Unit 6.3 Sustainable Functional Finishing and Textile Care

Content

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Why sustainable functional finishing of textiles?

Functional finishing aims to:

- Improve the chemical and physical properties of the fibres to impart desired functionality,
- Increase the performance of the textiles,
- Improve comfort and aesthetic properties,
- Add value to the product[1].

Disadvantages of the conventional chemical finishing are related to:

- **Finishing agents and**
- **Application processes.**

Table 1. Conventional versus sustainable chemical functional finishing[1,2]

Conventional approach	Sustainable approach
Use of harmful and hazardous chemicals	Use of nontoxic and safe chemicals
Toxic waste	Nontoxic waste
Air and water pollution (*unfixed agents*)	No water and air pollution
High consumption of water and energy	Low consumption of water and energy

Problem

Harmful and hazardous finishing agents and other chemicals:

- ***Formaldehyde-based chemical finishes:***
  - Durable press finishes.
  - Flame retardant finishes.
- ***Halogenated chemical finishes:***
  - Flame retardant finishes,
  - Water and oil repellent finishes,
  - Antimicrobial finishes.
- ***Cytotoxic chemical finishes:***
  - Antimicrobial finishes,
  - Insect repellent finishes,
  - Softeners.
- ***Toxic reducing and stabilizing agents***

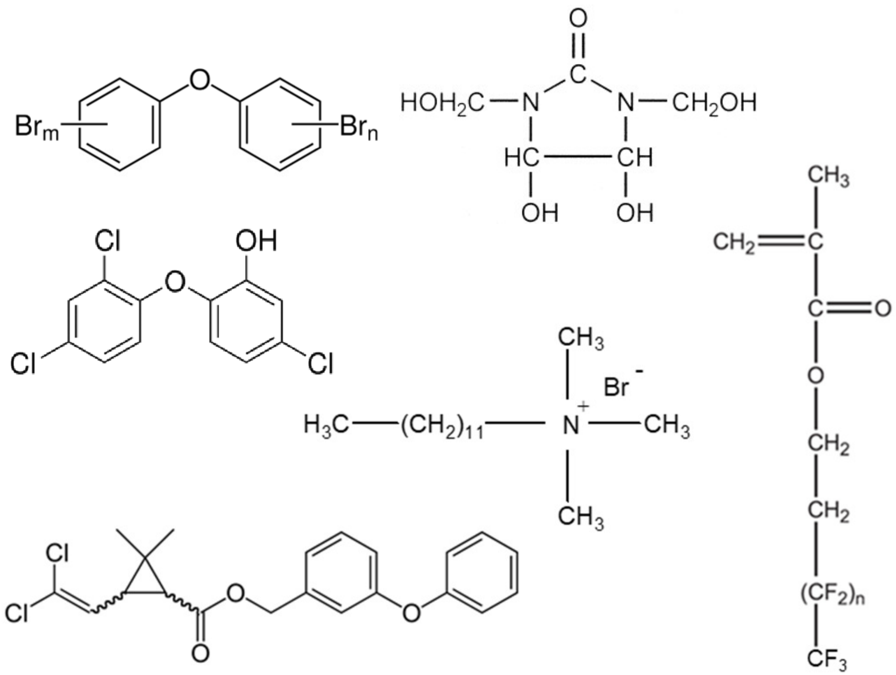

Figure 1. Chemical structures of some harmful finishing agents

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Solution

Nontoxic and safe finishing agents

A. Biomolecules:

- Biological substances produced by cells and living organisms; mostly organic compounds of a wide range of sizes and structures;
- Primary composed of C, H, O, P and S; other naturally occurring elements are present in small amounts;
- Include carbohydrates, lipids, proteins and nucleic acids[3].

B. Bio-sourced products:

- Organic and inorganic compounds from natural resources – occur in the natural state;
- Include compounds from plants, animals, and microbial sources, and bio-mimetic materials.

Figure 2. Green chemistry for sustainability[4-7]

Problem

Finishing processes with high consumption of water and energy

- ***Pad-dry-cure***

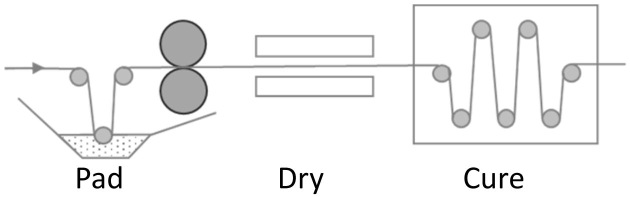


Figure 3. Pad-dry-cure application process[8]

Solution

Finishing processes with low consumption of water and energy

- ***Plasma treatment, Foam finishing, Spray coating***

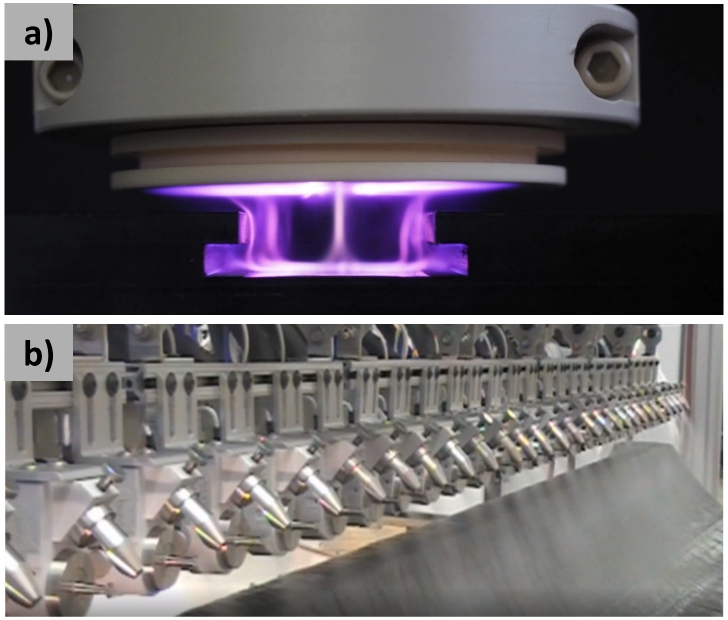
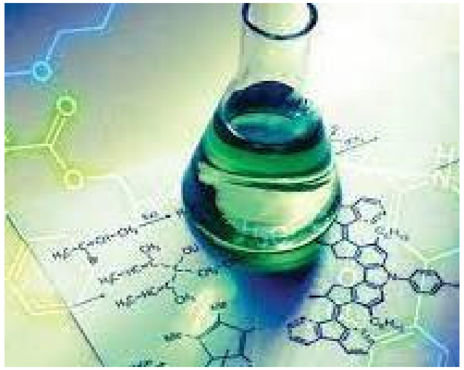


Figure 4. Plasma treatment (a), spraying (b)[9,10]

6.3.1 Biomolecules for functional finishing



Content

Functional biomolecules and bio-sourced products for textile modification:

- Flame retardant agents,
- Antimicrobial agents,
- Insect repellents,
- UV protective agents,
- Crosslinking agents.

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A. Biomolecules and bio-sourced products as flame retardant (FR) agents[11,12]

Classification of green FRs:

- ***Proteins:***
  - Whey proteins (S-rich),
  - Caseins (P-rich),
  - Hydrophobins (S-rich).
- ***Nucleic acids:***
  - Deoxyribonucleic acid (DNA) (P- and N-rich).
- ***Active agents from plants:***
  - Phytic acids (P-rich).

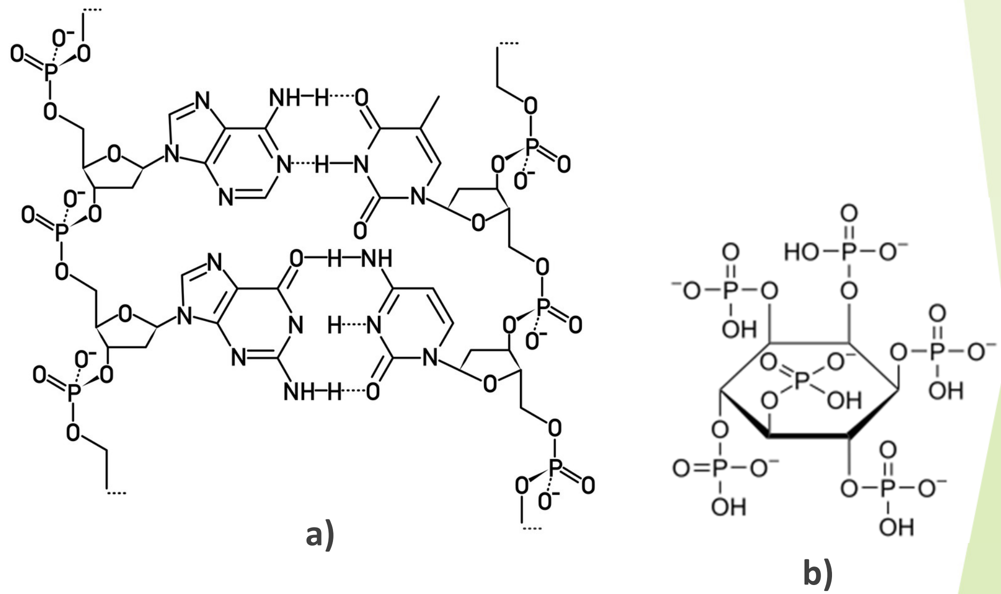

Figure 5. Chemical structures of DNA (a)[13] and phytic acid (b)

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A. Biomolecules and bio-sourced products as flame retardant (FR) agents[11,12]

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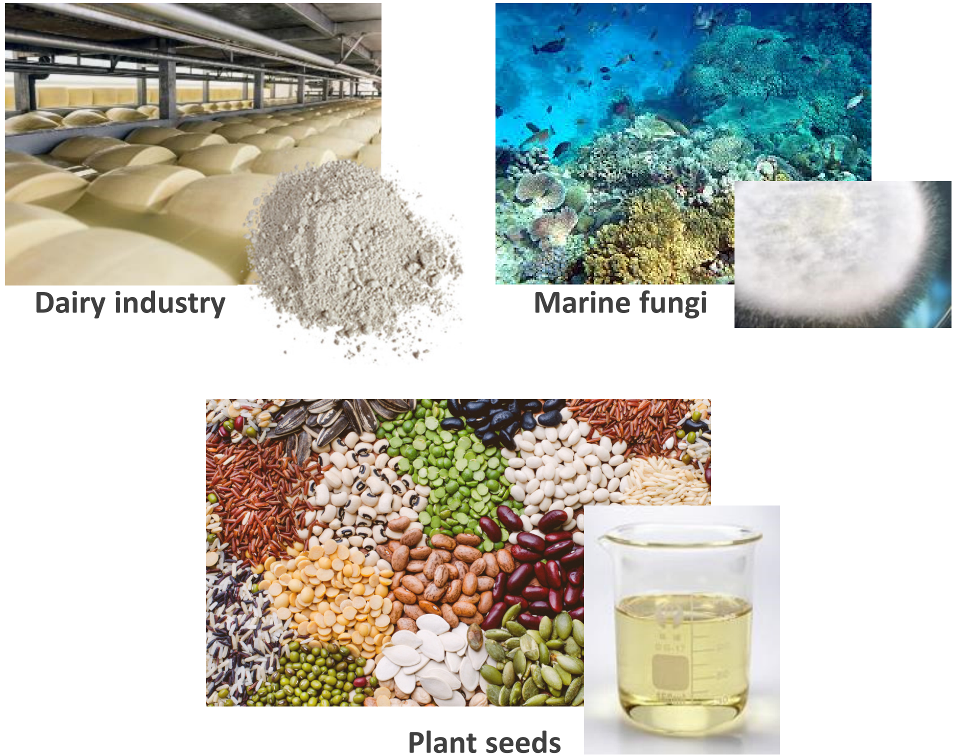

Figure 6. Sources for green FRs[14–16]

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A. Biomolecules and bio-sourced products as flame retardant (FR) agents[11,12]

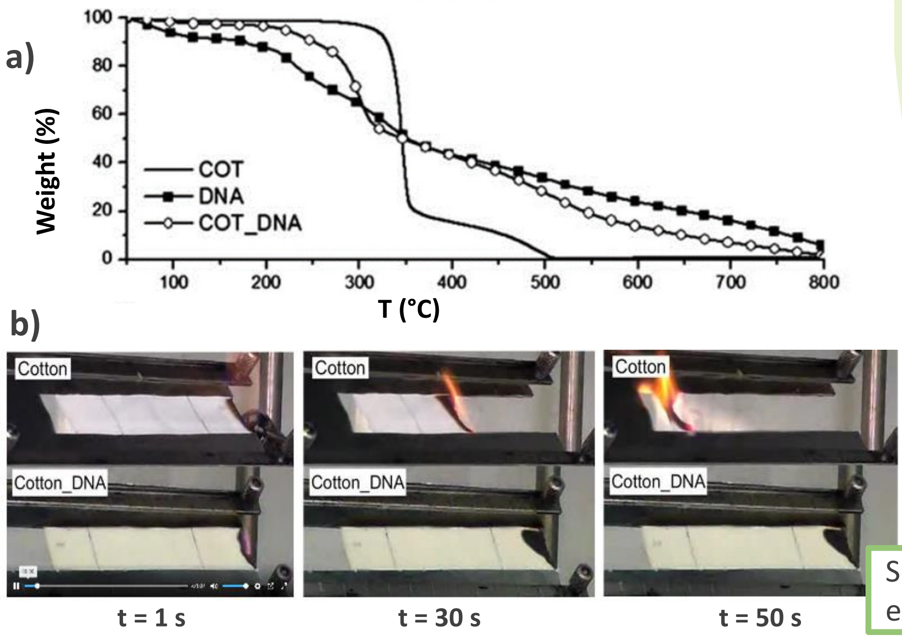
Mechanism of flame retardancy:

- ***P- and S-rich agents***: formation of a stable protective char.
- ***P- and N-rich agents***: formation of char and release ammonia; act as intumescent like compounds (charring and foaming).

Effects:

- Reduce the total burning rate,
- Increase the final residue,
- Lowering the heat release.

Limitations: non-durable coating, high stiffness.



