CHAPTER II

REVIEW OF LITERATURE

Literature review is a crucial component of any study based on a research topic. The chapter includes the core information pertinent to the theoretical literature and researches which were studied by the investigator. The data was collected from various secondary sources such as books, thesis, journals, and museums. Primary data was also collected by interacting with museum conservators and curators of Baroda Museum & Picture Gallery Library, Vadodara; National Museum and National Crafts Museum of New Delhi; Calico Museum, Ahmedabad; and Anne Lambert Clothing and Textile Collection of Department of Textiles, University of Alberta. Data was also collected from libraries like Smt. Hansa Mehta Library and the department of Clothing and Textiles library of The Maharaja Sayajirao University of Baroda, Vadodara; Calico Museum Library, Ahmedabad; and Cameron library of University of Alberta. Another significant source of collecting literature was through online books and research papers, and websites.

The following subsections were used to categorize and discuss the review of the literature:

2.1 Theoretical review

2.1.1. Heritage textiles

2.1.2. Deterioration of textiles

- a. Factors assisting the degradation of textiles
- b. Biodegradation of textiles

2.1.3. Preservation and conservation of textiles

2.1.4. Essential oils: Chemical composition, antimicrobial and insect repellent mode of action and its limitations and challenges

2.1.5. Nanotechnology

- a. Application of Nanotechnology for preservation and conservation of textiles
- b. Encapsulation: Methods, their mechanism, and advantages
- c. Application of chitosan as a polymer to develop essential oil nanocarriers

2.2 Research review

2.2.1. Approaches towards textile preservation and conservation

2.2.2. Application of natural agents using encapsulation method for developing antimicrobial and insect repellent properties

2.2.3. Application of chitosan as a polymer to develop essential oil nanoparticles

2.1.1 Heritage Textiles

The roots of the textile industry can be traced back to the Stone Age, where early humans used long plant fibers to create baskets and mats. From these primitive beginnings, the technique of basket making gradually evolved into weaving technology. The invention of spinning and twisting short fibers to create long threads enabled the production of textiles using materials such as wool, cotton, and silk. Later on with the development of spinning techniques, fibres like wool, cotton, and silk were used to create textiles (Hitchcock, 2016). Among the ancient civilizations, India was the first to discover colour and perfect the skill of dyeing and printing on textiles, particularly on cotton. Indian textiles remained unique commodities for trade for thousands of years in practically every region of the world (Pandey, 2016). India was the world's largest exporter of textiles starting in the 15th century. They were also given as presents to former rulers, traded commodities, or displayed at industrial exhibitions which are still displayed in the museums of the major cities across the world.

The term "Museum" comes from the Philosophy of Greek School. In India, especially in the late 19th century, the establishment of museums was regarded as the best way to increase public access to the knowledge of art and culture. They collect valuable and unique items like art, pottery, textiles, and other materials from diverse past and present civilizations and traditions. They are usually displayed in the galleries or exhibitions and some of them are preserved in storage (Pandey, 2016).

The variety of textiles in museum collections is remarkable. They are treasured for their cultural value, artistic worth, and historic interest. They are usually made of a combinations of fibres, dyes, and finishes with embroidery and non-textile materials like shell, bone, and metal are used to adorn some textiles. The fibres used in the ancient times were usually the ones obtained from natural sources like plants and animals (Hitchcock, 2016).

2.1.2 Deterioration of textiles

Among the most artefacts, textiles are the most delicate items in the museum collections. The textile artefacts are sensitive, vulnerable by a variety of factors, including light, an improper relative humidity and temperature, as well as dirt, pollution, abrasion, mould, insects, and a number of other things which easily causes damage, which results in degradation (Hitchcock, 2016).

A material degrades when it is broken down into its individual components by a physical, chemical, or biological process or a combination of these parameters (Khubaib et al., 2011). It is a major problem for all the textile materials, especially the natural ones that are obtained from plants and animals (Smith et al., 2017).

Damages on the textile can be divided into three types: Hitchcock (2016), Manek (2012) and Harmsen et al., (2021).

Physical damage: Mechanical stress brought on by improper handling, insufficient storage support, and incorrect environmental conditions results in physical damage. This includes damages such as (e.g. parts detached, broken yarns, tears, fractures, pieces missing, holes, loose parts).

Chemical damage: Chemical damage may occur as a result of the inherent qualities and compositions of textiles as well as the accelerating effects of external environmental factors. This includes deterioration such as metal tarnishing, acidity in paper or fabrics, ink corrosion, encrustation, and metal corrosion.

Biological damage: Biological damage is caused because of the activity of microbes that include bacteria, fungi; and insects. Factors like high humidity and warm temperature accelerates the action of deterioration over time. This includes damage like fractured yarns, breakage of yarns, irregular holes, stains).

2.1.2. a. Factors assisting the degradation of textiles

Many factors contribute to textile's degradation (Hitchcock, 2016). Preventive conservation plays a crucial role in avoiding agents of deterioration that can either occur naturally or be caused by external factors. Textile collections are particularly vulnerable to a variety of agents of deterioration, including:

1. Light
2. Dust, Soil and other contaminants

3. Climate (Temperature and Humidity)
4. Microorganisms and Insects
5. Display, Storage and Handling

1. Light

Light is one of the most detrimental factors to textiles and other organic materials, like paper, historical artifacts, artwork, and more. All of these items can be damaged by exposure to light. (Manek, 2012) In regions that experience intense sunlight for most of the year, the damage can be severe. Both natural and artificial light like fluorescent tubes and incandescent bulbs can cause severe harm. Colours can be bleached and fabrics can become damaged to the point of no return. One type of light degradation is caused by UV radiation. Ultraviolet light is found in natural sunlight and some artificial light sources.

When UV radiation hits a textile, it causes the fibers to break down, leading to fading and weakening of the fabric. Another type of light degradation is called photochemical gradation. The light wavelength range of 300-500 nm is mainly responsible for photo chemical degradation (Manek, 2012). This occurs when light interacts with chemicals on the surface of the textile, like dyes or finishes. This reaction produces new chemicals which can weaken the fabric and cause it to fade. Photochemical degradation is a common problem with natural fabrics like cotton and wool. Light also causes oxidation, which is a process of chemical reactions between oxygen and the textile fibers as figure 2.1. Oxidation weakens the fabric, leading to fading, discoloration, and brittleness. Incandescent lamps, also known as tungsten lamps, have little ultraviolet and blue light and are generally considered to be the safest source of light. Unfortunately, they give off a lot of heat, which can be an issue in museums, as light damage is determined by the strength of the light, the amount of ultraviolet radiation and the duration of light exposure (Buck, 1998).

The absorbed light energy can cause dyes to fade or change colour and make materials weakened or brittle as shown in figure 2.2. This damage is permanent and cannot be reversed Buck, A. (1998). It is suggested that the ideal level of lighting for textiles should not exceed 50 lux Hitchcock,A. (2016). To avoid any potential damage from UV rays, any light sources should be equipped with a filter. Limiting the amount of light exposure is recommended, such as using automatic dimmers to regulate the brightness or turning off lights when they are not needed. If possible, all daylight should be blocked out Buck, A. (1998). It is recommended to keep all the storage and display areas in the dark when not being used. Curtains, blinds, screens, and dust-sheets are cost-efficient ways to minimize the amount and time of light exposure.

Fig 2.1: Shattered weighted silk costume due to UV radiation
Picture source: https://www.canada.ca/en/conservation-institute/services/preventive-conservation/guidelines-collections/textiles-costumes.html

Fig 2.2: Exposure of light to a blue-dyed fabric causing fading
Picture source: https://www.canada.ca/en/conservation-institute/services/preventive-conservation/guidelines-collections/textiles-costumes.html

2. Dust, Soil and other contaminants

Textiles in museums are vulnerable to the damage caused by dust, dirt, and other airborne contaminants. These pollutants may enter the building through open windows and doors, or they may come from industrial sources in the environment. In addition, some materials used in the construction and decoration of the museum, such as paint, carpeting, and cleaning products, can produce pollutants from inside the museum (Hitchcock, 2016).

The problem of dust with clothing extends beyond simple aesthetics; it can also have damaging effects. Dirt being acidic in nature, attracts moisture which leads to increase in chemical activity (Manek, 2012). Furthermore, some dust particles are large enough to cut the textiles' fibres. These particles act like tiny knives, slicing into the fibres as the cloths expand and contract with the changes in humidity. Moreover, soiled or stained textiles are especially attractive to insects, rodents, and mould. For instance, the presence of silica in dirt and dust can cause damage to textiles, such as cutting and abrading of fibres, discolouration, and weakening (Hitchcock, 2016). Sulphur dioxide have a detrimental effect on textiles, such as bleaching, discolouration, and embrittlement. Hydrogen sulphide in the presence of moisture leads to darkening of lead pigments, and metals. Whereas, formaldehyde from paints can also damage dyes.

3. Climate (Temperature and Humidity)

Investigations conducted by scientists uncovered that the climate of the spot in which textile pieces are exhibited or stored has a substantial effect on them and the way they are preserved. All artworks are impacted by temperature and humidity, the two most important components of climate. Climate is determined by many factors like sunshine, precipitation, humidity and temperature dependent on the altitude, latitude, environment, closeness to the sea and mountains. It is a broad term employed to describe conditions in a wider region. Due to variations in climatic conditions across different regions, the term "microclimate" is used to refer to the specific climatic conditions within a confined area such as a city, building, or display case. Temperature and humidity have an interconnected relationship. Air can hold more moisture at high temperature than at low temperature, while the damp or dry atmospheric condition varies significantly depending on the modifications in temperature or the presence of moisture in the air. The effects of humidity on museums and their collections are not as much due to the mere presence of moisture in the air, but the extent to which the exhibits absorb or release moisture in such conditions. Relative humidity (RH) is what affects objects, and not absolute humidity. It has been found that a rise in temperature is accompanied by a 2% decrease in RH, and this relationship demonstrates how a sudden change in temperature can also cause a change in RH. It has been observed that RH has larger influence on deterioration than temperature. Humidity is responsible not only for chemical damage, but also for mechanical and biological damages.

For instance, when the relative humidity is high, textile fibres absorb moisture and expand; and if it is low, the fibres will lose water and shrink (Manek, 2012). Sudden shifts in the relative humidity can cause the fibres to swell and shrink quickly, leading to damage. When the fibers contracts and expands in response to the changing conditions, they can rub against each other, creating wear and tear. If there is dirt or dust present, it can cut through the fibers over time. High temperatures and high levels of humidity can cause the dye to bleed, change colour, or be affected by bacteria and fungi (Buck, 1998). Whereas, low humidity can cause the material to become brittle and dried out.

Storing textiles in locations where the temperature is too high and the humidity is either too high or too low will cause them to deteriorate at a quicker rate and will also attract pests (Hitchcock, 2016). It is thus recommended to store the textiles in an environment with a temperature of 65º - 75º F and a humidity of 50%. It's best to keep the level of humidity and temperature steady.

4. Microorganisms and Insects

There is an abundance of microorganisms which affects nearly everything in the world. These microbes can create either beneficial or destructive effects. Most of the time, however, they can cause harm to materials through their need for sustenance. As living organisms, microorganisms require nutrition to survive, which they get from the materials they inhabit, leading to their deterioration.

In tropical countries with humid climates, the deterioration of cultural artifacts, especially textiles, due to the presence of various microorganisms is a major issue. The fibres of the textile provide a breeding ground for these microorganisms as the chemical composition and structure of the fabric gives rise to bacterial growth. Infestations can spread pathogenic bacteria and create an unpleasant smell, as well as cause discoloration and the loss of performance properties. Natural fabrics are more vulnerable to this type of bio deterioration than synthetic ones, because of their composition and the use of starches, proteins, fats, and oils in textile finishes can also promote microbial growth. Even if only slight surface growth happens, the fabric can look unpleasant due to the presence of undesired discoloration. When the infestation is severe it can lead to the deterioration of fibers and physical modifications such as decreased strength or adaptability, which can lead to the fabric not performing up to standards. The material is also subject to chemical changes due to the enzymes generated by microorganisms for the purpose of nourishment. Fungi create microscopic spores which are always present in the atmosphere and occur in massive amounts. Since they do not have the capability to photosynthesize, they can cause damage to whatever they grow on. Most fungi need oxygen to survive, but some species are able to grow without air. This can lead to discolouring and staining of textiles. They cause a stain, if left on a textile for long cannot be easily removed. These spots on fabric can be seen in irregular shapes and of various colours such as grey, black, and green. They can even cause discoloration of fabrics and give off a musty smell. Silk is less vulnerable to damage if it has been fully degummed. Wool tends to break down more slowly, however the chemical and physical damage caused by the manufacturing process can make it more prone to damage.

Insects have been a threat to cultural properties for a very long time. In fact, the destruction caused by insects has been greater than that of fire and water, which is why not many organic antiquities have been preserved. The prevalence of insects is particularly high in tropical climates due to the warm temperatures and high humidity, causing even more destruction than in temperate zones. Fortunately, only certain insects are the greatest threats to museums. However, the main pests that feed directly on the textile materials, as well as those that feed on secondary substances, for instance on wood can still cause damage. Ranging in size from macroscopic to microscopic, various types of pests like silverfish, cloth moths, carpet beetles, flour/cigarette beetles, termites, and cockroaches are found in tropical region fig 2.3.

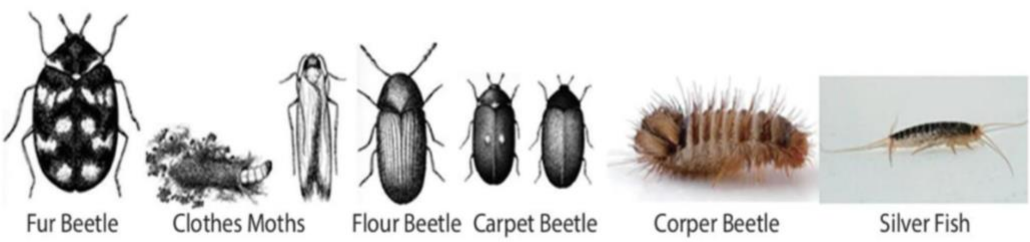

Fig 2.3: Insects causing degradation of textiles
Picture source: (Suza et al., 2022)

Silver Fish are typically white or grey with flattened scales which give them a greasy feel and a glossy look. They like to be in damp and dark places with a humidity higher than 55%, and temperatures ranging from 60-80°F. These fish consume starches such as gum, fabric sizing, and starchy and sugary items and are known to leave irregularly shaped holes from nibbling on the surface material. Cloth moths are notorious for infesting stored woollens, but they can also feed on a wide variety of other fabrics such as hair, fur, silk, and feathers. These pests can cause serious damage to clothing, bedding, floor coverings, and other items without being noticed. Cloth moths prefer dark and undisturbed areas like closets, basements, and attics, and are often found in the corners or creases of the fabric. The larvae are the ones responsible for the actual damage, as they eat many types of substances, especially protein-containing materials such as woollen textiles, feathers, and fur. The evidence of their feeding can range from irregular surface holes to completely eaten-through fabrics as shown in figure 2.4.

Fig 2.4: Irregular shaped holes in wool fabric caused by insect attack
Picture source: https://www.canada.ca/en/conservation-institute/services/preventive-conservation/guidelines-collections/textiles-costumes.html

Carpet Beetles can cause a great deal of harm as they feed indiscriminately on wool, fur, and silk, leaving behind neat, clean holes in the fabric with a powder of the same colour as the material. In tropical countries, cockroaches are a common sight. They are fond of dark, humid places and can cause destruction to paper products, book bindings, and fabrics. Additionally, their feces can result in unsightly stains when exposed to moisture. Termites consume fabrics made of plant material quickly and quietly, creating complex tunnels in the process. This can often lead to complete destruction of the material, leaving a thin outer layer as the only indicator of the damage that occurred beneath it (Khubaib et al., 2011). Cigarette beetles/ flour beetles are also the most abundant pests found in museums. They are typically found in dark, confined spaces, but will become active and fly around in brightly lit ones, likely in search of shelter. Not only can they chew through cardboard, containers, and packages, but their larvae can also burrow into wooden objects, weakening their structure (Hassan, G. M. et al., 2021).

5. Display, Storage and Handling

The usage of a textile, combined with environmental and maintenance conditions, can adversely affect its condition and require special care for its preservation. Good handling, display, and storage of a textile is essential to maintain its condition and ensure it is passed down to future generations. When choosing materials for cases, frames, or storage units for an exhibition, it is important to select materials that will maintain the stability of the environment. Wood, cardboard, and many plastics and metals are not suitable as they can give off volatile acids or chemicals. It is advisable to use polyethylene plastic and acid free cardboard boxes for storage. To further protect the items being stored, consider using acid free tissue paper or scoured and unbleached muslin fabric. Regular paper, cardboard, wood and wood products, as well as adhesives such as urea formaldehyde, should be avoided as they emit damaging acids.

Museums usually practice vertical, horizontal and rolling storage methods as shown in figure 2.5, 2.6, and 2.7.

