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CREATION OF AUTOMATED AIR PURIFIER USING DATE PALM LEAF FIBER (PHOENIX DACTYLIFERA) AND SPENT COFFEE GROUNDS (COFFEA ARABICA) AS ACTIVATED CARBON

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ABSTRACT

Air pollution in Qatar, driven by excessive air pollutants and marked by high Carbon Dioxide (CO_2) emissions, leads to respiratory illnesses. An experimental design was conducted to test the filtration efficiency of Spent Coffee Grounds (SCGs) and Date Palm Fibers using an ESP32 microcontroller to monitor air quality changes. The results showed that Date Palm Fibers reduced pollutants by 28.95%, activated SCGs by 34.85%, and their combination by 41.07%. The ESP32 sensor demonstrated a quick response time of 2.42 seconds and detected pollutants within a 5 cm range. This system effectively combined real-time monitoring with sustainable filtration, highlighting the potential of organic waste in improving air quality. It significantly reduced ppm levels and proved effective in air quality monitoring. Further improvements could be achieved by enhancing filtration using Zinc Chloride ($ZnCl_2$) or Phosphoric Acid and optimizing airflow for greater efficiency and reliability.

KEYWORDS: Activated Carbon Adsorption, Air Filtration, Carbon Adsorbents, IoT-Based Air Monitoring, Sustainable Materials

INTRODUCTION

Air pollution is one of the most pressing global challenges, affecting both climate change and public health. In Qatar, the worsening state of the environment has become a significant concern, impacting the overall quality of life. For instance, the 24-hour average concentration of PM_{10} has been around 150 μg/m³, while the annual average concentration is approximately 50 µg/m³—both higher than the World Health Organization's standards of 50 µg/m³ and 20 µg/m³, respectively (Lanouar et al., 2016). This emphasizes the immediate need for practical actions to reduce its negative impact. Pollution is closely linked to serious health problems, such as respiratory issues and even cancer. Research by Malik et al. (2023) pointed out that long-term exposure to pollutants could delay the diagnosis of diseases like lung cancer. Air pollution accounts for 3.1% of global health challenges (Cohen et al., 2017). Another study investigated the indoor air quality of schools in Qatar and found that many classrooms had elevated levels of CO_2 and particulate matter (PM_{10} and $PM_{2.5}$), exceeding recommended indoor air quality standards (Abdel-Salam, 2019). Additionally, the country ranked first globally for CO_2 emissions per capita (Lu, 2023).

Another critical concern was indoor air pollution, often more severe than outdoor pollution. Recent studies found that people spent approximately 90% of their time indoors, where air quality is frequently 2–5 times worse than outside (Mannan & Al-Ghamdi, 2021). The study by Pillarisetti, Ye, and Chowdhury provides quantitative data highlighting the severity of indoor air pollution, especially in low- and middle-income countries. For instance, they report that indoor concentrations of fine particulate matter ($PM_{2.5}$) in households using solid fuels can range from 300 to 500 µg/m³. This is significantly higher than the World Health Organization's recommended 24-hour average limit of 15 µg/m³ for $PM_{2.5}$. Such elevated levels indicate that indoor air quality in these settings can be substantially worse than outdoor air quality, posing serious health risks to occupants (Pillarisetti, Ye, & Chowdhury, 2022).

At the same time, the disposal of waste materials like spent coffee grounds (SCG) has created environmental challenges. Typically, spent coffee grounds end up in landfills, decomposing slowly and releasing harmful substances into the environment (Pan et al., 2019). Although this waste is often seen as a nuisance, it could be repurposed to create sustainable, environmentally friendly solutions. Spent coffee grounds, for example, were found to possess potential as a natural medium for air filtration (Hsieh & Wen, 2020).

Similarly, date palm fibers were a byproduct of the agricultural industry in the Middle East, particularly in regions like Saudi Arabia, where over 15,000 tons of date palm waste was generated annually (Ghori et al., 2018). Despite their potential, the fibers from the leaves, trunk, and other parts of the date palm tree were often underutilized. Studies have shown that they could be converted into high-surface-area activated carbon, effectively capturing carbon dioxide (CO_2) and other pollutants (Alazmi et al., 2021; Jahami et al., 2024).

Innovative solutions were necessary to address both air pollution and waste disposal issues. One promising approach involved using organic materials like SCGs and date palm fibers to create low-cost, sustainable air purifiers. An Arduino-based system powered by microcontrollers like the ESP32 enabled real-time air

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quality monitoring. The ESP32 was an affordable, low-power microcontroller with built-in Wi-Fi and Bluetooth capabilities, allowing for seamless data transmission and remote monitoring (Maier et al., 2017; Foltýnek et al., 2019). Its integration into air quality research enables real-time, low-cost, open-source monitoring of pollutants, ensuring accessibility and impact (Pérez-Sánchez et al., 2024).

This research explored using SCGs and date palm fibers as activated carbon mediums for an air purifier system, with real-time monitoring powered by the ESP32. By integrating sustainable materials with cutting-edge technology, this project aimed to offer a practical and environmentally friendly solution to combat air pollution in Qatar and beyond.

