Investigating Pomegranate Rind Dye for Wearable Health Monitoring: A Colorimetric Approach to Analyzing Sweat, Glucose, and Insulin

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Keywords - Colorimetric Sensing, Wearable Technology, Natural Dyes, Sweat Sensing, Smart Textiles

I. INTRODUCTION

This study investigates the potential of pomegranate rind dye, a natural source of pH-sensitive anthocyanins, in the field of health monitoring through the colorimetric detection of sweat analytes, markers of physiological states [1], [2]. Addressing the limitations of cost and complexity inherent in traditional sweat analysis methods prevalent in healthcare and sports science [2], [3], our approach utilizes colorimetric analysis. This technique, simpler and more cost-effective, relies on visual color changes in response to specific analytes for quantitative data acquisition [1]. Emphasizing sustainability and economic feasibility, our research highlights the potential of natural dyes, particularly pomegranate rind, in creating eco-friendly, cost-efficient textile-based indicators for health monitoring applications, including fertility and menstrual cycle tracking.

II. LITERATURE REVIEW

Reflecting a novel approach, this research examines the colorimetric sensing capabilities of pomegranate rind dye, owing to its rich anthocyanin content and focuses on the development of passive sensors using fabric infused with pomegranate rind dye, a groundbreaking concept in wearable technology. Such sensors are envisioned to detect sweat analytes, providing insights into individual well-being. This study not only aligns with the environmental shift towards sustainable materials but also addresses a critical research gap. It explores the potential of natural dyes, particularly pomegranate rind, in creating eco-friendly, reliable wearable bio-indicators with additional antimicrobial properties [1]. While previous studies have highlighted challenges in the consistent extraction and stability of natural dyes [1], [2], this research aims to overcome these hurdles, thereby contributing significantly to the paradigm shift towards sustainable, non-invasive, and personalized healthcare modalities.

III. MATERIALS & METHODS

The materials used in this study included Pomegranate Rind *(Punica Granatum)* peels, 100% cotton fabrics, and distilled water. The authenticity and purity of pomegranate peels was validated via a spectrophotometric assay for anthocyanin content. This approach was selected for its feasibility in a university lab setting. The process involved grinding dried pomegranate peels to enhance anthocyanin extraction efficiency, followed by extraction using acidified

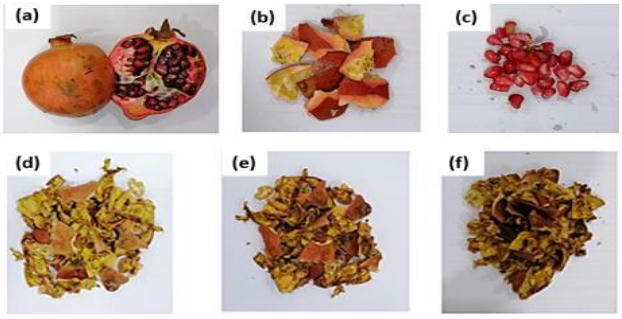

Fig. 1. Stages of Pomegranate Rind Preparation: (a) Whole Fruit, (b) Rind, (c) Seed, (d) 1-Week Dried, (e) 2-Weeks Dried, (f) 3-Weeks Dried

methanol. The extract was left overnight for thorough anthocyanin extraction, then filtered to isolate the anthocyanin-rich solution. We quantified anthocyanins by measuring absorbance at 520 nm using a spectrophotometer, comparing it against a calibration curve. This method, repeated for multiple samples, confirmed the peels' suitability for dyeing and their application in health monitoring textiles.

For preparation, the peels were thoroughly washed to eliminate contaminants, then shade-dried for 3-4 weeks to remove moisture, which is crucial for preventing microbial growth and maximizing dye concentration. The dried peels were ground into powder for uniform dye extraction. The dye was extracted by dissolving this powder in distilled water and heating, with temperature control to optimize anthocyanin extraction. The resulting vibrant dye was applied to cotton fabrics, chosen for their compatibility with natural dyes, using a double immersion technique to ensure color depth and uniformity for accurate sweat analyte analysis.

To augment the dyed fabrics' functionality, we employed microencapsulation, preparing sodium alginate mixed with pomegranate dye and forming microcapsules in a calcium chloride solution. This was done to control dye release and enhance fabric functionality in health monitoring. We carefully controlled the microcapsules' size, maintaining a 1-2 mm diameter to optimize surface area for sweat analysis. The microcapsules were evenly applied to the fabrics, properties for health monitoring. Post-treatment, fabrics were cured at 60°C to improve color fastness and stability against environmental factors. The colorimetric response of the dyed fabrics to sweat analytes was assessed using spectrophotometric methods ensuring consistent dye release and maintaining functionality. To ensure repeatability and consistency, we tested 30 samples for each method (dyeing, microencapsulation, combined) and analyzed the results statistically. Additionally, Scanning Electron Microscopy (SEM) was used to examine the dye distribution and microcapsule integrity on the fabrics.