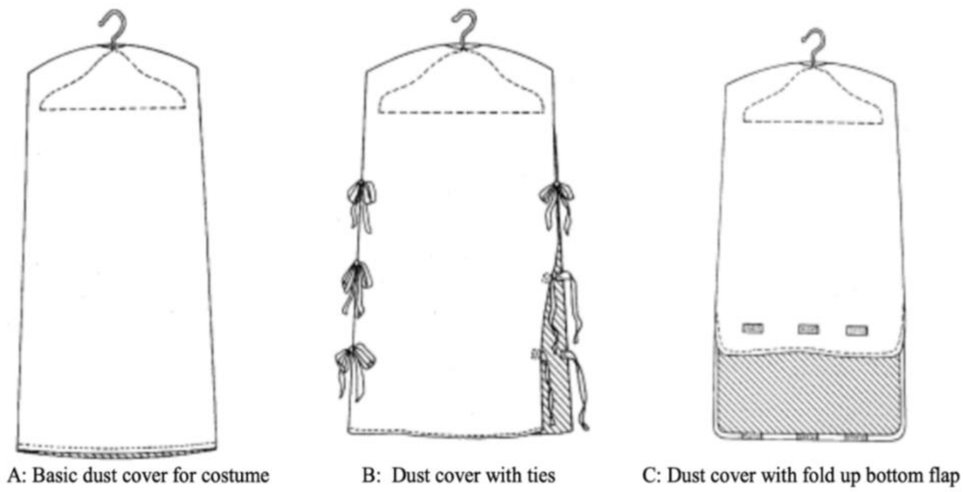

Fig 2.5: Types of dust covers for vertical storage system
Picture source: Manek (2012)

Fig 2.6: Horizontal/ flat laying of textile on acid free card support
Picture source: https://www.canada.ca/en/conservation-institute/services/preventive-conservation/guidelines-collections/textiles-costumes.html#a36

Fig 2.7: Example of suspension storage system for rolled carpets
Picture source: https://www.canada.ca/en/conservation-institute/services/preventive-conservation/guidelines-collections/textiles-costumes.html#a36

If a garment's shoulder area is strong, it is safe to hang it on a hanger with a fabric covering for extra protection. However, items which are delicate, have knitted fabrics or decorations, or have weak shoulder seams should not be hung. Bear in mind that wood, metal and plastic hangers can all cause damage to the fabric due to their acidity, oxidization and staining properties. Therefore, it is suggested to choose a hanger which is suitable for the clothing and to use padding to isolate the textiles from any potential harm as shown in figure 2.8. To protect the garment from tight folds and creases, place crumple acid free tissue or cotton knit tubes filled with polyester inside the sleeves or where ever needed in the garment as shown in figure 2.9. Make sure the hanger holds it up without putting too much pressure on its shoulders, collars, or sleeves. Followed by this, it is also recommended to cover the clothing with a loose muslin bag and hang it somewhere with good ventilation and enough space for it to hang. An alternate approach to storing textiles is by rolling them. This method is suitable for both large items like shawls, quilts and rugs, as well as small fabrics like lace. To ensure the fabric does not come into contact with any acidic material, it is best to use special acid-free cardboard tubes, or use a regular cardboard tube lined with a protective material like polyethylene plastic. When rolling the flat textile onto the tube, the right side usually faces inwards, except for fabrics with a raised texture such as pile carpets, velvets, or embroideries, which should be rolled with the right side outwards. It is important to lay the textiles out face up on a flat, clean surface and flatten out any bulges or creases. Once rolled, cover the roll with muslin, cotton sheeting, or acid-free tissue pests (Hitchcock, 2016; Manek, 2012).

Fig 2.8: Padded hangers for extra protection
Picture source: Manek, 2012

Fig 2.9: Padding the pleats with cotton knit tubing stuffed with polyester fibrefill to prevent folds and crease
Picture source: https://www.canada.ca/en/conservation-institute/services/preventive-conservation/guidelines-collections/textiles-costumes.html#a33

2.1.2.b. Biodegradation of textiles

Biodegradation is a process where a material is broken down by the action of living organisms, such as microorganisms, leading to mineralization or the formation of biomass. This process consists of three steps.

- **Biodeterioration -** Biodeterioration is the result of various degradative elements such as mechanical damage, thermal damage, moisture, oxygen, ultraviolet light, and pollutants. This leads to a large number of microorganisms adhering to the material's surface.
- **Bio fragmentation -** Bio fragmentation is the process where microorganisms spread and secrete enzymes and free radicals which break down macromolecules into smaller components.
- **Assimilation -** Assimilation is the final step, where energy, biomass, and metabolites are created by the microorganisms and released into the environment in the form of simple gaseous molecules and mineral salts (Khubaib, 2011).

Plant fibres are mainly composed of cellulose, the proportion of which varies between different types of fibre. Cotton fibres contain 94% cellulose, while linen has 80%; other fibres such as jute, sisal, and hemp contain between 63% and 77%. Cellulose is a polysaccharide made up of β glucose molecules joined together by 1,4- β glycoside bonds. The length of the chains of glucose molecules can be anywhere between 7,000 and 10,000. These chains may be laid out in a crystalline pattern or tangled to form an amorphous structure(Gutarowska & Michalski, 2012).

Bacteria and fungi are the two major microorganisms that cause cellulose to be broken down through enzymatic action. With bacteria, the destruction of cellulose fabrics begins at the outer layer and works its way inwards. With fungi, however, the cuticle is first recovered and then the organisms penetrate the secondary wall and grow inside the lumen (Pekhtasheva et al., 2012). This process breaks down cellulose into glucose through a step-by-step process that involves the utilization of enzymes such as 1,4-endo β-D-glucan cellobiohydrolase, endo-1-4-β-D-glucan glucanohydrolase, and glucohydrolase of β-D-glucosides (Gutarowska & Michalski, 2012).

Microorganisms can cause considerable damage to cotton fibers, fabrics and textile products, leading to the appearance of yellow, orange, red, violet spots and a putrefactive smell. Ultimately, the strength and quality of the product deteriorate as a result of the microorganisms' effect, which can be seen in a change in the chemical composition and physical structure of the cotton fibers. Electron microscopy has revealed that the degradation of the cotton fibers is most severe in areas with lower fibril density (Pekhtasheva et al., 2012). The level of cellulose decomposition can be determined by looking at the different colours of the stains on fabrics (carotenes, anthraquinones, excreted by microorganisms), a decrease in the degree of polymerization, disintegration of the fibre structure, and a drop in the tearing strength. In extreme cases, cellulose can be fully broken down.

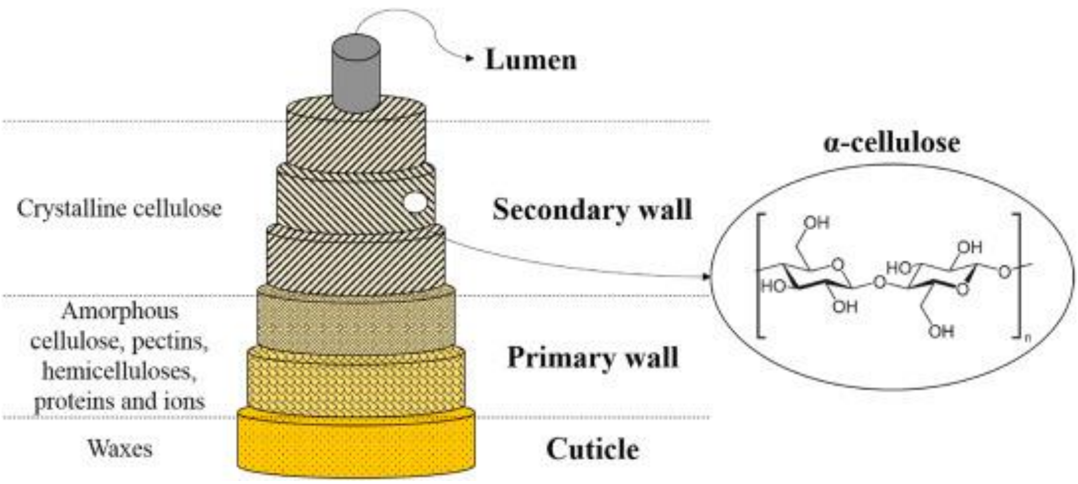

Fig 2:10: Morphological structure of cotton fiber sowing distrubtion of the components in various fiber layers

Picture source: Colombi et al., (2021)

Plant fibers contain minor quantities of compounds such as hemicellulose and lignin, typically less than 10%, which provide the fibers with stiffness. Additionally, they contain pectins which function as a form of adhesive. The chemical and morphological structure of the cotton fiber is shown in the figure 2.10 and figure 2.11.

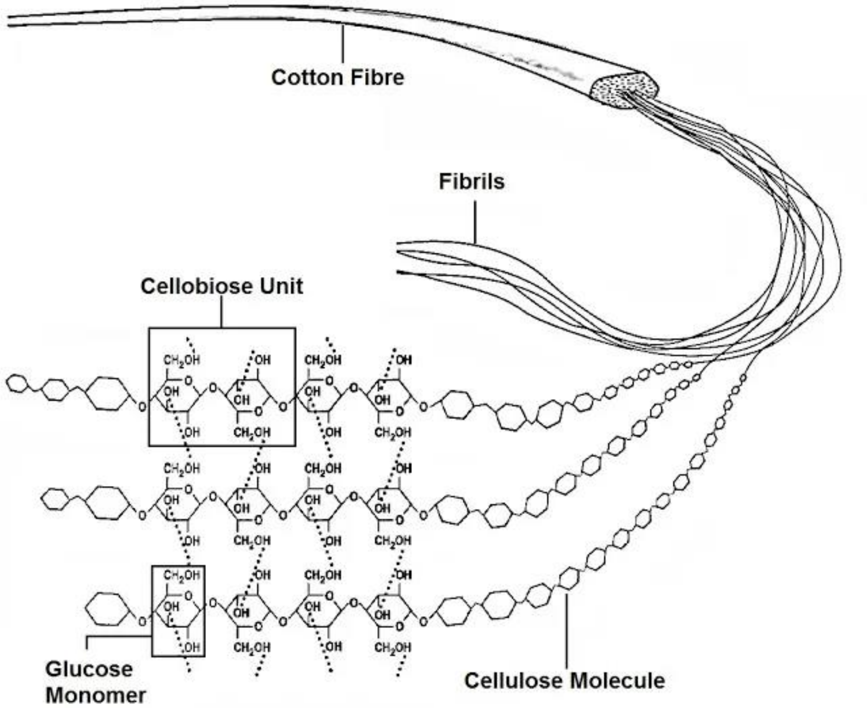

Fig 2.11: Chemical structure of cotton fiber
Picture source: https://textilelearner.net/structure-of-cotton-fiber/

Many microorganisms can make enzymes which can break down hemicelluloses and pectins (xylanase, galactosidase, mannosidase, glucuronidase, pectin esterase, glycosidase, and more). Lignin is least easily decomposed element of plants because of its structure, which consists of phenylpropane compounds connected by ether and carbon bonds and are highly resistant to enzymatic dissolution. Nevertheless, there are certain fungi and bacteria which can decompose lignin (*Chaetomium*, *Paeciliomyces*, *Fusarium*, *Nocardia*, *Streptomyces, Pseudomonas*, *Arthrobacter*, and others***)*** (Gutarowska & Michalski, 2012). It has been observed that the number of fungi that can damage plants is much less than that of fungi that can break down cellulose, such as *Chaetomium globosum*, *Aspergillus flavus*, *Aspergillus Niger, Rhizopus nigricans, and Trichothecium roseum*. These particular species are known to lessen the quality of raw cotton (Pekhtasheva et al., 2012). Figure 2.12 shows growth of fungal colonies on a cotton fabric.

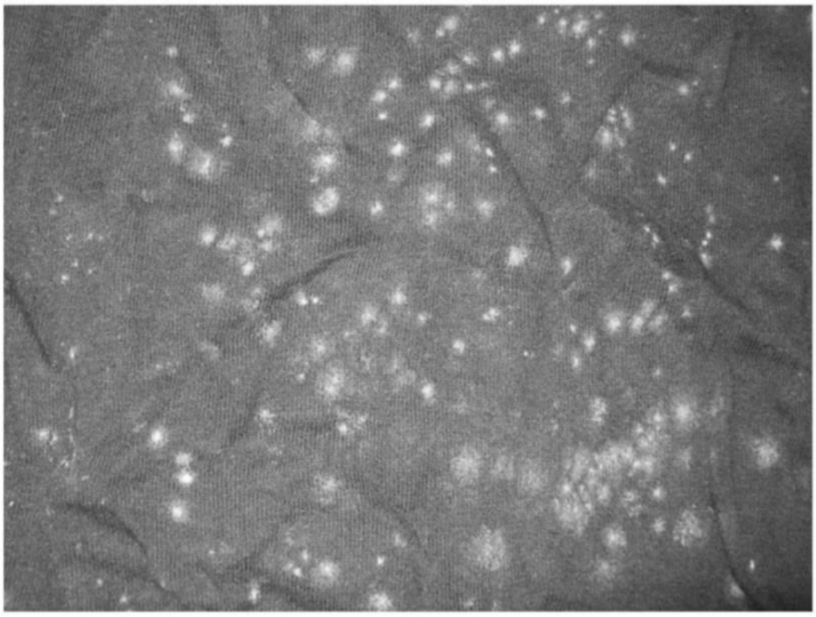

Fig 2.12: Growth of fungal colonies on a cotton fabric
Picture source: (Suza et al., 2022)

The chemical composition of natural plant-based fibres dictates their rate of decomposition, which is further affected by environmental factors, microorganisms present, thickness, weave, crystallinity, and orientation. Highly oriented fibres are less prone to biodeterioration, while amorphous cellulose is more vulnerable to degradation (Gutarowska & Michalski, 2012).

Wool, categorized as an animal fiber, is known for its strength, heat insulating properties, and ability to absorb moisture. It is composed of three types of keratins: low-sulphur, high-sulphur, and high-tyrosine. These keratins are connected to each other and to other proteins in the matrix by a variety of bonds, such as sulphide bridges, covalent bonds, hydrogen bonds, and hydrophobic bonds as shown in figure 2.13.

This network structure makes it durable and resistant to stretching, tearing, and environmental factors, including enzymatic degradation. Microorganisms with proteolytic and keratinolytic enzymes cause the deterioration of woollen fabrics. First, disulphide bridges are broken down, weakening the fabric's strength. Then, proteolytic enzymes break proteins into oligopeptides, and peptidases further decompose them into amino acids. These acids then undergo oxidative deamination, releasing ammonia as a by-product. Signs of microbial decay on wool can include variously coloured spots on the material, a specific odour (H_2S is produced when there is no oxygen), and weakening of the fabric's elasticity. There have been many reports of issues resulting from microorganisms on woollen fabrics, for instance with the stored carpets.

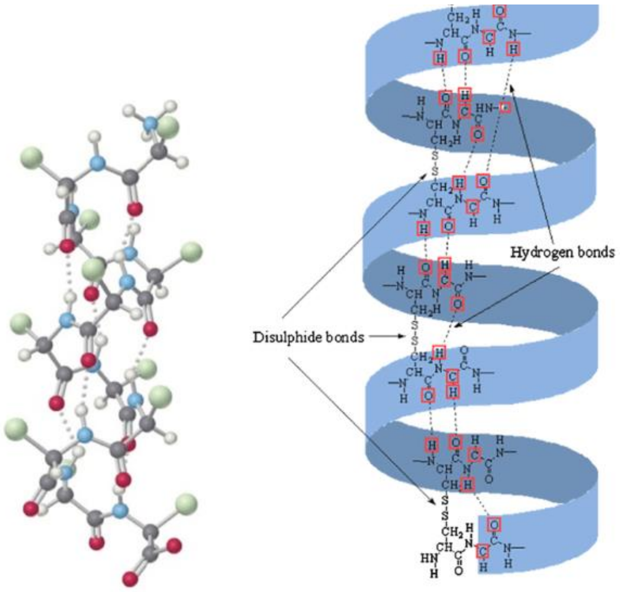

Figure 2.13: Helical structure of wool keratin
Picture source: Hassan & Carr (2019)

Silk is created from the protective cocoon of the mulberry silkworm, and is well-known for its strength, stretchiness, thermal insulation, and absorbency. The material is composed of protein fibres called fibroin, which are held together by the protein sericin, and connected via disulphide bridges that add to the strength of the material as shown in figure 2.14 . It is made up primarily of four amino acids - alanine, glycine, serine, and tyrosine - and has a crystalline structure, with 90% of its makeup coming from these (Gutarowska & Michalski, 2012).

Silk fibroin, being a protein, can break down when exposed to proteolytic enzymes such as chymotrypsin, actinase, and carboxylase (Yang & Wang, 2009). The rate of this degradation can vary greatly based on the structural and morphological features of the silk, as well as the characteristics of its environment (Wongnarat & Srihanam, 2012). Yang and Wang's paper suggests that the biodegradation of silk biomaterials typically occurs in two steps. Initially, enzymes bind to specific domains on the material's surface, followed by digestion as a result of enzymes. The effects of degradation vary depending on the form of the silk material and can lead to surface roughness, weight, and strength loss. It appears that microorganisms are better able to assimilate sericin than fibroin.

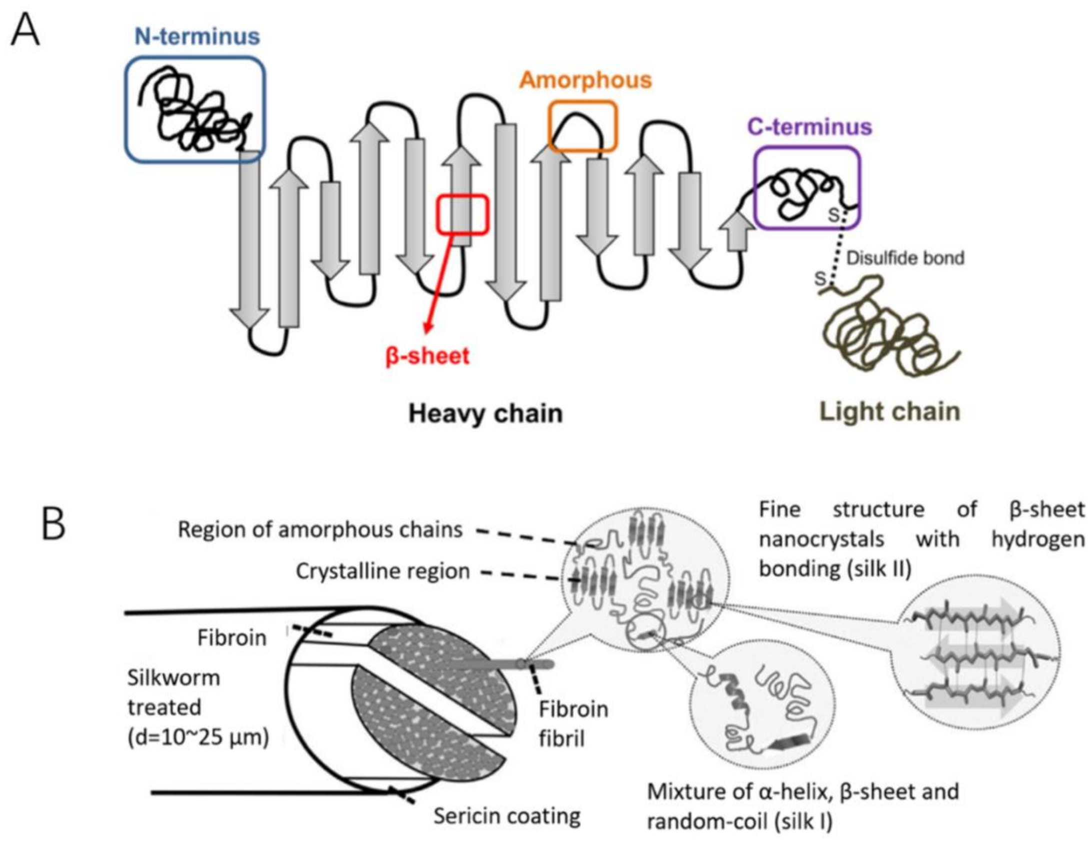

Figure 2.14: Schematic diagram of silk structure
Picture source: Sun et al., (2021)

2.1.3 Preservation and Conservation methods of textiles

The lifespan of a textile can be significantly extended if proper preventive maintenance is undertaken. Preservation and conservation of textiles in museums aims to prevent further deterioration of valuable artifacts, and involves careful management of the environment in which they are stored, as well as the use of special techniques to preserve, repair and clean them.