This study explored a unique combination that integrates a Wi-Fi-connected ESP32 system with sustainable, inexpensive materials, carefully crafting a dual focus on sustainability and innovation in its manufacturing process. Repurposing spent coffee grounds (SCGs) and date palm fibers as activated carbon filter media allows for sustainable, cheaper, and greener alternatives to traditional activated carbon. This provides cost-effective and efficient air filtration solutions and serves as a model for future studies. Such inspired studies may grow to aim for combining technology with newly recycled waste disposal methods to protect the environment, rather than just investigating these possibilities.

Moreover, the significance of this study on the creation of an automated air purifier using date palm leaf fibers (*Phoenix dactylifera*) and spent coffee grounds (*Coffea arabica*) as an activated carbon filter medium was to benefit the following:

This study can be a valuable example for students focused on research and development in science, technology, engineering, and mathematics fields. It can encourage them to explore various environmentally relevant areas. It can motivate them to combine environmental sustainability with innovative solutions, fostering a deeper understanding of how science and technology can address pressing environmental challenges.

This study would offer those who manage coffee industries a sustainable method to repurpose spent coffee grounds, reducing disposal costs and upholding eco-friendly brand images. Moreover, it would allow countries to explore the uses of date palm fibers beyond air purification.

The development of this device offers an affordable and sustainable solution to indoor air pollution. This study focused on utilizing easily accessible and renewable materials for air purification, contributing to environmental sustainability. Furthermore, integrating Arduino technology and the ESP32 for automation improves the system's efficiency and ease of use, making it adaptable to various applications.

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RESEARCH QUESTIONS

The objective of this study is the Creation of a Automated Air Purifier Monitoring System Using Date Palm Fiber (Phoenix dactylifera) and Spent Coffee Grounds (Coffea arabica) as Activated Carbon Media. Specifically, it aimed to answer the following questions:

1. How effective is the air filter in removing hazardous contaminants from indoor air using the following filters:
   - 1.1 date palm fiber paper;
   - 1.2 activated carbon spent coffee grounds; and
   - 1.3 date palm fiber paper and activated spent coffee grounds?
2. How effective is the performance of the air purifier in terms of:
   - 2.1 response time; and
   - 2.2 range?
3. What are the optimal conditions for maximizing the effectiveness of the air purifier in terms of:
   - 3.1 kitchen (2.6 m × 3.1 m × 2.5 m); and
   - 3.2 enclosed area of 2.6 m × 3.1 m × 2.5 m (combustion)?

HYPOTHESIS

H1: It is feasible to create an automated air purifier using Date Palm Leaf Fiber and Spent Coffee Grounds (SCGs) as an activated carbon medium, with the system effectively providing real-time monitoring of air quality.

METHODOLOGY

This study utilized the experimental design of research. Experimental research design was defined as being applied when the study sought to determine the cause-and-effect relationships between the dependent and independent variables (Tanner, 2018). The researchers believed that the most accurate way to gather information was through comprehensive testing. In this study, the spent coffee grounds and date palm fibers were the independent variables, and the air purification system was the dependent variable. Furthermore, the quantitative method was used to properly organize the experiment and acquire the appropriate type of data. This method was necessary because it provided a high level of control over the variables, demonstrating an outcome and offering an advantage in finding accuracy, consistency, and precision in its results.

RESEARCH LOCALE

The research study was conducted at a Philippine school in Qatar. he researchers, who are students at the school, chose this location due to the availability of necessary facilities that would support the

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development of their product.

DATA GATHERING PROCEDURE

The procedure describes the step-by-step process of how to make an ESP32-based automated air purifier that utilizes Date Palm Fiber and Spent Coffee Grounds (SCGs) as an activated carbon medium.

Activating the Spent Coffee Grounds

1. The collected SCG (Spent Coffee Grounds) was pre-dried for 2 hours at 120 degrees Celsius in the oven.
2. Heat the SCG for 2 hours at a constant temperature ranging from 480 to 600 degrees Celsius. This temperature must be maintained to facilitate the evaporation of volatile compounds, leaving behind carbon, or SCG charcoal. If performed outdoors with a wind barrier setup, it is essential to ensure minimal or no exposure to oxygen or air during the heating process, as the presence of oxygen may result in the combustion of the SCG, leading to the formation of ash.
3. When there is no more smoke being emitted, this indicates the charcoal-making process.
4. Let the pot cool down for 1-2 hours before removing the lid cover.
5. In making the activated carbon, calcium chloride was added to the substance to start the activation process. We need to ensure the correct proportion of the substance to the amount of charred SCG to maintain the base consistency. A ratio of 1 gram to 3 mL of solution was used.
6. Let the mixture react for 24 hours.
7. Rinse the mixture with a maximum of 1 liter of distilled water to remove the substance used.
8. Drain carefully to maximize the collection of SCG activated carbon.
9. Oven-dry the SCG activated carbon for 2 hours at 110 degrees Celsius.

