consumed up to 6 months.

2.4.3.5 Miyamikhri

*Miyamikhri* is one of the traditional fermented bamboo shoot product mainly consumed by tribes of North Cachar Hills district of Assam. The young edible bamboo shoots are defoliated and made into small pieces. These small pieces are wrapped in banana leaves and then put in earthen pot to ferment for about 4-5 days (Fig. 2.3(e)). When typical *miyamikhri* smell comes out it is shifted to a glass vessel. The local people use it for a year even as a pickle or mix with curry and serve it.
**Fig. 2.3.** Fermented bamboo shoot products of Assam, (a) *Khorisa*, (b) *Poka Khorisa*, (c) *Khorisa pani*, (d) *Kahudi* and (e) *Miyamikhri*
2.5 Antimicrobial metabolites

2.5.1 Bacteria as biopreservative

Recent approaches in preservation technology are directed towards alternative preservation offered by natural biochemical or biological systems or combinations of biological systems with a much reduced use of salt and chemical additives. This approach is in line with trends in consumer and industry demands for food products with less chemical preservatives. However, researchers searching for bacteria with new antimicrobial properties that could be used as protective starter cultures for foods, as probiotic and/or antibiotic properties. Antimicrobial metabolites of fermentation starter culture microorganisms that have the potential for use as biopreservatives in many foods that otherwise could be spoiled or involved in foodborne diseases from the growth of undesirable microorganisms. The successful fermentation of food depends on the production of antimicrobial metabolites by starter cultures. The antimicrobial activity of food-grade bacteria has long been attributed to the production of metabolites such as organic acids, hydrogen peroxide, ethanol and diacetyl. It has gradually become clear, however, that additional metabolites often contribute to the antimicrobial capacity of starter cultures.

Various bacterial cultures and its metabolites are identified as antimicrobial effects against *Listeria monocytogenes* and spoilage organisms, and could be used as food preservatives. Not only food but soil of Northeast India’s, Himalaya and other countries also used for isolating microorganisms which will found an interesting source of antibacterial and antifungal bioactive substances.

2.5.2 Antimicrobial potential of lactic acid bacteria

Lactic acid bacteria (LAB) are naturally found in various food items specially in fermented vegetables, milk, meat and other traditional fermented food products in order to improve the flavour and texture of the product. They have been shown to enhance the stability and nutritional value of food products by preventing the growth of pathogenic and spoilage microbes. Therefore, they have traditionally been used as natural
biopreservatives of food and feed. An important property of lactic acid bacteria has
been their ability to elaborate certain antimicrobial proteins known as bacteriocins.
These bacteriocins are having potential usefulness as natural substitute for chemical
food preservatives in the production of foods with enhanced shelf life and safety.
Biopreservation refers to extended shelf life and enhanced safety of foods obtained by
using the natural or added microflora and their antimicrobial products.\textsuperscript{105-107}

The preservative effect of lactic acid bacteria during the manufacture and
subsequent storage of fermented foods is mainly due to the acidic conditions that they
create in the food during their development. This souring effect is primarily due to the
fermentative conversion of carbohydrates to organic acids (lactic and acetic acid) with a
concomitant lowering of the pH of the food, an important characteristic that leads to an
increased shelflife and safety of the final product.\textsuperscript{108} Lactic acid bacteria are capable of
producing a variety of antimicrobial substances, such as organic acids, alcohols, carbon
dioxide, diacetyl, hydrogen peroxide and bacteriocins. These substances are
antagonistic to a wide spectrum of microorganisms, and thus can make significant
contributions to their preservative action.\textsuperscript{109-110}

