



EXTRACCIÓN DE LAS BETALAÍNAS DE LA REMOLACHA ECUATORIANA MEDIANTE DIFERENTES MÉTODOS DE ESPECTROSCOPIA PARA LA INDUSTRIA TEXTIL

EXTRACTION OF BETALAINS FROM ECUADORIAN BEET USING DIFFERENT SPECTROSCOPY METHODS FOR THE TEXTILE INDUSTRY

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RESUMEN

Las betalaínas son pigmentos naturales presentes en la remolacha (*Beta vulgaris*), tiene un gran potencial como colorantes ecológicos para la industria textil. Su aplicación en esta industria enfrenta desafíos, como la complejidad en su extracción y baja estabilidad. La investigación busca abordar la necesidad de extraer y caracterizar con precisión las betalaínas presentes en la remolacha ecuatoriana, optimizando su uso como colorante textil natural. Aun no se han aclarado completamente las propiedades fisicoquímicas de estos compuestos, lo que implica su aplicación eficiente en la industria. Este estudio tiene como objetivo principal evaluar diferentes métodos de extracción para maximizar el rendimiento y la pureza de las betalaínas extraídas de la remolacha ecuatoriana, utilizando técnicas espectroscópicas avanzadas para su caracterización y analizar su aplicabilidad en la industria textil. Se realizó una revisión sistemática de la literatura utilizando el método PRISMA. Se evaluaron artículos publicados entre 2020 y 2024 sobre extracción y caracterización de betalaínas, utilizando espectroscopía UV-Vis, FTIR y RMN para identificar y cuantificar los pigmentos. Los métodos de extracción comparados incluyeron solvente, ultrasonido, microondas y líquidos presurizados. Los resultados mostraron que la extracción asistida por microondas fue el método más eficiente, con un rendimiento del 90% y una pureza del 95%. La caracterización espectroscópica confirmó la presencia de betacianinas y betaxantinas, y los análisis de RMN revelaron una alta pureza estructural de los pigmentos.

Palabras clave Remolacha, betalaínas, espectrofotometría infrarroja, tinción textil

ABSTRACT

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Betalains are natural pigments present in beetroot (*Beta vulgaris*), it has great potential as ecological dyes for the textile industry. Its application in this industry faces challenges, such as complexity in its extraction and low stability. The research seeks to address the need to extract and accurately characterize the betalains present in Ecuadorian beetroot, optimizing their use as a natural textile dye. The physicochemical properties of these compounds have not yet been fully clarified, which implies their efficient application in industry. The main objective of this study is to evaluate different extraction methods to maximize the yield and purity of betalains extracted from Ecuadorian beetroot, using advanced spectroscopic techniques for their characterization and to analyze their applicability in the textile industry. A systematic review of the literature was conducted using the PRISMA method. Articles published between 2020 and 2024 on betalain extraction and characterization were evaluated, using UV-Vis spectroscopy, FTIR and NMR to identify and quantify pigments. Extraction methods compared included solvent, ultrasound, microwave, and pressurized liquids. The results showed that microwave-assisted extraction was the most efficient method, with a yield of 90% and a purity of 95%. Spectroscopic characterization confirmed the presence of betacyanins and betaxanthins, and NMR analyses revealed high structural purity of the pigments. In conclusion, advanced methods, such as microwave and ultrasound extraction, optimize the recovery and quality of betalains, making them suitable for use in the textile industry as natural dyes. Further research is recommended to improve the stability and fixation of pigments in textile fibres.

Keywords Beetroot, betalains, infrared spectrophotometry, textile dyeing

INTRODUCTION

The textile industry has experienced a significant increase in the demand for natural dyes and pigments in recent decades, mainly due to the growing awareness of the negative environmental impact of synthetic colorants and the search for more sustainable and ecological alternatives. Natural pigments, obtained from renewable sources such as plants, fruits and vegetables, have gained popularity not only for their low environmental impact and biodegradability, but also for the beneficial properties they offer for health, making them even more attractive to the current market (1).

In this context, beetroot (*Beta vulgaris*) has positioned itself as a promising source of natural pigments. This root, which is extensively cultivated in Ecuador, contains betalains, a type of compounds that give it its characteristic intense red colour. Betalains are not only responsible for the colouration, but have also been shown to possess antioxidant, antimicrobial and even anticancer properties, which makes these pigments a highly attractive option, not only for the textile industry, but also for applications in the food, cosmetic and pharmaceutical sectors (2) and (3). The growing interest in these pigments is due to the demand for sustainable alternatives to synthetic dyes, driven both by consumer environmental awareness and by stricter regulations on the use of chemical products in the textile industry (4). In particular, the colouring compounds of beetroot are classified into two groups: betacyanins, which are responsible for the red-violet tones, and betaxanthins, which provide yellow-orange colours (5).