Creating the Date Palm Fiber Leaf Filter Paper

1. Measure approximately 82 grams of date palm leaves, wash carefully with warm water to clean from impurities.
2. Measure approximately 42 grams of sodium hydroxide (NaOH) pellets.
3. Prepare 800 mL of water.
4. Heat the 800 mL of water in a stainless-steel pot and bring it to a boil for 5 minutes.
5. Add 42 grams of sodium hydroxide pellets to the boiling water.
6. Stir to ensure the sodium hydroxide pellets are fully dissolved in the boiling water.
7. Cut the 82 grams of date palm leaves into smaller pieces to facilitate the breakdown of cellulose.
8. Add the cut date palm leaves to the sodium hydroxide-water solution.
9. Boil and simmer the mixture for 2 hours.

10. Allow the solution to cool for 10 minutes.
11. Drain the sodium hydroxide solution from the treated leaves.
12. Transfer the leaves into a blender.
13. Prepare 200 mL of distilled water.
14. Add 200 mL of distilled water to the blender containing the leaves.
15. Blend the leaves and distilled water until a jelly-like pulp is formed.
16. Prepare a silk screen sieve and a deep basin.
17. Fill the basin with water and mix in half of the leaf pulp.
18. Submerge the sieve in the basin and evenly distribute the pulp onto the silk screen, flattening it to the desired size and shape.
19. Use a sponge to press against the pulp and remove excess water.
20. Leave the pulp to dry on the silk screen under direct sunlight for one day.
21. Once dried, carefully peel or scrape the pulp from the silk screen.
22. Set aside the dried pulp, which serves as the completed date palm leaf filter paper.

Coding of the ESP32 system

1. Connect the two MQ135 air quality sensors to the ESP32 microboard which is then connected to the breadboard.
2. Solder spare wires to the breadboard due to lack of space.
    a. Power both MQ135 sensors:
        i. Connect the VCC pin of both sensors to the 3.3V pin of the ESP32.
        ii. Connect the GND pin of both sensors to the GND pin on the ESP32.
    b. Signal connections
        i. Connect the AOUT pin (analog output) of MQ135 Sensor 1 to Analog Pin 34 on the ESP32.
        ii. Connect the AOUT (analog output) of MQ135 Sensor 2 to Analog Pin 35 on the ESP32.
3. Create a Blynk Account and Project
    a. After creating an account, create a new template in the Blynk dashboard:
        i. Set the template name.
        ii. Note down the Template ID and Auth Token for later use.
    b. Add an ESP32 device to the project:
        i. Select ESP32 as your hardware.
        ii. Copy the Auth Token provided by Blynk.
        iii. Install Blynk and ESP32 Libraries in Arduino IDE from the board manager.
4. Configure the Code for MQ135 Sensor and Blynk

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   a. In the code, add Blynk Template ID, Auth Token, and WiFi network credentials.
   b. Assign the analog pin on the ESP32 where the MQ135 sensor is connected.
   c. Initialize the Sensor and WiFi in the setup() function:
      i. Set the MQ135 sensor pin as input.
      ii. Start serial communication to debug sensor readings.
      iii. Connect the ESP32 to your WiFi network and Blynk server.
5. Read Sensor Data and Calibrate in the loop() Function
   a. In the loop(), continuously read the analog data from the MQ135 sensor.
   b. Apply calibration when needed for accuracy.
   c. Map the sensor values to the AQI (Air Quality Index) scale of 0-500.
6. Determine Air Quality Index (AQI) Status
   a. Classify the air quality based on the scaled AQI value and display the corresponding status.
7. Send Data to Blynk App:
   a. Send the AQI value and status to Blynk using virtual pins.
   b. Configure the corresponding widgets in the Blynk app.
8. Run the Blynk App
   a. Open the Blynk app on your mobile device.
   b. Add widgets and link them to virtual pins for real-time monitoring.
9. Upload Code to ESP32
   a. Connect the ESP32 to your computer.
   b. Upload the code from the Arduino IDE to the ESP32.
   c. Open the Serial Monitor to view live sensor readings and AQI status for debugging.

Constructing the Air Purifier container

1. Measure the exhaust fans, activated carbon filter, and date palm leaf filters.
2. Create protective side covers for the fans by cutting two rectangular pieces of illustration board according to the fan's dimensions.
3. Attach the cut pieces to the sides of each fan, ensuring a snug fit.
4. Repeat for the second fan following the same process to create side covers for the other fan.
5. Construct a three-sided box for support by cutting three pieces of illustration board that connected the two fans.
6. Ensure there is enough space inside the box to accommodate the activated carbon filter and additional filter layers.
7. Place the two fans at opposite ends of the box structure ensuring they are aligned properly for efficient airflow.

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8. Create supports for the filters by cutting U-shaped pieces from the illustration board to hold the date palm fiber filter in place.
9. Ensure they are positioned at both ends of the activated carbon filter for stability.
10. Place the activated carbon filter in the center of the box.
11. Position the U-shaped supports on either end of the activated carbon filter.
12. Insert the date palm fiber filter into the supports, ensuring a secure fit.
13. Connect the ESP32 board to the sensors on each side.
14. Connect each ESP32 Board to a power supply.
15. Enclose the air purifier container on all sides by attaching a cover made of plexiglass to the top and securing it with hinges.