Self-extinguish

Figure 7. TG curves of cotton (COT), DNA and COT_DNA samples in air (a)[17]; horizontal flame test (b)[18]

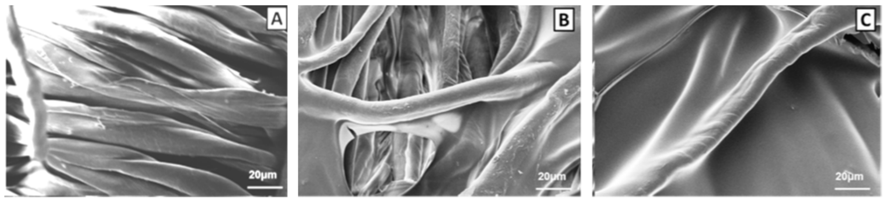


Figure 8. SEM images of cotton (A), cotton/caseins (B) and cotton/hydrophobins (C)[19]

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B. Biomolecules and bio-sourced products as antimicrobial agents[11,20,21]

Classification of green antimicrobial agents:

- ***Carbohydrates:***
  - Chitosan.
- ***Plant extracts (chemically):***
  - Phenolics and polyphenolics (phenolic acids, flavonoids, tannins, coumarins),
  - Terpenoids,
  - Curcuminoids,
  - Acemannan polysaccharide.
- **Sources:**
  - Shells of sea crustaceans, fungi,
  - Plant roots, bark, leaves, petal, fruits, seeds.

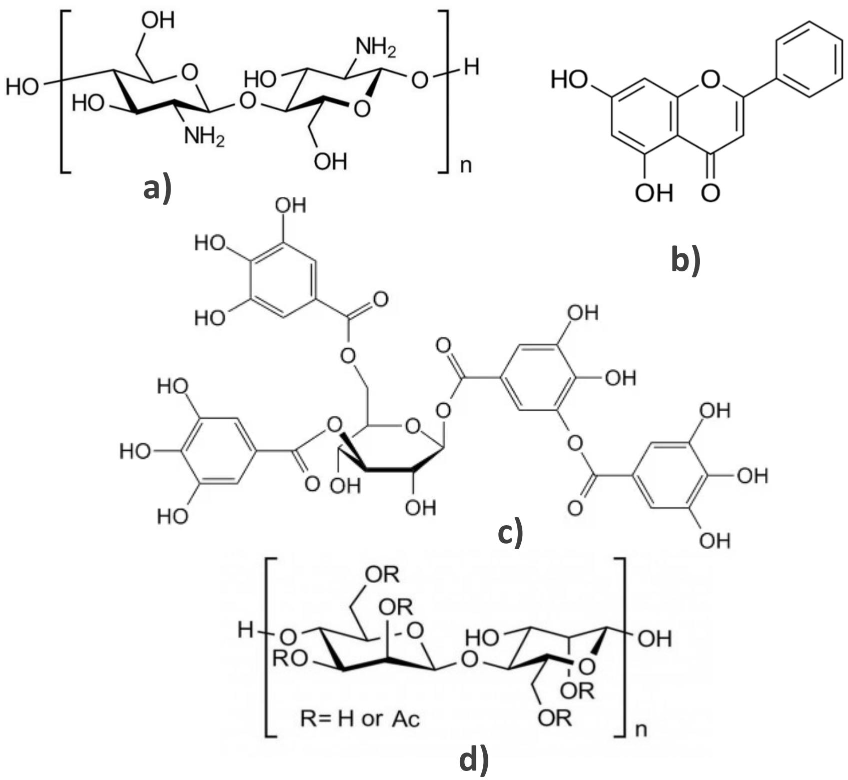

Figure 9. Chemical structures of chitosan (a), flavonoid (b), tannin (c), acemannan (d).

B. Biomolecules and bio-sourced products as antimicrobial agents[11,20-22]

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  - Curcuminoids,
  - Acemannan polysaccharide.
- **Sources:**
  - Shells of sea crustaceans, fungi,
  - Plant roots, bark, leaves, petal, fruits, seeds.

Figure 10. Sources of green antimicrobial agents[23–26]

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B. Biomolecules and bio-sourced products as antimicrobial agents[11,20-22]

Mechanism of antimicrobial activity:

- ***Chitosan:*** electrostatic interactions, binding of chitosan with microbial DNA, chelation of metals present in the cell wall;
- ***Flavonoids:*** complex formation with extracellular soluble proteins;
- ***Tannins:*** inhibition of extracellular microbial enzymes, inhibition of oxidative phosphorylation;
- ***Terpenoids:*** membrane disruption by lipophilic compounds.

Effects: Biostatic to biocidal activity.

Limitations: week adhesion to fibres and non-durable coating.

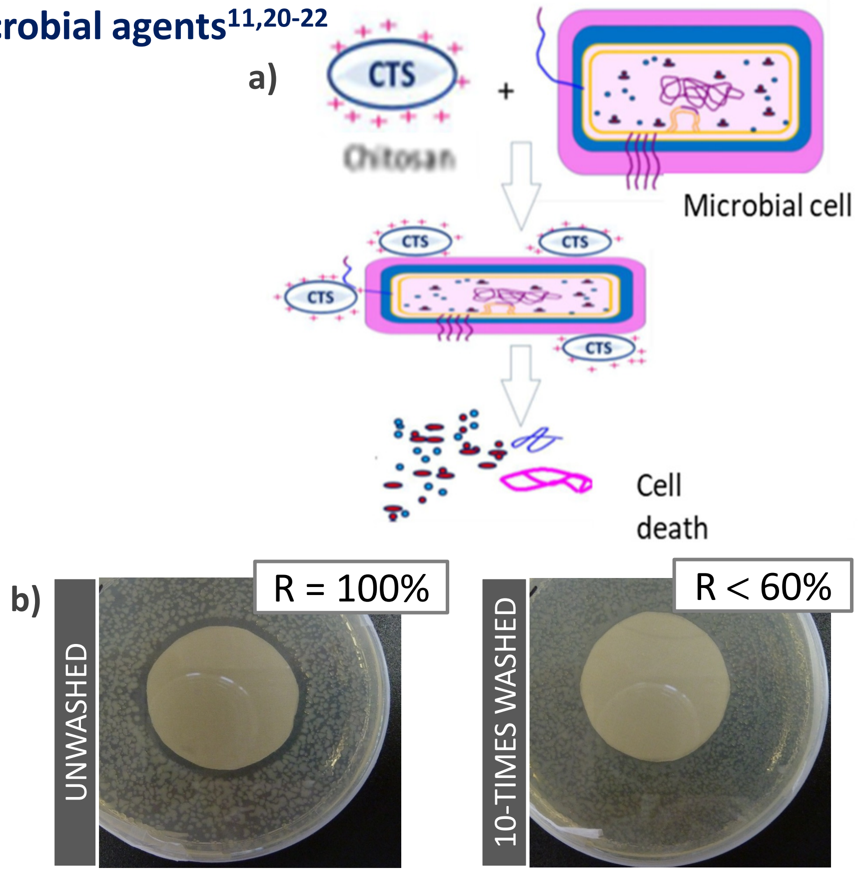

Figure 11. Mechanism of antibacterial activity of chitosan (a)[27], controlled release mechanism (b)

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C. Biomolecules and bio-sourced products as insect-repellent agents[11,28–30]

Classification of bio-based insect-repellent agents:

- ***Essential oils – chemically:***
  - Terpenoids,
  - Phenolics,
  - Alkaloids.
- ***Natural oil – chemically:***
  - Triglyceride.
- ***Plant extracts – as essential oils:***
  - Lemon eucalyptus oil,
  - Citronella oil,
  - Lavender oil,
  - Neem oil,
  - Peppermint oil.

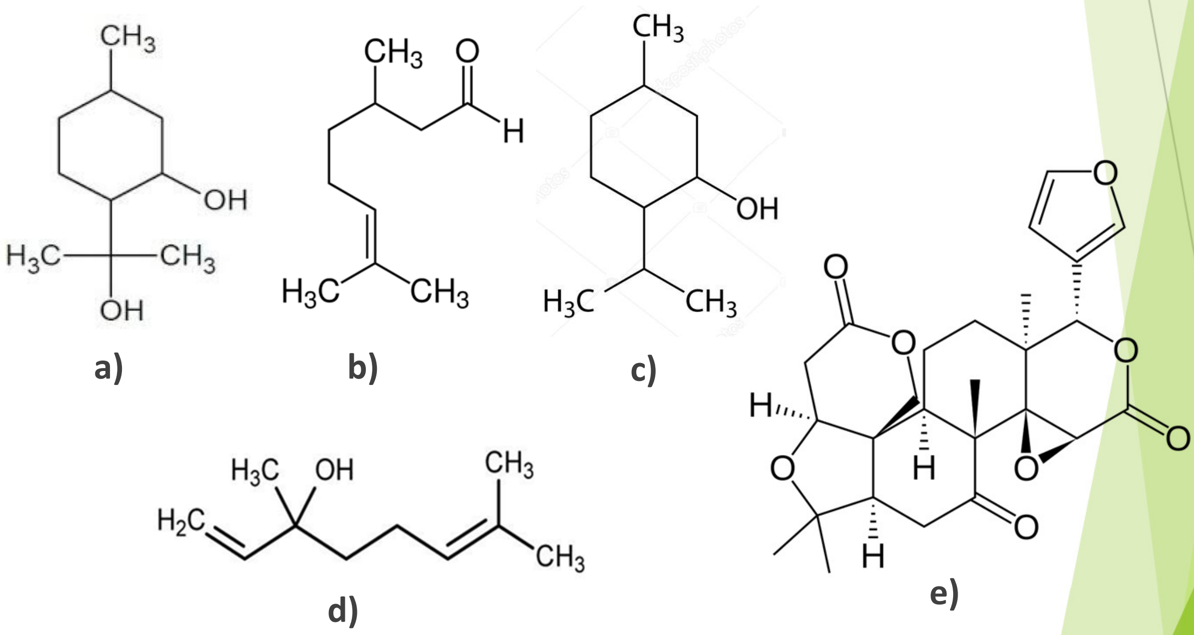

Figure 12. Chemical structures of p-Methane-3,8-diol (a), citronellal (b), methol (c), linalool (d), limonoids (e).

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C. Biomolecules and bio-sourced products as insect-repellent agents[11,28–30]

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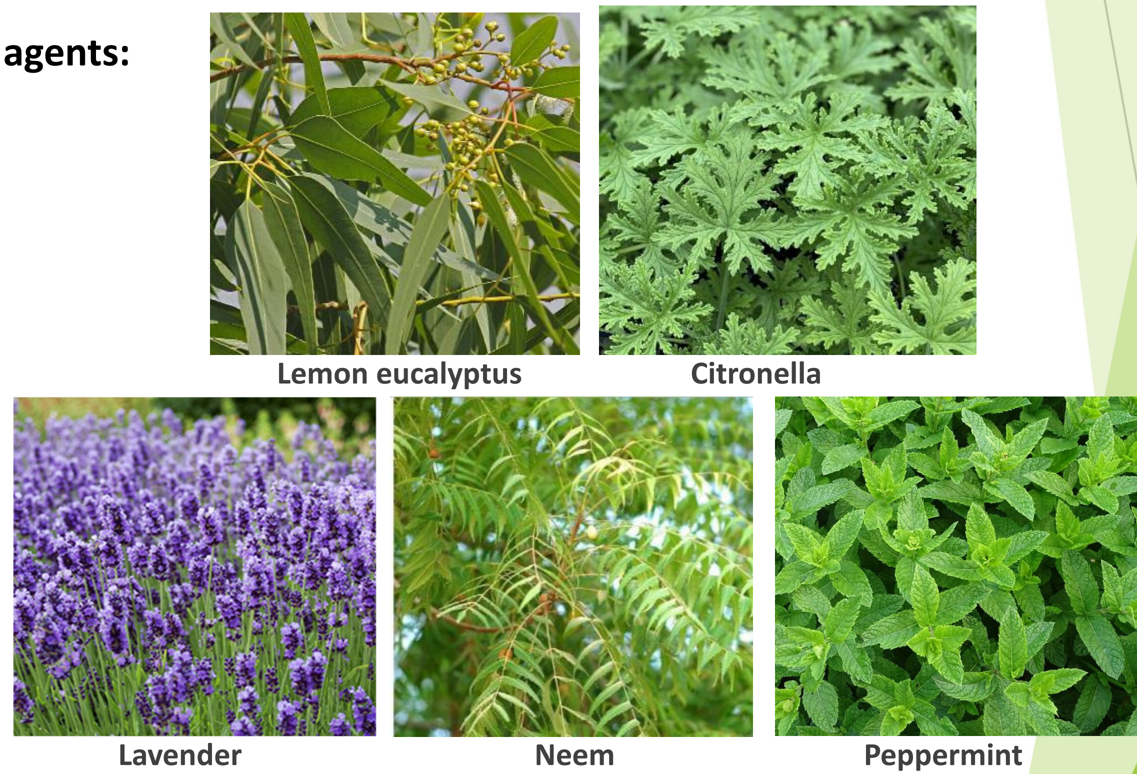

Figure 13. Some of plants used for the essential oils with insect-repellent activity[31–35]

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C. Biomolecules and bio-sourced products as insect-repellent agents[11,28–30]

Mechanism of insect-repellent agents:

- ***Terpenoids, alkaloids, phenolics***: formation of a layer of vapor on the skin with an unbearable odor to the insect.

Effects: Mosquito-repellent, anti-bugs.

Limitations: high release rate of the volatile oils, non-durable coating.