2.1.3.a. Preventive conservation:

Preserving something for an extended period of time is what conservation is all about. It is broken down into two categories: preventive measures which stop the item from naturally or accidentally deteriorating and curative/ remedial conservation, which repairs the item. Museums have the responsibility of maintaining and protecting their collections, whether stored, displayed, or in transit. It is important for them to regularly monitor the condition of the artefacts and determine when they need conservation and the services of a professional conservator. Preventive conservation is an important part of museum policy and collection care, and it focuses on creating and preserving a favourable environment for each object in order to prevent deterioration. According to the International Council of Museums (ICOM), preservation is the action taken to prevent damage or decay of cultural properties by controlling their environment and/or treating their structure in order to keep them as close to their original state as possible.

When it comes to bacteria and mildew, moisture is the primary thing that keeps growth in museums in check. It is important to have good air flow, which helps stop the spreading of fungal spores and generally keeps contamination levels lower. To allow air to move freely, objects should not be placed too tightly on shelves. It's also important to examine all possible sources of water, such as water pipes, bathrooms, kitchens, air conditioners, and flowerpots. No openings or breaks should be present in any of the building's components (walls, floors, ceilings) in order to keep insects from entering and proliferating. All entrances must be blocked off and sealed. Soft and absorbent materials like wood, paper, cardboard, cloth, and insulation can attract insects. Therefore, the use of wood should be kept to a minimum. To prevent fungal harm, the relative humidity should not be higher than 60% for an extended time period. In order to prevent damage from mould, the main and most important condition to control is the humidity. The temperature in textile storages should be below 20C. Cleaning must be done on a regular basis in order to avoid biological pests, which will depend on how quickly dust accumulates. Vacuum cleaners that are equipped with high-efficiency particulate air (HEPA) or P3 filters should be used and the filters should be changed regularly. It is recommended to store woollen textiles and furs separately from other materials. Metal shelves are recommended and tightly enclosed enclosures, cabinets, and display cases should be used to prevent biological pests from accessing the objects. Inspections of the premises should be conducted periodically at least once a month to look for signs of fungal or insect damage. The procedure for examining clothing should begin with the collar and the area under the collar, followed by the sleeves, the back, and the hems. The reverse side of the clothing should also be checked, with particular attention paid to seams, folds, wrinkles and pockets. If the objects are sealed, they must be taken out of the packaging in order to be inspected. Any items that have been affected by both mould and insects must be removed from storage at once, as they can contaminate other objects and the space around them. To stop the transmission of insects and bacteria to other areas, the damaged items should be stored in isolation and sealed in airtight plastic bags before being transported (Kurmo et al., 2022).

Sahoo and Mohanty (2021) in their article discuss traditional preservative practices for books, manuscripts, and textiles, which include utilizing herbal and natural products to ward off microbial and insect infestations. For instance, small packets of dried and powdered of ashwagandha leaves, black cumin, mint leaves dried ginger lemon-grass, powdered roots of dried sweet flag (known as Bacha) prevents microbial growth. Some repositories use vermillion or kumkum fruit powder (which is red in colour), powdered ajwain/ carom, custard apple seed powder, and sandal wood dust works as an insect repellent, killer and fungicide. Additionally, small bags filled with also provides medicinal value and insecticidal power. Oil extracts of natural products such as black pepper, sandalwood and clove help restore flexibility to palm leaf manuscripts. It is known that a combination of neem leaves, karanja, nirgundi, and citronella has insecticidal qualities and can be utilized to protect manuscripts. Tobacco leaves, when dried, also keep insects away from the manuscripts. To keep the leaves effective, they must be placed in small cloth bags or spread on the shelves where the manuscripts are stored. The presence of nicotinic acid in the leaves helps to repel bugs. The use of Neem oil, dried Neem leaves, and seeds have been known since ancient times for their ability to keep away insects. Limonoids, a type of compound found in Neem oil, act as anti-feedants or growth regulators, meaning that the insects are not killed immediately but the next generation is wiped out as the young are prevented from maturing and the adults cannot reproduce.

2.1.3.b Remedial/Curative Conservation:

This involves any type of action taken by a conservator that has a direct impact on the cultural material. This can include cleaning, stabilization, repair, or even replacement of parts of the object. It is important that the conservator thoroughly justifies any work they do, and they should document the work done before, during, and after the treatment to avoid any doubts later on. In essence, it is the action taken to address existing damage, protect the object from further harm, and maintain or restore it to a good condition. The practice of textile conservation is used to keep fabrics and fabrics-related items from deteriorating over time. It involves strategies such as preventive measures, interventive treatments, and other procedures that help to slow down the rate of deterioration. These objects may include tapestries, carpets, quilts, flags, garments, curtains, upholstered furniture, dolls, fans, parasols, gloves, and headgear. A conservators role is to minimize or at least slow down the deterioration of an item through preventive and interventive methods (Pandey, 2016).

If preventive measures have been ineffective and there is evidence of damage or the spread of pests is escalating, control measures are used. The disinfection process used in the museum must meet certain criteria, such as that it should not be detrimental to the health of workers or visitors, be environmentally friendly, be effective against different species of pests in all stages of life, not adversely affect the items being treated, require minimal preparation and post-treatment, be suitable for a variety of materials, a simple and cost-effective use of technology. Museums are employing two different disinfecting techniques: physical disinfection and chemical disinfection.

Physical disinfection methods, such as freezing, heating, changes in atmospheres, gamma radiation, and mechanical removal, are becoming more popular than chemical disinfection methods. Although these methods offer the advantage of not using potentially damaging chemicals, they do not always effectively protect materials from further damage, and their effectiveness can vary depending on the type of biological pest.

Freezing: Using cold temperatures is an extremely efficient way of dealing with insect-related issues in fabrics. Most pests in museums have a low tolerance for cold temperatures and the most popular method is to cool the material to -30°C for 72 hours. This method causes all of the pests to die regardless of what stage of their life cycle they are in. Before freezing, the fabric is usually placed in an airtight container, like a plastic bag. After the freezing process, the container needs to be kept closed for a minimum of 48 hours so that the water evaporated from the bag can dissipate. Microorganisms are more resistant to the cold temperatures and freezing will not kill them, it merely slows them down. This method is not known for damaging textiles.

Heating: A commonly used traditional approach to disinfection is heating. This technique can be used to annihilate all living organisms. Temperatures ranging from 50°C to 75°C in a brief span of time are already fatal to insects. As the moisture content of materials may change while heating, it is necessary to moisten the heated air.

Altered atmosphere: Organisms that utilize oxygen to live (aerobes) can be destroyed by replacing the environment's gaseous atmosphere with one that is unsuitable for the organism's survival. This can be done by either reducing the oxygen concentration with an inert gas like nitrogen or argon, or by eliminating the oxygen with an oxygen absorber. Increasing the carbon dioxide in the environment (CO_2 fumigation) is also an option. However, it is important to consider that the humidity level of the inert gas must be the same as the object's moisture content, as a gas with a humidity level less than 10% can cause rapid moisture release, leading to deformations. The processing time for this is at least 15 days, and the recommended temperature range is 20°C to 29°C. It should be noted that this approach does not work for anaerobic organisms, instead stimulates their growth. Although the growth of fungi can be restrained, there is no fatal impact and the growth will recommence when normal conditions are reinstated. This method is an effective way of killing insects, but the effect on microorganisms varies, so the species and the effect must be examined individually. Moreover, this method is safe for workers and the environment, and there are no negative impacts on the materials that are being treated.

Gamma radiation (γ-radiation): It is a type of high-energy, short-wavelength electromagnetic radiation with a wavelength of 10-10-10-14 m. It is commonly produced from the fission of the radioactive isotope cobalt-60 nuclei. Gamma radiation has been used to effectively kill both insects and microorganisms, as well as to disinfect wood, leather, textiles, and paper. The lethal dose of gamma radiation for insects is between 0.5 and 2 kGy (kilogray), while for fungi it is between 4.5 and 18 kGy. The recommended dose for most cases is 10 kGy. On the other hand, the impact of gamma radiation on all materials is highly damaging, which can significantly reduce the mechanical strength of the materials. Cellulose is highly vulnerable to such deterioration, and doses greater than 3-4 kGy can have adverse effects. Although gamma radiation treatment is comparatively inexpensive, it necessitates specialized equipment and safety measures.

Mechanical removing: To get rid of biological pests, one must physically remove them from the damaged objects. A common method used for mould damage is to dry, clean and return the material to a regulated setting. Vacuums and special suction tubes can be used to get rid of fungal colonies. It is important to keep in mind that this treatment could spread spores and mycelial particles throughout the air and contaminate other areas of the material, thus putting the health of the person conducting the treatment at risk. To prevent this, the process should be done in a separate room with protective gear like rubber gloves, respirators and separate clothing should be worn. For insect damage, insects, larvae, eggs and pupae can be collected and then destroyed. This is difficult to do since insects are typically concealed in obscure areas. Cleaning alone won't completely remove the damage, but paired with other methods, it can be effective.

Chemical disinfecting method: The use of chemical compounds or biocides to treat damaged heritage objects is known as chemical control. It is important that the biocide used does not cause further damage to the textiles. Alcohols, such as ethanol and propanol, have a moderate antimicrobial effect and can be used in concentrations between 70% to 80% as a spray, brush, swab, immersion, or vapours. Quaternary ammonium compounds (QACs) are cationic detergents that can be used as bactericides and fungicides. Pyrethroids, such as permethirine and deltamethrin, are synthetic compounds that are used to kill insects. It is important to steer away from using insecticides such as tablets or aerosols that are readily available for purchase. When considering chemical control, one must be aware that a lot of biocides are composed of chlorine, which can cause irreversible discoloration of fabrics. Furthermore, it is difficult to preserve textiles that have been treated with chemicals, as biocides stuck between the fabric fibers could release volatile organic compounds that may pose a health risk when washed. Additionally, caution must be taken when dry cleaning textiles that have been chemically treated (Kurmo et al. 2022).

2.1.4. Essential oils: Chemical composition, antimicrobial and insect repellent mode of action and its limitations and challenges

Biologically active properties have been observed in compounds of natural origin, with essential oils from aromatic and medicinal plants known to have properties that can scavenge radicals. Plants and other natural sources can provide a vast array of complex and structurally different compounds. These extracts and essential oils from different parts of the plants of which some are referred in table 1.1 (Shetta, 2017). have been reported to possess antifungal, antibacterial, and antiviral characteristics and have been studied around the world as potential sources of novel antimicrobial compounds, agents that support food preservation, and alternative treatments for infectious diseases (Bassolé, & Juliani, 2012).

Table 1.1: Parts of plants providing essential oils

Parts	**Plants**
Leaves	Basil, eucalyptus, thyme, peppermint, oregano, mint, citronella, tea tree, patchouli, common sage, lemon grass, bay leaf neem, tobacco, etc.
Seeds	Almond, cardamom, anise, coriander, cumin, nutmeg, carom, neem, etc.
Bark	Cinnamon, cassia, etc.
Wood	Camphor, sandalwood, rosewood, Himalayan cedarwood, etc.

Roots	Ginger, turmeric, vetiver, etc.
Flowers	Clove, lavender, chamomile, cumin, jasmine, orange, rose, carom, patchouli, etc.
Peel	Grapefruit, lemon, lime, orange, etc.
Fruits	Nutmeg, zanthoxylum, black pepper, etc.

Plants generate a wide variety of secondary metabolites, which play a vital role in defending them from herbivores and microbial threats. These substances have a biocidal function against microbes. The three main categories of secondary metabolites are terpenes, phenylpropanoids, and compounds containing nitrogen and sulphur. (Bassolé & Juliani, 2012) Phenylpropenes are a subfamily of organic compounds grouped under the umbrella term of phenylpropanoids, which are synthesized from the amino acid precursor phenylalanine in plants. Eugenol, which is a clear to pale yellow oily liquid, is a particularly well-studied phenylpropenes, and is extracted from clove oil, nutmeg, cinnamon, basil, and bay leaves. This compound has been demonstrated to damage cell walls, cause cell lysis, and prevent enzyme action. The effectiveness of phenylpropenes as antimicrobials varies depending on the type of microbe, the substituents on the aromatic ring, and experimental conditions such as temperature and growth medium. Cinnamaldehyde is a type of phenylpropene that provides flavor and odor and is a pale-yellow viscous liquid naturally occurring in the bark of cinnamon trees and other Cinnamomum species. Although it can inhibit the growth of Escherichia coli and Salmonella typhimurium, it is unable to break down the outer membrane of gram-negative bacteria (Chouhan et al., 2017).

Aromatic oily liquids, also known as essential oils or volatile oils, can be extracted from different parts of plants, including leaves, buds, fruits, flowers, herbs, twigs, bark, wood, roots, and seeds. The majority of their makeup consists of up to 85% of major components, with the remainder being composed of trace amounts of other elements. The efficacy of essential oils is largely dependent on their composition, the functional groups present in their active components, and the synergistic interactions between them. Examples of some constituents present in essential oils with antimicrobial properties include p-cymene, limonene, menthol, eugenol, anethole, estragole, geraniol, thymol, γ-terpinene, and cinnamyl alcohol (Chouhan et al., 2017). Research has shown that essential oils with aldehydes or phenols as the main components, such as cinnamaldehyde, citral, carvacrol, eugenol or thymol, were found to have the strongest antibacterial activity, followed by those with terpene alcohols. However, those with ketones or esters, such as β-myrcene, α-thujone or geranyl acetate, had much weaker activity; terpene hydrocarbons were usually inactive (Bassolé & Juliani, 2012) The structure of some of the bioactive compounds present in the essential oils are shown in below fig 2.15.

The different terpenoid components of essential oils can interact in a way that either reduces or increases their antimicrobial effectiveness. This interaction can result in four distinct effects: indifferent, additive, antagonistic, or synergistic. An additive effect occurs when the combined effect is the same as the sum of the individual effects. Antagonism is seen when the effect of the combined compounds is less than when they are used separately. Synergism occurs when the combined action of two or more substances produces an effect that is greater than the sum of their individual effects, while indifference occurs when the substances do not interact with each other. It was observed that phenolic monoterpenes and phenylpropanoids, which usually have strong antimicrobial properties, can make the bioactivities of mixtures more effective. A combination of thymol, carvacrol, and eugenol is especially successful against E. coli strains. Additionally, a mix of cinnamaldehyde and either carvacrol or thymol has both synergistic and additive effects against E. coli and S. typhinurium (Mith et al. 2014).

It is possible that Thymol or carvacrol could be the reason for successful inhibition of S. typhinurium. This is due to the fact that Thymol or carvacrol have the potential to enhance the permeability of the cell membrane, making it easier for cinnamaldehyde to enter the cell. Moreover, these compounds could also increase the number, size, or longevity of pores formed by the binding of cinnamaldehyde to proteins in the cytoplasmic membrane, leading to a synergistic effect when used in combination (Bassolé & Juliani, 2012).

The mechanism of antimicrobial action can be influenced by the particular strain of microorganism or type of essential oil used. Studies have indicated that bioactive components of essential oils may attach to the surface of the cell, and then enter the phospholipid bilayer of the cell membrane. This disruption of the cell membrane's structural integrity can have a negative effect on the cell's metabolism and eventually result in cell death as seen in figure 2.16 (Chouhan et al., 2017).

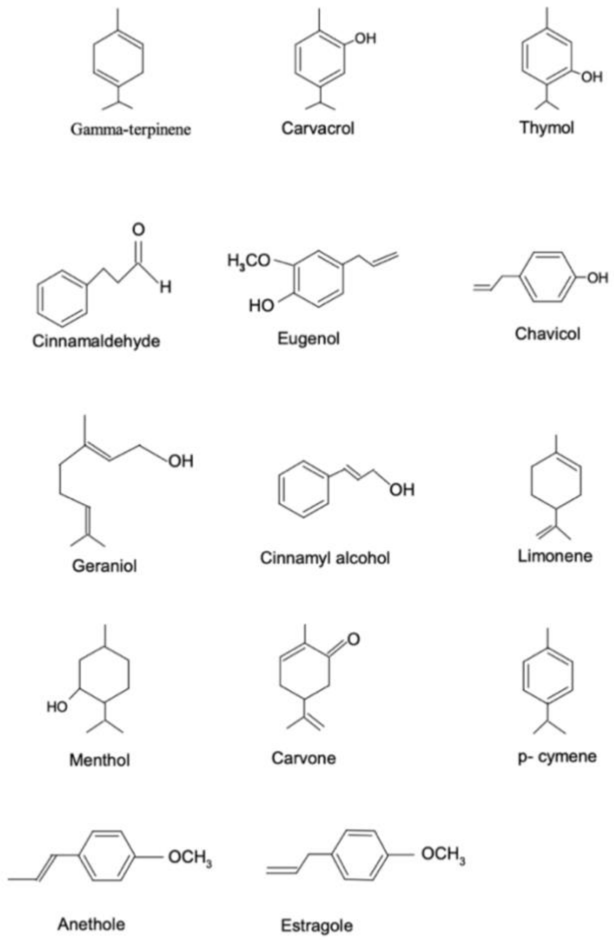

Figure 2.15: Bioactive compounds present in essential oils
Picture source: (Chouhan et al., 2017).

