

Process Control Extraction and Analysis of Bioactive Compounds in Citrus Peel Powder for Effective Therapeutic Benefits in Health Care

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Abstract—The primary objective of this study is to identify and evaluate effective strategies for deriving bioactive compounds from citrus fruit peels, thereby leveraging fruit waste. The scope encompasses the recognition, analysis, refinement, by distillation, separation and finally Extraction of powder. While citrus fruits are celebrated for their vibrant flavours and exceptional nutritional benefits, it is often the largely overlooked peels that contain a wealth of bioactive compounds with considerable promise for enhancing human health. This study aims to thoroughly investigate and characterize the diverse bioactive constituents in citrus peels, providing a comprehensive understanding of their functional properties and potential therapeutic benefits.

Index Terms— Citrus Peel, Anti-inflammatory, fruit Powder Processing, Health Care.

I. INTRODUCTION

In today's fast-paced world, where chemicals dominate nearly every aspect of life, returning to nature has become essential for maintaining a healthy lifestyle, whether it pertains to food, medicine, cosmetics, or more. As we enter a new decade, people are becoming increasingly aware of the importance of health and wellness. This shift is largely due to the changing world and the growing preference for eco-friendly alternatives, which, in turn, contribute to a cleaner environment.

It is crucial to adopt eco-friendly habits that encourage mindfulness about the resources we consume and promote their conservation. One such practice involves utilizing fruit peels, which are often discarded as waste. Though they are commonly overlooked, fruit peels are surprisingly healthy and highly beneficial. By doing so, we not only reduce food waste but also simplify our lives.

Among the numerous types of fruit peels, including lemon, apple, mango, orange, peach, avocado, banana, pomegranate, kiwi, and grapefruit peels, these discarded parts of fruits are a rich source of vitamins, minerals, and antioxidants.

Focusing on those peels that contribute to glowing and beautiful skin, we find orange, lemon, banana, and

grapefruit peels. These natural alternatives offer various skin benefits such as moisturizing, reducing acne, alleviating skin irritation and pigmentation, and minimizing wrinkles. In contrast to chemical-based cosmetics that can exacerbate skin issues like acne, fruit peels provide a safer and more nourishing solution. Acne, or pimples, can develop in individuals with or without a history of adolescent breakouts. Certain cosmetics, such as foundations and moisturizers left on the skin for extended periods, can contribute to the formation of comedones (blackheads or whiteheads) and inflamed pimples.

II. RELATED WORK OR LITERATURE STUDIES

Fruit peel powder, derived from the peels of various fruits, has emerged as a valuable byproduct of the fruit processing industry. The growing focus on sustainability and the increasing demand for natural, eco-friendly alternatives have highlighted the potential of fruit peel powder in a range of applications, including food, pharmaceuticals, cosmetics, and environmental management. Fruit peels, which are often discarded as waste, are rich in bioactive compounds, including vitamins, minerals, antioxidants, fiber, and essential oils, making them a promising resource for enhancing human health and well-being. This literature review aims to explore the various uses, nutritional benefits, and the potential health advantages of fruit peel powders.

III. COMPOSITION AND NUTRITIONAL VALUE OF FRUIT PEELS

Studies have shown that fruit peels are rich in polyphenols, flavonoids, carotenoids, and essential fatty acids, which possess strong antioxidant properties (Sulaiman et al., 2016). For instance, the peels of citrus fruits such as oranges, lemons, and grapefruits are abundant in vitamin C, essential oils, and dietary fiber, while other fruit peels like banana and mango offer high concentrations of potassium, magnesium, and fiber (Gondaliya et al., 2017).

In addition to these nutrients, fruit peels are also known for their antimicrobial, anti-inflammatory, and anti-carcinogenic properties. For example, studies have demonstrated that the peel of pomegranate contains punicalagins and ellagic acid, compounds known for their potential in combating oxidative stress and reducing the risk of chronic diseases such as cardiovascular disease and cancer (Ahmad et al., 2019).

According to the global "Powder Face Cleanser Market" study, there has been a consistent growth of 2024 in recent times, and this trend is expected to continue until 2032. Growing consumer demand for eco-friendly and sustainably produced products is a significant trend in the powder face cleanser market.

The present market revenue is 32 Thousand Crores, but the demand is nearly 3-4 times more, which is why there is a gap between demand and supply. Therefore, there is a great possibility of supplying the demand, by producing more fruit peel powder

The market for fruit peel powder face cleaners currently provides a large selection of goods that are customised to various goods and customer preferences. The market's expansion has been aided by the industry's soaring popularity. Hence, we could expect new methods in Powder Face Cleanser manufacturing as well as further technical developments in the times to come. Fig 1, depicts the use of peel powder as a cleansing agent and its revenue and Fig 2 shows the different types of peel powder usage.