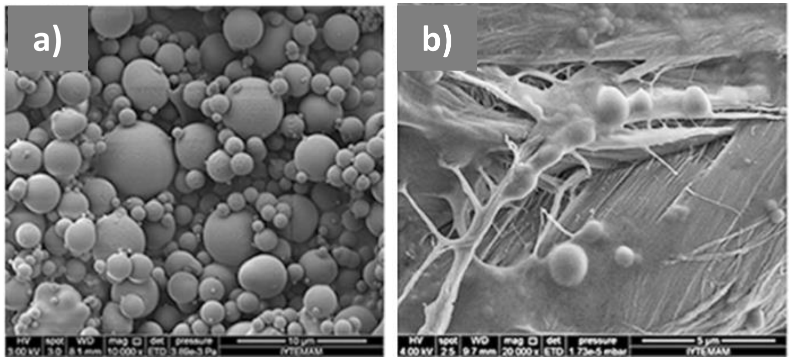

Figure 14. SEM image of limonene capsules (a), cotton treated with limonene capsules (b)[36]

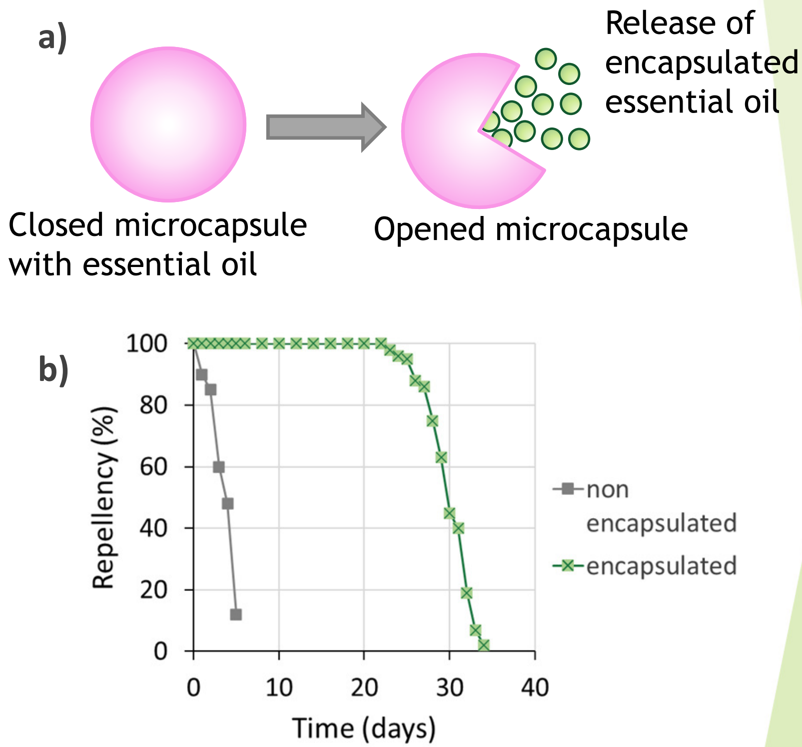

Figure 15. Controlled release of the encapsulated essential oil (a), essential oil repellency as a function of time (b)

D. Biomolecules and bio-sourced products as UV protective agents[11,28,37,38]

Classification of natural organic UV absorbers:

- ***Plant extracts – chemically:***
  - Flavonoids, curcuminoid, tannins, lutein, carotenoids, aloin, alkaloids.
- ***Biomolecules:***
  - Lignin, sericin.
- ***Plant sources:***
  - Root extracts (turmeric, carrot, red onion),
  - Leaf extracts (tea, *Aloe Vera*, eucalyptus),
  - Flower extracts (marigold)
  - Fruit extracts (mulberry, grape).

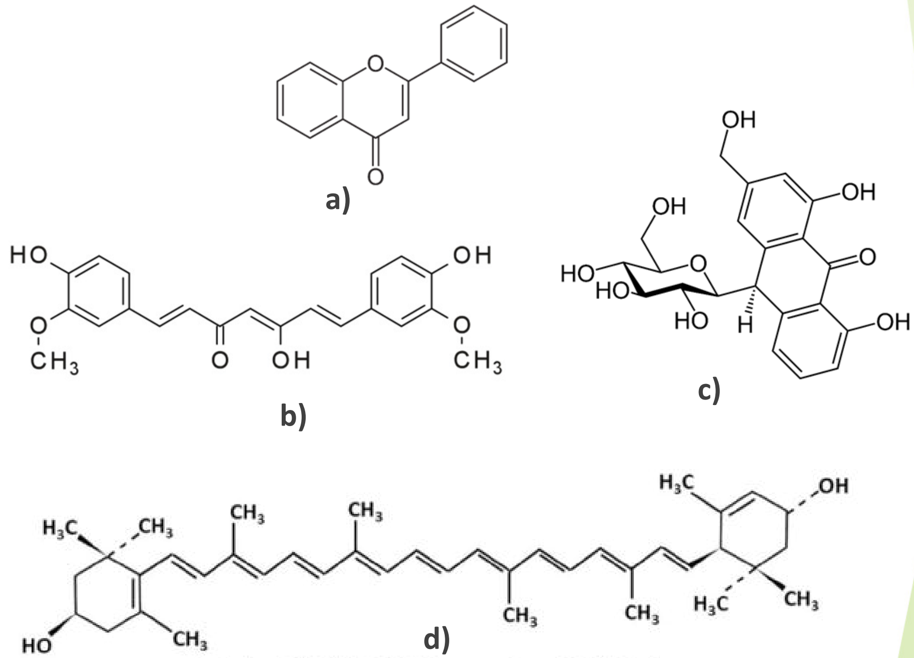

Figure 16. Chemical structures of flavone (a), curcumin (b), aloin (c), lutein (d).

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D. Biomolecules and bio-sourced products as UV protective agents[11,28,37,38]

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  - Fruit extracts (mulberry, grape).

Figure 17. Some of the plants for extracting of natural UV absorbers[39–44]

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D. Biomolecules and bio-sourced products as UV protective agents[11,28,37,38]

Mechanism of natural organic UV absorbers:

- Absorption of UV radiation.

Effect:

- Textile fabrics with high UPF factors.

Limitations: low light and washing fastness

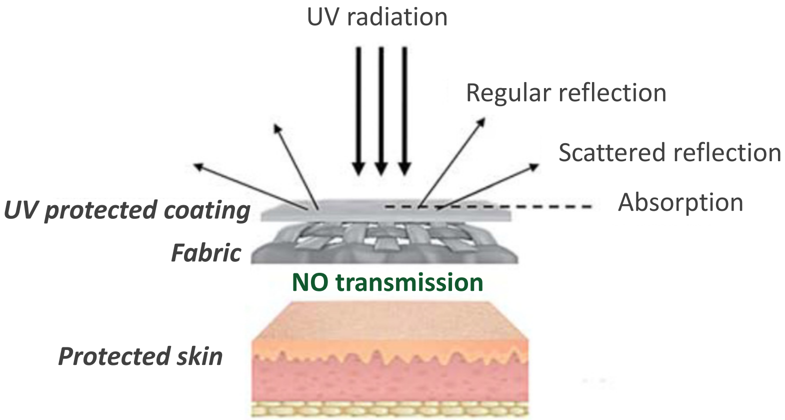

Figure 18. Mechanism of UV protection[38]

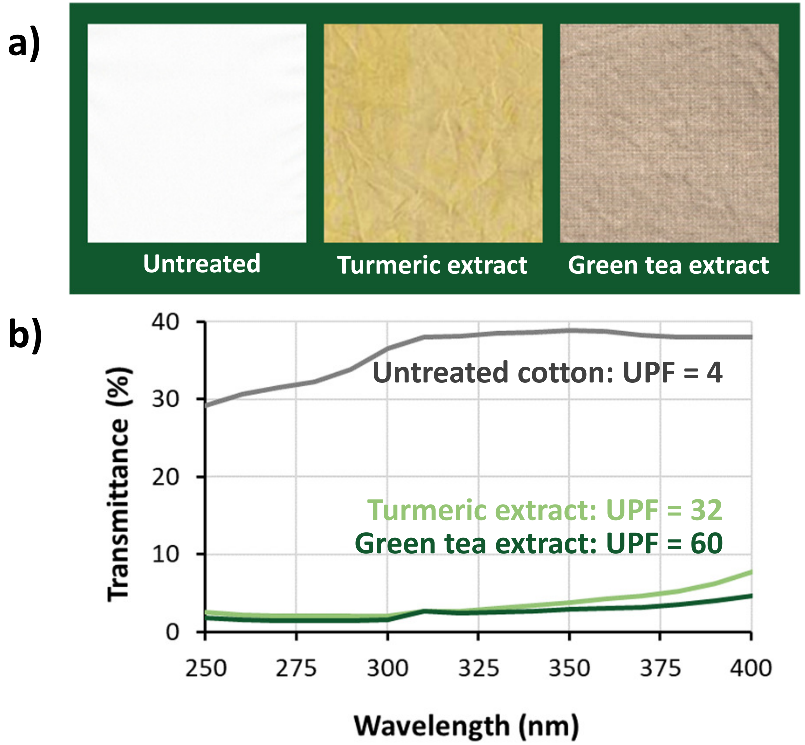

Figure 19. Untreated and turmeric and green tea extracts treated cotton (a)[45,46], UV transmission spectra of the samples (b)

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E. Biomolecules and bio-sourced products as crosslinking agents[47–49]

Classification of green crosslinking agents:

- ***Bio-based polycarboxylic acids:***
  - Citric acid,
  - Malic acid,
  - Tartaric acid,
  - Succinic acid,

- ***Plant sources:***
  - Fruits (citrus, apples, plums, grapes),
  - Maize,
  - Sunflower seeds,
  - Lignocellulosic biomass.

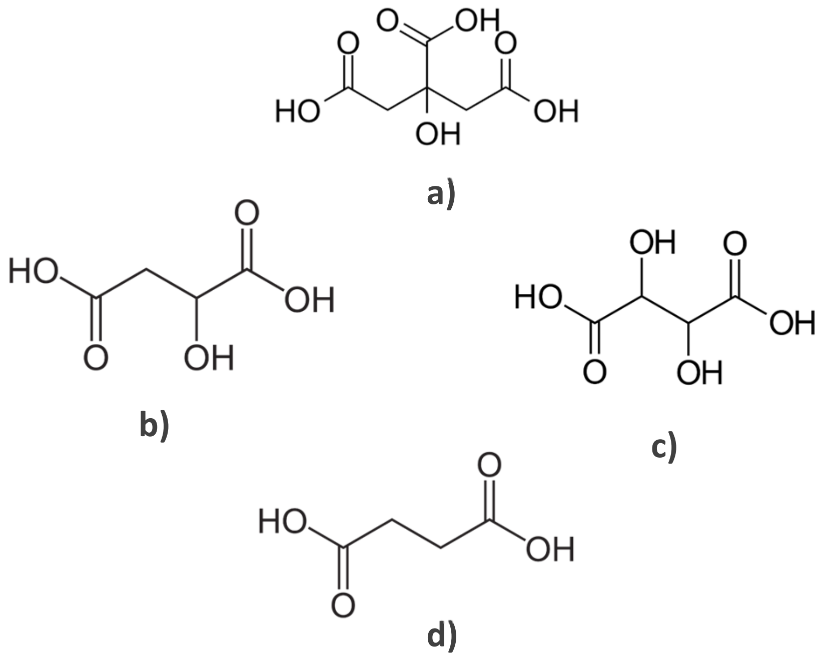

Figure 20. Chemical structures of citric acid (a), malic acid (b), tartaric acid (c), succinic acid (d).

E. Biomolecules and bio-sourced products as crosslinking agents[47–49]

Classification of green crosslinking agents:

- ***Bio-based polycarboxylic acids:***
  - Citric acid,
  - Malic acid,
  - Tartaric acid,
  - Succinic acid,

- ***Plant sources:***
  - Fruits (citrus, apples, plums, grapes),
  - Maize,
  - Sunflower seeds,
  - Lignocellulosic biomass.

Figure 21. Sources of green crosslinking agents[50–55]

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E. Biomolecules and bio-sourced products as crosslinking agents[47–49]

Mechanism of natural crosslinking agents:

- Chemical crosslinking of two fibre macromolecules,
- Attaching/anchoring of functional agent to fibre macromolecule.

Effects:

- Cellulose easy care, wrinkle resistance, crease recovery;
- Durability of coating.

Limitations: stiffness, yellowing.

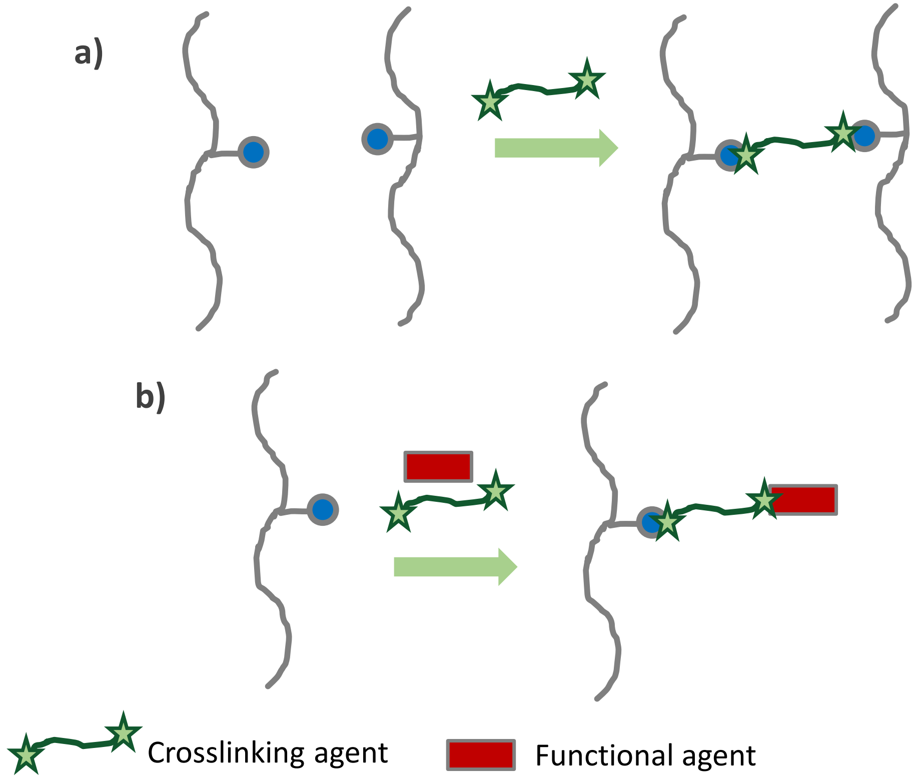


Figure 22. Mechanism of cellulose crosslinking (a) and anchoring the functional agent (b)