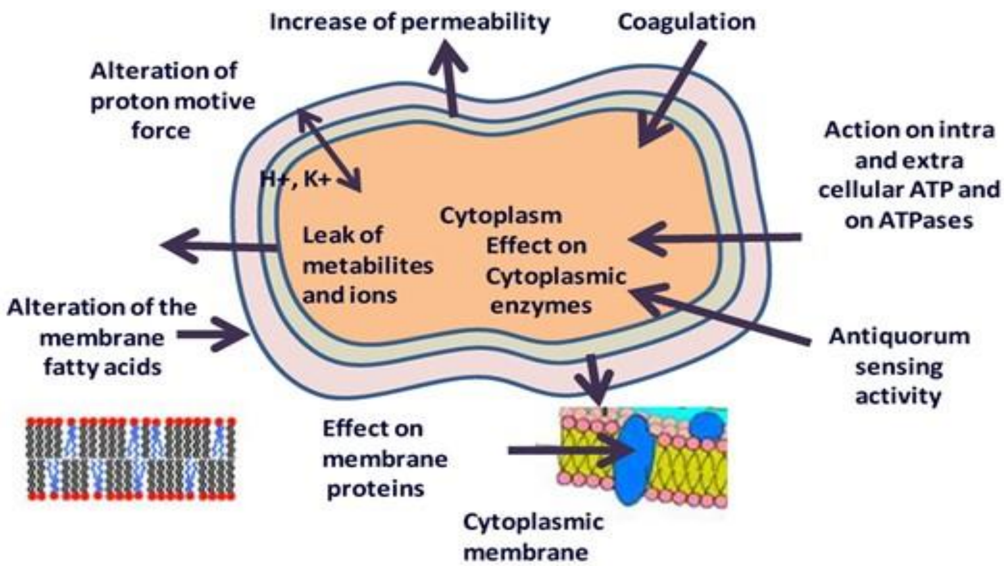

Figure 2.16: Action mechanism of essential oils on microbes
Picture source: (Shetta, 2017)

According to a study conducted by Shetta in 2017, essential oils have a complex composition that makes them effective in fighting against microbes. The phenolic components found in these oils, which include thymol, carvacrol, eugenol, peppermint, and green tea, can alter the composition of bacterial cell membranes by increasing the amount of saturated fatty acids (C16-C18) and decreasing the amount of unsaturated fatty acids (C18). As a result, the cell membrane becomes more permeable. Oregano essential oil, on the other hand, can interfere with the ATP generation system, leading to a reduction in intracellular ATP levels in S. aureus. Additionally, certain essential oils such as p-cymene can disrupt the proton motive force of bacterial cell membranes, which inhibits flagellar movement and ultimately results in cell death.

Essential oils can be classified according to the speed of their action; some are fast-acting, whereas others take longer. Carvacrol, cinnamaldehyde, and geraniol are known for their fast-acting antimicrobial properties, as they can inactivate certain bacteria in five minutes or less. Conversely, compounds with slower action often take between 30 to 60 minutes to demonstrate significant antimicrobial activity (Chouhan et al., 2017).

Studies suggests that essential oil nanoparticles can repel or kill insects through a specific mechanism (figure 2.17). In particular, it was found that charged nanostructured alumina, which is present in some essential oil nanoparticle formulations, can attach to the cuticle of beetles through triboelectric forces. This attachment leads to the insect's dehydration by sorbing its wax layer via surface area phenomena. Essentially, the nanoparticles disrupt the insect's protective wax layer, causing them to lose moisture and eventually leading to their death. (Jasrotia et al., 2022).

Despite their advantages, essential oils also have some limitations. The antibacterial properties of essential oils can have an inhibitory effect on the growth of some gram-positive bacteria like *S. aureus,* Listeria monocytogenes and *Bacillus cereus*, but their efficacy is less pronounced against gram-negative bacteria like *E. coli* and *Salmonella Enteritidis* due to the direct interactions between essential oils components and the bacterial cell membrane. The hydrophilic nature of the gram-positive bacterial cell wall is likely to be the cause of their increased resistance to plant essential oils (Shetta, 2017). Essential oils are not stable and degrade over time. They are made up of small, volatile molecules which evaporate quickly when exposed to air, meaning they do not remain on surfaces for a long time. The degradation of essential oils is accelerated by exposure to oxygen, light, and heat. Oxygen accelerates the oxidation process, while light and heat accelerate evaporation leading lead to change in their viscosity, their organoleptic properties, leading to decomposition of the chemical compounds. This is because the small molecules have a low molecular weight and a low boiling point, which allows them to easily turn into vapour when exposed to air at room temperature. They also have a low viscosity, which enables them to spread quickly and evaporate quickly. Additionally, essential oils have a high surface tension, meaning they are more likely to evaporate than other liquids, which makes them more prone to quick evaporation. As they are made of aromatic compounds that are liquid at room temperature. These compounds are hydrophobic molecules, meaning they do not interact with water molecules. They are composed of long hydrocarbon chains that are nonpolar, and therefore, do not dissolve in water (Ribeiro et al., 2017; Chouhan et al., 2017)

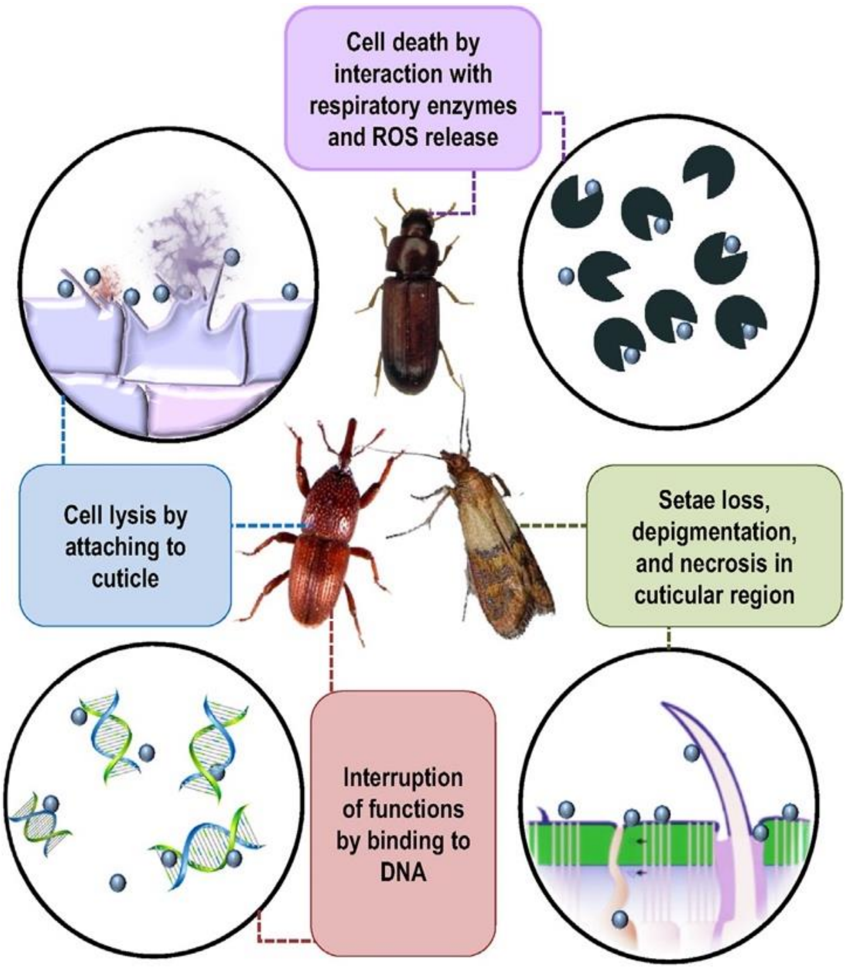

Fig 2.17: Action mechanism of essential oil nanoparticles on insects
Picture source: Jasrotia et al., (2022)

An interdisciplinary approach that brings together materials science, chemistry, microbiology and art history is necessary to come up with ways to care for, preserve and conserve these delicate artifacts. This comprehensive viewpoint is essential to slowing down the deterioration and helping to keep the distinctive features of museum textiles from further aging (Shroff et al. 2022).

2.1.5. Nanotechnology

The utilization of nanoscience in the development of new technologies has the potential to bring about strategies for the conservation and protection of historic fabric and costumes. Nanomaterials are classified as particles that are between 1- 100 nm in size. Examples of organisms seen in the below figure 2.18 within the same size range include DNA molecules of 2-12 nm wide and viruses of 10-150 nm in width (Shroff et al., 2022).

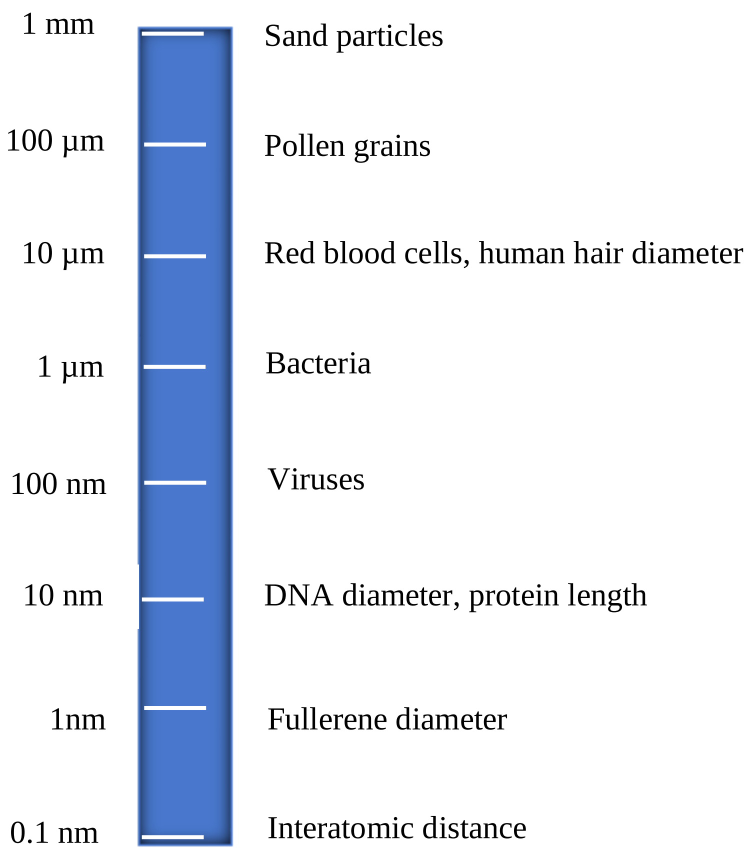

Fig 2.18: Size scale of objects between 0.1 nm and 1 mm
Picture source: (Shroff et al., 2022)

Based on their dimensionality nanomaterials are usually classified into four classes (figure 2.19).

1. Zero-dimensional materials (0D): Nano-objects with zero dimensions, measuring less than 100 nm in all three external dimensions, include nanoparticles, quantum dots, nanoflowers, nanorings, nanoshells, and nano capsules.
2. One-dimensional materials (1D): If two of the external dimensions are less than 100 nanometers and the third is at a microscale level, these materials are referred to as nanotubes, nanowires, or nanofibers and are classified as one-dimensional nanomaterials.
3. Two-dimensional materials (2D): Objects that are two-dimensional have a dimension that is lower than 100 nanometers. Examples of this kind of object include thin films, nanolayers, and nanocoating.
4. Three-dimensional materials (3D): Nanomaterials that are three-dimensional (3D) only possess internal nanoscale features. Examples of these include nanocomposites, which consist of two or more substances that are not mixable, with at least one of them at the nanoscale, and nanostructured materials, like nanofoam.

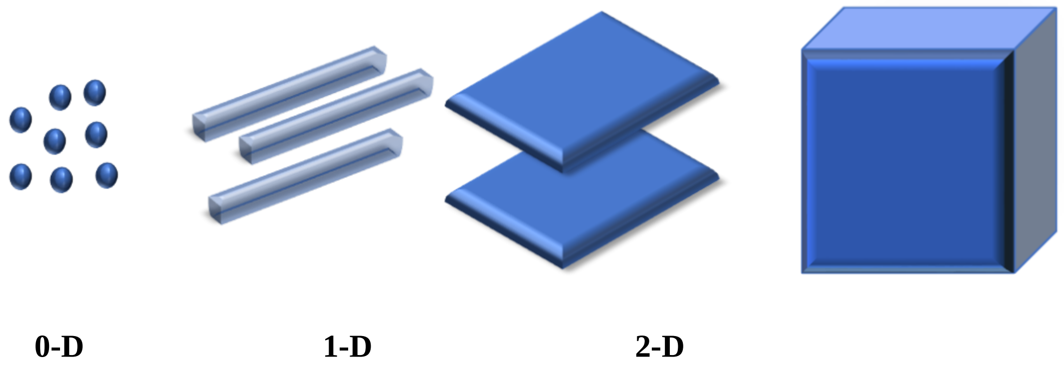

Fig 2.19: Classification of nanomaterials based on their nanoscale dimensionality
Picture source: (Shroff et al., 2022)

Two techniques are utilized to govern the structure of matter on the nanoscale: the top-down and bottom-up methods (Figure 2.20). The top-down strategy entails using mechanical, chemical, electrical, light, or electron beam means to break down bulk matter into nanoscale objects. As for the bottom-up approach, atoms and molecules are combined through chemical reactions and physical processes in order to construct structures. Recent advances unite both strategies for the formation of intricate systems. Additionally, research into the bottom-bottom technique, or mechanosynthesis, is being conducted to create nanostructures through self-assembly of atoms.

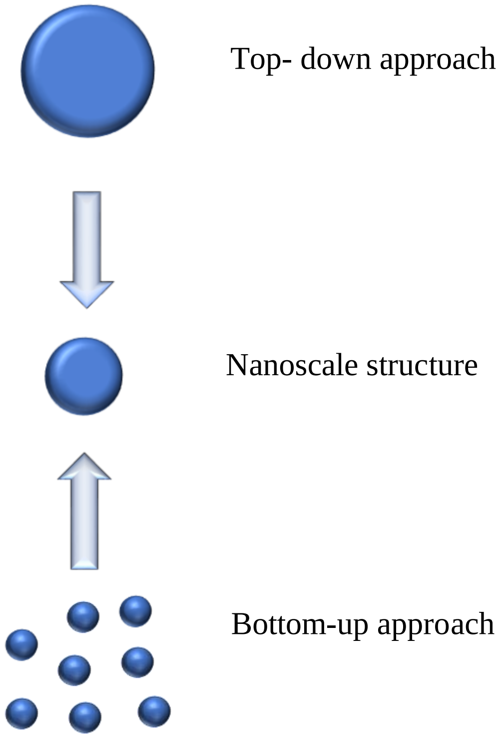

Fig 2.20: Schematic diagram of top-down and bottom-up approaches for preparing nanomaterials
Photo source: (Shroff et al., 2022)

Evidence of the usage of nanomaterials in textiles dates back to 2600 BC in China, when dyes on a nanoscale were used to give colour to fabrics and fibers. In comparison, the current utilization of nanotechnologies in the sector of textile finishes and coatings has rapidly improved. Nevertheless, the textile industry has taken up nanotechnology to take advantage of its benefits. The three main methods of applying nanostructured finishes to textiles are functionalizing the fabric surface with a layer of nano-objects at the fiber or yarn stage or directly on the fabric after it has been made; dispersing the nano-objects in a polymer matrix or binder and applying it to the fabric's surface; and forming a nanofiber web coating on the textile's surface. It is vital that a strong bond is formed between the nano-object and the fabric material in order to achieve a lasting finish.

The use of nanotechnology is a highly specialized method of diagnosing, restoring, and preserving old textiles. This method has a higher penetrability and unique thermal and magnetic properties that offer a better performance than traditional techniques and materials.

Nanomaterials can be used to treat textiles without changing their original characteristics, which is not the case for polymers typically used for conservation. Nanotechnology can also reduce the amount of toxic and hazardous chemicals needed for treatment, as the amount of organic solvents in oil and water microemulsions is usually much lower than in traditional cleaning processes. As an example, oil and water microemulsions developed for cleaning purposes typically contain less than 10% organic solvents, a much lower quantity compared to traditional cleaning treatments. Moreover, processes based on nanotechnology tend to demonstrate increased efficiency due to the large surface area of the nanoscale features. Additionally, nanotechnology can help address specific issues that may arise during restoration activities, such as by recognizing components produced in the treated materials (Shroff et al., 2022).

2.1.5.a. Application of Nanotechnology for preservation and conservation of textiles

Nanoscience and nanotechnology have been developed on a global scale, giving rise to novel conservation science techniques that can restore artifacts to their original state or impede the deterioration process. At the close of the 1980s, nano-science was initially used for the conservation of artifacts, in the form of a microemulsion to remove wax stains and clean paintings in the Brancacci chapel in Italy (Baglioni et al., 2015). Nanotechnology now is used to develop new methods of cleaning and restoring museum textiles that have been damaged by pollution, the environment, or prior treatments (Baglioni et al., 2019). To avoid affecting other areas, it is crucial to apply the treatment selectively to specific areas i.e. spot treating. (Berger, 2019).

The use of water-based micelles, microemulsions, and nanostructured gels offers an effective yet gentle method for cleaning fragile objects. Nanoscale compounds with a polar head and non-polar tail, which makes them very efficient at surfactant action are called Micelles. This allows them to remove oily materials through the processes of rolling-up, emulsifying and solubilizing. Microemulsions, also known as nanocontainers, that are oil-in-water droplets of nanoscale which are formed by combining an organic solvent with a surfactant in a water-based environment (Baglioni et al., 2012); (Pramanik, 2017). A thermodynamically stable and isotropic solution is created when oil, water, and amphiphilic compounds are combined. Microemulsions possess a detergency property, making them ideal for removing dirt particles from the surface of textiles, as they swell up due to their high surface area (Baglioni, 2014). The dirt particles are then unable to redeposit on the object, as they are surrounded by water that does not allow for it. (Udina, 2018). These emulsions are largely made up of water, usually ranging from 75-99%, with a low amount of organic compounds such as solvents and surfactants, which can range from 0.5-15%. Because of this, they are less likely to alter the physiochemical properties of the artifacts. They have proven to be a better alternative to hydrocarbon-based organic solvents such as petroleum distillates. For instance, using a combination of ethyl acetate, propylene carbonate, a surfactant and a co-surfactant in an amphiphilic water solution, the removal of acrylic-vinyl copolymer from the surface of Maya and Nahua murals in Mexico was successful. In a similar manner, the Annunciation Church in Israel utilized ethyl acetate and propylene carbonate microemulsions to remove silicone coatings from their paintings. The emulsions were effective as they combined the detergency of surfactants and the solvating action of organic solvents.

