

## Colourful nature in your clothes

# Natural dyes info sheet

Natural dyes are substances derived from plants, animals and minerals that were used by ancient humans because of their colourful properties. As the time passed, humans improved the processes and deepened the knowledge about colourful compounds.<sup>[1,2]</sup> Nowadays, scientists know that their colours come from chemical compounds containing conjugated systems (alternating double and single bonds), such as **polyphenols**, that allow the compound to absorb light in the visible part of the electromagnetic spectrum.<sup>[3]</sup>

**Polyphenols** are a diverse group of natural compounds found in plants and vegetables that give them their colours. They are characterised by the presence of multiple phenolic groups, that feature several substituents made up of hydroxyl units (figure 1), which give them antioxidant properties and the ability to bind to other molecules, such as metals or textile fibres. Two main groups of polyphenols can be distinguished: tannins, responsible for shades ranging from brown to yellow, that are found in tea and tree bark; and anthocyanins, water-soluble pigments that give flowers and fruits their bright colours, ranging from red to blue, as seen in red cabbage. Plants contain a wide variety of these molecules, which vary in their composition and therefore their properties. Red cabbage and gold onions, for example, contain high levels of anthocyanins, which give them their characteristic violet or orange hues. Avocado, on the other hand, contains a mixture of tannins and anthocyanins, which creates softer and warmer shades.<sup>[4]</sup>

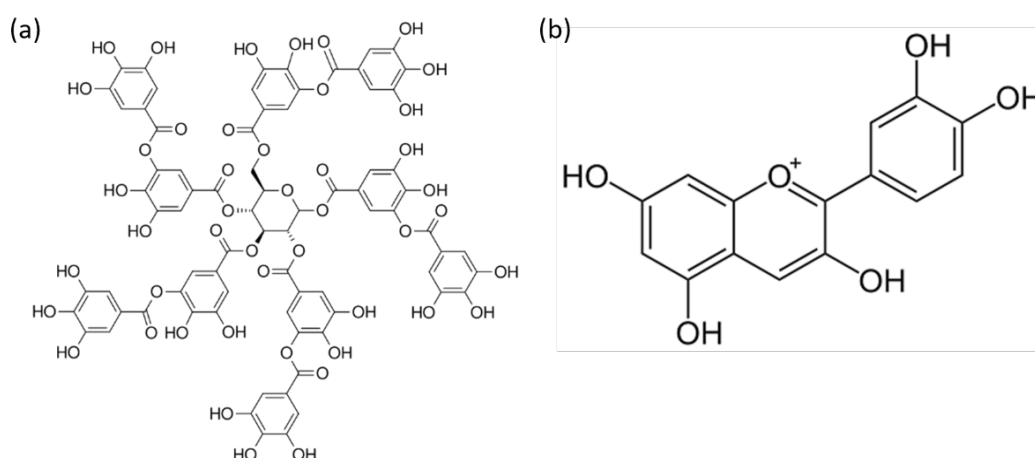


Figure 1: Polyphenol examples of a) tannic acid and b) a typical structure of an anthocyanin  
Image courtesy of the authors

In terms of stability, tannins are relatively resistant, whereas anthocyanins are known for their sensitivity to pH, causing significant colour changes depending on the surrounding environment.<sup>[5,6]</sup> However, not all anthocyanins behave in the same way. Some are relatively stable and can be extracted even in tap water (those in gold onions), while others are more sensitive (those in red cabbage). Of note, the salts dissolved in tap water affect the structure of anthocyanins, resulting in an unstable dyeing bath that begins to degrade after just a few hours. Consequently, the dyeing process becomes less effective as part of the pigment breaks down before it can bind to the fabric.

Over time, artisans, artists and dressmakers understood that these compounds alone do not bind efficiently to textiles, and that the use of another substance (called ‘mordant’) is necessary for permanent dyeing.<sup>[3]</sup> In our case, when using cellulose as the substrate, the mordanting bath is composed of an aluminium salt and sodium carbonate. Sodium carbonate helps open the cotton fibres, allowing for a more even distribution, while the aluminium salt acts as mordant.

A schematic representation of how the mordanting helps to adhere the polyphenol-coloured molecules to the textile can be seen in figure 2. The mordant (represented by grey triangles) binds to cotton fibres (represented by yellow lines) during the mordanting process. Under the subsequent dyeing phase, polyphenols (indicated by red circles) bind to the mordant through specific functional groups present in their structure.

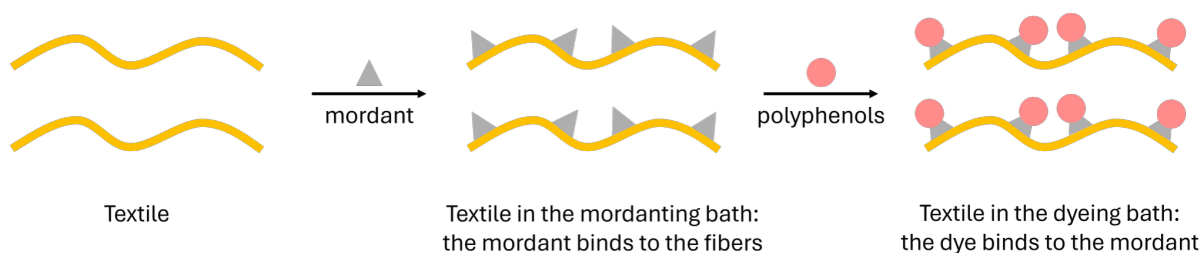


Figure 2: Schematic representation of the mordanting and dyeing process.  
Image courtesy of the authors