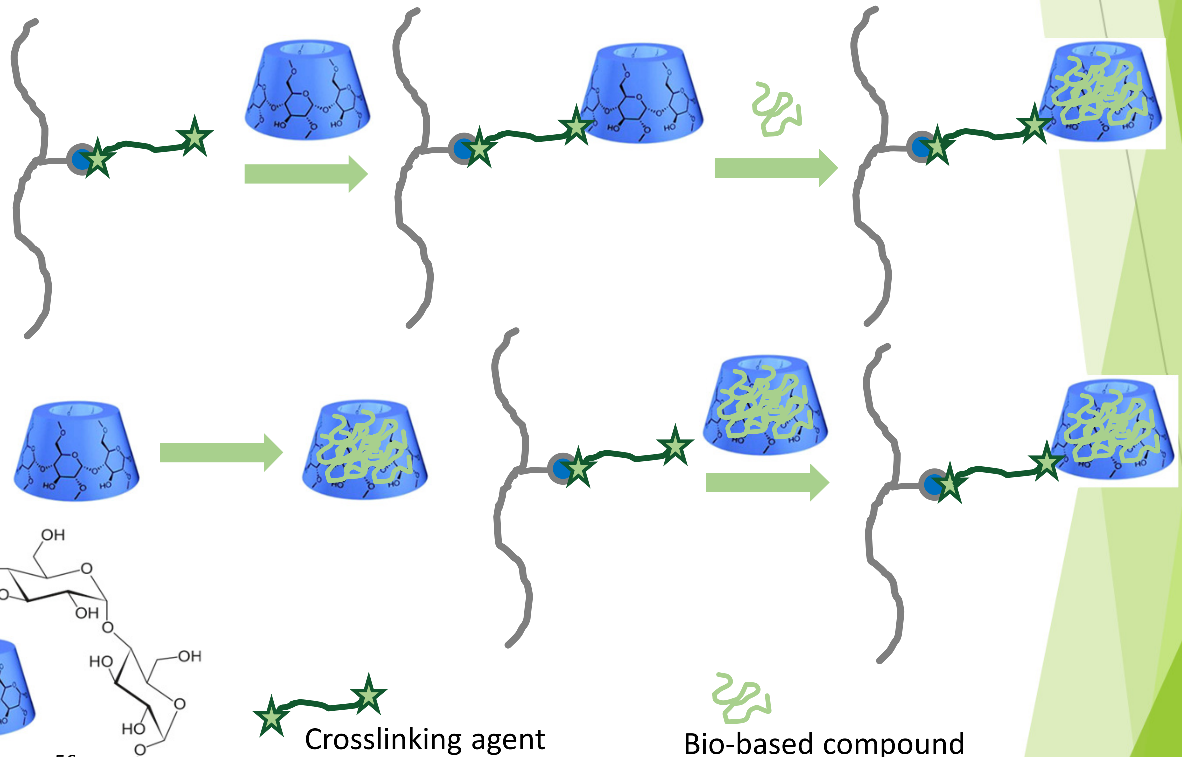
E. Biomolecules and bio-sourced products as crosslinking agents[47–49]

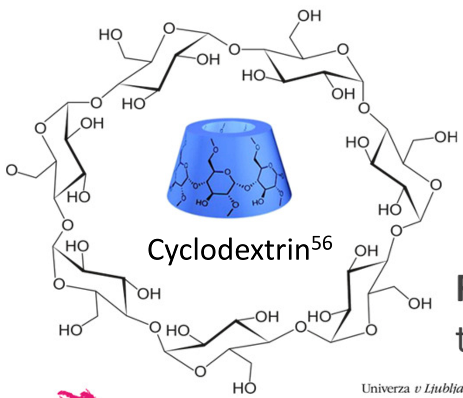
Mechanism of natural crosslinking agents:

- Attaching/anchoring of functional biomolecules to cellulose macromolecule.

Effects:

- Permanent or temporary host bioactive molecules and essential oils:
  - Controlled release antimicrobial activity,
  - Insect-repellency,
  - UV protection.





Cyclodextrin[56]

Figure 23. Schematic presentation of anchoring the cyclodextrin to cellulose macromolecule

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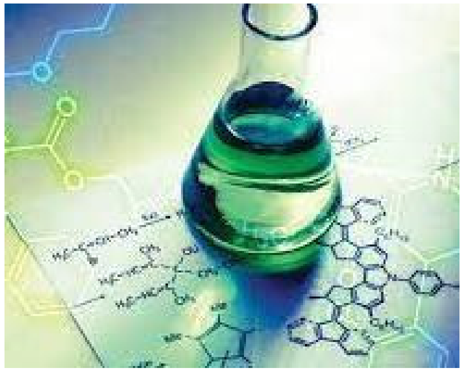
6.3.2 Nano finishing guided by green chemistry



Content

Synthesis of metal and metal oxide nanoparticles by green chemistry

Green chemistry principles and strategies:

- Reduce the inherent hazards of chemicals and materials.

Key strategies of greener syntheses of nanomaterials:

- Use of safer solvents and reagents,
- Reduction or elimination of solvents,
- Reduction of waste,
- Elimination of the need for purifications.

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Synthesis of metal (M) and metal oxide nanoparticles (NPs) by green chemistry[57–59]

Biological pathways for *ex situ* or *in situ* synthesis:

- Plant extract mediated,
- Biopolymer mediated,
- Microbial mediated.

Plasma-assisted *in situ* synthesis:

- Low-pressure cold plasmas,
- Atmospheric-pressure cold plasma.

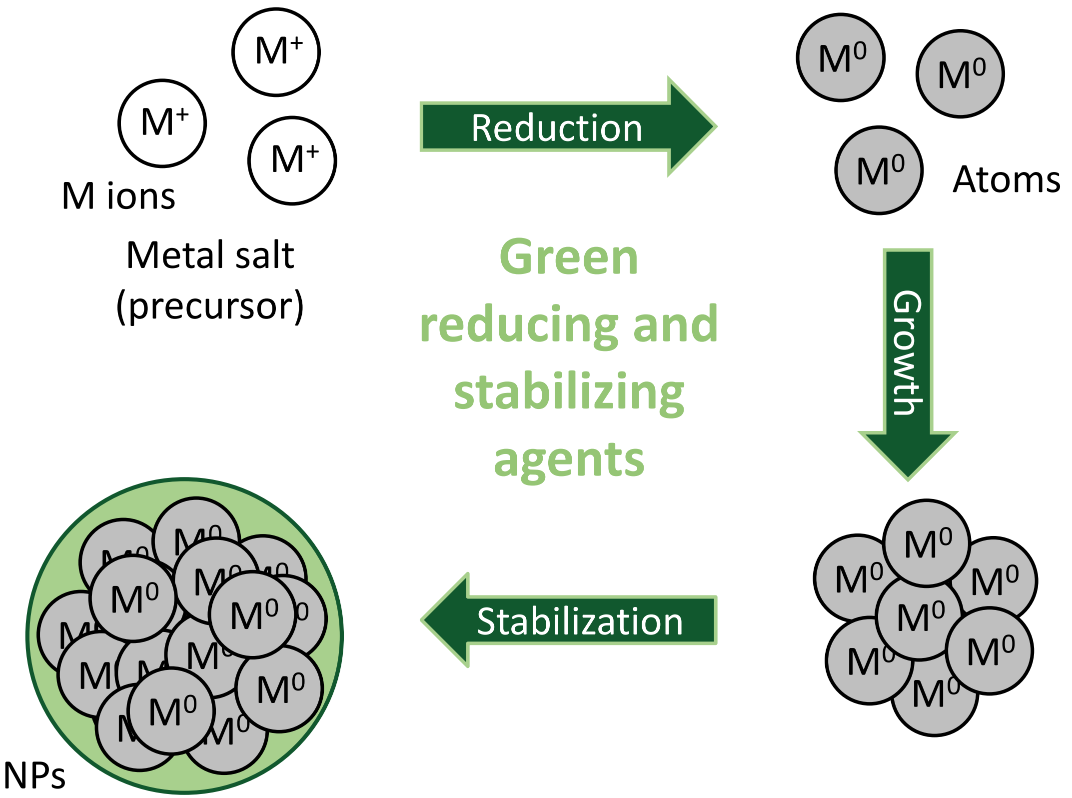

Figure 24. Mechanism of NP synthesis

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Synthesis of metal (M) and metal oxide nanoparticles (NPs) by green chemistry[57–59]

Biological pathways for *ex situ* or *in situ* synthesis:

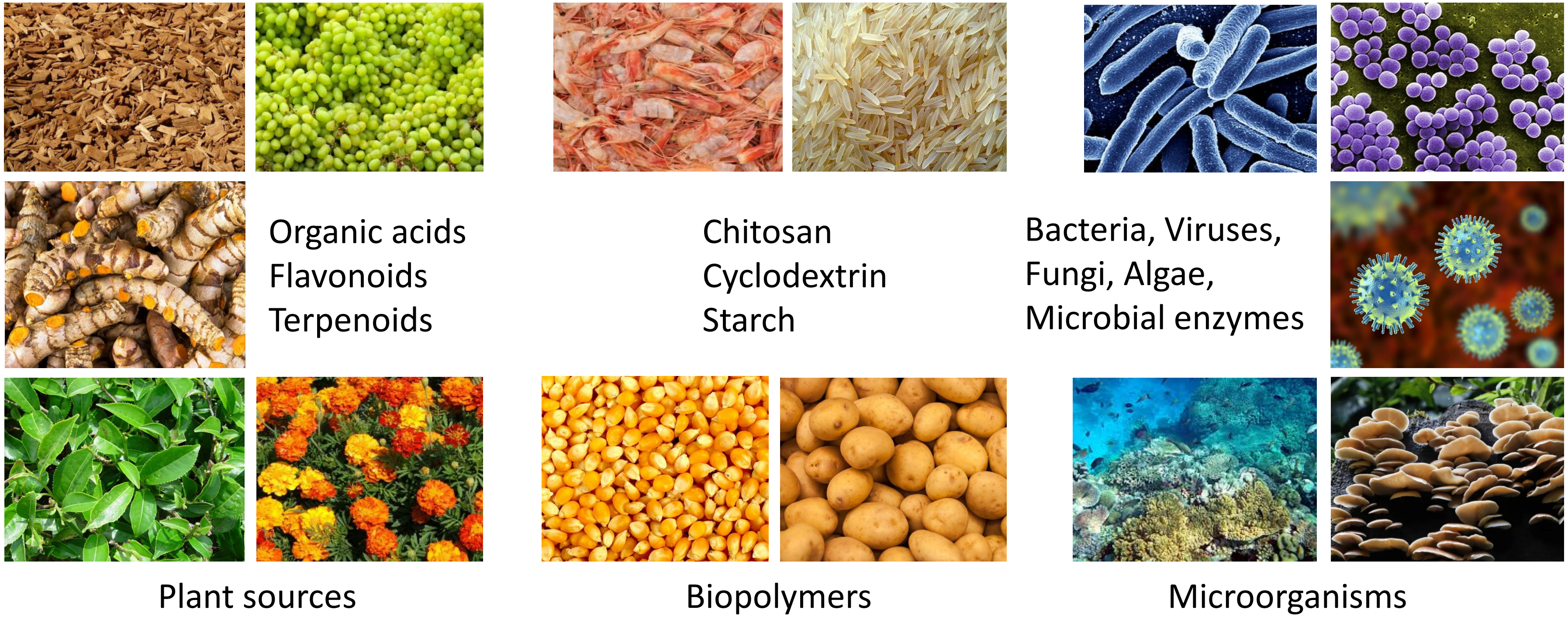

Figure 25. Biobased reducing agents and their sources[15,23,39,42,44,53–55,60–65]

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Synthesis of metal (M) and metal oxide nanoparticles (NPs) by green chemistry[57–59]

Biological pathways for *ex situ* or *in situ* synthesis:

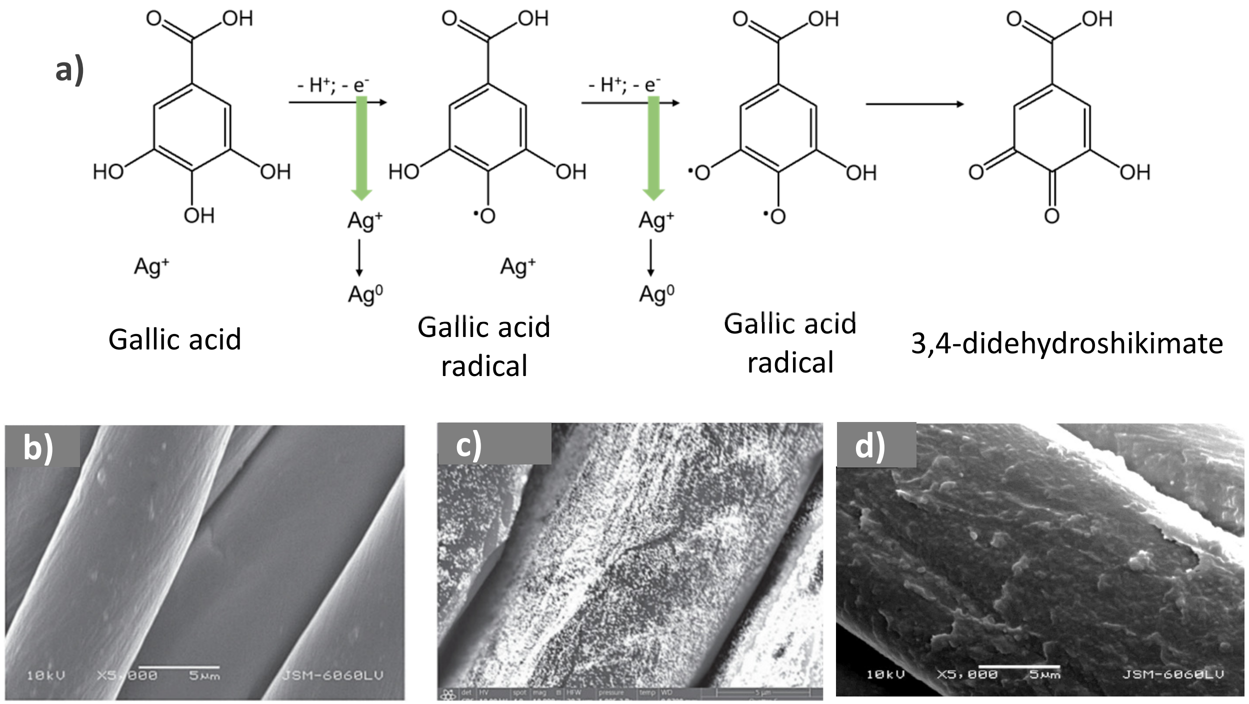


Figure 26. The proposed hypothetical reduction mechanism of Ag^+ to Ag^0 in the presence of Gallic acid (a)[66], SEM image of untreated cotton (b), SEM/BSC image of Ag/Cotton (c)[66] and SEM image of ZnO/Cotton (d)[67]

Synthesis of metal (M) and metal oxide nanoparticles (NPs) by green chemistry[57–59]

Plasma-assisted *in situ synthesis of Ag NPs:*

- adsorption of metal ions on fibre surface,
- reduction of adsorbed ions by plasma species.