In the recent years, nanostructured gels have also been serving as a cleaning agent without causing any damage to delicate items due to their ability to attach both hydrophobic and hydrophilic materials to their surfaces. Thus, making them soft and stable colloidal systems. These gels are usually reusable, for example hydrogels can be simply rinsed with distilled water whereas to reuse the organogels a non-polar solvent can be used to rise them (Baglioni et al., 2014).

Cellulosic textiles such as cotton and linen tend to break down mainly due to hydrolysis. This process is driven by two factors: the acid hydrolysis of glycosidic bonds and oxidation. To slow down this degradation and maintain the strength of these fabrics, deacidification agents are applied. These agents help to balance out the acid by-products that are created from oxidation, which then limits the speed of hydrolysis. For this purpose, application of calcium and magnesium hydroxide nanoparticles to cellulosic paper reduces acidity and protect against hydrolytic deterioration. Carbonates are formed when the particles react with carbon dioxide in the air. Sodium Y zeolite modified with magnesium oxide is also an effective way of keeping the paper's pH level between 7.5 and 9.1 and preventing break down. One of the main benefits of this approach is that it does not change the paper's colour or wettability, something that is not the case with traditional deacidification techniques (Baglioni, 2012).

For the deterioration caused in textiles due to the biological factors
A method of using chitosan cross-linked with silver-loaded selenium oxide nanoparticles to treat linen textiles was created and tested on a linen fabric painted and aged to resemble an ancient Egyptian linen shroud from a Cairo Museum. This treatment demonstrated good

bacterial resistance against the bacteria from the funeral shroud, and the colour of the linen fabric was not affected. Unfortunately, it did not perform well in antifungal activity (Kareem et al., 2014). An alternate option is to use titanium dioxide nanoparticles. No significant change in the tensile strength of paper specimens coated with hydroxypropyl cellulose was observed after 15 days of ageing at 90°C when Titanium dioxide nanoparticles were applied. Additionally, the coating prevented any fading of the paper's colour under UV accelerated ageing. It was also found to have a biocide function, which was attributed to its ability of hindering the adsorption of bacteria and fungi on the paper's surface. Additionally, nanoparticles of kaolinite, titanium dioxide, and silver have been found to be highly effective in protecting wool from moth damage (Shroff et al., 2022).

2.1.5.b. Encapsulation: Methods, their mechanism, and advantages:

Encapsulation is a process in which active materials are enclosed within a heterogeneous matrix, forming micro/nano-capsules. It is commonly used in the food, agricultural, pharmaceutical and cosmetic industries, as it provides a number of benefits. The process of encapsulation involves entrapping active agents within a biodegradable material or matrix to form micro or nano-systems. It is often used in the food, agricultural, pharmaceutical and cosmetic industries as it can provide protection for unstable bioactive compounds from harsh processing conditions like high temperatures or oxygen, secure volatile compounds like essential oils, facilitate targeted delivery systems, alter physical characteristics of the core material, mask unpleasant flavours or smells, increase aqueous solubility, etc (Detsi et al., 2020).

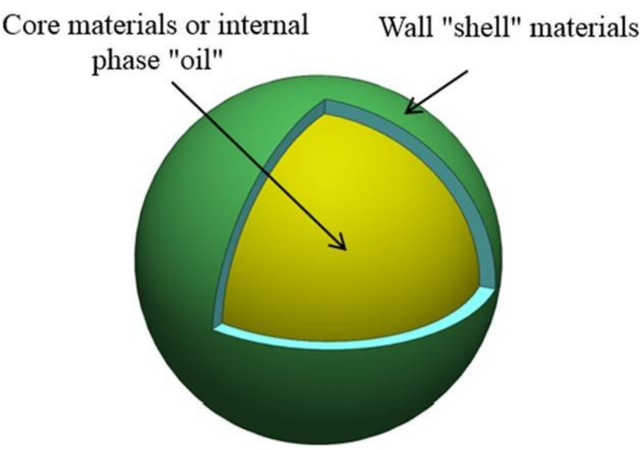

Fig 2.21: Schematic diagram of a formation of a microcapsule containing oil
Picture source: (Bakry et al., 2016)

The capsules developed are made by enclosing a solid, liquid, or gaseous substance within another material in a tiny sealed capsule. This core material slowly passes through the capsule walls, allowing for the controlled release of the substance under designated conditions (Bakry, A. et al. 2016).

As seen in figure 2.21 , microcapsules are usually composed of an internal phase or core, and an outer wall, also known as a coating, shell, or membrane. The material of the wall plays a crucial role in the stability, production, and protection of the core. Synthetic polymers and natural biomaterials are the most commonly used materials for the microencapsulation of oils. There are six types of nano/ microcapsules formed such as observed in figure 2.22. (i) simple microcapsule, (ii) matrix (microsphere), (iii) irregular microcapsule, (iv) multicore microcapsule, (v) multiwall microcapsule, and (vi) assembly of microcapsule.

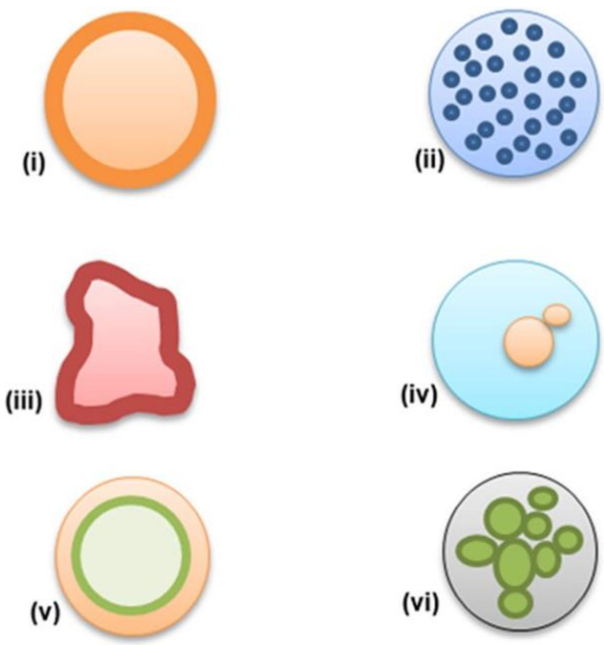

Fig 2.22: Types of micro/ nanocapsules
Picture source: (Bakry, A. et al. 2016)

The dimensions and formation in terms of shape as of the produced microcapsules are usually determined by the type of material used for the wall and the process used for their manufacture. The active/ core compounds enclosed are made available to a designated area and time at an exact rate with the help of a controlled release mechanism as shown in figure 2.23. By using a physical or chemical interaction, encapsulation keeps the essential oil stable for a longer period of time. The active agent is dispensed after encapsulation through diffusion, external stimuli, or the breakdown of the matrix. It is also imperative that the matrix and any remains from its degradation do not cause any harm to the environment (Maes et al., 2019). This technology delivers various elements such as drugs, pesticides, odors, or flavors in a regulated manner, resulting in better effectiveness and safety.

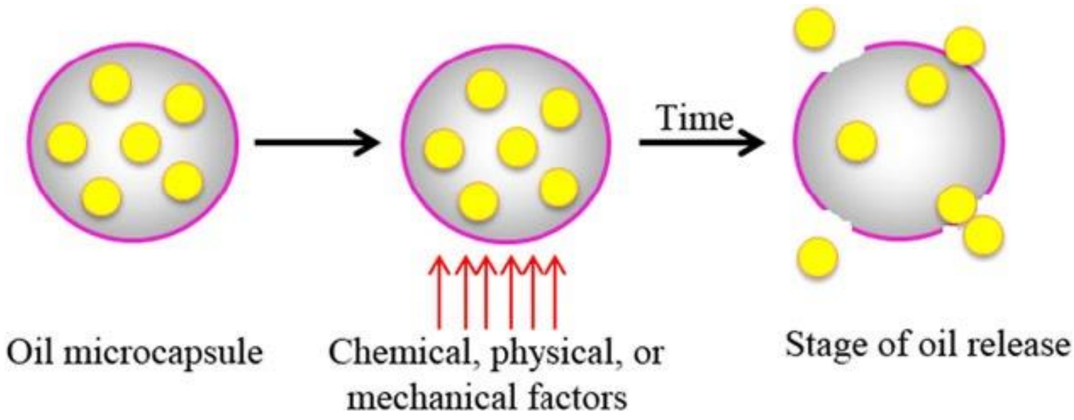

Figure 2.23: Schematic diagram showing control release mechanism of an oil capsule
Picture source: (Bakry, A. et al. 2016)

In recent years, various techniques for encapsulating natural products, such as extracts, essential oils or pure natural bioactive compounds, have been developed using a range of matrices. They can be divided into chemical, physico-chemical and physico-mechanical techniques, including spray drying, spray congealing, emulsification, fluid bed coating, ionic gelation, coacervation, centrifugal extrusion, melt extrusion, pan coating, emulsion solvent evaporation, polymerization, and liposome entrapment. Among all, emulsion, ionic gelation, spray-drying, and coacervation (simple or complex) methods are the most commonly used encapsulation techniques (Detsi et al., 2020) as follows:

Emulsification: The process of emulsification is an essential part of encapsulating oils. This technique is employed to incorporate bio-actives into an aqueous solution that can be used in a liquid form or dried into powder. It involves the dispersion of two immiscible liquids, typically oil and water, with one liquid being broken down into small droplets and dispersed within the other. When the oil droplets are dispersed in an aqueous phase, it is referred to as an oil-in-water (O/W) emulsion, and when water droplets are dispersed in an oil phase, it is known as a water-in-oil (W/O) emulsion. Other more complex emulsions, such as oil-in-water-in-oil (O/W/O) or water-in-oil-in-water (W/O/W) emulsions have also been developed. To ensure that the solution is stable, emulsifiers and texture modifiers are often added to the emulsion system. This is done by homogenizing the oil, water, and emulsifier together with a mechanical device. An O/W emulsion is composed of tiny oil globules that have been spread out within an aqueous environment, and are encapsulated by a thin boundary layer made up of emulsifier molecules figure 2.24 (Bakry et al., 2016).

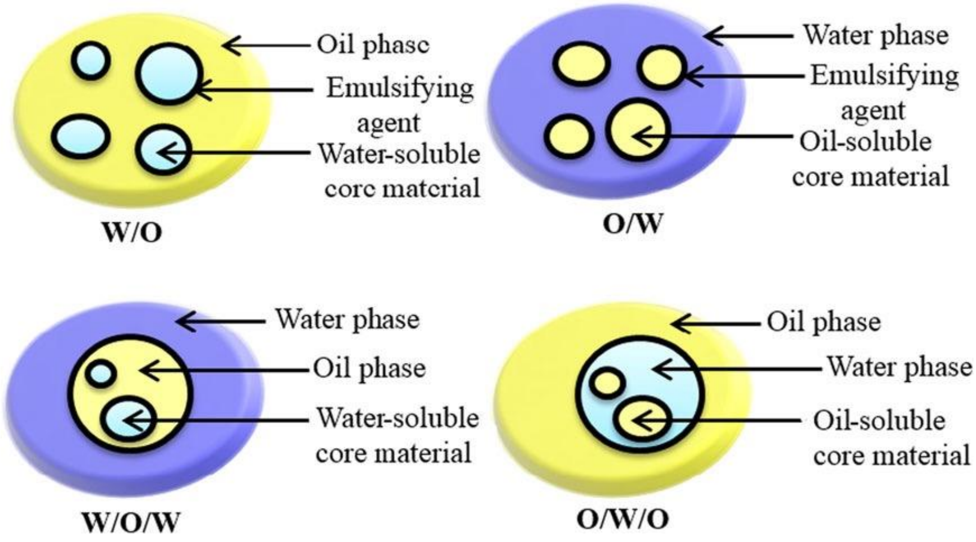

Fig 2.24: Oil and water emulsion systems
Picture source: (Bakry et al., 2016)

The upside of these systems is they are easy to set up and inexpensive, however they are not very sturdy if subjected to heating, cooling, freezing, drying, pH levels, and do not provide much control over the release.

Ionic gelation: The Calvo et al. discovery of the ionic gelation technique is a chemical process for synthesizing microparticles or NPs that involves electrostatic interactions between ions of differing charges (Hoang et al., 2022). Ionic gelation is a gentle and uncomplicated way of making stable micro and/ or nanoparticles without using organic solvents. It is a process for forming micro/ nano encapsulation of a core material using an ionically charged material (polymer) to form a gel structure around the core. The process involves the combination of a positively charged polymer, and a negatively charged material to form a gel-like matrix around the core material. The final step in the process involves the addition of a crosslinking agent to the gel solution. The crosslinking agent causes the positively and negatively charged particles to bind together and form a gel matrix around the core material (figure 2.25). Although this technique has a high capacity for loading, the major drawbacks are the large particle sizes, sensitivity to pH, and the broad range of particle sizes (Pateiro et al., 2021); (Detsi et al., 2020).

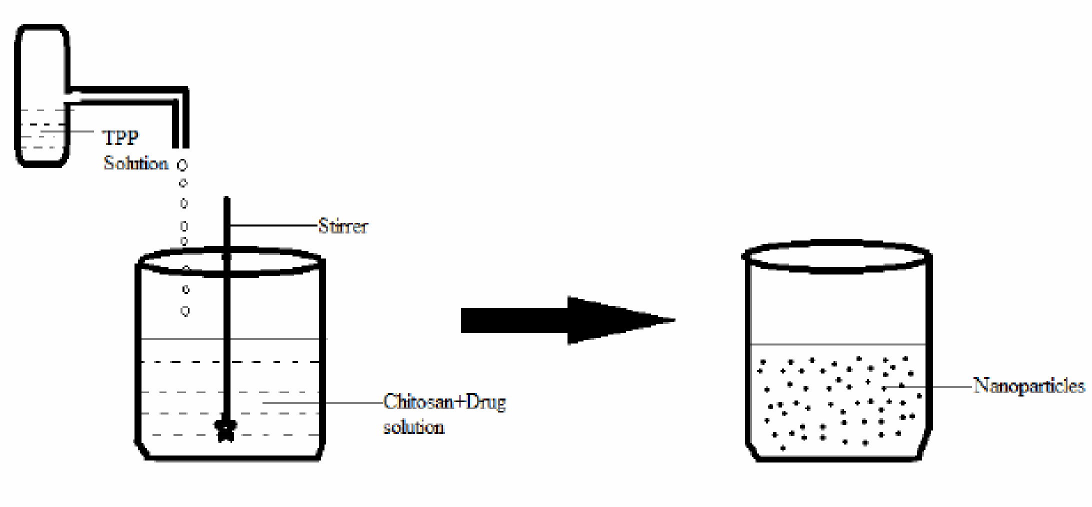

Fig 2.25: Ionic gelation method with TPP (sodium tripolyphosphate) as a cross-linking agent, chitosan as a polymer matrix and the drug solution as a core material
Picture source: (Mudgil et al., 2012)

Coacervation: Coacervation is an encapsulation process that has been employed for a long time and is still widely used. It is based on the electrostatic attraction between two biopolymers with opposite charges, and the formation of coacervates is restricted to a specific pH range. Coacervation can be further divided into simple and complex coacervation. Simple coacervation relies on salt-out by electrolytes such as sodium sulphate, desolvation through the addition of a water-soluble solvent like ethanol or temperature alteration to promote macromolecule-macromolecule interaction. The process makes it easy to create microcapsules that contain hydrophobic materials like sea, vegetable, and essential oils. Whereas, the complex coacervation process of microencapsulation of oil involves four steps. Firstly, Initially, the oil is emulsified in an aqueous solution that contains two distinct polymers. This dispersion process occurs at a temperature and pH level that is higher than the gelation and isoelectric point of the polymer. Secondly, the liquid phase is separated from the insoluble polymer phase. Thirdly, the polymer phase is deposited around the hydrophobic droplets to create the wall. The temperature is then lowered below the point required for gelling. Finally, wall hardening of the microcapsules is accomplished by the addition of cross-linking agents. Simple coacervation has several benefits over complex coacervation, such as lower costs and a more versatile production process. Moreover, complex coacervation is relatively expensive as it relies on costly hydrocolloids. A schematic diagram of a complex coacervation process has been shown in figure 2.26.

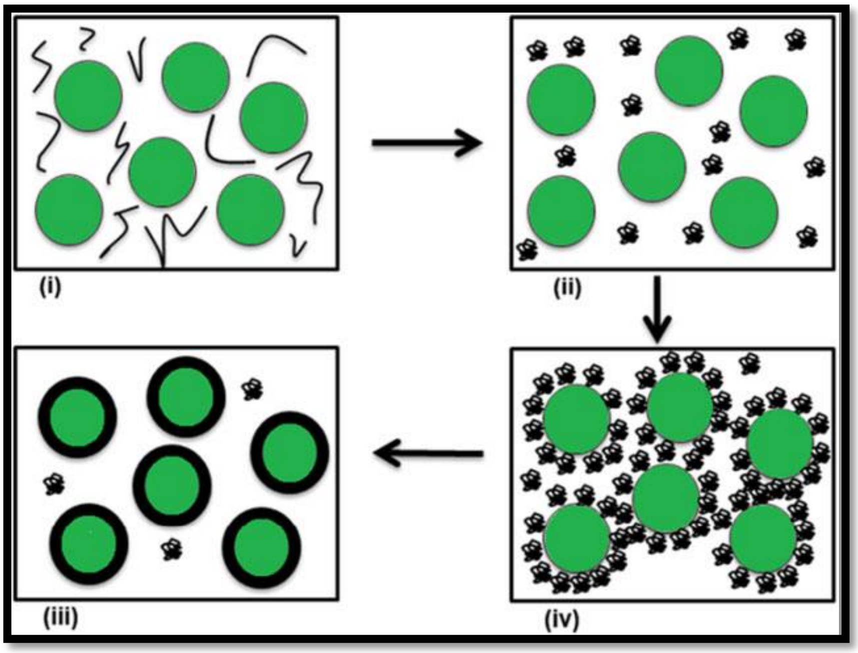

Fig 2.26: Schematic diagram of the steps of complex coacervation method
Picture source: (Bakry et al., 2016)

Spray-drying: Spray-drying is a popular commercial process that can be accomplished quickly and inexpensively. As shown in figure 2.27, the bioactive compounds are combined with a matrix, and the resulting solution is left at room temperature or refrigerated to ensure that the polymer molecules are fully saturated and to prevent any temperature-related changes. An emulsifier can be added to the solutions with the core materials, depending on the wall materials emulsifying properties, before entering the second stage. The emulsion created must be able to remain steady for a certain period prior to the spray-drying process. Its viscosity should be kept low to avoid any air bubbles from being trapped in the particles and the oil droplets should be small. Viscosity of the emulsion and dimensions of the particles play an important role in the microencapsulation via the spray-drying technique, as large and stretched out droplets could occur (Bakry et al., 2016). This method has many advantages; it converts liquid feeds into powder form, it provides higher stability, it enables the production of large quantities in a continuous mode, which reduces storage and transportation costs, and it is straightforward to utilize. (Detsi et al., 2020).