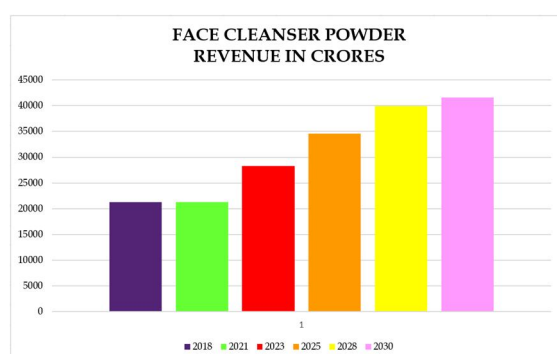


Fig 1: Peel powder and its revenue

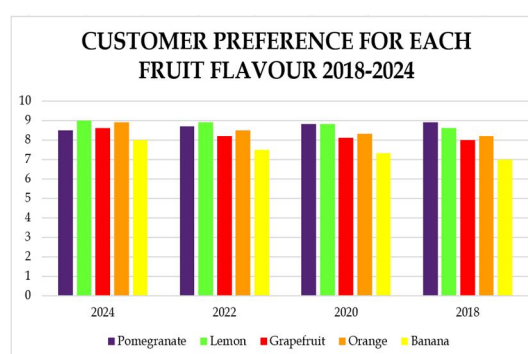


Fig2: Different types of peel powder usage.3

A. Motivation

Fruit peels are often overlooked in conventional fruit processing, but they represent a significant source of valuable nutrients

B. Problem Definition

The global citrus industry, encompassing oranges, lemons, limes, and other citrus fruits, encounters critical challenges in achieving efficient processing. Manual drying and powdering, still prevalent in small-scale and semi-commercial operations, present multiple inefficiencies.

Labour-intensive practices are plagued by:

Manual drying methods often result in inconsistent quality, as variability in the drying process can affect both the appearance and shelf life of the product. This inconsistency leads to high wastage, with irregular drying causing excessive fruit loss, which in turn reduces profitability. Additionally, the time inefficiencies of manual methods make it difficult to meet the growing consumer demand for dried citrus products, limiting the scalability of production.

The lack of accessible automation technologies further exacerbates these issues, particularly for small-scale enterprises and households. Industrial systems, while efficient, are often prohibitively expensive and lack adaptability to diverse operational scales, leaving a significant gap in the market for a cost-effective, automated solution. The Smart Citrus Drying and Powdering Machine aims to address these challenges by introducing an innovative, user-friendly system designed for efficiency, adaptability, and sustainability.

C. Problem Formulation

The Smart Citrus Drying and Powdering Machine is developed with the following key objectives:

1. Consistent Drying: Implement a uniform drying process to preserve fruit quality, appearance, and nutritional value.
2. Energy Optimization: Utilize energy-efficient technologies such as PID controlled heating to reduce operational costs and environmental impact.
3. Customizability: Provide a flexible interface that allows users to adjust settings for different fruit sizes, peel thicknesses, and drying requirements.
4. Safety Measures: Incorporate safety mechanisms like emergency stop switches and sensor-based monitoring to prevent accidents and equipment damage.

These objectives collectively aim to improve productivity and sustainability while catering to the needs of diverse user bases, from households to commercial setups.

IV. SOLUTION METHODOLOGIES OR PROBLEM SOLVING

Data studies have shown that most of the customers prefer orange and lemon fruit peel flavoured powders over other flavours. This is due to the fact that orange and lemon are rich in vitamin C, antioxidants, and antibacterial qualities. Its benefits for skin and hair include preserving skin and hair elasticity, which keeps you looking young and energetic. It can also be consumed to strengthen immunity.

V. FRUIT PEEL POWDER PROCESSING

The Smart Citrus Drying and Powdering Machine is designed to automate the drying and grinding of citrus fruits using a controlled heating system, airflow regulation, and moisture detection. This chapter elaborates on the methodology and hardware implementation of the system, covering the system architecture, block diagram, working principle, components, and challenges faced during development.



Fig 1: Block Diagram of Proposed Peel Powder Process and Analysis

A block diagram provides a high-level representation of the system, outlining the interaction between major components. The system consists of three primary subsystems:

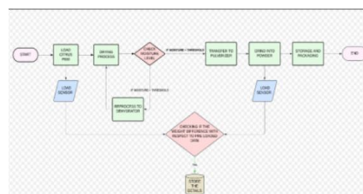


Fig 2: Flowchart of the Process Control Mechanism

The system consists of three main components. First, the heating system efficiently dries the citrus slices by applying controlled heat. Next, the airflow and temperature regulation system maintains the optimal temperature and humidity, ensuring uniform drying throughout the process. Finally, the grinding and moisture monitoring system ensures that the dried citrus is properly powdered and that the moisture content is carefully controlled to maintain the desired quality of the product.