The addition of plantaricin LP84, a bacteriocin produced by \textit{Lactobacillus
plantarum} to idli batter at 1\% (v/w) level was able to retard the growth of the
pathogenic microorganisms viz. \textit{Bacillus cereus, Escherichia coli} and \textit{Staphylococcus
aureus} etc.\textsuperscript{111} Røssland et al.\textsuperscript{112} produced antimicrobial metabolites by strains of
\textit{Lactobacillus} or \textit{Lactococcus} which were effective against \textit{Bacillus cereus} in milk. Also,
\textit{Lactobacillus plantarum} isolated from raw Tenerife goats’ cheese were also screened
for the production of antimicrobial substances and the bacteriocin (plantaricin TF711)
was active against the Gram-positive bacteria \textit{Bacillus cereus, Clostridium sporogenes}
and \textit{Staphylococcus aureus}; and against the \textit{Enterobacteriaceae Shigella sonnei} and
\textit{Klebsiella pneumoniae}.\textsuperscript{113} Zhang et al.\textsuperscript{114} assessed the antimicrobial activity of
lactobacilli strains isolated from traditional Chinese fermented foods towards \textit{Shigella
sonnei, Escherichia coli} and \textit{Salmonella typhimurium}. Bacteriocin produced by
\textit{Pediococcus pentosaceus} K23-2 isolated from Kimchi, a traditional Korean fermented
vegetable is heat stable and shows wide antimicrobial activity against Gram-positive bacteria, especially *Listeria monocytogenes*.110

### 2.5.3 Metabolites extraction and purification

Burianek and Yousef115 developed a solvent extraction method to concentrate bacteriocin (lacidin) from the culture of *Lactobacillus acidophilus* OSU133. The culture supernatant fluid was mixed with different organic solvents viz., hexane, ether, chloroform, isopropanol, chloroform–isopropanol, and chloroform–methanol etc. The study shows the rapid and efficient separation of bacteriocin from culture supernatant fluid by chloroform and is effective than other solvents.

### 2.6 Microwave assisted extraction

Microwave assisted extraction (MAE) is a relatively new extraction technique, which utilizes microwave energy to heat the solvent and the sample to increase the mass transfer rate of the solutes from the sample matrix into the solvent.116 MAE has a number of advantages, e.g., shorter extraction time, less solvent, higher extraction rate and lower cost, over traditional method of extraction of compounds from various matrices, especially natural products. This is cost-effective extraction methods which could be combine with advance techniques like pressurized microwave assisted extraction (PMAE) and solvent free microwave assisted extraction (SFMAE).117

Various conventional extraction techniques viz., liquid–liquid extraction, solid–liquid, soxhlet extraction etc. are popularly used for extraction and analytical purpose.118-120 However, these conventional extraction methods are time consuming and the efficiency of extraction is very low. However, other techniques such as supercritical fluid extraction, pressurized liquid extraction, ultrasound assisted extraction, pressurized hot water extraction and microwave assisted extraction are mostly used for extraction to enhance extraction efficiency and yield. But for all these techniques elevated temperatures and pressures are needed to improve the overall extraction efficiency.121
There are two microwave technologies, namely (i) closed vessels (under controlled pressures and temperature) and (ii) open vessels (under atmospheric pressure). In closed vessels, the solvent is heated above its boiling point at atmospheric pressure to enhance its extraction rate and efficiency. This system allows temperature control and also has high sample throughput as several vessels could be used in a single extraction process. They are placed on a turntable to ensure homogenous heating. The main drawback is that volatile solutes could partition into headspace. Therefore, the vessels must be cooled to room temperature before opening to avoid loss of volatile solutes. This step increases the overall extraction time. In open systems, the maximum extraction temperature is determined by the boiling point of the solvent at that pressure.121

MAE is a simple, cheap procedure than solvent extraction method, and also has less polarity limitations for the extractant. It offers higher degree of reproducibility, simplified manipulation, shorter extraction time, lesser use of solvent and high extraction rate compared to conventional solvent extraction methods.122 Conductive and convective processes to heat the sample is used in conventional solvent extraction methods, whereas microwave heating occurs by direct energy transfer to the sample.123-124 Microwave heating is volumetric in nature so microwave irradiation efficiently produces internal heating by coupling microwaves with polar components inside the solvent and the sample. According to the cell-wall broken theory,125 there are certain solvents which are microwave transparent, while some are microwave absorbing. By using microwave transparent solvents, there is more energy for the plant material to absorb. Cellular structures contain water, which absorbs the microwave energy. This creates a sudden increase in temperature, results in the rupture of the cell wall and release of constituents into the surrounding solvent. Several studies have also used non-polar solvents which are transparent to microwave and in these cases only the sample matrix gets heated leading to release of analytes in a cold solvent.126 This shows the higher extraction of polyphenolic compounds in acetone compared to methanol, ethanol or water.127 Higher extraction of polyphenolic compounds was observed, when solvent polarity was modified by addition of water in the solvent.128 Microwave extraction shows promising advantages over conventional solvent extraction system and is an
efficient method for extracting active biological compounds. Polyphenolic compounds from waste peanut shells, grape seeds, citrus mandarin peels and tea leaves have also been successfully extracted by MAE technique.