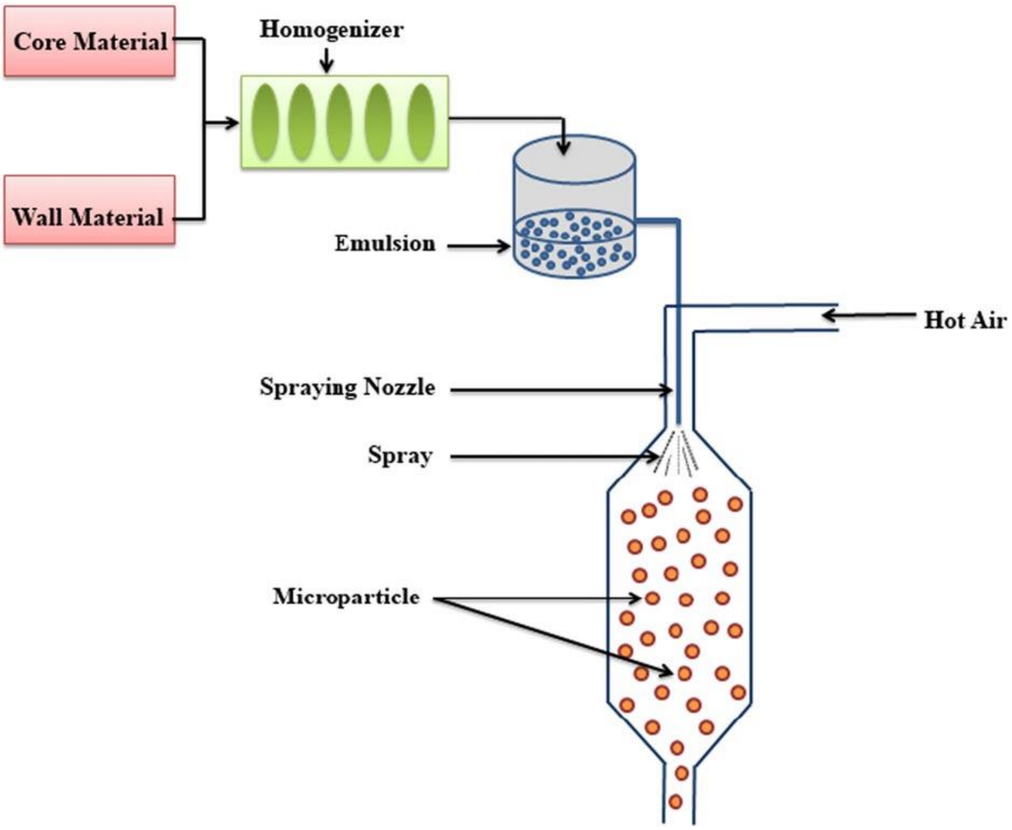

Fig 2.27: Schematic diagram of spray-drying microencapsulation process
Picture source: (Bakry et al., 2016)

Advantages of encapsulation technique:

In recent years, the increasing interest in using essential oils as natural antimicrobials and preservatives is a result of consumer demand for natural products that have improved microbial safety and fresh-like sensory properties. However, essential oils with effective antimicrobial properties have limited applications due to their volatility, low solubility, and susceptibility to oxidation. To overcome the challenges, nano/ micro encapsulation of these bioactive compounds with antimicrobial properties can be beneficial in protecting essential oils during their integration process into a polymeric matrix. This can help protect the essential oils from oxidation, light-induced reactions, and other factors that reduce their stability and effectiveness. This technique also has the potential to improve their bioavailability by reducing the size of the particles from micro-range to the nano-range. Moreover, the use of nanoencapsulation for essential oils can enhance their efficacy by increasing the surface to volume ratio by decreasing the size of particles into the nano meter range (Ribeiro et al., 2017).

The selection of an appropriate encapsulation system depends on the intended application of the final product, considering factors such as the size, shape, and properties of the active ingredients. Nano-emulsions are a suitable option for supporting the use of essential oils because they improve the dispersion of the oils in areas where microorganisms thrive, minimize any negative impact on the product's quality, and enhance the antimicrobial effectiveness of the oils (Chouhan et al., 2017). The use of nanotechnology-based processes has the potential to be advantageous due to the ability to bypass the use of toxic and hazardous solvents and chemicals. The control and release mechanism of the capsules provides durable and long-lasting finish. Furthermore, the improved performance that can be achieved with the help of nanoparticles, which have greater penetrability, thermal, and magnetic properties, is a significant benefit.

2.1.5.c Chitosan nanoparticles

Chitosan is a type of renewable polymer that is derived from chitin, which is a poly-(1,4)-2-acetoamido-2-deoxy-β-D-glucose. Chitin is obtained from the shells of crustaceans, like crabs and shrimp, by dissolving calcium carbonate with acid before then solubilizing the proteins with alkaline extraction.

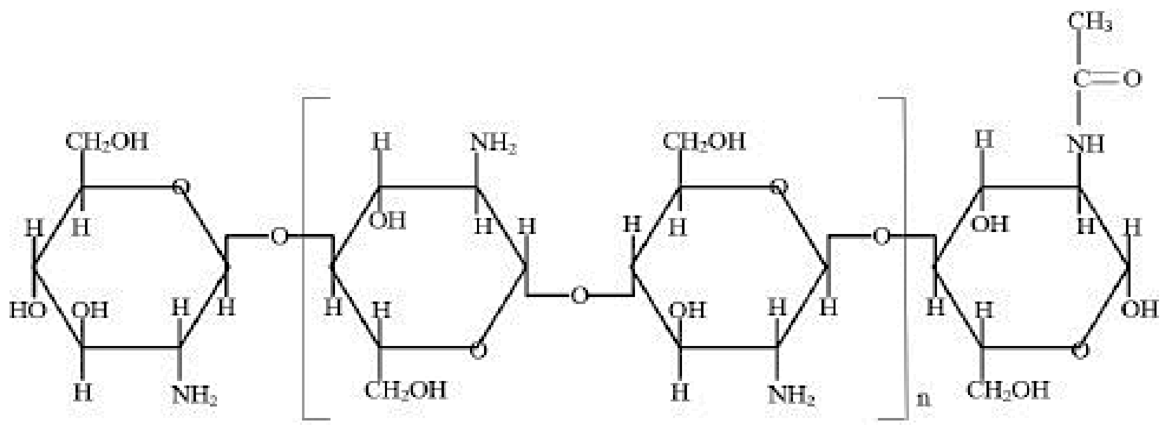

Fig 2.28: Molecular structure of Chitosan
Picture source: Zhou et al., 2022

As observed in figure 2.28, the linear polyamine is structurally similar to both cellulose and chitin, apart from the amino group (NH2) being present in the C-2 position instead of a hydroxyl (-OH) group. Because of the -NH2 groups, chitosan can become a polyelectrolyte when dissolved in acidic aqueous media due to the protonation. The pH of the solution determines the characteristics of the chitosan (Zhou et al., 2022).

In recent years, Chitosan, a cationic natural polysaccharide, has become an increasingly appealing biomaterial due to its advantageous qualities of biocompatibility, biodegradability, and low toxicity. It has been used extensively to form matrices for encapsulating different compounds. When choosing the matrix that is best suitable for a specific application, the encapsulation efficacy, stability of the resulting nanostructures, and release rate of the incorporated molecules must be taken into consideration. Alginate, Chitosan, and Cyclodextrin are some of the common natural macromolecules that are used to encapsulate essential oils, thanks to their capability to be utilized with a variety of encapsulation methods and their natural origins. Chitosan has been used extensively to encapsulate with four different methods, all giving different results. For instance, with O/W emulsion and their modified versions researched by various researches forming a nanogel, forming nanoparticles with the help of emulsification and ionic gelation combined together, for developing nanoparticles using nanoprecipitation technique, and by spray-drying method (Detsi et al., 2020). The physicochemical properties of chitosan, such as its deacetylation degree, average molar mass, solubility, crystallinity, viscosity and water content, determine how it is used in various scientific and industrial applications. It is also able to possess antimicrobial properties and inhibit the growth of particular fungi, bacteria, and yeasts. When in the form of nanoparticles, the enhanced antimicrobial, antioxidant and lipid-lowering activities of chitosan can be attributed to its high surface to volume ratio, which boosts the potency of the encapsulated compounds or natural products. Chitosan's versatility in being able to be changed into multiple forms, such as nano/micro-particles, emulsions, fibers, hydrogels, films and membranes, is why it has become so popular for use in a wide variety of applications (Zhou et al., 2022); (Detsi et al., 2020).

Research shows there has been steadily increase in use of chitosan with regards to essential oils, especially for polyphenolic compounds. Studies utilizing the ionic gelation technique commonly use clove and thyme essential oils as encapsulants, with a range of applications. Furthermore, over the last five years, a variety of essential oils-based chitosan nanoparticles have been studied, such as mint, cardamom, krill oil, lime, orange, lavender, Achillea millefolium, Cymbopogon martini, citrus, clove, Piper nigrum, and peppermint or green tea essential oils. For this purpose, the most effective encapsulation technique used is ionic gelation using sodium tripolyphosphate.

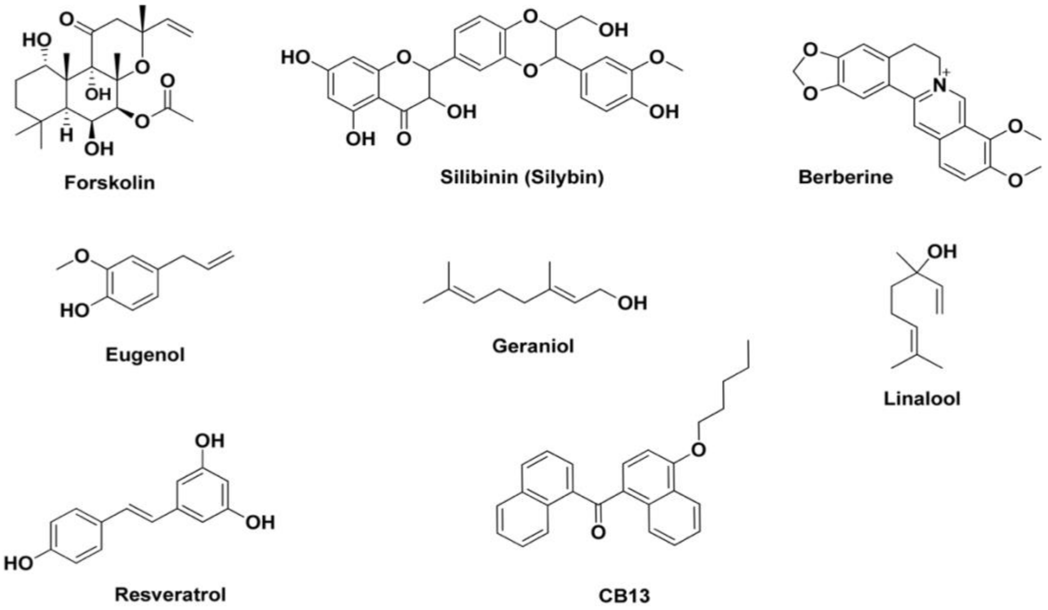

Fig 2.29: Chemical structure of phytochemicals encapsulated in chitosan or modified chitosan nanoparticles
Picture source: (Detsi et al., 2020)

Other than polyphenolic compounds, studies have also demonstrated potential positive results for the encapsulation of phytochemicals in chitosan, such as eugenol, berberine, silibinin, geraniol, and linalool (figure 2.29). It has been stated that chitosan, when utilized as a matrix, can have an entrapment efficiency of essential oils in the range of 13-90%, depending on its structure and the encapsulation method employed (Detsi et al., 2020).

Chitosan is also utilized as a coating material for polymeric and lipid-based nanoparticles to improve their characteristics when loaded with natural products. The advantages of chitosan-covered nanoparticles include increased muco-adhesion, tissue penetration, controlled drug release, and anti-inflammatory and antimicrobial activity. Derivatives of chitosan that have been altered in order to adjust the surface chemistry have become popular in recent years due to their higher solubility in water, customizable release pattern, and increased biological activity, allowing for the development of systems with individualized properties. (Detsi et al., 2020).

2.2. Research review

2.2.1 Approaches towards textile preservation and conservation

Brennan (2008), developed the first anoxic storage system to protect their textile collection in a cost-effective manner in the Textile Museum in Bhutan. This system created oxygen-free microenvironments, which guarded against insects, aerobic biological pests and dust. The textiles were first left outside or in a heated room to guarantee they were completely dry. Then, a multi-layered barrier film and Ageless®, a combination of ferrous oxide, chloride salt and humectants, was used to form a sealed environment. The fabrics were folded a few times to reduce creasing and placed in the bag. Lastly, a vacuum cleaner was used to remove the air containing oxygen from the injection hose. The removal of oxygen from the bag causes it to compress and almost "shrink wrap" the textile. Once most of the air has been removed, the vacuum is turned off, and nitrogen is used to fill the bag to the right level. This level of oxygen must be less than 0.05% in order to prevent pests and other aerobic biological growth from surviving. This also increases the bag's volume, protecting the textiles from crushing. An Ageless Eye® or indicator is a small tablet that turns from pink to purple when oxygen levels exceed 0.05%. The tablet is taped to the inside of the microclimate bag so it can be observed easily. This allows for the long-term stability and security of textile artifacts to be monitored constantly. The anoxic storage system is an economical solution to the problems faced with long-term storage in Bhutan.

In the paper Berzolla et al. (2011) discussed that nitrogen-based controlled atmospheres are a safe and effective method for both objects and humans. Over the past two decades, the use of this technique to protect museum pieces from pests has gained much attention. The recommended protocol suggests maintaining oxygen levels lower than 1% for at least three weeks. However, since the main problem of controlled atmospheres is the prolonged treatment time and low oxygen levels, it is essential to come up with more flexible protocols that involve higher oxygen levels or shorter treatment times, taking into account temperature and/or humidity.

Reagan (1982) explored the use of microwaves and radiowaves as a nonchemical alternative for disinfesting textiles. This method is an alternative to chemical method of disinfecting textiles that has the benefits of being fast, efficient, and free of toxic, hazardous, or polluting residues. Additionally, insects are not likely to become resistant to radiation as they sometimes do with chemical insecticides. In the study, woollen fabrics were exposed to eggs, larvae, and adult stages of the webbing cloth moth, and then placed in film bags and microwaved for 0.5, 1.0, 2.0, 2.5, 3.0, 4.0, or 5.0 minutes at full power. The eggs were counted for mortality 30-40 days after exposure, while the larvae and adult moths were examined approximately one hour later of being irradiated. The study found that mortality percentages of eggs, larvae, and adults of the webbing clothes moth rise as the duration of microwave exposure increases. It only took 3.0, 2.0, and 2.0 minutes to reach 100% mortality in each stage, respectively. This means that 3.0 minutes is enough to kill all three stages of the insect. However, it should be noted that keeping the fabric in the microwave for too long can be detrimental, as temperatures higher than 100°C can cause the wool to degrade. In the experiment, 10 minutes of microwave irradiation resulted in internal fabric temperatures of 149°C, causing an increase in alkali solubility, shrinkage, and colour change in comparison to fabrics that were not exposed or exposed for 3 minutes. The research paper suggests that using microwaves may be a viable option for disinfecting woollen textiles that are in good condition. However, other chemical and non-chemical methods, like freezing and traditional heating, may damage already-worn fabrics. It is important to take out any metallic objects from the fabric before microwaving to ensure the fabric and oven are not damaged. Furthermore, textiles that contain metal threads should not be exposed to microwaves.

In her report on the conservation project undertaken at the Sarabhai Foundation, Ahmedabad, Landi (1998) suggested two primary methods of supporting fragile fabrics: traditional stitching and the quicker application of adhesive. During her examination of an old Kalamkari fabric, dust and insect excretions were noticed under a magnifying lens, as well as the shape of the holes suggesting mould and insect damage. Areas too delicate for stitching were instead supported on a polyester fabric treated with thermoplastic adhesive before attaching it to the main backing. The polyester film was then spread on a flat, even surface with no creases or flaws on the surface. The fabric to be used as support was laid on the surface and a mixture of Stabiltex 0 and Vinamul 6815 was applied evenly with a flat brush after diluting it in the water in a 1:1 ratio. Once dried, the reinforced film of adhesive was peeled away from the polyester film by detaching one end and rolling it onto a small roller. The Stabiltex was then placed face-down on the delicate Kalamkari fabric, with the unattached parts arranged in their rightful spots. Heat and light pressure was applied to the fragments and surrounding area with the help of a small electric iron set at 90°Celsius and a silicone paper as the separator between the adhesive and the iron. To stop dust from sticking to the exposed surface and reduce the unpleasant sheen of the adhesive, the surplus glue was removed from the front of the fabric using acetone.

Abdel et al. (2008) and his colleagues conducted research on the conservation of an unusually decorated ancient Egyptian textile from the Cairo Museum of Egyptian Antiquities. They assessed the effectiveness of a reactivation consolidation technique for reinforcing the painted textiles and utilized a range of methods to identify the fibres, paints, and other materials that composed the artifact. Additionally, they evaluated the object's condition. A separate artificially deteriorated newly prepared linen textile samples was used to evaluate the reactivation consolidation technique. In this study, the effects of three different adhesives (Vinyl acetate / acrylic ester copolymer, Vinyl acetate / dibutyl maleate copolymer; Butyl acrylate / methyl methylacrylate; and Methyl hydroxyethyl cellulose) at concentrations of 5%, 10%, and 15% were tested on aged textile samples. It was determined that Butyl acrylate / methyl methyl acrylate at 10% was the best option and that silk screen was superior to polyester support fabric. The results suggest that the consolidation technique is suitable for reinforcing deteriorated linen textiles.