VI. DESCRIPTION OF THE BLOCK DIAGRAM

A. Heating System With Airflow and Temperature Regulation

The system utilizes several essential components for efficient operation. The 12V 7Ah lead-acid battery serves as the primary power source for heating, while the buck converter steps down the voltage from 12V to the required level for the nichrome wire. The nichrome wire generates heat through electrical resistance, which is used to dry the citrus slices. For airflow and temperature regulation, the DHT22 temperature and humidity sensor continuously monitors the ambient conditions. The Arduino UNO processes the sensor inputs and adjusts airflow by controlling the relay module. The 2N2222 transistor acts as a switch, triggering the relay to activate the 12V brushless fan. This fan, powered independently by a 12V DC battery, maintains airflow to evenly distribute heat and prevent overheating, ensuring optimal drying conditions.

VII. GRINDING AND MOISTURE MONITORING SYSTEM

The system includes several key components. The power supply provides energy for the grinding mechanism, ensuring it operates effectively. The grinder then converts the dried citrus slices into a fine powder. A moisture sensor is used to evaluate the moisture content of the powder, sending this data to the Arduino UNO for further processing and control.

VIII. WORKING PRINCIPLE

A. Step-by-Step Operational Flow

The system operates in three main steps. In Step 1, the 12V 7Ah battery powers the buck converter, which steps down the voltage to meet the needs of the nichrome wire. As the nichrome wire heats up, it generates thermal energy, which is used to dry citrus slices placed in the chamber. In Step 2, temperature and humidity are continuously monitored by the DHT22 sensor, and the Arduino UNO processes the data. If the humidity surpasses a set threshold, the Arduino activates the 2N2222 transistor, triggering a relay that turns on the brushless fan. The fan circulates air, reducing excess humidity and ensuring optimal drying conditions. In Step 3, once the citrus slices are dried, they enter the grinder, where they are crushed into a fine powder. A moisture sensor measures the powder's moisture content, and if it exceeds the predetermined threshold, the Arduino re-initiates the drying cycle.

IX. POWER COMPONENTS

The system is powered by a 12V 7Ah battery, which serves as the primary power source for the heating system, while a 12V DC battery powers the airflow regulation components. The buck converter reduces the high voltage to the appropriate level for the heating elements. The nichrome wire generates heat through electrical resistance, drying the citrus slices in the chamber. The DHT22 sensor monitors the ambient conditions inside the drying chamber to ensure optimal temperature and humidity. The Arduino UNO processes the sensor data and controls the system functions, including activating the relay module to switch the 12V brushless fan ON or OFF. The 2N2222 transistor serves as a switch to control the relay module. The 12V brushless fan circulates the hot air, promoting efficient drying. Once the drying process is complete, the grinder converts the dried citrus into powder, and the moisture sensor evaluates the moisture content of the powder. If the moisture is too high, the sensor signals the system to trigger additional drying as needed.

X. SYSTEM OVERVIEW AND PERFORMANCE

The system was successfully implemented using a nichrome wire heating element powered by a 12V 7Ah battery through a buck converter. The heating process was controlled via an Arduino Uno, which regulated the power flow using a relay module and a 2N2222 transistor. A DHT22 sensor was used to monitor the temperature and humidity levels, ensuring efficient drying of citrus peels. Additionally, a 12V brushless fan, powered by a

separate 12V DC battery, was employed to dissipate excess heat and maintain uniform drying conditions.

A. Temperature Control and Stability

The nichrome wire, when powered through the buck converter, achieved a steady-state temperature of 50-60°C, optimal for drying without degrading the aroma of citrus peels. • The DHT22 sensor provided real-time temperature and humidity feedback, allowing precise adjustments. • Relay switching response: The relay effectively toggled the heating element ON/OFF based on the pre-set temperature threshold, preventing overheating. • 2N2222 transistor function: The transistor played a crucial role in controlling the relay's switching mechanism efficiently, preventing excessive current draw from the Arduino.