Atmospheric pressure and low-pressure cold plasma:

- Dielectric barrier discharge plasma (e^-).

Plasma-forming gasses:

- Ar, Air, Ar/H_2.

Benefits:

- No chemical reducing agent.

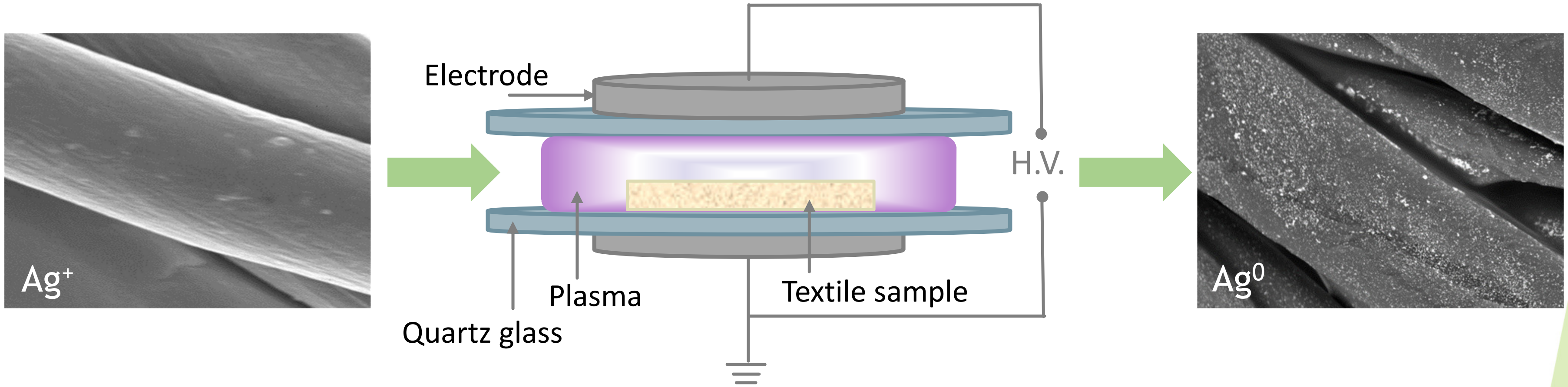
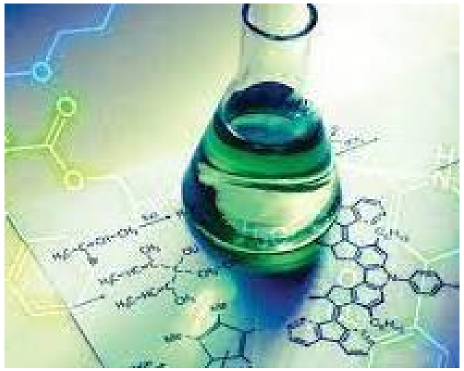


Figure 27. Schematic diagram of the plasma assisted *in situ* synthesis of Ag NPs on cotton fibres

6.3.3 Plasma coating for textile surface functionalization



Content

Plasma-enhanced chemical vapor deposition:

- **Plasma Polymerization.**

Plasma-enhanced physical vapor deposition:

- **Magnetron Sputtering.**

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A. Plasma polymerization for hydrophobic functionalization of textiles[68,69]

Plasma polymerization is a method for direct deposition of very thin and dense films on the substrates.

Process characteristics*:*

- Performance in cold plasma (low temperature and low pressure),
- Use of liquid precursors and plasma forming gases.

Non-fluorinated liquid precursors:

- Hexamethyldisiloxane (HMDSO), Hexamethyldisilane (HMDS), Hexametyldisilazane (HMDSN), dodecyl acrylate, styrene.

Plasma-forming (carrier) gasses:

- Ar, O_2, N_2.

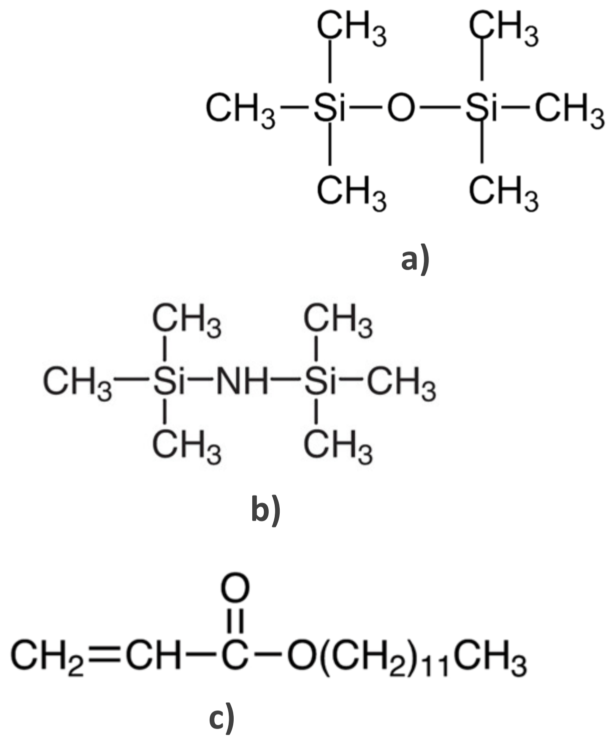

Figure 28. Chemical structures of HMDSO (a), HMDSN (b), dodecyl acrylate (c)

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A. Plasma polymerization for hydrophobic functionalization of textiles[68,69]

Principle of plasma polymerization:

- Evaporation of the liquid precursor,
- Mixing with the carrier gas,
- Activation by plasma,
- Fragmentation in the plasma state,
- Adsorption to the substrate,
- Rearrangement to plasma polymer.

Parameters affecting the coating quality:

- Precursor and gas,
- Energy and power density,
- Frequency,
- Temperature of the electrons.

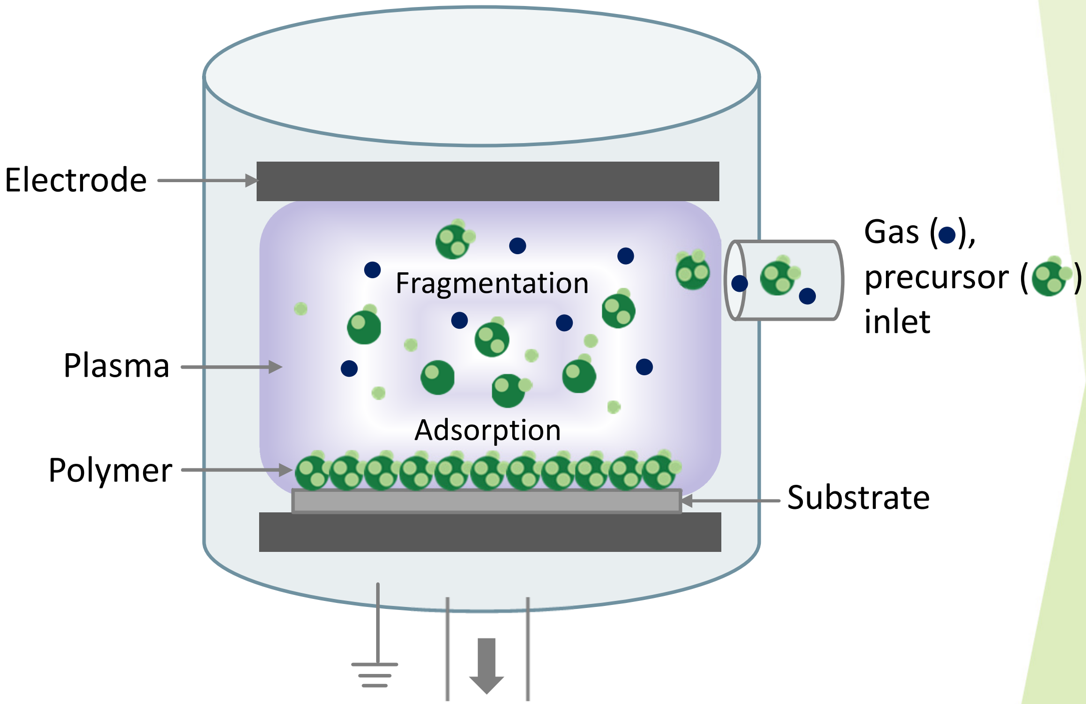
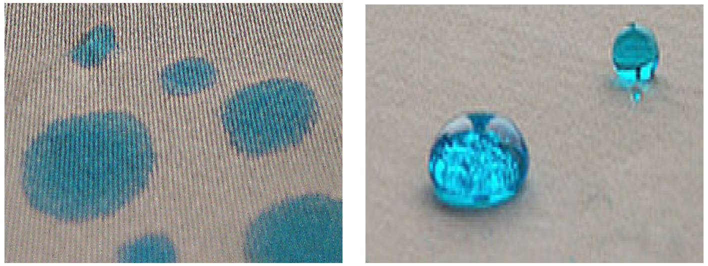


Figure 29. Principle of plasma polymerization

A. Plasma polymerization for hydrophobic functionalization of textiles[68,69]

Benefits of plasma polymerization:

- Free of hazardous chemicals,
- No solvent, no catalyst,
- No temperature increase,
- Coating on nm range,
- Coating durability,
- Asymmetric wetting behaviour.



a) b)

Figure 30. Water droplet on the fibre surface before (a) and after plasma polymerization (b)

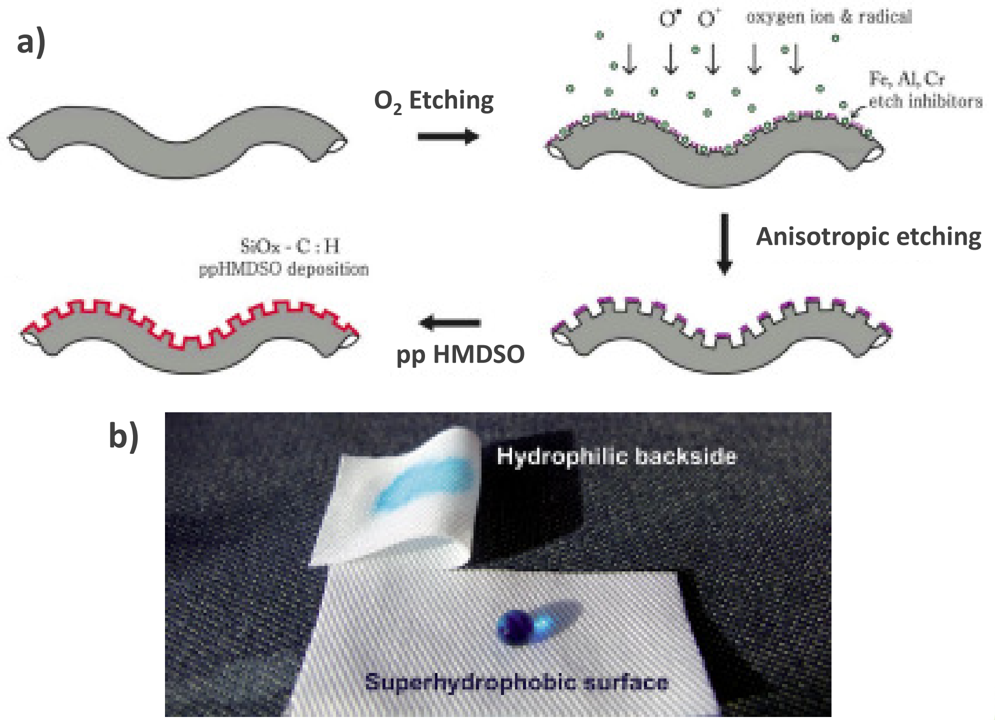


Figure 31. Tailoring of superhydrophobic coating by plasma etching and plasma polymerisation (pp) (a), asymmetric wetting behaviour (b)[70]

B. Magnetron sputtering for textile fibre coating with metal and metal oxide[59,71]

Magnetron sputtering is a coating method used to deposit thin films of metal and metal oxide on the substrate.

Process characteristics*:*

- Cold plasma with Ar as the operating gas,
- Sputtering target is located in front of the cathode,
- Substrate is located in front of the anode,
- Targets: Ag, Cu, Ti, Zn, their combinations.

Parameters affecting the coating quality:

- Deposition pressure,
- Gas flow, current supply system,
- Distance between the target and the substrate.

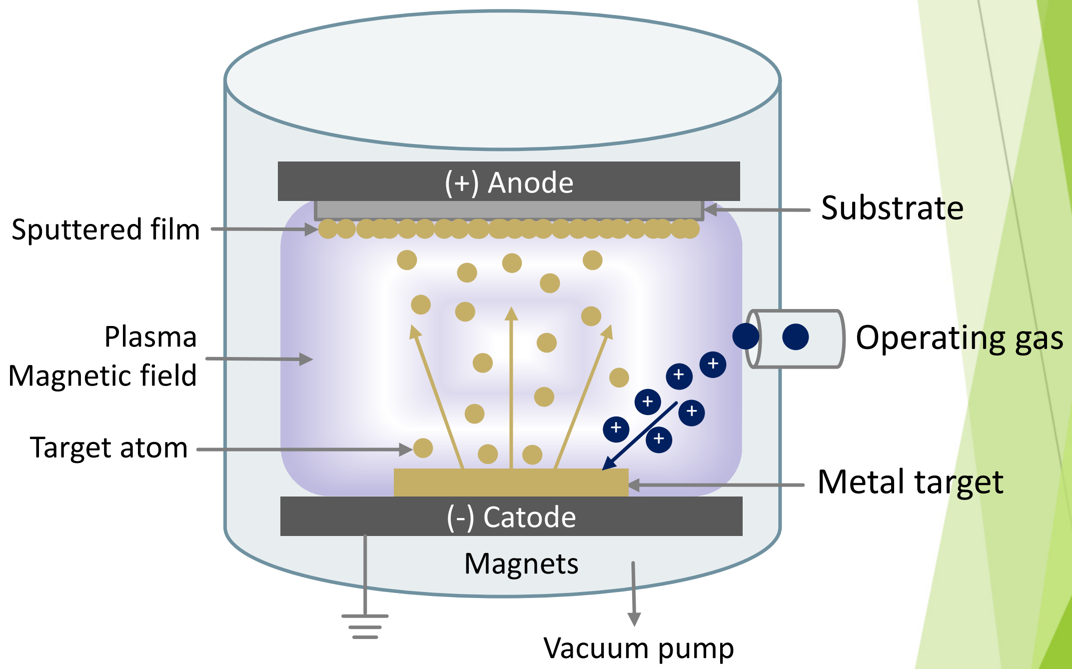


Figure 32. Schematic presentation of textile coating by magnetron sputtering

B. Magnetron sputtering for textile fibre coating with metal and metal oxide[59,71]

Principle of magnetron sputtering:

- Energetic gas cations are accelerated toward a target,
- Cations strike the target, causing the target atoms to be ejected from the surface,
- Atoms move onto the substrate and form the film.