Later, scientists noticed that mordants are generally metal salts. The metals act as chemical bridges, forming coordination compounds between the dye molecules and the functional groups on the fibre. The formation of coordination compounds is schematised in figure 3: the aluminium cation (positively charged) present in the salt interacts with the polyphenols by attracting electrons from the functional groups, especially from the hydroxyl (OH) groups, present in these molecules. In

these complexes, the aluminium cation ( $\text{Al}^{3+}$ ) is coordinated by 6 donors (electronegative groups that can “donate” electrons to the cation, such as hydroxyl groups). Polyphenol molecules often bind to the cation in a bidental mode, meaning they coordinate using two different functional groups of the same molecule. Bidental coordination is very common, due to the close proximity of the functional groups in the molecular structure. Another component that is usually involved in these coordination complexes around the aluminium cation is water. Finally, the hydroxyl groups of cellulose can also serve as donors for the  $\text{Al}^{3+}$  cation and join the complex. The fixation of the colour is also enhanced by the hydrogen bonds between the complex and the cellulose fibre. All together this leads to an insoluble and stable connection between the three constituents (fibre, aluminium cation and dye), resulting in long-lasting colouration of the textile.

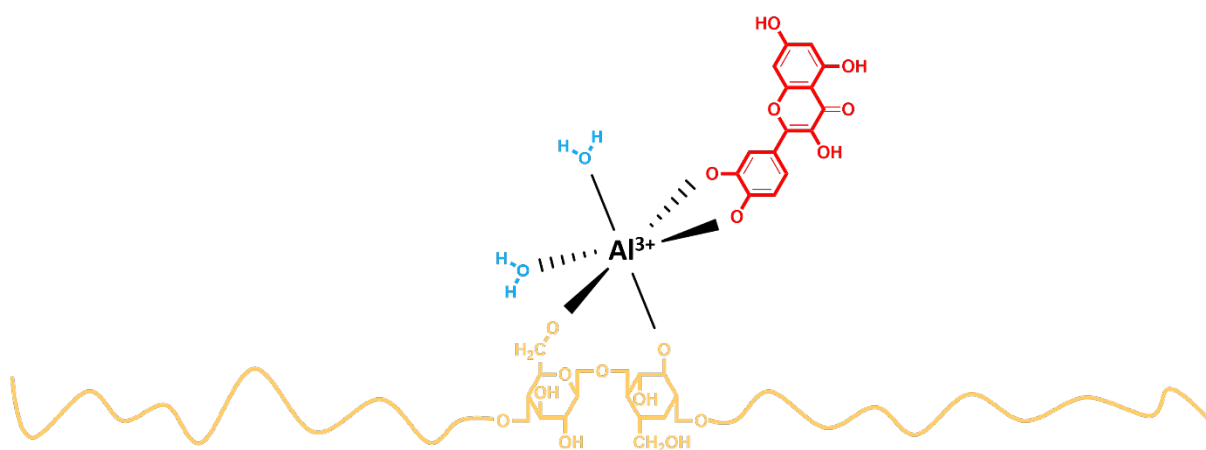


Figure 3: Schematic representation of coordination compounds serving as chemical bridges among cellulosic fibres and polyphenol compounds: the aluminium cation (black) coordinates one molecule of polyphenol in a bidental mode (red), the textile fibre (yellow) and two water molecules (light blue), which arrange around the cation in an octahedral shape.

Image courtesy of the authors

## References

- [1] Utami H et al. (2021) [The Leaching of Natural Dyes from Avocado \(Persea Americana Mill\) Seeds Using the Ultrasonic-Assisted Extraction Method and Its Application to Cellulose Fibers](#). *Jurnal Rekayasa Kimia & Lingkungan* **16**: 100–108. doi: 10.23955/rkl.v16i2.20140
- [2] Dabas D et al. (2011) [A Colored Avocado Seed Extract as a Potential Natural Colorant](#). *J. Food Sci.* **76**. doi: 10.1111/j.1750-3841.2011.02415.x
- [3] Prabhu KH, Bhute AS (2012) [Plant based natural dyes and mordant: A Review](#). *J. Nat. Prod. Plant Resour.* **6**: 649–664.



- [4] Lyu X et al. (2023) [Phenolic Compounds Profiling and Their Antioxidant Capacity in the Peel, Pulp, and Seed of Australian Grown Avocado](#). *Antioxidants* **12**. doi: 10.3390/antiox12010185.
- [5] Yang L et al. (2024) [Recent advances on pH-responsive polymers integrated with nature colorants: from preparation to applications](#). *Textile Research Journal* **94**: 2316–2329. doi: 10.1177/00405175231225831
- [6] Van der Schueren L, De Clerck K (2012) [Coloration and application of pH-sensitive dyes on textile materials](#). *Coloration Technology* **128**: 82–90. doi: 10.1111/j.1478-4408.2011.00361.x