Wiring and Automating Fan

1. Wire the relay to the microboard.
    a. Connect the DC + wire to the VIN Pin.
    b. Connect the DC - wire to the GND Pin.
    c. Connect the IN 1 wire to the D12 Pin.
    d. Connect the IN 2 wire to the D14 Pin.
2. Connect the inlet fan to Sensor 1, the relay, and the microboard.
    a. Connect the fan's black wire to the - DC jack.
    b. Connect the fan's red wire to COM 1 on the relay
3. Connect the outlet fan to Sensor 2, the relay, and the microboard.
    a. Connect the fan's black wire to the - DC jack.
    b. Connect the fan's red wire to COM 2 on the relay
4. Set the code to automate the fan with the relay.
    a. Configure the code to pins 12 and 14 on the microboard for relay.
5. Upload the code.

RESULTS

This section presents the performance outcomes of the automated air purifier using date palm leaf fiber and coffee grounds as the activated carbon medium. The data collected from air quality sensors highlight the system's effectiveness in reducing airborne particles and improving overall air quality during testing.

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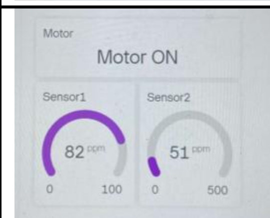
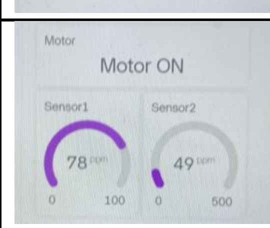
1. **Measure of air quality in ppm from entry point to exit point with air quality difference in percentage through different filters**

Table 1

Effectiveness of the ESP32-based Air Purification System using different filters

Medium	**Air Quality from Entry Point (ppm)**				**Air Quality from Exit Point (ppm)**				**AQ Difference (%)**	**Photos (Figure 1.1, 1.2, 1.3)**
	T_1	T_2	T_3	**Ave.**	T_1	T_2	T_3	**Ave.**		
Date palm fiber paper	72	75	81	76	52	53	57	54	28.95%	
Activated spent coffee grounds	82	79	77	79.3	51	56	48	51.67	34.85%	
Date palm fiber paper and activated spent coffee ground	79	82	78	79.67	45	47	49	47	41.07%	

Location: Closed room (2.4 m × 1.2 m × 2.5 m) **Pollutant:** Combustion of 1 g paper

Table 1 shows the air quality index (AQI) of using date palm fibers as a medium by measuring the AQI before and after the automated air purification system is activated, using combustion as the pollutant, and the air quality MQ135 inside a closed room (2.6 m × 3.1 m × 2.5 m). The device uses two sensors to monitor air quality: one at the entry point and one at the exit point. The entry sensor measures the AQI before it passes through the filter, while the exit sensor measures the AQI after filtration. The researchers compared the readings between the two sensors to determine the extent of improvement in air quality. Moreover, the researchers used BreezoMeter, as it can be a valuable tool for assessing AQI. It utilizes

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various data sources, including local air quality monitoring stations, to provide real-time hyperlocal air quality information. Lastly, the researchers utilized the Air Quality Index Chart, which is shown in the table below:

Figure 1.4, Air Quality Index

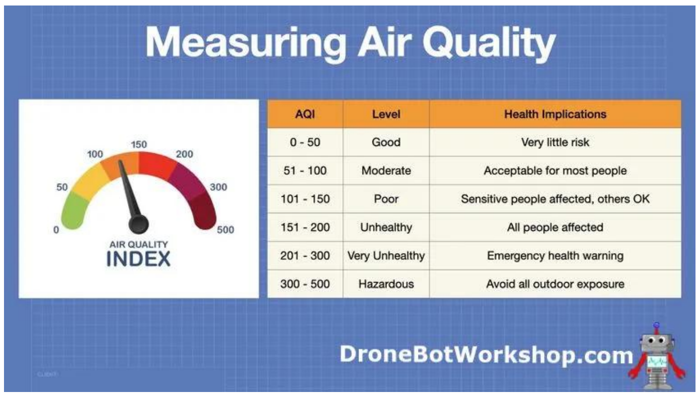

Table 1 presents the air quality filtration results for three different mediums: date palm fiber paper, activated spent coffee grounds, and a combination of both. In the first trial set using date palm fiber paper alone, air quality at the entry point measured 72 ppm, 75 ppm, and 81 ppm across three trials, with an average of 76 ppm. After filtration, the exit point readings dropped to 52 ppm, 53 ppm, and 57 ppm, averaging 54 ppm, resulting in a 28.95% reduction. To ensure consistency, all trials filtered smoke emitted from 1 gram of paper, positioned 5 cm away from the entry sensor. These findings suggest that while date palm fiber paper is capable of reducing air pollutants, its filtration efficiency is moderate. Nonetheless, this supports previous studies, such as that of Alharbi et al. (2022), which reported that activated carbon derived from *Phoenix dactylifera* leaf fibers exhibits effective adsorption characteristics suitable for air filtration.