Manek (2012) chose a naturally aged, delicate silk fabric for its conservation using adhesives. To secure the fabric, a clean wooden table was covered with a non-stick plastic film that was held in place by cello tape on all four sides. A nylon net fabric of the appropriate size was then laid on the table, and two adhesive solutions were prepared using Polyvinyl Acetate (PVA) and Polymethyl Methacrylate (PMMC) in concentrations of 10% and 20%. The adhesive was then lightly brushed onto the nylon net fabric. The goal was to form a film from the adhesive that the silk fabric would be embedded in. The prepared nylon nets with concentrations of 5% and 10% were attached to the silk fabric using both cold and hot processes. For the cold process, the reverse side of the aged fabric was placed against the front side of the backing fabric and held together by brushing on an acetone solution. It was then allowed to dry. Similarly, the hot sealing method involved pressing the adhesive-coated backing textile onto the back side of the aged silk fabric, using a light and warm iron. According to the findings, the optimal method for chemically consolidating the aged silk textile was using a 10% solution of Polyvinyl Acetate through the cold adhesion process, as it effectively preserved the original characteristics of the silk material.

Simpso (1991) did an experiment to look into how abrasive the backing materials were for historic textiles that were used for conservation, exhibit and storage. Four kinds of unbleached 100% cotton fabrics (muslin, duck, sailcloth and warp sateen) were picked out to be studied of different weights and weave. The Crock meter was the instrument that was used to measure the abrasiveness of both the front and back of the backing fabrics. The study showed that muslin, the light plain weave fabric, had the least abrasive nature.

Preservation of cultural heritage necessitates a cautious and comprehensive cleaning process, as inappropriate cleaning techniques can lead to damage. Nanostructured fluids (NSFs) are preferred over non-confined organic solvents due to their potential risks. Although the efficacy of NSFs in removing polymeric coatings has been established, their cleaning mechanisms still require further investigation. To expand on existing research, Baglioni M. et al. (2019) conducted a study to investigate the effects of a four-component NSF on different types of acrylic and vinyl polymer films applied to three substrates (glass, marble, and polystyrene) with varying hydrophilicity and wettability. The NSFs were applied either unconfined or confined in cellulose poultices or highly retentive chemical gels to understand the impact of the confining matrix on the removal process. The study discovered that the interaction between the NSF and the polymer film is heavily influenced by the film's structure and composition. Polymer films created from solutions can be swollen and dewetted using water/organic solvent mixtures or surfactants added to the cleaning fluid. In contrast, films formed from polymer latexes tend to swell but are challenging to remove. The substrate material also plays a role in the removal of polymer films. For example, an acrylic polymer on polystyrene can only be removed through highly selective cleaning using NSF-loaded chemical hydrogels. These findings are critical for art conservators as they offer new strategies to overcome the challenges, they face in preserving art.

2.2.2 Application of natural agents using encapsulation method for developing antimicrobial and insect repellent properties

Kyatham et al. (2015) developed an antimicrobial micro-encapsulated cotton fabric by using extracts from the leaves of Punica granatum (Pomegranate), Cassia ariculata (Matura tea tree, Ranawara or Avaram), and Catharanthus roseus (Periwinkle) as the core material and gum acacia, guar gum, and bagawathi gum as the wall material. The fabric was then tested for its effectiveness against *E.coli* and *S. aureus* bacteria, and the SEM test revealed that the microcapsules present in the fabric ranged between 1.24 μm to 2.29 μm. The AGAR test results showed that the Periwinkle extracts with the different gum sources had a higher zone of inhibition against *Escherichia coli* than *Staphylococcus aureus.*

R, Anitha et al. (2011) in their study explored the encapsulation of lemon grass oil in 100% polyester fabric for use as a mosquito repellent. To do so, the oil was extracted from lemon grass via methanolic and aqueous processes. A mixture of 3% sodium alginate and surface agents was prepared with 30 ml of the extracts and then sprayed into calcium chloride solution and retained for 15 minutes. Finally, the microcapsules were acquired after decantation and washed with iso propyl alcohol and dried at 45°C for 12 minutes. The microcapsules were incorporated into the fabric by running it through a padding mangle at 15 m/min and 15 kgf/cm2 to expel any remaining liquid, and then air drying it. To test its mosquito repelling properties, an Excito Chamber was employed and the results demonstrated a 92% repellency activity when the polyester fabric was finished with the aqueous extract lemon grass microcapsules. In contrast, the polyester fabric, coated with methanolic lemon grass microcapsules, registered only 80% mosquito repellency activity. FTIR results displayed an increase in peaks in the range of 2000-3600 nm-1 in the microcapsule finished fabric when compared to the unfinished polyester fabric.

Annapoorani et al. (2015) created a natural herbal encapsulated adhesive tape made entirely out of bamboo spun fabric, which contained extracts of green tea and coffee as its core material, and calcium chloride as its wall material for the medical purposes. The microcapsules were synthesized on the fabric using a exhaust method. To determine the effectiveness of the fabric, AGAR diffusion tests were conducted against Staphylococcus aureus and Escherichia coli. The results revealed that coffee had the highest activity levels, reaching 44 mm against Staphylococcus aureus and 39 mm against Escherichia coli, while green tea had an activity of 42 mm against Staphylococcus aureus and 33 mm against Escherichia coli.

Selvamohan et al. (2012) conducted a study to evaluate the antimicrobial properties of extracts of seven medicinal plants - Aloe vera, Phyllanthus emblica, Phyllanthus niruri, Cynodon dactylon, Murrya koenigii, Lawsonia inermis, and Adhatoda vasica - on certain human pathogenic bacteria. The extraction of these plants was done using methanol, ethanol, and aqueous methods. To test the efficacy of these extracts, the invitro antimicrobial activity was measured using the agar well diffusion and disc diffusion methods. The results showed that the ethanolic and aqueous extracts had minimal antimicrobial activity when compared to the methanolic extract. Interestingly, the methanolic extract of Phyllanthus niruri (also known as stone breaker) had the most potent activity against Staphylococcus species.

Thilagavathi & Rajendrakumar (2005) created a textile finish that was eco-friendly, using herbs. The methanolic extracts of the active substances was done from neem leaves, prickly chaff flower, tulsi leaves, and pomegranate rind were applied to cotton fabric through the exhaust method and tested for antimicrobial activity against Staphylococcus aureus and E. coli. The AATCC standards of agar diffusion and parallel streak method were used to evaluate the antimicrobial properties of the herbs. Results showed that neem leaves had the highest antimicrobial activity, followed by pomegranate and prickly chaff flower. Although tulsi showed a lower antimicrobial level in the qualitative test, it still managed to reduce bacterial levels by 73% in the quantitative test.

Sumathi et al. (2015) investigated the antimicrobial capability of organic cotton fabric treated with microencapsulated herbal extracts. They used the exhaust method to finish the fabric with medicinal herbs such as Camellia sinensis (green tea), Azadirachta indica (neem leaf) and Maranta arundinacea (aerro root). The finished fabrics were tested for their antibacterial activity using the ENISO 20645 (qualitative) and AATCC 100-2004 (quantitative) standard test methods. The durability of the finished fabric was increased by microencapsulating the herbal extracts with different concentrations using the ionic gelation technique. Neem gum was used as the polymer, and a surfactant such as tween 20 was combined with the herbal extract to form a smooth, viscous dispersion. This mixture was then sprayed into a calcium chloride solution with a sprayer and left there for 15 minutes. The microcapsules were obtained via decantation and further washed with isopropyl alcohol before being dried at 45°C for 12 hours. Finally, the microcapsules were used to finish the fabric with a binder, and the results revealed a high efficacy against microorganisms.

In their research, Ramaya & Maheshwari (2014) developed a fabric with an eco-friendly mosquito repellent made from the herbal extract of the Andrographis paniculata plant. To make the microcapsules containing the extract, they used the ionic gelation technique with 3% of sodium alginate as a wall cover. An equal mixture of Sodium alginate and the extract was sprayed into calcium chloride solution with a sprayer, and the droplets were left in the solution for 15 minutes to harden the capsules. The microcapsules were then obtained by decanting and washing with isopropyl alcohol, followed by drying at 45C for 12 hours. The exhaust method was employed to apply the finish to the fabric in two ways: direct application and microencapsulation. A mosquito repellency behavioural test was then used to assess the efficiency of the fabrics. The results revealed that the direct application method was 96% efficient, while the microencapsulated sample was 94% efficient. Moreover, the direct application fabrics exhibited good resilience activity in up to 10 washes because the extracts are only on the surface of the fabrics without bonding. The microencapsulated samples, however, had good resilience activity in up to 30 washes because of the sustained release of the encapsulated extracts. This demonstrated that microencapsulated fabrics have higher retention of the repellent activity when compared to the directly applied ones.

Ferrándiz et al. (2015) conducted a work analysis and characterization study on oregano and sage essential oil microcapsules created through interfacial polymerization using polyurea as a wall material. Several analytical techniques such as optical microscopy, particle size analysis, Fourier transform infrared spectroscopy (FTIR), differential scanning calorimetry (DSC), Thermogravimetric analysis (TGA), spectrophotometry, antimicrobial testing and chromatography were used to analyse the characteristics of the microcapsules. The results indicated that oregano and sage oil possess antimicrobial properties which remain intact within the microcapsules.

Fernanda et al. (2009) examined the antimicrobial properties of microencapsulated lemongrass essential oil and how experimental parameters impacted the size and form of the microcapsules. Lemongrass essential oil, known for its wide-ranging antimicrobial effects, was microencapsulated through a simple coacervation process, using poly(vinyl alcohol) with 78,000 Da and 88 mol% degree of hydrolysis along with glutaraldehyde as wall-forming polymers. The stirring rate and oil volume fraction were analysed to evaluate their effect on the microcapsule size distribution. Sodium dodecyl sulphate and Poly(vinyl pirrolidone) were tested to prevent microcapsules from agglomerating during the process, resulting in microcapsules ranging from 10 μm to 250 μm. It was also established that when SDS at 0.03 wt.% was used, the microcapsules did not agglomerate. The composition and antimicrobial characteristics of the encapsulated essential oil were measured, confirming that the microencapsulation process did not harm the oil.

Isabel et al. (2009) developed microcapsules of thyme oil using the coacervation technique. The intention was to create a novel process to encapsulate thyme oil in polylactide

(PLA) for use in cosmetics. This approach involved dissolving PLA in dimethylformamide (DMF) - a good solvent for PLA that is also highly soluble in water. When this solution came into contact with water, PLA precipitated around the thyme oil core, forming microparticles. The produced microcapsules had a bimodal particle size distribution in volume, with a mean particle size of 40 micron. Microscopy analysis showed that the particles were spherical in shape and had a rough surface, with an estimated wall thickness of 5 micron. Gas chromatography was used to quantify the amount of thyme oil encapsulated, which revealed that apolar compounds were preferentially encapsulated.

Verica et al. (2010) carried out an investigation that involved preparing microcapsules with different oils using a segregative coacervation technique. The emulsions' continuous phase comprised a 1% blend of hydroxypropyl methylcellulose and sodium carboxymethylcellulose in a mass ratio of 0.7/0.3, along with varying concentrations (0%, 0.35%, and 1%) of the anionic surfactant sodium dodecyl sulphate. The components interacted in the emulsion's continuous phase, and this influenced the structure and characteristics of the protective layer around the oil droplets. When NaCMC molecules are present, HPMC/SDS complexes undergo phase separation to create a coacervate that adheres to the oil droplets and forms a microcapsule wall. The researchers utilized sunflower oil, pumpkin seed oil, and a mixture of sunflower and linseed oil as the core materials. The emulsions were then subjected to spray drying to produce solid microcapsules. The study evaluated the stability of the emulsion, the particle size, particle size distribution of the emulsion and microcapsule suspension, as well as the oil content of the microcapsules. The impact of the type of oil on the microcapsule characteristics was also investigated. The study concluded that a stable and compact microcapsule wall that prevented oil extraction was formed at 0.35% SDS. The properties of the oil significantly affected the selection of oils for microencapsulation using this method.

2.2.3. Application of chitosan as a polymer to develop essential oil nanocarriers

Rasanganie & Perera (2018) developed Cinnamon oil (CO) microcapsules using chitosan and gum arabic as wall materials via complex coacervation for the purpose of reducing its negative effects and enhancing its usability. These CO microcapsules were of an irregular shape and had a rough surface, as seen from optical and scanning electron microscopy. UV-visible analysis showed an average encapsulation rate of 860 μg/g. In addition, the Folin-Ciocalteu assay determined that the microcapsules had an antioxidant capacity of 2930 ± 74 μg PGE/mg. The brine shrimp lethality assay also demonstrated that the toxic effects of CO were reduced upon microencapsulation. Disk diffusion assays found that the microcapsules had antibacterial properties against specific bacterial strains. Moreover, when tested in solutions mimicking the stomach and intestine, the microcapsules released 47% and 32% of the core oil, respectively, resulting in a total of 79% release in a controlled manner.

The study conducted by Rozman et al. (2020) looks into the use of essential oil of Homalomena pineodora as a potential wound dressing for diabetic patients. In order to increase its efficacy, the authors synthesised the essential oil into nanoparticles with chitosan using an ion gelation method. These particles had a size of 70 nm and a strong positive surface charge of +24.10 mV. The entrapment efficiency and loading capacity was calculated by performing UV-VIS spectrophotometery. The nanoparticles showed an initial burst release followed by a slow-release pattern for 72 hours. Furthermore, the antimicrobial activity on a broad microbial spectrum was measured using disc diffusion method showed average 7 nm repellent zone, and the nanoparticles also had a concentration-dependent killing behaviour. Finally, when tested on 3D collagen wound models, the nanoparticles reduced microbial growth by 60-80%. All in all, these results indicate the potential of H. pineodora nanoparticles in controlling microbial growth on diabetic ulcers.

The anti-pathogenic capabilities of essential oils in a biobased nano-carrier system were explored by Bushra et al. (2016). Six essential oils were initially tested on multidrug-resistant bacterial pathogens, and cardamom oil was found to have the strongest antimicrobial activity. The researchers then used an ionic gelation method to load cardamom oil onto chitosan nanoparticles, achieving a high encapsulation efficiency of over 90% and a size of 50-100nm. The resulting nanoparticles exhibited a stable nano-dispersion with a Zeta potential of over +50mV. Cardamom oil-loaded chitosan nanoparticles were effective in combatting Escherichia coli and Staphylococcus aureus. To further analyze the structure of the nanoparticles, surface characterization was carried out using SEM and Atomic force microscope. The research concluded that the cardamom oil-loaded chitosan nanoparticles can safely and effectively treat multidrug-resistant pathogens, offering a potential alternative to current antibiotic therapies.

In this study, Rajkumar et al. (2020) investigated the potential of peppermint oil (PO) nano-encapsulated in chitosan nanoparticles (CS NPs) for the management of two stored grain pests. They developed peppermint essential oil nanoparticles using chitosan as a polymer matrix using ionic elation method. They also performed Gas chromatography analysis of the peppermint oil and identified 11 compounds representing 97.44% of oil and the major compounds were l-menthone (32.27) and menthol (23.47), while other compounds identified lies between 0 and 10%. The nano-encapsulated PO (CS/PO NPs) had a size of less than 563.3 nm, a Zeta potential of -12.12 mV, an encapsulation efficiency of over 64%, and a loading capacity of over 12.31%. Toxicity studies showed that the CS/PO NPs were significantly more effective against the two stored product pests than the control. The inhibition of AChE activity ranged between 37.71% and 52.43% for S. oryzae and 31.29% and 37.80% for T. castaneum. The results suggest that chitosan nanoparticles loaded with essential oil could be a promising and innovative approach for managing stored food pests.

Nguyen and Le (2021) developed chitosan nanoparticles that contained palmarosa essential oil (PEO-CNPs). They used two methods, emulsion formation and ionotropic gelation encapsulation, to create these nanoparticles. The researchers optimized encapsulation by testing three parameters: chitosan concentration, initial oil loading in the emulsion, and TPP concentration. They evaluated the effects of these parameters on encapsulation efficiency (EE) and loading capacity (LC). EE increased initially and then decreased with changes in the three parameters, while LC increased with increasing initial oil loading but decreased with changes in polymer and sodium tripolyphosphate concentrations. To evaluate particle size, Dynamic Light Scanning (DLS) was used on the sample with the highest encapsulation efficiency (EE), which had a combination of 10.0 g/L of chitosan, 5.0 g/L of TPP, and 30.0 g/L of PEO. The DLS analysis revealed a z-average diameter of 235.3 nm and a particle size distribution ranging from 100 - 500 nm.

Granata et al. (2021) created chitosan nanoparticles that contained Thymus capitatus and Origanum vulgare essential oils (Th-CNPs and Or-CNPs) using ionotropic gelation and evaluated their characteristics. The nanosystems exhibited high loading capacity (26-27%) and encapsulation efficiency (80-83%) and showed excellent homogeneity and stability with spherical shape, as evidenced by low PDI values (<0.7) and high zeta potential values (>40 mV). The physicochemical properties of the nanoparticles remained unchanged even after exposure to varying temperatures (4 and 40°C) and storage times (7, 15, 21, and 30 days), suggesting that they can effectively act as essential oil reservoirs under different conditions. Moreover, the antibacterial activity of both Th-CNPs and Or-CNPs was greater against foodborne pathogens (S. aureus, E. coli, L. monocytogenes) compared to pure essential oils, highlighting their potential as natural preservatives and their significance in promoting food safety and human health.

Li et al. (2013) studied that combining the right surfactants with chitosan produces small and heat-stable emulsion droplets that can be spray-dried to form microcapsules. These capsules can then be deposited onto cotton fabrics by either water or detergent. The best results were achieved when Tween 40 and Span 20 were used in a 4:1 weight ratio and the chitosan was 1% (w/w) acetic acid. In addition, the inlet temperature for spray-drying was 150°C and a 1:2 (w/w) ratio of oil to chitosan was used for the encapsulation efficiency of orange oil. The microcapsules were less than 20μm in diameter and had a regular particle shape. After washing with normal detergent solution, the orange oil in the microcapsules was still present in the cotton fabrics. This process is low-cost, non-toxic, bio-compatible, and biodegradable.