Advantages:

- Low environmental impact,
- Controllable film thickness,
- High purity of films,
- Good film adhesion,
- High speed, low temperature.

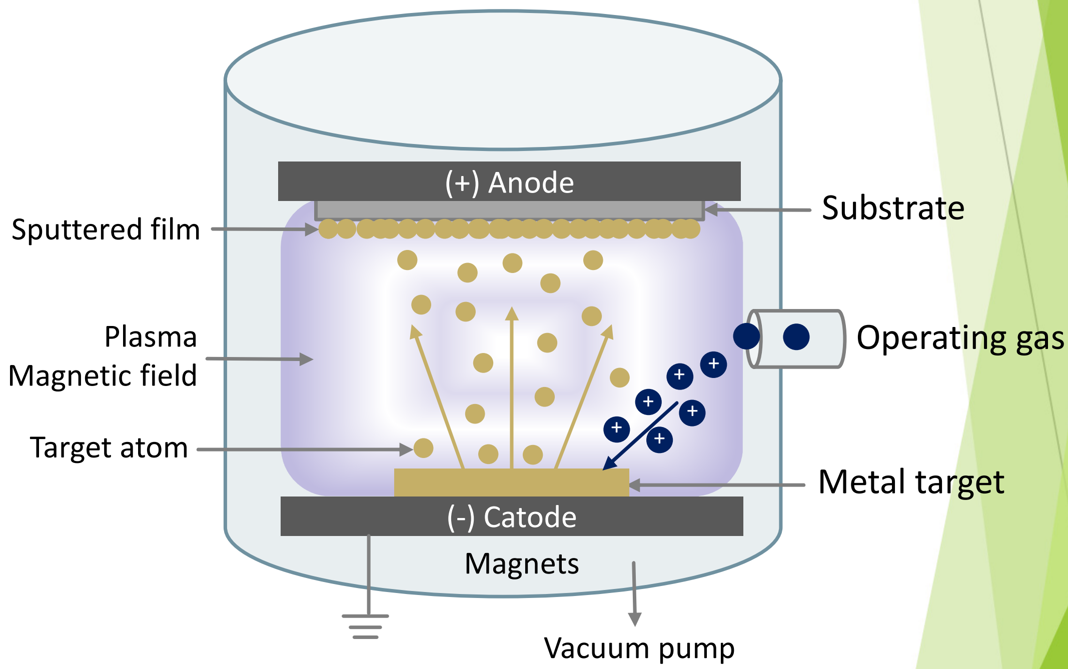


Figure 32. Schematic presentation of textile coating by magnetron sputtering

B. Magnetron sputtering for textile fibre coating with metal and metal oxide[59,71]

Textile functionalities:

- Antimicrobial (Ag, Cu, Ti, Zn),
- Photocatalytic self-cleaning (Ti, Zn, Ag/Ti),
- UV protection (Zn, Ti, Cu, Ag),
- Electrical conductivity, anti-static, electromagnetic shielding (Cu, Ag, Ti, Zn, Al, Ni),
- Thermal conductivity (Ag, Cu, Al).

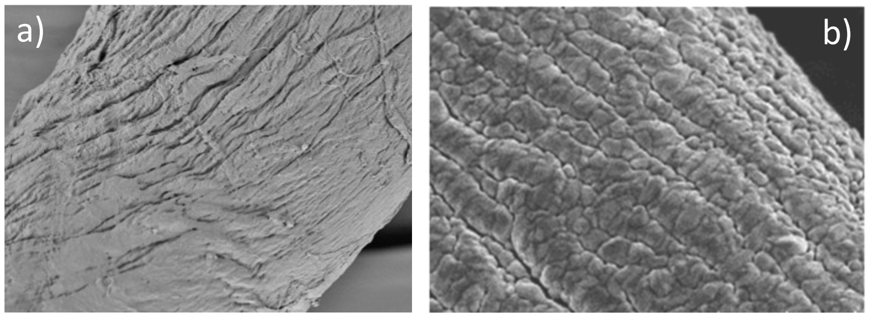


Figure 33. Untreated (a) and Ag coated (b) cotton[72]

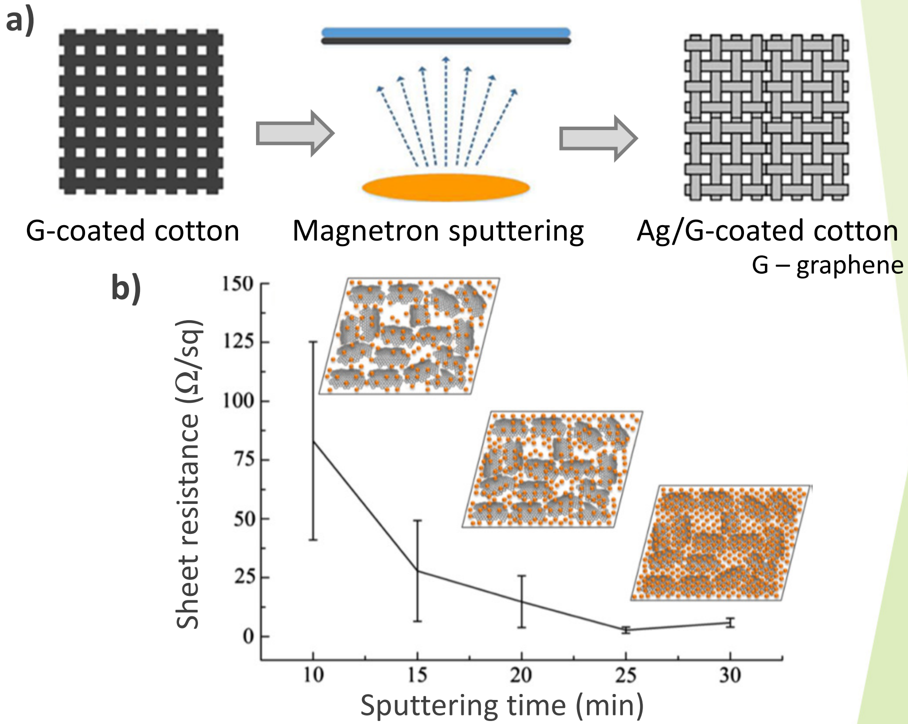
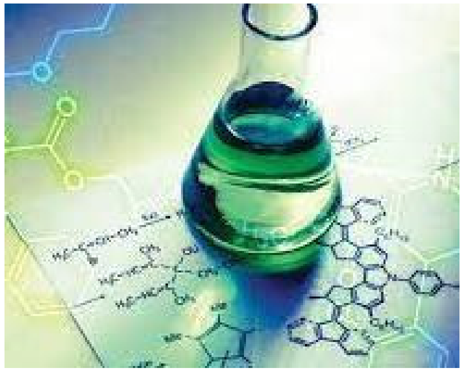


Figure 34. Preparation of Ag/G-coated cotton with electrical conductivity (a), sheet resistance of Ag/G-coated cotton versus sputtering time (b)[73]

6.3.4 Foam finishing and spray coating



Content

Eco-friendly alternatives to conventional padding:

- Save water,
- Save chemicals,
- Reduce energy,
- Reduce processing costs,
- Higher production speed.

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A. Foam finishing[74,75]

Conventional pad-dry-cure process:

- High consumption of water, chemicals and energy,
- Generation of a large amount of waste water.

Foam finishing advantages:

- Few finishing agents,
- Low wet pickup,
- Low drying energy,
- No residual liquor left,
- High running speed,
- More finishing effects,
- One-side application possibility.

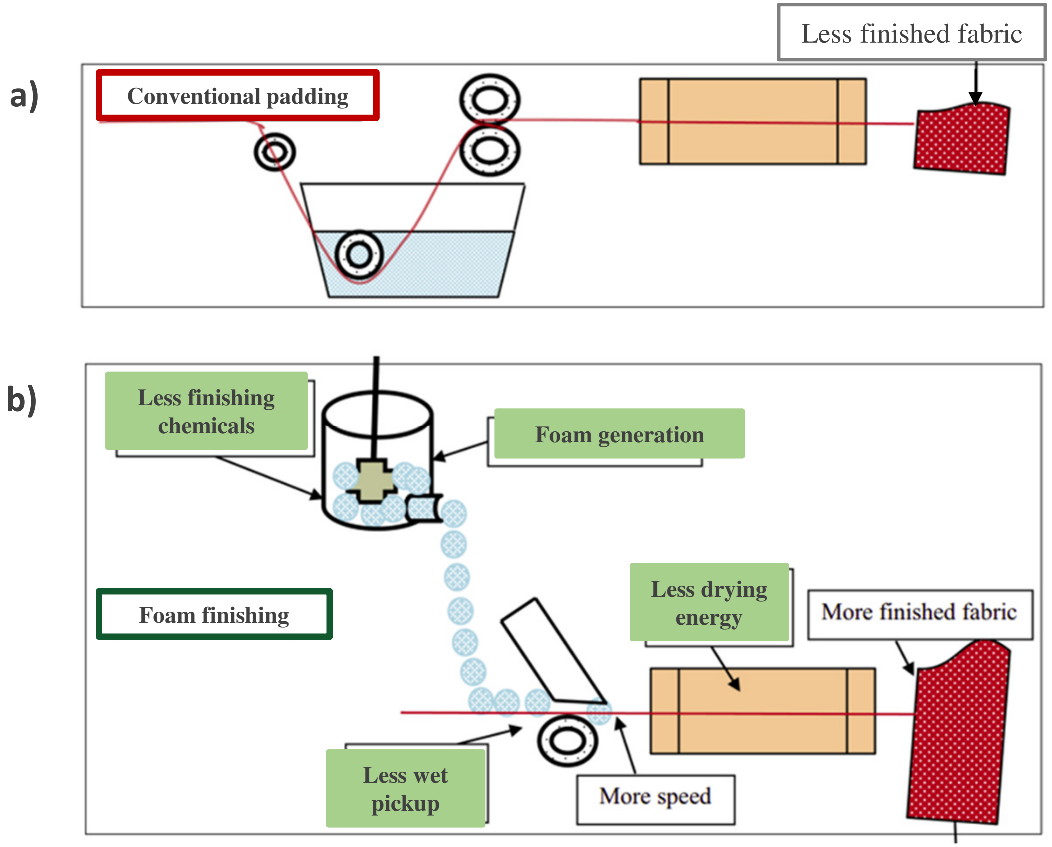

Figure 35. Comparison between conventional padding (a) and foam coating (b)[74]

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A. Foam finishing[74,75]

Coating methods:

- One side foam application (knife over roll, kiss roll, gravure roll),
- Two side foam application (horizontal padding, transfer rolls).

Challenges:

- Foam stability and reproducibility,
- Incomplete wetting due to little foam application,
- Fluctuation in wetting due to uneven foam drainage,
- Lower liquor stability due to high concentration of finish.

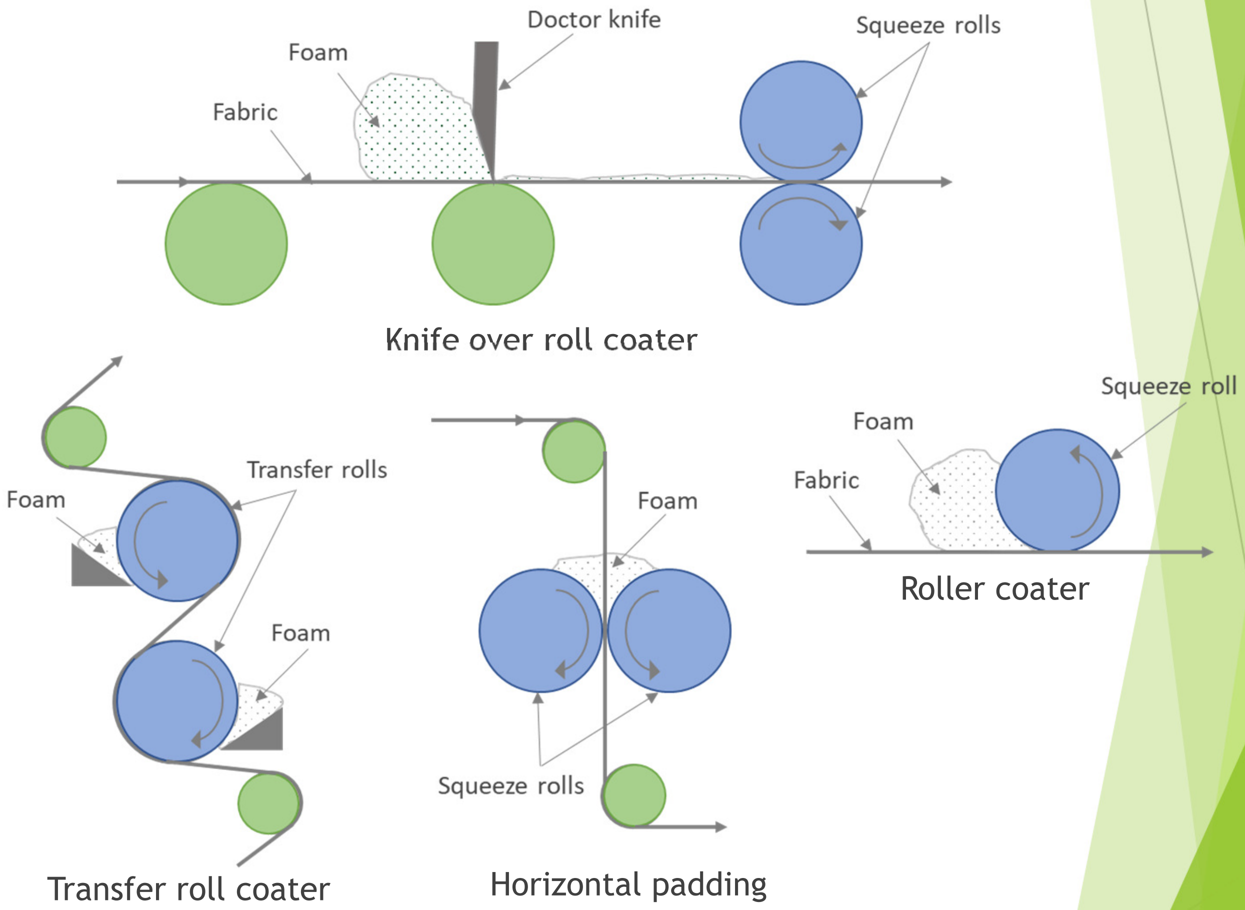

Figure 36. Foam applicators[1,75]

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B. Spray coating[10,76]

Benefits of spraying technology:

- Non-contact application of liquids,
- Minimum amount of water and chemicals required,
- One side or two side application,
- Up to 50 % less water or chemistries,
- 50 % less energy consumption due to elimination of drying,
- Significant time saving – eliminates drying time, speeds up production time.