In contrast, the second set of trials using activated spent coffee grounds yielded higher efficiency. The entry point readings were 82 ppm, 79 ppm, and 77 ppm, averaging 79.3 ppm, while the exit point readings dropped to 51 ppm, 56 ppm, and 48 ppm, averaging 51.67 ppm. This corresponds to a 34.85% reduction in air pollution. These results affirm findings by Figueroa Campos et al. (2021), who demonstrated that activated carbon produced from spent coffee grounds and parchment exhibits high surface area and adsorption capacity. This indicates that the activation process significantly enhances the pollutant-absorbing properties of spent coffee grounds.

The combination of date palm fiber paper and activated spent coffee grounds showed the most effective performance. Air quality at the entry point measured 79 ppm, 82 ppm, and 78 ppm, with an average of 79.67 ppm. After filtration, the exit point readings were 45 ppm, 47 ppm, and 49 ppm, averaging 47 ppm. This resulted in the highest reduction rate of 41.07%. This combination leveraged the strengths of both

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mediums, making it the most effective. These results are in accordance with Figueroa Campos et al. (2019) and Alharbi et al. (2022), which demonstrated that activated spent coffee grounds enhance the pollutant-absorbing properties and *Phoenix dactylifera* leaf fibers exhibit effective adsorption characteristics suitable for air filtration.

2. Average performance of the air purifier in terms of response time and effective range

Table 2 Functionality and Performance of ESP32-based Air Purification System

Concentration: 50 ppm **Location of Sensor:** Entry Point

Functionality	**Distance**												
	1cm				**3cm**				**5cm**				**8cm**
Response time (s)	T_1	T_2	$\boldsymbol{T_3}$	**Ave.**	T_1	T_2	$\boldsymbol{T_3}$	**Ave.**	T_1	T_2	$\boldsymbol{T_3}$	**Ave.**	N/A
	2.7	1.9	2.56	2.42	3.2	2.8	3.1	3.03	4.1	3.7	4.0	3.93	
Range	Detected				Detected				Detected				Undetectable

Table 2 evaluates the functionality and performance of the automated air filter by measuring its response time and range. The response time is assessed by introducing smoke near the sensor until the air quality reading exceeds 50 ppm. Once the sensor detects 50 ppm, the fans activate, marking the end of the response time measurement. Range, on the other hand, is measured by evaluating the system's response at varying distances of the controlled variable, specifically at 1 cm, 3 cm, 5 cm, and 8 cm from the sensor.

The response time trials for 1 cm resulted in an average of 2.42 seconds, with measurements of 2.79s, 1.9s, and 2.56s. The fastest response time of 1.9 seconds indicates the device's highest efficiency, while the lowest response time of 2.79 seconds shows the device's slowest response. According to Mahetaliya et al. (2021), ESP32-based systems consistently deliver rapid and reliable response times in real-time monitoring scenarios.

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The response time trials for 3 cm resulted in an average of 3.03 seconds, with measurements of 3.2s, 2.8s, and 3.1s. The fastest response time of 2.8 seconds indicates the device's highest efficiency, while the lowest response time of 3.2 seconds shows the device's slowest response. According to Mahetaliya et al. (2021), ESP32-based systems consistently deliver rapid and reliable response times in real-time monitoring scenarios. The response time trials for 5 cm resulted in an average of 3.93 seconds, with measurements of 4.1s, 3.7s, and 4.0s. The fastest response time of 3.7 seconds indicates the device's highest efficiency, while the lowest response time of 4.1 seconds shows the device's slowest response. According to Mahetaliya et al. (2021), ESP32-based systems consistently deliver rapid and reliable response times in real-time monitoring scenarios.

Further, the tests for range determined the sensor's ability to detect smoke at different distances. The sensor successfully detected smoke at 1, 3, and 5 centimeters but failed at 8 centimeters, indicating that 5 centimeters is the range where sensor performance declines. This finding is consistent with studies on gas and smoke sensors, which show that performance declines beyond a certain threshold due to reduced pollutant concentration and sensor sensitivity (Aimudo et al., 2023).

3. **Average of PPM readings and percentage difference in air quality under the optimal conditions of the air purifier**

Table 3 Optimal Conditions of the ESP32-based Air Purification System in terms of ppm

Location	Air quality from the Entry Point (ppm)				After Quality from Exit Point (ppm)				AQ Difference in Percent	Photos
	T_1	T_2	$\boldsymbol{T_3}$	Ave.	T_1	T_2	$\boldsymbol{T_3}$	Ave.		

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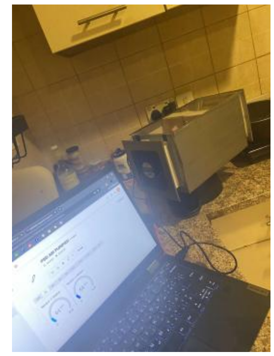
Kitchen (2.6 m × 3.1 m × 2.5 m)	61	63	61	61.67	56	54	54	54.67	11.35%	
Enclosed area (combustion) (2.4 m × 1.2 m × 2.5 m)	78	79	78	78.33	47	45	45	45.67	41.71%	

Table 3.1 measures the Parts per Million (ppm) of the Real-time Monitoring ESP32-Based Air Purification System using Date Palm Fibers and Spent Coffee Grounds as an activated carbon filter as Medium by measuring the ppm before and after the air purification system is activated using the Air Quality MQ135 in locations such as the Kitchen and Closed Room (Combustion). Then, the researchers compared the AQI readings to determine the extent of improvement in air quality. Moreover, the researchers utilized BreezoMeter, as it can be a valuable tool for assessing the Air Quality Index (AQI). It utilizes various data sources, which include local air quality monitoring stations, to provide real-time hyperlocal air quality information. Lastly, the researchers utilized the Air Quality Index Chart.