Osanloo et al. (2019) in this paper studied the GC-MS analysis was used to identify the components of tarragon (Artemisia dracunculus) essential oil. Out of the 48 components found, the five major components were estragole (67.623%) followed by cis-Ocimene, beta-Ocimene Y, Limonene, and 3-Methoxy cinnamaldehyde. Chitosan nano capsules were created using the ionic gelation method, which was confirmed by FT-IR analysis. The researchers reported that the nano capsules had an encapsulation efficiency of 34.91 ± 2% and a size of 203 ± 16 nm. The study also demonstrated the development of a green larvicide that remained active against Anopheles stephensi for 10 days, which is a novel finding. The nano formulation was found to be as non-toxic to human skin normal cells (HFFF2) as the synthetic larvicide temephos. This nanoformulation has the potential to be a good alternative to synthetic larvicides because of its long-lasting activity, effectiveness, and green constituents.

Gupta et al. (2022) The researchers conducted preparation and characterization of thyme oil nanoemulsion and its chitosan encapsulation with the use of a high energy approach to manage three mosquito species, Anopheles stephensi, Aedes aegypti, and Culex tritaeniorhynchus. The synthesized formulations were tested for their thermodynamic stability, with the 1:0.5 ratio of oil and surfactant found to be the most stable for the nanoemulsion and a 1:1 ratio of nanoemulsion and chitosan solution for the encapsulation. The dynamic light scattering and transmission electron microscopy methods were used to determine the size and shape of the droplets of thyme oil nanoemulsion and its chitosan encapsulation, which measured 52.18 ± 4.53 nm and 50.18 ± 2.32 nm, respectively. The nanoemulsion droplets were observed to have a flower-like shape, while the chitosan encapsulation had a mitochondria-like appearance. An in-vitro release study showed that 91.68% and 73.41% of the total oil concentration was released into the environment after 48 hours from the nanoemulsion and chitosan encapsulation, respectively, demonstrating controlled release. The insecticidal potential of both the nanoemulsion and its chitosan encapsulation against certain mosquito species was found to be effective. The most potent activity of thyme oil nanoemulsion was seen against C. tritaeniorhynchus (LC50—22.58 ppm) after a 24 hour exposure period, whereas its chitosan encapsulation had the best results against A. stephensi (LC50—18.88 ppm) after the same amount of time. Visible changes in the structure of mosquito larvae occurred due to the substances. Consequently, these nanoemulsions and encapsulations should be studied further for possible use against other agricultural pests.

Oluoch et al. (2021) developed, characterize, and measured the effectiveness of thymol and eugenol loaded chitosan nanoparticles (TCNPs and ECNPs) against Ralstonia solanacearum, the bacterium that causes potato wilt. These nanoparticles were synthesized using ionic gelation, and their particle size distributions, encapsulation efficiencies, loading capacities, and in-vitro release characteristics were examined. Their antibacterial activity was tested with agar dilution and colony counting, and the minimum inhibitory concentration was determined with a 96-well broth micro-dilution method. The use of scanning electron microscopy revealed that TCNPs and ECNPs were spherical in shape, with an average particle size of 590 nm and 555 nm, respectively. Chitosan nanoparticles had an average size of 375 nm. The encapsulation efficiency of TCNPs (with 48.3% LC) was 72.9%, and ECNPs (with 49.5% LC) was 71.7%. Additionally, the release of thymol and eugenol from the microcapsules was pH dependent, with the highest release at pH 1.5. The growth inhibition of R. solanacearum by TCNPs and ECNPs was 92% and 94%, respectively. Moreover, the MIC of thymol and eugenol decreased from 175 and 275 μg/ml to 22.5 and 45 μg/ml after encapsulation. Therefore, encapsulating thymol and eugenol in chitosan nanoparticles may provide a promising alternative to traditional bactericides for R. solanacearum and could be beneficial in controlling this soil-borne phytopathogen.

Purwanti et al. (2018) investigated the stability of emulsions containing clove oil when chitosan and sodium alginate were used as encapsulating agents. The emulsions were prepared using various homogenization speeds and included 1% w/w chitosan (CC emulsions) and 2.5% w/w sodium alginate (CA emulsions) with Tween 80 as the surfactant. After 29 days of storage, the emulsions had a size of 2-3 μm and a 90% stability rate, resulting in a polydisperse emulsion. The concentrations of the active compounds in the emulsions were not significantly affected by different homogenization speeds. However, when sodium alginate was used, significant changes in concentrations were observed after 29 days of storage with homogenization speeds ≥ 10,000 rpm. The instability of emulsions made from sodium alginate was attributed to the high viscosity of the solution and high energy dissipation during homogenization. Chitosan allowed for a longer processing time, and the clove oil-in-chitosan matrix emulsion was more stable before the solidification step compared to sodium alginate.

Shetta (2017) investigated the encapsulation of peppermint oil (PO) and green tea oil (GTO) into chitosan nanoparticles (CS NPs) using a two-step process involving emulsification and ionic gelation. The size and shape of the resulting CS/PO and CS/GTO nanoparticles were analyzed using transmission electron microscopy (TEM), while Fourier transform infrared (FT-IR) spectroscopy and powder X-ray diffraction (XRD) were used to assess the encapsulation. The thermal stability of the oils was measured using thermogravimetric analysis (TGA), and it was found that both oils exhibited enhanced thermal stability when encapsulated, with PO and GTO showing 2.18 and 1.75 times more stability, respectively. The encapsulation efficiency (EE%), loading capacity (LC%), and in-vitro release of the nanoparticles were measured using UV-vis spectroscopy. The EE% of CS/PO NPs and CS/GTO NPs were found to range from 82-78% and 22-81%, respectively, with LC% ranging from 8-22% and 2.2-23%. In-vitro release studies showed an initial rapid release profile followed by a slow release at two different pH conditions - acidic (acetate buffer) and neutral (phosphate buffer saline). The stability of the total phenolic contents (TPC) of both oils when encapsulated in CS NPs was measured using Folin–Ciocalteu reagent, while the antioxidant activity was tested using the 2,2-diphenyl-1-picrylhydrazyl radical (DPPH) assay. The antioxidant activities of CS/PO and CS/GTO NPs were increased by approximately 2 and 2.4 times, respectively. The antibacterial effects of both pure and encapsulated PO and GTO against Gram positive (Staphylococcus aureus) and Gram negative (Escherichia coli) bacteria were evaluated using agar dilution and colony counting, with encapsulated PO displaying an enhanced antibacterial activity of 39.63% against Gram positive bacteria and 3% against Gram negative bacteria, and encapsulated GTO showing an improved antibacterial activity of 57.5% against Gram positive bacteria and 1.8% against Gram negative bacteria.

Nouri & Khodaiyan (2021) explored how chitosan encapsulation affects the physical and chemical characteristics of ginger essential oil. In order to do this, a variety of samples were created by combining chitosan and ginger essential oil in different ratios (1:0, 1:0.4, 1:0.8 and 1:1.2 (w/w)) and sodium tripolyphosphate concentrations (0.5 and 1% w/v) using the emulsion-gel method. The samples were then evaluated for their encapsulation efficiency, loading capacity, particle size distribution and zeta potential. Furthermore, Fourier-transform infrared spectroscopy, total phenolic compounds, free radical scavenging and minimum inhibitory concentration (MIC) tests were conducted on the selected and control samples. The results of the physical tests indicated that the best sample was obtained with a chitosan to essential oil ratio of 1:0.8 w/w and a salt concentration of 0.5% w/v. This nanocapsule was found to have an effective encapsulation capability (23.1%), an optimal particle size (734 nm) and a positive zeta potential (29.2 mV). The use of chitosan nanocapsules containing ginger essential oil resulted in higher minimum inhibitory concentrations (MIC) for Escherichia coli (0.97 μg/ml), Staphylococcus aureus (1.9 μg/ml), Salmonella typhimurium (3.90 μg/ml) and Pseudomonas aeruginosa (0.97 μg/ml) compared to the control samples. In addition, there was a notable increase in the antioxidant activity (97%) and the total phenolic compound (980 mg/g) of the optimal chitosan nanocapsule. This discovery indicates that chitosan nanocapsules can be used as a natural substitute for chemical additives in order to enhance the functional properties of ginger essential oil.

Dima et al. (2014) investigated the use of chitosan and chitosan/k-carrageenan microspheres for encapsulating Pimenta dioica (P. dioica) essential oil. The essential oil was obtained from P. dioica (L) Merr. berries using supercritical CO2 extraction. GC analysis identified 23 components, primarily composed of eugenol (68.06%) and methyl eugenol (9.37%). The antioxidant activity of the P. dioica essential oil was assessed and the IC50 (DPPH) value was found to be significantly lower ($p \leq 0.05$) than that of butylated hydroxytoluene (BHT) and ascorbic acid (AAC). O/W emulsions were extruded, using chitosan and chitosan/k-carrageenan in different mass ratios, to prepare the microspheres containing P. dioica essential oil. The swelling degree of chitosan microspheres was found to be significantly higher than that of chitosan/k-carrageenan microspheres ($p<0.05$). The release behavior of P. dioica essential oil from chitosan/k-carrageenan microspheres was studied, and it was observed that microspheres with a 1:1 mass ratio followed a zero-order release kinetics or a case II transport mechanism, whereas microspheres with mass ratios of 1:0, 3:1, and 2:1 showed a non-Fickian release mechanism. The researchers also analyzed the morphology, encapsulation efficiency, and antimicrobial activity of the crude and microencapsulated P. dioica essential oil. The results showed that the microencapsulated essential oil was effective against *Candida utilis, Bacillus cereus,* and *Bacillus subtilis*.

Adding specialized nanocarriers as additives to substances can enhance their chemical stability and solubility, as well as slow down their degradation and reduce evaporation. To test this, Valinezhad et al. (2022) prepared chitosan Ferula gummosa EO-nanocomposite (CS-FEO) was conveniently made using ionic gelation method and its antibacterial properties were evaluated by the agar well diffusion assay method against Escherichia coli, Staphylococcus aureus, and Bacillus cereus. A transparent and flexible CS-FEO biopolymer film was also prepared and studied. The results showed that CS-FEO nanocomposite had significant antibacterial activity. Its interaction with chitosan and FEO was confirmed by Fourier transform infrared spectroscopy (FTIR) and the degree of crystallinity was determined by examining the X-ray diffraction (XRD) pattern. The findings suggest that CS-FEO nanocomposite could be a potential material for food and biomedical applications due to its unique interactions and features.

In this paper, Hasani et al. (2018) determined if encapsulation is a viable method for preserving essential oils and to assess the colloidal properties of nano capsules. To begin, the active compounds of Citrus Limon L. essential oil were identified using Gas Chromatography (GC). Afterwards, an Oil-in-water emulsion with a ratio of 1:4 Essential oils: coatings (chitosan and modified starch) with different ratios (0.5:9.5, 1:9, and 1.5:8.5 % w/v) was prepared by sonication and freeze drying. Results from examining the physical and chemical properties of the emulsion and nano capsules revealed that increasing chitosan concentrations yielded higher stability and viscosity. The droplets were also observed to be smaller and more uniform in size distribution with higher concentrations of chitosan. Additionally, differences in moisture content, encapsulation efficiency, and particle size were observed based on the different ratios of wall materials. Finally, the morphology of the nano capsules showed that those with higher encapsulation efficiency had smoother surfaces, with no gaps, and least porosity.

Nwokwu et al. (2017) aimed to improve the pharmacokinetic profile, bioavailability, solubility, and toxicity of gedunin, a compound with potential anticancer properties found in the neem plant, by encapsulating it in chitosan nanoparticles. The study tested the inhibitory activity of gedunin (1.5625 - 50 µg/mL) and the nano-formulation (0.469 - 15 µg/mL) on NCI-H292 cells for 24, 48, and 72 hours, with paclitaxel used as a positive control. The Sulphorhodamine B assay was used to evaluate the inhibitory activity of these treatments, while a phase-contrast microscope was used for microscopic visualization. The encapsulation efficiency of gedunin in chitosan was found to be 98%, with an average particle size of 163.2

± 24.28 and a zeta potential of +24.2 ± 3.75. Dose- and time-dependent cytomorphological changes were observed, resulting in cell death. The nano-gedunin showed significantly greater antiproliferative activity against NCI-H292 cells ($p < 0.05$), with mean IC50 values of 26, 23, and 20 µg/mL at 24, 48, and 72 h respectively, while chitosan-encapsulated gedunin had a 3 to 8-fold decrease in IC50 values (7.5, 5, and 2 µg/mL). The chitosan nano-delivery system enhanced the cytotoxic activity of gedunin in vitro against NCI-H292 cells and reduced its cytotoxicity towards normal lung fibroblasts (MRC-5).

The emergence of antibiotic resistance in K. pneumoniae is a major global problem caused by the misuse of antimicrobial drugs. To combat this, Zhang et al. (2020) looked into the use of plant material and essential oils. This investigation focused on the medicinal plant guava leaves and their essential oils to treat multi-drug resistant bacterial infections. High Resolution Liquid Chromatography-Mass Spectrometry (HRLC-MS) was used to screen and confirm the essential oils. The antibacterial properties of the compounds were then loaded into chitosan nanoparticles and confirmed using Fourier Transform Infrared Spectroscopy (FTIR). The morphology of the chitosan loaded essential oils was compared to chitosan alone via SEM analysis, which indicated that the oils were successfully loaded. The anti-bacterial ability of the material was then tested with an agar well diffusion method, and was found to be effective against multi-drug resistant K. pneumoniae even at the lowest concentration of 100 µg/ml. The minimum inhibition concentration experiment further confirmed the efficacy of the chitosan loaded essential oils. Therefore, it was demonstrated that the essential oils were successfully loaded into the chitosan nanoparticles and had greater anti-bacterial activity than chitosan alone against multi-drug resistant K. pneumoniae.

Wang et al. (2011) studied the effectiveness of three natural essential oils (clove bud oil, cinnamon oil, and star anise oil) combined with chitosan films as antimicrobial agents was assessed. Cinnamon oil had the strongest antimicrobial activity against Escherichia coli, Staphylococcus aureus, Aspergillus oryzae, and Penicillium digitatum compared to the other two oils. Chitosan solution had a good inhibitory effect on the bacteria, but not the fungi. The combination of cinnamon oil and chitosan film yielded more synergistic effects than clove bud oil and chitosan film. This could be associated with the continuous release of the oil from the film. Furthermore, the chitosan and cinnamon oil exhibited greater compatibility when compared to chitosan and clove bud oil. However, the addition of either oil had an impact on the mechanical strength, water vapor transmission rate, moisture content, and solubility of the chitosan film. Additionally, there was evidence of a chemical reaction between cinnamon oil and chitosan, while a phase separation occurred between clove bud oil and chitosan.

Luque et al. (2016) developed Nanoparticles composed of chitosan (CS) and essential oil from the pepper tree (Schinus molle) (CS-EO) were synthesized using the nanoprecipitation method, and their antifungal activity against Aspergillus parasiticus spores was evaluated in vitro. The shape, size, and surface charge of the bio-nanocomposites were investigated with scanning electron microscopy (SEM), dynamic light scattering (DLS), and zeta potential, respectively. The influence of the complex on cell viability was analysed using the XTT technique and morphometric analysis through image processing. SEM and DLS revealed the CS-EO bio-composites to be spherical particles with larger diameters. Zeta potential values for CS nanoparticles were higher (+11.1 ± 1.60 mV). The results indicate that there is a potential chemical reaction occurring between chitosan and pepper tree essential oil. The concentration of CS-EO complex that was the most effective caused a 40-50% reduction in the viability of A. parasiticus. The combination of pepper tree oil and CS nanoparticles appears to be a viable option to increase antifungal activity, where the effects of the individual components are amplified.

Tariq et al. (2022) successfully encapsulated spearmint oil (SMO) in chitosan microstructures using the emulsion formation method. SMO is a valuable medicinal product, but its instability and high volatility make it difficult to use in medical and functional textiles. Encapsulating it in chitosan could improve its stability and make it suitable for these applications. The SMO-encapsulated chitosan microstructures were analysed using various techniques, and then applied to cotton fabric with a green crosslinking of citric acid. SEM and FTIR analyses showed that the microcapsules had adhered to the fabric surface successfully. The tensile strength of the treated fabric decreased slightly, but it had improved crease recovery behaviour and good antibacterial activity against different kinds of bacteria, reducing their population by 99%. The stiffness of the fabric had increased slightly. These value-added multifunctional textiles could be used for medical and healthcare applications without compromising their comfort properties.

Wu et al. (2018) synthesized chitosan nanoparticles embedded with Torreya grandis aril essential oils (TEOs) using an emulsion-ionic gelation technique. Mannosylerythritol lipid A (MEL-A) was used as the emulsifier and an ionic liquid (IL) was used instead of acetic acid to dissolve the chitosan. The physical characteristics, size, shape, embedding rate, and antibacterial properties of the TEO-loaded chitosan (CS) nanoparticles were evaluated. The study found that chitosan nanoparticles could be effectively synthesized using an ionic liquid based system. The diameter of the nanoparticles in acetic acid and ionic liquid solutions were 144.1 ± 1.457 and 219.0 ± 4.045 nm, respectively. The addition of essential oils resulted in an increase in the size of the nanoparticles to 349.6 ± 10.55 and 542.9 ± 16.74 nm. The antibacterial activity was assessed by measuring the inhibition zone against S. aureus. The results showed that the nanoparticles loaded with TEO, which were synthesized in both acid and ionic liquid based solutions, exhibited much stronger antibacterial activity than the CS nanoparticles.

The results of this chapter suggest that nanotechnologies have the potential to provide promising strategies for the conservation of artifacts made of fabric in museums. Due to their small size, nanomaterials can result in improved performance or entirely new properties. This could lead to new ways of cleaning these ancient textiles with reduced risks, as well as improved consolidating and protecting properties to stop further deterioration. For example, chitosan-based nanostructures seem to be an effective way of using naturally derived products due to their increased biological activity, improved physicochemical characteristics and greater stability. A variety of essential oils, plant extracts and pure phytochemicals have been incorporated to chitosan nanoparticles to this end. Chitosan-coated nanoparticles have many advantages, such as improved muco-adhesiveness, tissue penetration, tailored prolonged drug release, anti-inflammatory and antimicrobial activity. This suggests they can be used in many different ways in various sectors. One of these ways is to protect ancient textiles from the damage caused by microorganisms and insects. Researcher, therefore, plan to encapsulate biologically active essential oils extracted from herbs and spices into a chitosan polymer shell, and coating on a separate fabric with the developed essential oil-containing nanoparticles. Thus creating a preservative environment for the heritage textiles from microorganisms and insects for a longer period and thereby enhancing its durability for the future. This is an ideal solution to as it allows the ancient textiles to remain undamaged, avoiding any direct application of the essential oils.