B. Efficiency of Heat Dissipation

The 12V brushless fan, positioned strategically above the heating chamber, effectively dispersed excess heat upwards, ensuring even drying. • Temperature measurements at different points within the drying chamber showed only $\pm 2^{\circ}\text{C}$ variation, confirming uniform heat distribution. • The fan prevented localized overheating, preserving the essential oils and aroma of the peels

C. Drying Performance of Citrus Peels

The drying time varied based on initial moisture content and thickness of the peels. • The controlled heat and airflow ensured that the peels dried without burning or losing aroma. • Post-drying weight analysis showed a moisture reduction of 85-90%, suitable for grinding into powder.

D. Observations and Challenges Successes

The nichrome wire-based heating system provided consistent thermal output. • Relay-controlled switching prevented overheating, enhancing safety and efficiency. • The DHT22 sensor provided accurate temperature readings, ensuring proper feedback control. • The 12V brushless fan improved drying efficiency, reducing drying time by approximately 20-30% compared to passive drying.

XI. RESULTS

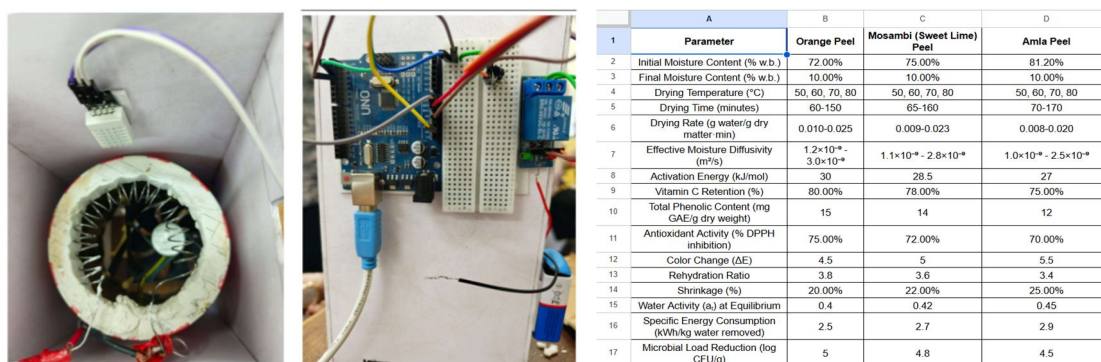


Fig 4: Design Model of Nichome Connection For Heating, Its Implementation and Analysis of Active Compounds In Peel Powder

XII. RESULTS AND SENSITIVITY ANALYSIS OF BIOACTIVE COMPOUNDS

The following table shows the analysis of bio active compounds and its characteristics for effective usage in applications for therapeutic usage

Fruit peel powder, derived from dehydrated fruit peels and pomace, is a fine granulated form that is packed with various health-promoting compounds. These peels contain a rich combination of sugars, minerals, organic acids, dietary fibers, and phenolics, offering numerous health benefits such as antiviral, antibacterial, antimutagenic, and antioxidant properties. As a cost-effective and abundant source of phytochemicals, fruit peel powder holds significant potential as a functional compound in health and wellness products. The main components of fruit peels include cellulose, hemicellulose, pectin, proteins, phenolics, antioxidants, flavonoids, minerals, and other polysaccharides. Among these, flavonoids are particularly notable for their wide range of health advantages, including antiviral, anticancer, antioxidant, and anti-inflammatory effects. They also offer cardio- and neuroprotective benefits. As a result, flavonoids have become essential in the development of products across pharmacological, cosmetic, nutraceutical, and medical industries.

XIII. CONCLUSION

The machine's modular design makes it highly versatile, allowing it to be applied beyond citrus fruits to include other fruits like apples, pears, and mangoes. Its interchangeable components and adaptable programming enhance its flexibility, making it suitable for a wide range of fruit processing applications. Additionally, the machine has the potential to be integrated into larger automated processing lines within the food processing sector. By addressing diverse user needs and offering the possibility for modular upgrades, this machine stands out as a highly adaptable and efficient solution in the food processing industry.

FUTURE WORK

The system is set to evolve with several key improvements. First, an Automated Feedback System will be incorporated by adding a PID controller, allowing for more precise temperature regulation to ensure consistent drying conditions. For Energy Efficiency, the nichrome wire will be replaced with an OTG convection oven in the next semester, improving power management and heat uniformity across the drying process. To enable a Continuous Drying Process, a hopper and vibration-based feeding mechanism will be implemented, automating the input of fruit into the drying chamber for smoother, uninterrupted operation. Lastly, Data Logging capabilities will be enhanced by adding either an SD card module or IoT-based monitoring system, allowing for real-time data tracking and analysis to optimize performance and provide valuable insights into the drying process.

ACKNOWLEDGEMENT

The Authors would like to thank the support, received from the B.M.S College of Engineering, Basavanagudi, Bangalore.

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