Table 3 provides a closer look at how well the air purification system performed in two different environments: the kitchen and an enclosed area (combustion). In the open kitchen, the system reduced pollutant levels from 61.67 ppm to 54.67 ppm, an 11.35% decrease. While this shows some improvement, the impact was relatively moderate. This is likely because the open nature of the kitchen allows air to circulate freely, letting pollutants disperse before the purifier can remove them. Research supports this, indicating that air purification is less effective in well-ventilated or open spaces where pollutants aren’t as concentrated (Kumar et al., 2022).

The results were much more pronounced in the closed room (combustion), where pollution levels dropped from 78.33 ppm to 45.67 ppm—a significant 41.71% reduction. This aligns with findings from Song et al. (2025), who observed that air purification systems work best in enclosed areas with high levels of pollutants, where the concentration gradient helps improve filtration efficiency. These results suggest that while the system is effective in different environments, its impact is greater in areas with poor ventilation and higher pollution levels.

HYPOTHESIS

H1: The researchers' hypothesis, which states that it is feasible to develop an automated air purifier using Date Palm Fiber and Spent Coffee Grounds (SCGs) as an activated carbon medium, is accepted. The results have shown that the system effectively provides real-time monitoring of air quality.

DISCUSSION

According to the results, the creation of an Automated Air Purifier using Date Palm Leaf Fiber (*Phoenix dactylifera*) and Spent Coffee Grounds (*Coffea arabica*) as activated carbon mediums demonstrated varying degrees of efficiency depending on the materials used and the surrounding environment. Among the tested filtration mediums, date palm fiber paper reduced air pollutants by 28.95%, lowering pollution levels from 76 ppm to 54 ppm. Activated spent coffee grounds performed even better, cutting pollutants by 34.85%, from 79.67 ppm to 52 ppm. However, the combination of both materials proved to be the most effective, achieving a 41.07% reduction from 79.67 ppm to 47.3 ppm, suggesting that the two materials work well together. The system also demonstrated a quick response time, averaging 2.42 seconds, with the fastest detection at 1.9 seconds and the slowest at 2.79 seconds, confirming its efficiency in real-time air quality monitoring. Additionally, tests on sensor sensitivity showed that it could reliably detect smoke up to 5 cm away but struggled at 8 cm, which aligns with studies on sensor performance at varying distances. Environmental testing further revealed that the purifier was significantly more effective in enclosed spaces, reducing pollutants in an enclosed area (combustion) by 41.71%, compared to an 11.35% reduction in an open kitchen. These findings highlight the system's potential in improving air quality, especially in areas with poor ventilation where pollutants are more concentrated.

Carbon nanomaterials are often utilized in air purification, though they come with a high cost (Chaplin, 2018). These high costs have led researchers to seek alternative materials that are both affordable and environmentally friendly. In this regard, locally abundant materials such as date palm fibers and spent coffee grounds present promising alternatives (Jeníček et al., 2022). These materials are not only cost-effective but also readily available in regions like Qatar, where large quantities of date palm byproducts and spent coffee grounds are produced annually (Castillo et al., 2023). By using these materials in air filtration systems, it is possible to reduce reliance on expensive carbon nanomaterials while promoting

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sustainability and reducing waste.

CONCLUSION

The findings show that the Automated Air Purification System was effective in improving air quality using different filtration materials. The system successfully reduced pollutants by 28.95% with date palm fiber, 34.85% with activated spent coffee grounds, and an impressive 41.07% when both were combined. It also demonstrated a quick response time, averaging 2.42 seconds, and performed well at distances of 1 cm, 3 cm, 5 cm, and 8 cm from the sensor. In real-world environments, the device improved air quality by 11.35% in the kitchen and 41.71% in enclosed areas (combustion), proving its adaptability to different conditions.

Although the air purification system has shown promising results, there is still potential for further enhancement. A significant improvement could be achieved by activating the carbon filter using Zinc Chloride ($ZnCl_2$) or Phosphoric Acid (H_3PO_4). This activation process increases the surface area of the carbon, which in turn enhances its ability to adsorb air pollutants. In comparison, Zinc Chloride ($ZnCl_2$) activation leads to a higher surface area compared to Calcium Chloride ($CaCl_2$) activation, resulting in more efficient adsorption properties. Activated carbon with a greater surface area and smaller pore sizes has been shown to perform better in air purification tasks, as seen in the study of Zhang et al. (2018), which found that polyethylenimine (PEI)-impregnated mesoporous silica (SBA-15) exhibited a CO_2 adsorption capacity of 3.93 mmol/g at 298 K and 100 kPa. The optimal CO_2 adsorption was observed in SBA-15 with a pore size distribution centered around 6.5 nm, indicating that mesoporous materials with appropriate pore sizes enhance CO_2 uptake. Ghosh et al. (2017) found that while $CaCl_2$ activation results in a smaller surface area than $ZnCl_2$, it leads to an increase in porosity, meaning more pores are created. This increase in pore volume can enhance adsorption capacity, particularly for larger molecules, but the overall efficiency for air purification may be less than that of activated carbon with a higher surface area like that produced by $ZnCl_2$ activation. Studies on activated carbon derived from spent coffee grounds further support this, as activation using $ZnCl_2$ has been found to significantly improve the material's adsorption efficiency for air purification (Figueroa Campos et al., 2021). Therefore, using Zinc Chloride ($ZnCl_2$) or Phosphoric Acid (H_3PO_4) activation could increase the performance of the air purification system by improving the carbon's capacity to adsorb harmful particles from the air, ultimately enhancing its overall effectiveness.