IV. RESULTS & DISCUSSION

A. Colorimetric Analysis and Color Changes in the Pomegranate Extract

The colorimetric response of the extract to chemical stimuli is as shown in Fig 2. The extract's color transitioned from pale yellow to reddish yellow upon the addition of Sodium Hydroxide (NaOH), consistent with the known pH sensitivity of anthocyanins. Conversely, Hydrochloric Acid (HCl) decolorized the extract, highlighting anthocyanin's reactivity to acid. The extract also displayed varied color responses to Aluminum Potassium Sulphate, Sugar solution, and Insulin solution, turning green to ash/black, bright yellow, and vivid yellow, respectively, and adopted a vivid yellow hue with an Insulin solution, indicating complex interactions between the anthocyanins, metal ions, and various molecules, demonstrating the extract's capacity as a versatile colorimetric instrument for physiological assessments.

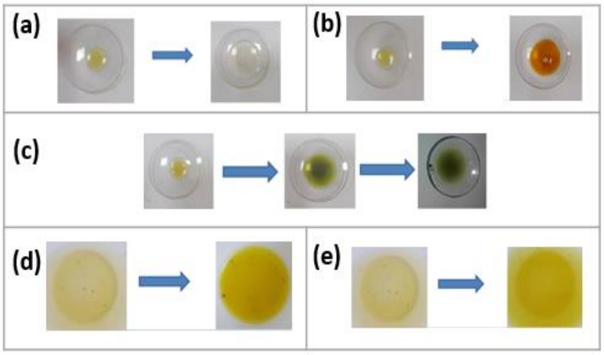

Fig. 2. Colorimetric Responses of Pomegranate Dye: (a) 20% NaOH, (b) 20% HCl, (c) 10% $AlK(SO_4)_2$, (d) 10% Sugar Solution, (e) 10% Insulin Solution.

B. Comparison of Color Strength

The spectrophotometric analysis of the pomegranate rind dyed samples; dyed, encapsulated, and both dyed and encapsulated, as depicted in Fig.3, reveals insightful differences in their color / colorimetric properties. The analysis focused on three main aspects: lightness (DL), chroma (Da, Db), and hue (DH).

The dyed samples, both with and without encapsulation, exhibited a darker tone as indicated by their negative DL values, with the purely dyed sample showing a slightly darker appearance than its dyed and encapsulated counterpart. This darker tone in the dyed samples is associated with a higher chroma, suggesting a richer color saturation. In contrast, the Pomegranate Rind Encapsulated samples displayed a lighter shade, evidenced by their less negative DL value. This lighter coloration is crucial for health monitoring textiles where color change is a key indicator of analyte presence. The lighter shade provides a more distinct contrast, making it easier to observe and quantify color shifts that indicate changes in sweat analyte concentrations, which could be less perceptible against a darker background.

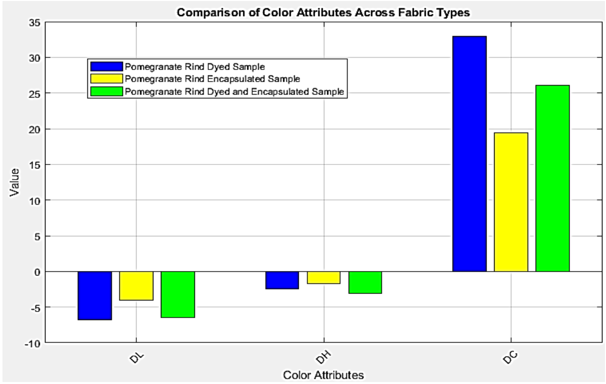

Fig. 3. Comparison of Color Strength of treated vs untreated samples

Moreover, encapsulation improves color fastness, protecting the dye from environmental factors and ensuring the stability and longevity of the color. This aspect is critical in health monitoring applications, where the durability of the colorimetric response is as important as its accuracy. While the dyeing process alone imparts a more intense color, the encapsulation process, yielding a lighter shade, is more advantageous for health monitoring. It balances visibility, crucial for detecting colorimetric changes, and durability, ensuring the longevity of the fabric's functional properties. The hue analysis across all samples indicated a shift towards bluer tones, with the purely dyed sample showing a more pronounced shift. This shift in hue, alongside the observed differences in lightness and chroma, demonstrates the significant impact of the dyeing and encapsulation processes on the color properties of the fabrics. Thus, the findings highlight the versatility of pomegranate rind extract as a natural dye, offering diverse coloration possibilities for various applications, particularly in the field of responsive health monitoring textiles.

V. CONCLUSION

This study explores the potential of encapsulated pomegranate rind dyes as effective colorimetric indicators for health monitoring. These dyes exhibit notable sensitivity to a range of chemical stimuli, making them suitable for detecting specific health markers. The encapsulation process enhances their distribution and stability, crucial for consistent and reliable colorimetric responses. While challenges such as data analysis latency, contamination risks, and limitations in current microfluidic systems remain, continued research is essential to address these issues. Advancements in these areas will further solidify the role of pomegranate rind dyes as valuable tools in personalized healthcare diagnostics.

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