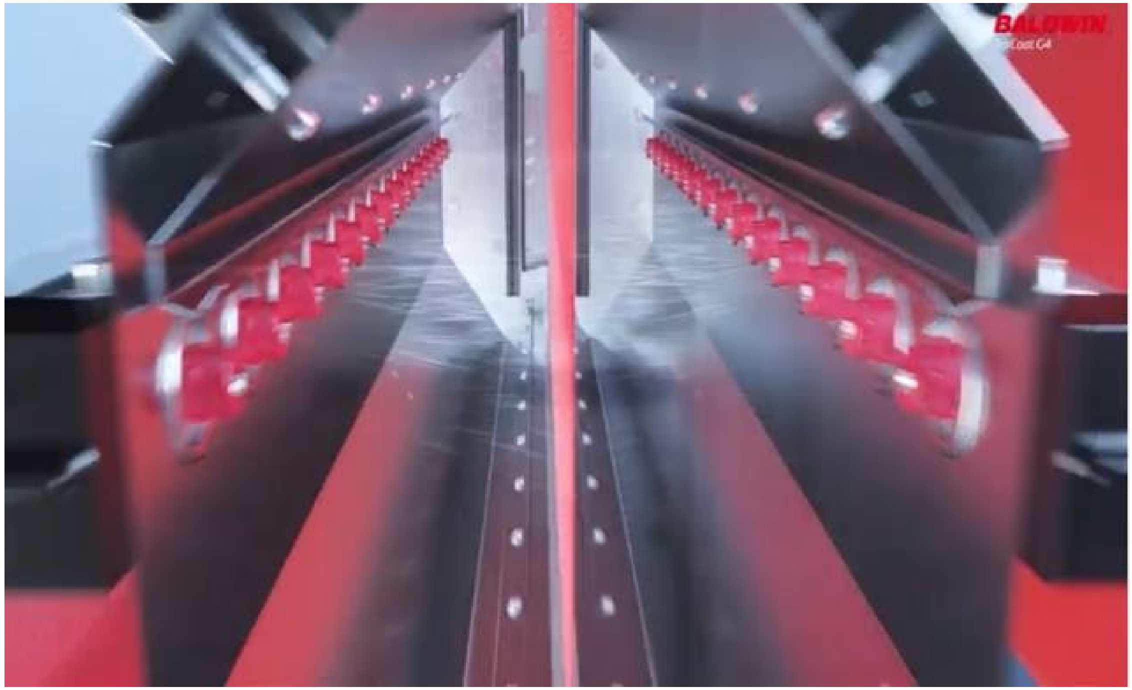

Figure 37. One side or both side application of finishing bath by spraying technology[76]

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B. Spray coating[10,76]

Figure 38. Multiple nozzles for wide area coating system[10]

B. Spray coating[10,76]

Advantage of ultrasonic spraying technology:

- Non-clogging,
- Creation of uniform micron sized droplets,
- Tight drop distribution,
- De-agglomeration of particles in solution,
- Creation of a more homogenous coating,
- Less overspray,
- Less atmospheric contamination,
- Less waste.

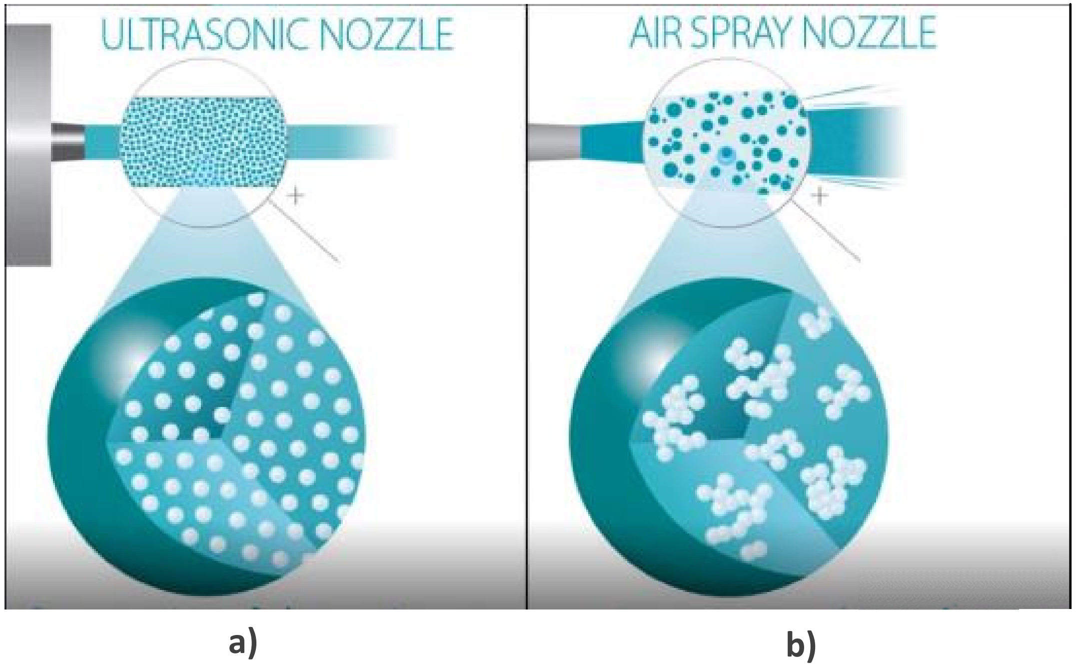

Figure 39. Cross section of ultrasonic (a) and air (b) spray nozzles[10]

Why sustainable textile care?

- **39 % of greenhouse gas emissions from textile and apparel industry globally** derives **from energy consumption** during **product care** by consumers (i.e., laundering, drying, ironing and other maintenance processes).
- Both **washing machines** and **tumble dryers** were amongst the **top sixteen appliances consuming the most energy** in households.

Domestic **laundering needs to become substantially less carbon intensive** to meet EU policy targets in reduction greenhouse gas emissions by 80% by 2050[77].

Figure 40. Clever care for sustainability[4,78,79,80]

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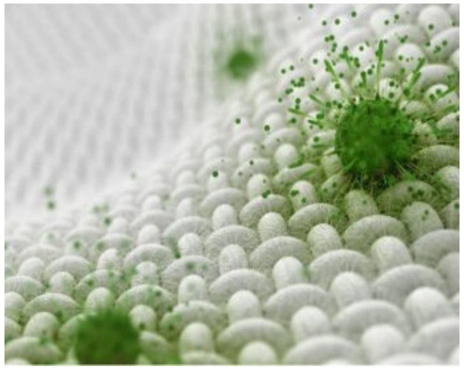
6.3.5 Laundry for circular economy requirements



Content

- Sale of a product versus sale of use
- Product-service-system (PSS)
- Four steps of PSS introduction to WM industry
- Drivers and barriers of PSS for WM

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A. Sale of a product versus sale of use

To meet circular economy requirements washing machine (WM) industry needs to adopted the concept of **Product-Service-System** (PSS)[81,82].

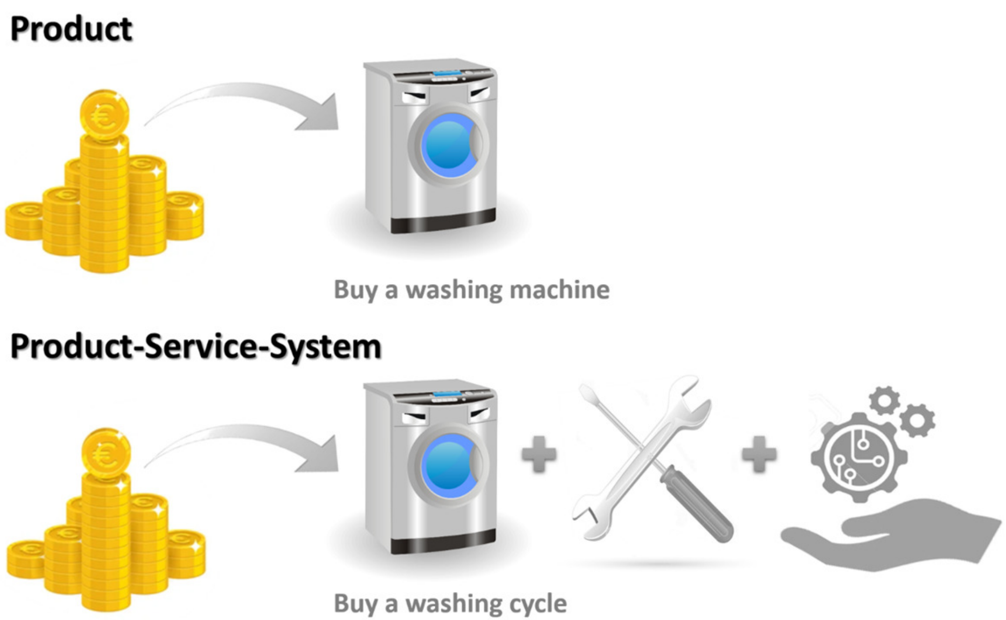

Figure 41. „Washing machine“ product and „washing cycle“ product-service-system[83,84]

B. Product-Service-System (PSS)

PSS is defined as a system of product, service, supporting network and infrastructure that is desinged to be competitive, satisfy custumer needs and have a lower environmental impact[85].

Source: Southern management[78]

Why WMs industry is suitable for PSS?

- WMs have all the characteristics for PSS strategy[86].
- Usage phase of WMs is perdominant over the total cost of ownership[87].
- WMs have large potential for environmental improvement[88,89].

C. Four steps of PSS introduction to WM industry

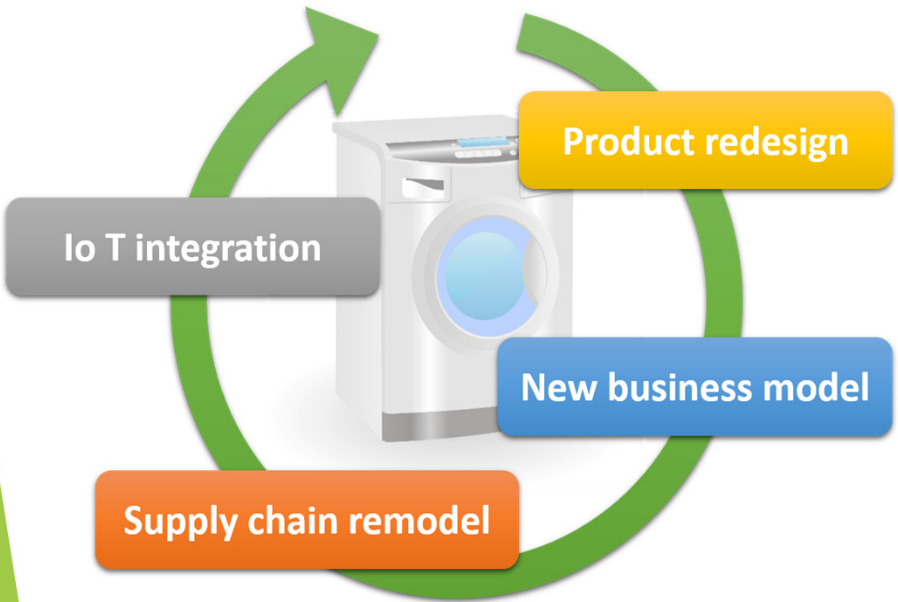

Figure 42. Four step action to introduce PSS business model for WMs[81]

- **PRODUCT REDESIGN**: employing design for reliability, durability and serviceability, design for standardization and compatibility and/or design for End-of-Life WMs[90,91].
- **NEW BUSINESS MODEL**: establishment of Sharing, Pay per use-performance and/or Leasing of refurbished WMs[81,92].
- **SUPPLY CHAIN REMODEL***:* establishment of the acquisition process, followed by recovery and remarketing processes[93,94].
- **INTERNET OF THINGS (IO T) INTEGRATION**: aiming to collect, send and act on data acquired from devices that use embedded systems[81].