The researchers recommend further exploration to improve the device's performance and reliability. Future advancements, such as refining airflow mechanisms and experimenting with alternative eco-friendly filtration materials, could enhance its efficiency. With continued development, the device has the potential to evolve into a more reliable and versatile solution for air quality improvement.

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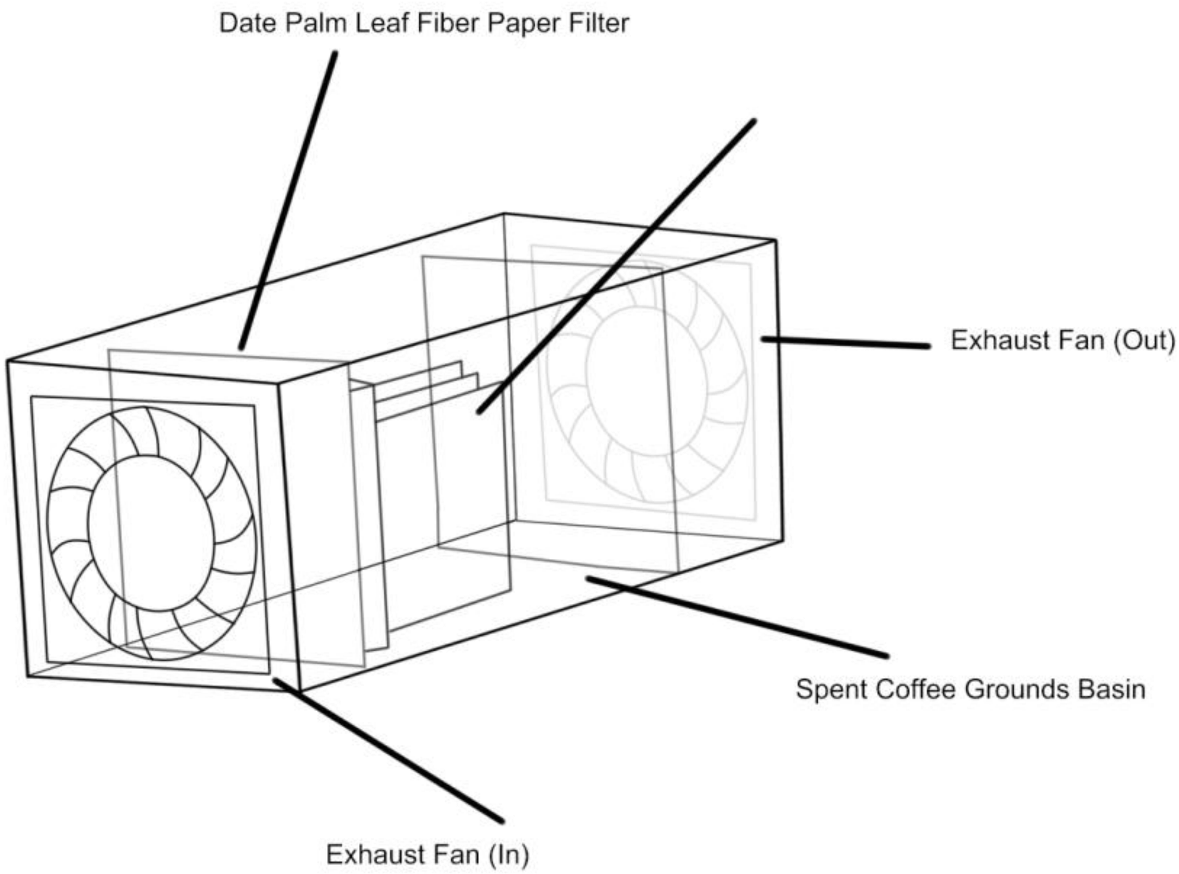

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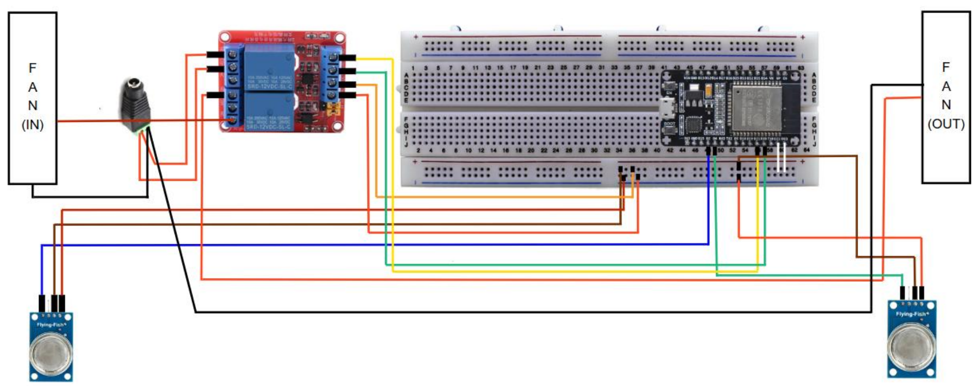

