Hybrid pigment structures with superior stability and tunable functional properties

The current rate of resource consumption to sustain civilizational advancement has reached unprecedented levels, leading to climate change and severe environmental degradation. Can we design durable and eco-friendly solutions that could replace conventional colorants in everyday products, such as packaging? In response to pressing climate challenges, researchers are advancing technologies based on natural biocomposites and environmentally friendly additives to mitigate the negative environmental impact of industry.

One promising direction in this field is the development of hybrid pigments that integrate the characteristics of organic chromophores with those of inorganic mineral carriers. These hybrid pigments demonstrate remarkable stability, exhibiting high resistance to light exposure, elevated temperatures, and organic solvents, while significantly minimizing migration within the materials in which they are embedded. Additionally, the broad color range achievable with these pigments offers diverse applications, from decorative uses to functional roles, such as pH-sensing and antibacterial activity.

This project aims to develop and implement various synthesis strategies for hybrid pigments, where natural dyes are stabilized on mineral supports functionalized with compounds such as silanes and biopolymers. The objective is also to perform comprehensive analyses of the pigments' physicochemical and functional characteristics, including their color, thermal and chemical stability, as well as antibacterial and hydrophobic properties.

Research on hybrid pigments seeks not only to develop more sustainable materials but also to advance understanding of the interactions between organic and inorganic components, and to examine the structural dependencies that impact their properties. Thanks to their versatile functions, these pigments can impart not only aesthetic qualities but also enhance the performance of polymeric materials used in packaging, improving durability, resistance to external factors, and functionality.

The core research objectives of this project include:

- the synthesis and characterization of hybrid pigments based on organic dyes, mineral supports and modifying agents (silanes and biopolymer coatings),
- the investigation of pigment structure, color, thermal and chemical stability as well as additional functional properties (e.g. pH sensing or antibacterial) under varying conditions,
- analysis of the impact of these pigments on the color and functional properties of polymer composites intended for smart packaging systems.

Achieving these research goals will contribute significantly to the development of hybrid materials, modern colorants, and pH indicators. The project outcomes have the potential to revolutionize the packaging market by offering more durable, intelligent, and environmentally sustainable solutions.