2.7 *Garcinia pedunculata* Roxb.

*Garcinia pedunculata* Roxb. (GPR) is a globose shaped fruit with fleshy aril, found mostly in the states of Northeast India. It belongs to the genus *Garcinia* and family Clusiaceae (Guttiferae). The mature fruit is eaten cooked or raw and is locally known as Borthekera in Assam, a Northeastern State of India. The fruit of GPR is roundish red brown with a diameter ranging between 8 to 12 cm and juicy interior with edible arils. The fruit usually matures during the month of April and is collected, cut into small pieces and sun dried. Dried pieces of the fruit are stored and used by the indigenous people throughout the year. The raw and dried GPR is shown in Fig. 2.4

![Fig. 2.4. Raw and dried fruit of *Garcinia pedunculata* Roxb.](image)
The indigenous people of Northeast India use it for various medicinal uses. One survey showed that, among different plants GPR is popularly used in treating diabetes mellitus and related symptoms for the primary health care of the people living in rural Dhemaji district of Assam.\textsuperscript{137} It is also used for preparing herbal recipes during the cultural festival (Rongali Bihu) of Assam.\textsuperscript{138} In Arunachal Pradesh GPR is preserved and used for stomach disorder and for a treatment against blood dysentery;\textsuperscript{139-140} however, in Meghalaya it is consumed as raw.\textsuperscript{141} The traditional starter cultures used for preparing fermented bamboo shoot product of Manipur, India is made by mixing acidic juice extract of GPR fruit (1 to 1.5 kg) with rice washed water (10–15 L).\textsuperscript{83} Soidon is fermented bamboo shoot product of Manipur and during its preparation GPR is added in the fermenting vessel to enhance its flavour.\textsuperscript{88}

The water extract of the dried pellets of GPR are used as antidiarrhoeic and antidysenteric\textsuperscript{142} and it is rich in benzophenones, pedunculol, garcinol and cambogin.\textsuperscript{143} High antioxidant activity has been reported in GPR by Gogoi et al.\textsuperscript{144} and Mudoi et al.\textsuperscript{145} GPR is a rich source of secondary metabolites including xanthones, flavonoids, benzophenones, biflavonoids, lactones and phenolic acids with wide range of biological and pharmacological activities.\textsuperscript{146-148} The crude hexane and chloroform extracts from the fruit rinds of GPR showed antibacterial activity against food borne pathogens and spoilage bacteria such as such as \textit{Bacillus cereus}, \textit{Bacillus coagulans}, \textit{Bacillus subtilis}, \textit{Staphylococcus aureus} and \textit{Escherichia coli}.\textsuperscript{149}

### 2.8 Edible coatings and films

#### 2.8.1 Functions and materials

Edible films and coatings are thin layers of edible materials applied on food products that play an important role on their conservation, distribution and marketing. Some of their functions are to protect the product from mechanical damage, physical, chemical and microbiological activities.\textsuperscript{150} An edible coating is a thin layer of edible material formed as a coating on a food product, and this film is a preformed, thin layer,
made of edible material, which once formed can be placed on or between food components.\textsuperscript{151}

The use of films and coatings in food applications and especially highly perishable products such as horticultural produce, is conditioned by the achievement of diverse characteristics such as cost, availability, functional attributes, mechanical properties, optical properties, the barrier effect against gases flow, structural resistance to water and microorganisms and sensory acceptability. These characteristics are influenced by parameters such as the kind of material implemented as structural matrix, the conditions under which films are preformed and the type and concentration of additives.\textsuperscript{152-153}

Edible coatings and films are usually classified according to their structural material. Edible coatings and films are generally produced from renewable natural and abundant biodegradable polymeric materials such as polysaccharides, proteins, lipids, or the combination of these components.\textsuperscript{154-155} These materials are generally combined with the aim of taking advantage of the properties of each compound and the synergy between them. The mechanical and barrier properties of these films not only depend on the compounds used in the polymer matrix, but also on their compatibility.\textsuperscript{156} Various materials like carboxymethyl cellulose, casein, alginate, gum from different plant sources, pectin, starch of potato, maize, cassava, wheat gluten etc. were successfully utilized by different authors. However, CaCl\textsubscript{2} is added during coating and film preparation as a cross linking material which are affecting mechanical properties, water solubility, moisture content, film thickness etc.