APPENDIX B (MATERIALS AND EQUIPMENT)
Materials

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Material	Quantity	Unit	Price	Pictures
Spent Coffee Grounds	505	grams	N/A	
Date Palm Leaves	82	grams	N/A	
ESP32 Microboard	1	piece	39 QAR	
DC Fan	2	pieces	N/A	

Calcium Chloride Powder	75	grams	N/A	
Sodium Hydroxide Pellets	42	grams	N/A	
Distilled water	1.2	liters	N/A	
Air Quality Sensor MQ-135	2	pieces	19 QAR	
Full-size Breadboard	1	pieces	20 QAR	
Short Jumper Wires (Male to Female)	1	pieces	7 QAR	

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Short Jumper Wires (Male to Male)	1	pieces	7 QAR	
DC Barrel Jack	1	pieces	4 QAR	
2 Channel Relay Module	1	pieces	22 QAR	
Micro USB Cable	1	pieces	N/A	
Power Source Adaptor	1	pieces	N/A	

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Duct Tape	1	pieces	N/A	
Illustration Board	2	pieces	N/A	
Plexi Glass	32.5 x 19	cm	25 QAR	
Aerobag Fiters	1	pieces	N/A	
TOTAL		162 QAR		

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Equipment

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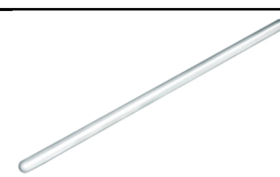
Equipment	Purpose	Pictures
Topload balance	The topload balance was used to measure and quantify the amount of spent coffee grounds required for carbon production and date palm leaves for filter creation accurately.	
Mixing bowl	The mixing bowl was used to mix the activated carbon precursor (spent coffee grounds) with any additional activating agents (calcium chloride) or binders uniformly.	
Glass Stirring Rod	The glass stirring rod stirred the sodium hydroxide, distilled water, and date palm leaf solution	

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	in the blender.	
Blender	The blender was used to blend the sodium hydroxide, distilled water, and date palm leaves into a pulpy solution.	
Oven	The oven was used to heat the spent coffee grounds to eliminate oxygen..	
Induction Stove	The induction stove was used to heat-treat the coffee grounds and activate them to create activated carbon, as well as to heat the date palm leaf fiber solution.	

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Computer/Laptop	The computer/laptop was used to program and upload code to the Arduino Uno, as well as to monitor and analyze data collected during the experiment.	
Soldering Iron	The soldering iron was used to solder the wires into the breadboard of the device.	
Blynk	The Blynk application provides real-time air quality data, enabling better monitoring and analysis of the air purifier's effectiveness in improving indoor air quality.	

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Basin	The basin was used to collect liquid from the silk screen, helping maintain a clean and organized workspace.	
Stainless Steel Pot	The basin was used to collect liquid from the silk screen, helping maintain a clean and organized workspace.	
Stainless Steel Pan	The stainless steel pan was used to further heat up the spent coffee grounds after the use of the oven.	
Silk Screen	The silk screen was used to form the date palm leaf fiber paper for the filter.	

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Thermal Gloves	To ensure the safety of the researchers and participants during experimental procedures, especially when handling the chemicals used in the study.	
Ruler	The ruler was used to measure the length and width of the DC fans as a basis for the exterior of the device.	
Pencil	The pencil was used to mark the length and width of the illustration board as a basis for the exterior of the device as measured by the ruler.	

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Cutter	The cutter was used to cut the illustration board based on the size of the DC fans measured by the ruler.	
Scissors	The scissors were used to cut up the date palm leaves for easier cellulose break down and assist in cutting the illustration board.	

APPENDIX C (RESEARCH PROCEDURE DOCUMENTATION)

Figure 1.1, 1.2, 1.3: Creating the date palm leaf fiber paper filter

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Figure 2.1, 2.2: Activating the spent coffee grounds

Figure 3: Creating the exterior

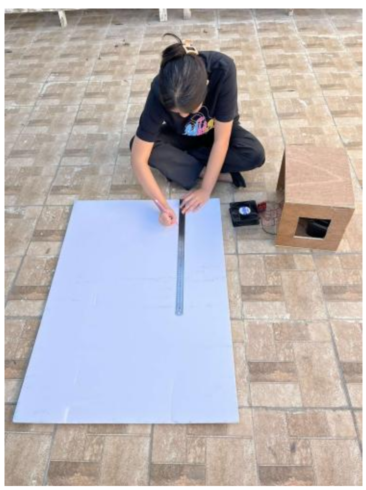

Figure 4.1, 4.2: Programming and wiring the device

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