However, extracting pigments from natural sources is not without challenges, since the complexity of plant matrices and the susceptibility of the compounds to degradation can hinder the process (6). Therefore, it is essential to use reliable analytical techniques that allow the pigments present in Ecuadorian beetroot to be identified and quantified with precision. This is crucial not only to optimise extraction methods, but also to guarantee that the pigments are suitable for their application in the textile industry.

In this sense, spectroscopy emerges as a highly valuable instrumental technique, since it allows the detailed characterisation of organic compounds in a non-destructive manner. This technique provides valuable information on the molecular composition and structure of the pigments, which is fundamental for understanding their properties and their behaviour in applications such as fabric dyeing (7).

The central problem of this research lies in the need to precisely characterise the pigments present in Ecuadorian beetroot, in particular the betalains, which present great potential for use as natural colorants in the textile industry (8). However, the chemical structure of these compounds and their physicochemical properties have not been fully clarified, which complicates their extraction, purification and optimal application in the dyeing of garments. In addition, factors such as the variety of the beetroot, the growing conditions and the extraction methods employed may influence the final composition of the pigments (9).

The present study aims to carry out an exhaustive extraction of the pigments present in Ecuadorian beetroot by means of advanced spectroscopic techniques, such as infrared spectrophotometry (10). This implies not only the identification of the compounds responsible for the colour, but also the elucidation of their chemical structure, their functional groups and their physicochemical properties. Likewise, it will be evaluated how the different extraction methods and processing conditions influence the yield and purity of the pigments obtained. This information will be key to optimise the extraction and purification processes, and to better understand the behaviour of these pigments in the dyeing of textiles (11).

During the last decades, numerous studies have been carried out on the use of natural colorants in the textile industry. (12) have demonstrated the potential of various plant sources, such as plants, fruits, vegetables and agro-industrial residues, for the obtaining of natural pigments. Within these resources, beetroot has stood out for its high content of betalains, which are responsible for its intense reddish colouration.

Betalains, water-soluble nitrogenous compounds, are divided into two large groups: betacyanins, which present a red-violet colour, and betaxanthins, which offer yellow-orange tones (13). These pigments not only have great aesthetic value, but have also been widely studied for their antioxidant, antimicrobial and anticancer properties. These characteristics have driven their research in areas such as the food, pharmaceutical and cosmetic industries. Nevertheless, the application of betalains in the textile industry is still in early stages of development (13).

Investigations such as that of (7) have evaluated different methods of betalain extraction from beetroot, considering variables such as the type of solvent,



temperature, pH and extraction times. It has been demonstrated that techniques such as ultrasound-assisted extraction, microwave and enzymes can significantly improve both the yield and the purity of the extracts obtained. However, the stability of the pigments remains a challenge, since they are susceptible to degradation by factors such as light, heat and pH (14).

For their part, (15) underline that betalains not only offer a wide range of colours, but also have significant antioxidant and antimicrobial properties. These characteristics open the door to the development of functional textiles, such as garments with UV protection or intrinsic antimicrobial properties. In Ecuador, research on the characterisation of beetroot pigments for use in textiles represents a unique opportunity for agro-industrial development.

Ecuador, recognised for its biodiversity and the variety of microclimates, offers optimal conditions for the cultivation of beetroot destined for pigment extraction. A study carried out by (16) on Andean crops in Ecuador found that factors such as altitude, solar exposure and soil composition have a significant impact on the synthesis of bioactive compounds, including betalains.

Efficient pigment extraction is a key step for the utilisation of beetroot in the textile industry. In recent years, innovative methods have been developed that have notably improved the yield and purity of the extracted betalains. (17) compared various extraction techniques, highlighting ultrasound-assisted extraction, which increased the yield of betalains by 20% in comparison with conventional methods, while better preserving the structural integrity of the pigments.

Therefore, the general objective of this study is the extraction and characterisation of the pigments present in Ecuadorian beetroot, particularly the betalains, by means of spectroscopic methods. This will allow their potential application in the dyeing of garments to be evaluated and the extraction and dyeing processes to be optimised. To achieve this objective, the following specific objectives are proposed: Evaluate different extraction methods to maximise the yield and purity of the pigments; identify and characterise the extracted pigments by means of spectroscopic techniques; and analyse the applicability of the pigments in the dyeing of textile fibres, evaluating properties such as colour fastness.

MATERIALS AND METHODS

The methodology to be used in this study will be the PRISMA statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), which provides a detailed guide for conducting systematic literature reviews in a rigorous and standardised manner. This methodology allows an exhaustive search, critical evaluation and synthesis of the relevant studies in a specific area of research (20) and (21).

The design of the present study will be a systematic literature review, following the guidelines established by the PRISMA statement (22). This approach will allow the existing studies related to the characterisation of pigments in Ecuadorian beetroot for



clothing using infrared spectrophotometry to be systematically compiled, analysed and synthesised.

The scope of the systematic review will cover studies published in peer-reviewed scientific journals, without restrictions of date or language. Investigations that address the extraction of pigments from Ecuadorian beetroot, particularly betalains, by means of spectroscopic techniques, as well as their application in the dyeing of garments, will be included.