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D. Drivers and barriers of PSS for WM

Table 2. Some of key drivers and barriers of the PSS introduction to the WM industry [95,96]

Drivers	Barriers
Environmental aspects due to lower production and disposal.	Consumers could use shared or leased product less carefully than the products they own.
Transfer of product maintenance and repair responsibility to producer.	Consumer acceptance - pride of ownership.
Transfer end-of-life management to producer	Concerns of hygiene of shared products.
Products of higher quality with more efficient energy and water savings.	Uncertainty in residual product value at the end of sharing or leasing period.
Ease of technology improvement.	Predictability and reliability of the product return flow
Increasing job opportunities.	Lack of support from related policy, laws and regulations

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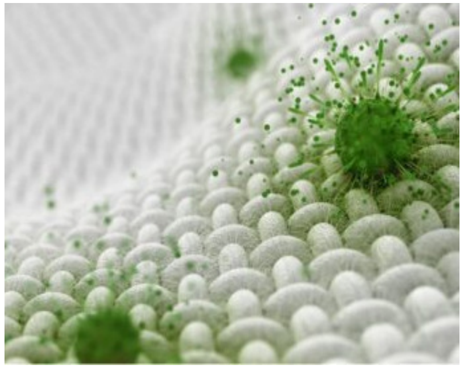
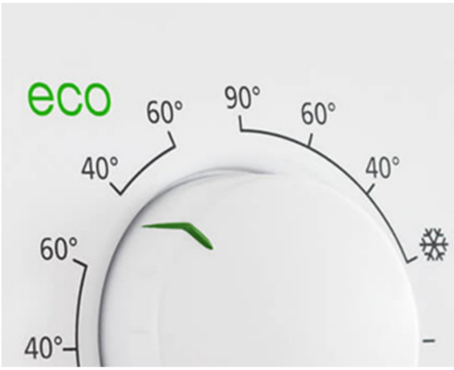
6.3.6 Clever textile care





Content

- Factors involved in cleaning: sinner’s circle
- Low temperature washing
- Barriers of low temperature washing
- Possible solutions for hygienic clever textile care

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A. Factors involved in cleaning: sinner's circle[97]

- **Time, temperature, chemical action and mechanical action** are variable factors.
- They can be **combined in different ways** depending on the soil, the type of fibers and the available resources.
- If **one** of the **factors is reduced**, it should be **compensated** for by **one or more of the other factors** in order to obtain a good quality end result of the laundry washing process.
- Following the Sinner's circle, **a decreased temperature can be compensated by the increase of one or more other variables** (e.g. extension of the washing time).

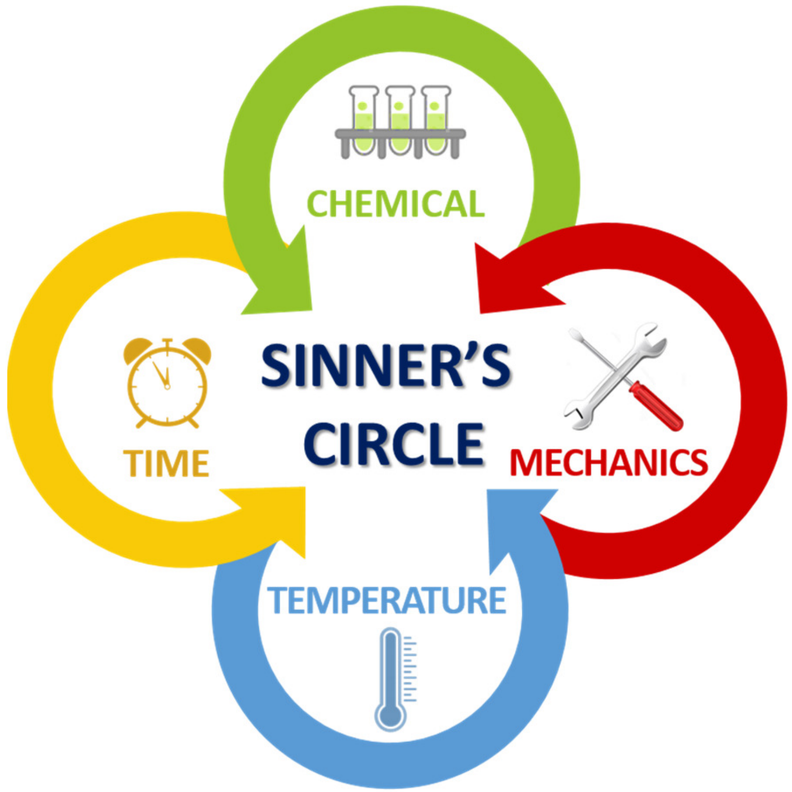

Figure 43. Variable factors of Sinner's circle

B. Low temperature washing[98]

- **Lowering washing temperatures** can help **save energy**.
- According to the I prefer 30° campaign[99], the electricity consumption of more than 300,000 inhabitants could be saved if everyone in Europe lowered their average washing temperature by just 3°.
- When using modern detergents, cleaning and stain removal performance at lower temperatures is good[99].

What about laundry hygiene?

Source: I prefer 30° [100]

C. Barriers of low temperature washing[99]

- **HYGIENICALLY INAPPROPRIATE TEXTILES:** as low temperature washing does not completely removes and inactivates microorganisms present on textile. **Of particular concern is cross-contamination of pathogenic microorganisms from different environments** (home and work) which increases the possibility for development of **new diseases and their spread.**
- **RISK OF SECONDARY CONTAMINATION OF ALREADY WASHED LAUNDRY:** It has been shown that the **washing machine is a source of re-contamination** of textiles through biofilm on the internal parts of the washing machine**. Biofilm can transferr to the laundry**.

Source: BactiBlock[79]

D. Possible solutions for hygienic clever care[101]

- Washing powders which contain **oxidizing bleaching agents** (AOB - Active Oxygen Bleaches) **in the form of perborates or percarbonates** (bleaching components) can partly solved the laoundry hygiene maintainance.
- **Use ecologically acceptable disinfectant** that do not pollute wastewater and do not pose a risk for the development of long-term resistance of microorganisms in case of their increased use.
- Among the environmentally friendly disinfectants**,** **hydrogen peroxide** and **peroxyacetic acid** take an important place. Both are characterized by high efficiency and a broad spectrum of antimicrobial activity and are already used in professional textile care.

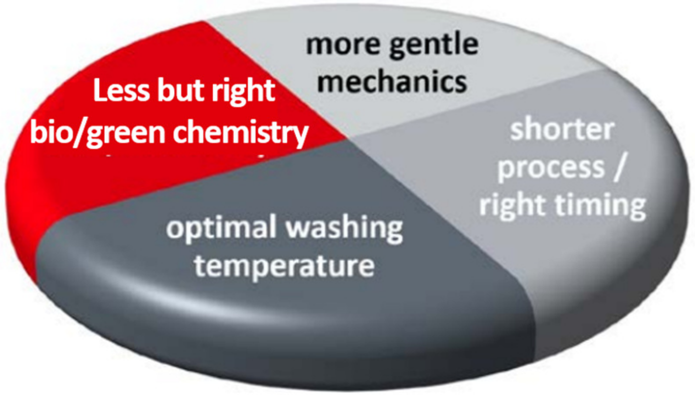

Figure 44. Opportunities of Sinners circle to meet hygienic clever care[102].

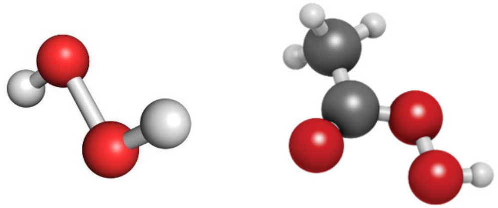

Figure 45. Hydrogen peroxide and peroxyacetic acid

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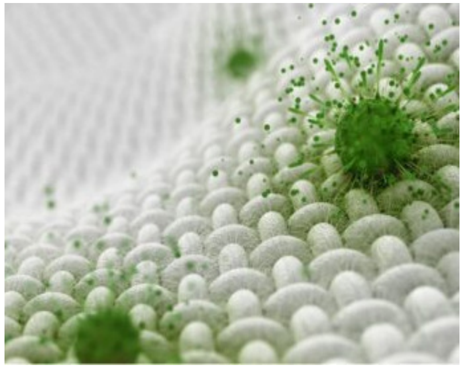
6.3.7 Eco-labelling relating to environmental impact



Content

- Objectives of eco-labeling
- Eco-labeling in textile industry with major criteria assessed
- Approaches of the criteria for granting eco-labels
- Key eco-labels in Europe
- Future trend

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A. Objectives of eco-labeling

The Eco-label is a **legally protected label** and is awarded to a product which ensures compliance with certain predefined environmental and sometimes social criteria**.** It thus makes a positive statement about the **environmental aspects of a product** and **it** is a reward to the authority for its environmental leadership that the product embodies[103].

Eco-labels have three general objectives[104]:

- to avoid misleading of environmental advertising,
- to aware and encourage consumers for taking environmentally preferable decisions and
- to provide market-based incentives with less environmental impacts on products and production.

Source: Make the label count[105]

B. Eco-labeling in textile industry with major criteria assessed[106]

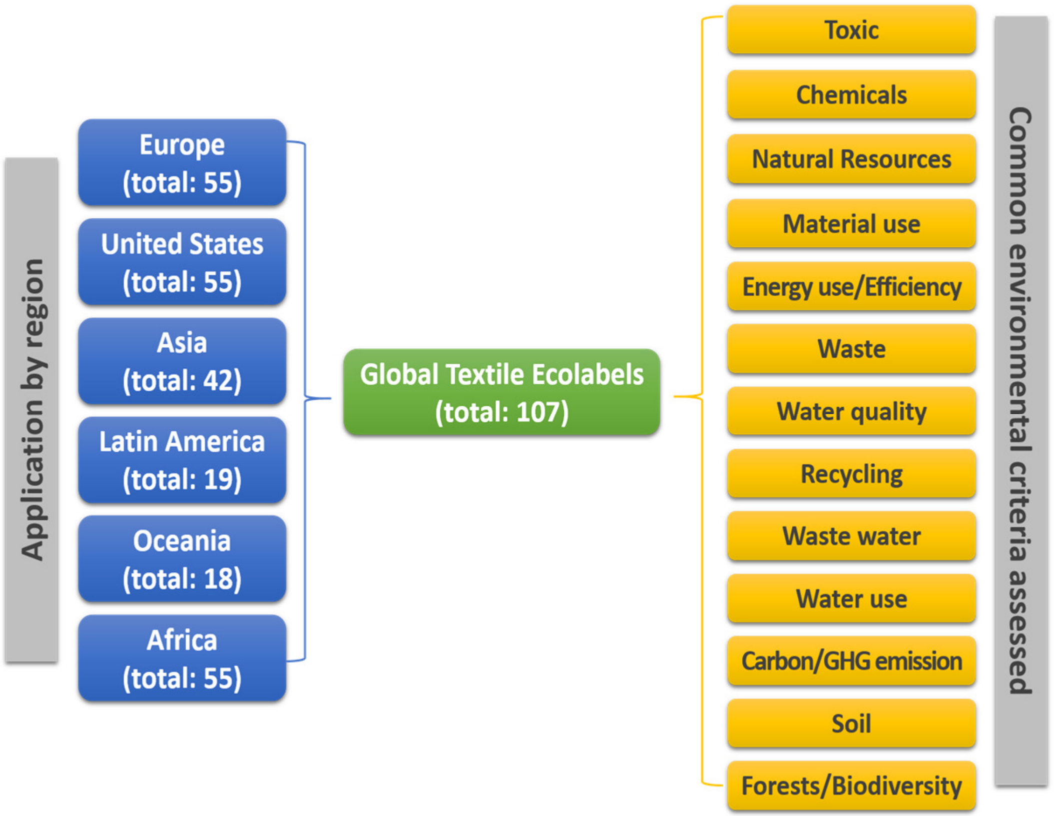

Figure 46. Eco-labeling in textile industry[106]

- 107 global textile ecolabels were identified.
- 20 major criteria are used to assess the sustainability of the industry.
- Toxicity, Chemicals and natural resources has given the highest priority globally within eco-label development.
- Animal welfare, biodiversity and Genetically Modified Organisms (GMO) has given a less priority.

C. Approaches of the criteria for granting eco-labels

Source: Freepik[108]

The criteria for granting eco-labels are based on different approaches [106,107]:

- **„CRADLE TO GRAVE“**: developed within the scope from raw material acquisition to disposal.
- **„CRADLE TO GATE**“: developed within the scope range from raw material acquisition to any stage before disposal.
- **„GATE TO GATE“:** consider the scope of any stage after raw material acquisition to any stage before disposal.
- **„GATE TO GRAVE“**: from any stage after raw material acquisition to disposal.

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C. Key eco-labels in Europe

Table 3. Key eco-labels in Europe and their scope[109]

Scope	EU Ecolabel	Nordic Ecolabel	Blue Angel	Okotex 100	Okotex 1000	GOTS
Fibers	•	•	•			•
Sustainable resource use	Cotton, recycled content	Natural fibers, recycled content				Cotton
Production	•	•	•		•	•
Energy consumption	•	•			•	
Air/water pollution	•	•	•		•	•
Substance restriction	•	•	•	•	•	•
Social/ethical criteria		•	•		•	•
Consumer health	•	•		•		
Fitness for use	•	•	•	•		•
End of life						

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E. Future trend

Source: IPC Worldwide[110]

- Educating, enabling, and encouraging people to act towards sustainability is key for the success of any eco-label. **Once the consumers are educated, then they may be encouraged to prefer buying more sustainable products**.
- **Eco-labels are not simple to understand**, so they may not be as appropriate marketing tools as suggested.
- It is difficult to track down the whole life cycle stages of the manufacturing process by a single eco-label, as majority of countries tend to export materials required for the processes. **Country-specific eco-labeling frameworks considering "gate to gate" approach needs to be developed.**

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Conclusions

- Biomolecules and bio-sourced products are suitable candidates for functionalization of textile fibres to achieve flame retardancy, antimicrobial activity, insect repellency, UV protective properties and crease resistance. An important challenge that remains is to increase the coating durability.
- Biological mediated and plasma assisted synthesis of metal and metal oxide nanoparticles represents environmentally-friendly and fast method for nanoparticles production.
- Plasma polymerisation, magnetron sputtering, foam finishing and spray coating are eco-friendly alternatives to conventional padding as they save water, chemicals and energy.
- The washing machine industry needs to move from a product-only to a product-service-system business model, aiming at lower production but of higher quality and higher energy efficiency products and consequently lower disposal.
- For hygienic and sustainable textile care, an increasing proportion of green and/or biotechnological materials needs to be introduced within the chemistry variable of the Sinner's circle.
- Eco-labelling provides environmental and social information to consumers to purchase more sustainable products. As eco-labelling continues to evolve, the creation of country-specific eco-labels with a gate-to-gate approach was deemed necessary.

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