Tongdeesoontorn et al.\textsuperscript{154} studied the effect of addition of carboxymethyl cellulose (CMC) in different proportion (0, 10, 20, 30 and 40 %w/w total solid) on mechanical properties of cassava starch based film. Results concluded that the addition of CMC to the cassava starch films increased tensile strength and reduced elongation at break of the blended films. The barrier and mechanical properties of corn starch-based edible film also got improved with addition of citric acid (CA) and CMC. The water vapor barrier property and the ultimate tensile strength were improved significantly as the CA percentage increased from 0 to 10% (w/w), however, with addition of CMC at
the level of 15% (w/w) the starch films showed the lowest water vapor permeability values.\textsuperscript{157} Fazilah, et al.\textsuperscript{158} prepared edible films from sago starch: alginate mixtures with ratios of 1:0, 4:1, 3:1, 2:1, 1:1 and 0:1. The physical and mechanical properties of films were modified with the addition of calcium chloride. Ghanbarzadeh et al.\textsuperscript{159} also prepared modified starch/CMC composite films and studied the effects of CMC addition on some physical properties of the resulted blend films. The addition of CMC at the level of 20% w/w starch caused an increase in the ultimate tensile strength of film without any significant decrease in the strain to break.

2.8.2 Antimicrobial and antibrowning edible films and coatings

Edible coatings might also serve as carriers of food additives such as antibrowning and antimicrobials agents, colourants, flavours, nutrients and spices. Edible films and coatings with antimicrobial properties have innovated the concept of active packaging, being developed to reduce, inhibit or stop the growth of microorganisms on food surfaces.\textsuperscript{160} Incorporating antimicrobial compounds into coating and film have been shown to be an efficient alternative in the control of food contamination, improve its safety and shelf life.\textsuperscript{161} Spoilage and pathogens could be reduced by incorporating antimicrobial agents into edible films and coatings.\textsuperscript{162} Some of the more commonly used antimicrobials include benzoic acid, sorbic acid, sodium benzoate, citric acid, lysozyme, potassium sorbate, lactoferrin, bacteriocins and plant-derived secondary metabolites, such as essential oils and phytoalexins.\textsuperscript{163-166}

Rojas-Graü et al.\textsuperscript{163} used apple puree-alginate edible coating as carrier of antimicrobial agents to prolong shelf-life of fresh cut apples. Cellulose acetate based mono and multilayer films including potassium sorbate as an antimicrobial agent were used for its controlled release during package storage.\textsuperscript{167} Natural plant extract of different commodity like olive, rosemary, onion, capsicum, cranberry, garlic, oreganum etc. could be use for the development of antimicrobial film and coating.\textsuperscript{168}

The microbiological stability of food products plays an indispensable role in its quality, but also sensory aspects are essential parameter for its acceptability. The edible films and coatings become successful to control the food browning and polyphenol
oxidase activity of food product. Polyphenol oxidase (PPO) is the main enzyme responsible for these changes in vegetable tissues that contain phenolic or polyphenolic molecules.

Some researchers have proved the effectiveness of edible films and coatings on the control of browning processes and polyphenol oxidase activity. Alginate and gellan-based edible coatings were used as carriers of antibrowning agents for application on fresh-cut apples. Significant reduction in the rates of O₂ depletion and CO₂ production was also observed in coated sample. Chitosan-coating treatments effectively retarded the enzymatic browning of minimally processed apples during storage and they effectively retarded or avoided tissue softening. Hui-Min et al. studied the effect of coating of carrageenan, carboxymethyl cellulose (CMC) and sodium alginate and their combinations on browning parameters of fresh cut peach fruits during storage at 5 °C.
References


Review of literature