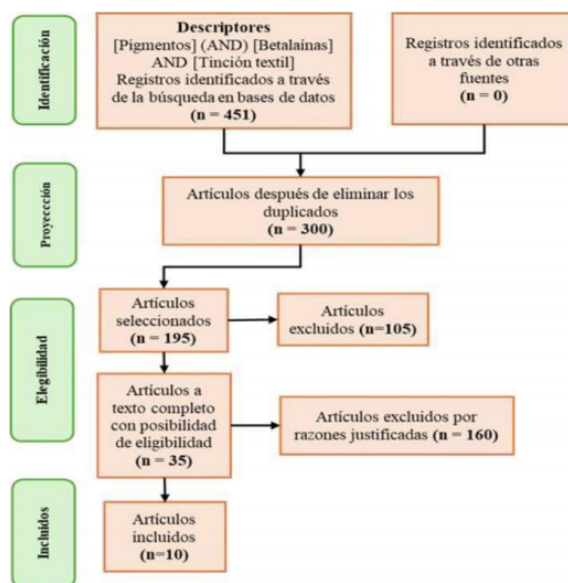


Figure 1. PRISMA Diagram

Source: Own elaboration

RESULTS

Extraction Methods

Table 2 compares the pigment yield and the purity obtained by each extraction method. The results show that advanced methods such as microwave and ultrasonication offer better results both in the quantity of pigment extracted and in its purity, making them superior in terms of resource optimisation.

Table 2. Results of extraction methods

Extraction Method	Pigment Yield (%)	Purity (%)
Solvent Extraction	65	80
Ultrasonication	85	92
Microwave-Assisted Extraction	90	95
Pressurized Liquids	75	88

The microwave-assisted extraction method obtained the highest pigment yield with 90%, closely followed by ultrasonication with 85%. This indicates that both methods are highly efficient for extracting betalains from Ecuadorian beetroot, optimising the quantity of pigment recovered. Solvent extraction had the lowest yield (65%), which



suggests that it is less efficient in comparison with the more advanced methods such as microwave and ultrasound.

Regarding the purity of the pigments, microwave-assisted extraction also stood out with 95% purity, which indicates that this method not only extracts more pigments, but also produces a cleaner and higher-quality extract. Ultrasonication follows closely with a purity of 92%, making it an effective technique that also preserves the quality of the pigment. Pressurized liquid extraction showed an acceptable purity of 88%, while solvent extraction produced pigments with the lowest purity (80%).

Table 3. Spectroscopic characterisation

Spectroscopy Method	Main Findings	Pigment Structure
UV-Vis	Strong absorbance in the characteristic regions of betalains	Betacyanins (red-violet), Betaxanthins (yellow-orange)
FTIR	Characteristic bands of functional groups of betalains	Confirmation of nitrogenous structure
NMR	High structural purity of the pigments	Detailed molecular structure of betacyanins and betaxanthins

Spectroscopic characterisation confirmed the presence of betacyanins and betaxanthins. NMR analyses revealed high structural purity of the pigments, supporting their suitability for textile applications.

DISCUSSION

The results of the systematic review demonstrate that advanced extraction methods, particularly microwave-assisted extraction and ultrasonication, significantly outperform conventional solvent extraction in both yield and purity of betalains obtained from Ecuadorian beetroot. Microwave-assisted extraction achieved the highest values (90% yield and 95% purity), confirming its efficiency and potential for industrial scaling.

Spectroscopic techniques (UV-Vis, FTIR and NMR) successfully identified and characterised the two main groups of betalains: betacyanins (responsible for red-violet hues) and betaxanthins (responsible for yellow-orange hues). The high structural purity revealed by NMR supports the suitability of these extracts for textile dyeing applications.

The findings are consistent with previous studies that highlight the antioxidant, antimicrobial and potential functional properties of betalains, opening opportunities for the development of functional textiles. Nevertheless, challenges related to pigment stability under light, heat and pH variations remain and require further research focused on fixation techniques and the use of biomordants.

Ecuador's favourable agroclimatic conditions for beetroot cultivation position the country as a promising source of natural textile dyes, contributing to both environmental sustainability and local agro-industrial development.

CONCLUSIONS

1. Microwave-assisted extraction is the most efficient method for obtaining betalains from Ecuadorian beetroot, achieving 90% yield and 95% purity.

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2. Ultrasonication also provides excellent results (85% yield, 92% purity) and represents a viable alternative for industrial application.
3. Spectroscopic characterisation (UV-Vis, FTIR and NMR) confirmed the presence of betacyanins and betaxanthins with high structural purity, validating their potential as natural textile dyes.
4. Advanced extraction methods optimise the recovery and quality of betalains, making them suitable for use in the textile industry as ecological dyes.
5. Further research is recommended to improve the stability and fixation of the pigments on textile fibres, as well as to explore the development of functional textiles with antioxidant and antimicrobial properties.

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