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A Novel Multifaceted Approach to the Detection and Analysis of Formalin's Effect on Enhancing the Shelf Life of Apples

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ABSTRACT

The prevalent saying that an apple a day keeps the doctor away may have much merit because of its valuable minerals, vitamins and antioxidant contents that benefit humans. However, because of the circulating news of apples being adulterated with formalin in Bangladesh, a considerable number of people are discouraged from consuming them. The research investigates the effect of formalin on the shelf life of apples. In this research, we have adulterated apples with three different concentrations (20%, 30%, 40%) of formalin and use three different methods to study the presence of formalin on the surface of the apples: (1) spectrophotometry, (2) a formalin test kit developed by the Bangladesh Council of Scientific and Industrial Research (BCSIR), and (3) an MS1100 gas sensor that functions as an E-nose. The test kit detection and spectrophotometry enabled the detection of the presence and the concentration of formalin on the apple, respectively. The E-nose is able to deduce the decay profile of formalin on the surface of the apples. The measurements showed the emission of formalin drops to their natural or pure form after approximately 30 hours. Formalin does not improve the shelf life of apples, and visibly, it arguably makes them appear less fresh. The phenomenon has also been explained by theory, which states that formalin primarily affects foods with relatively high protein content. Hence, shopkeepers who presumably use formalin do not benefit from its application.

Keywords: Food adulteration, formaldehyde, formalin, nutritional quality, shelf life

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INTRODUCTION

It has been reported that over the last decade, food adulteration and contamination with harmful chemicals have been practiced extensively and have consequently become a concerning issue in Bangladesh (Dey & Nagababu, 2022; Kamruzzaman, 2016; Headlines and Global News, 2014). Use of

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harmful colors, wax-coated fruit (Guo, 1994), Calcium carbide-based artificial ripening (Bini et al., 2019; Nura et al., 2018; Essien et al., 2018), pesticide residues (Ahmad et al., 2024), and formalin-based fruit preservation (Protano et al., 2021) are all different methods of food adulteration. Not all the methods are harmful, provided they are used in controlled amounts and with caution. However, it has become a matter of concern in Bangladesh, and the news of the harmful effects of food adulteration is widespread. According to the news, features and articles published in numerous newspapers and other mass media over the past decade have become a deadly worrying concern in Bangladesh. Based on a survey conducted in 2004 by the City Corporation, over 76% of the food items were found adulterated at varied levels, ranging from 70% to 90% (Rahman et al., 2015). As per a government official statistic, about 50% of the food samples tested by the Institute of Public Health from 2001 to 2009 were adulterated (Directorate General of Health Services, 2012).

Consumption of adulterated food has caused numerous deaths as well (Ali, 2013a; Ali, 2013b)—lack of storage and refrigeration, loose regulatory controls. Inadequate transportation infrastructure and rising consumer demand fuel the tendency to use fraudulent methods to increase shelf life (United Nations, 2007). In Reza et al. (2023), research was conducted on various fruits, in which the impact of formalin on the post-harvest quality and nutritive properties has been investigated. Machine Learning (ML) has been utilized to detect formalin in fruits by Brighty et al. (2021). For the last 30 years, more than 1582 publications have been published regarding formaldehyde in food, signifying the importance of the scientific findings (Rahman et al., 2023). In recent years, extensive research has been conducted on the development of formaldehyde detection sensors, further emphasizing the relevance of the topic (Fan et al., 2024; Yang et al., 2024; Zhang et al., 2023).

Among the wide variety of adulterants, formalin is the most famous in Bangladesh. Formalin, which is a colorless, 37%–50% aqueous solution of formaldehyde, is reported to be frivolously used in foods in Bangladesh and Southeast Asian countries (Kawamata & Kodera, 2004; Uddin et al., 2011). Formaldehyde is a naturally occurring substance composed of carbon, hydrogen and oxygen (CH_2O) (American Chemistry Council, 2025). It is produced naturally by the human body, and fruits and vegetables are produced in low amounts. Formaldehyde is also manufactured industrially since it is applied in various sectors, such as wood products, cosmetics, adhesives, plastics, nail hardeners, and disinfectants (International Agency for Research on Cancer, 2006). However, in 2004, formaldehyde was classified as carcinogenic to humans (International Agency for Research on Cancer, 2004). Formaldehyde is deadly harmful if inhaled above 300 ppm and ingested above 30 mL (American Chemistry Council, 2025; National Center for Biotechnology Information, 1999). However, it is metabolized rapidly at lower levels, converted to carbon dioxide, and exhaled.

In Bangladesh, everyone from producers to wholesalers is accused of illegally applying formalin to increase the shelf life of fruits and vegetables (Huda, 2025; Tamanna, 2024; Mohiuddin, 2019). Tons of food have been destroyed due to the detection of formaldehyde by the mobile court, as reported in the mass media, without scientifically validating whether the level is in the permissible range. The presence of formalin was detected using handheld detectors (Z-300) with a concentration range of 1–30 ppm (Alam, 2013; The Daily Star, 2014). Formaldehyde is emitted naturally: 6–20 mg/kg in meat and fish, 3–60 mg/kg in various fruits and vegetables, and 1 mg/kg in dairy products (World Health Organization, 2000). According to the European Food Safety Authority (EFSA), the maximum allowable exposure to formaldehyde from food of both animal and plant origin is 100 mg/kg food per day. If the natural level of formaldehyde emission is not considered, all food may be adulterated.

Fruits are a source of valuable minerals, vitamins and fiber. Fruits and vegetables are inevitable components of a healthy diet. Since no fruit or vegetable provides all the nutrients, variety is more important than quantity. Consumers are left uncertain whether their fruit is nutritious or potentially harmful. According to the U.S. Environmental Protection Agency, the permissible limit of average daily exposure to formaldehyde is 0.75 ppm (Jia et al., 2024). Theoretically, formaldehyde can only help extend the shelf life of foods with high protein content. Hence, formaldehyde is ineffective on fruits and vegetables since they generally have low protein content (Kiernan, 2000).

Table 1 depicts that most fruits emit a certain level of formaldehyde, and the value calibration is necessary in case of any adulteration calculation. If we go to the supermarket and take measurements with gas sensors, it will detect formaldehyde, but if it does not exceed the natural level, then there is nothing to worry about. As mentioned earlier, formalin is a 37%–50% aqueous formaldehyde solution.

When we observe the reaction of formalin with protein, two particular reactions will happen. Firstly, the formation of Schiff Base. Secondly, the exact process of crosslinking relations between DNA using formaldehyde and proteins. This process leads to the formation of covalent bonds between proteins and DNA, altering their structure and potentially affecting their function. How effectively formalin can act as a preservative depends most on the proportion of protein content constituting the object that needs to be preserved.

Table 1
Naturally occurring formaldehyde from few fruits (Brighty et al., 2021)

Fruit Name	Naturally Occurring Formaldehyde (ppm)
Apple	6.3–22.3
Apricot	9.5
Banana	16.3
Cucumber	2.3–3.7
Grape	22.4
Pear	38.7–60
Plum	11.2
Tomato	5.7–13.3
Watermelon	9.2

For a very long time, preservatives have been utilized to resist autolysis and putrefaction. The preservative basically reacts with cadaveric tissue to form an inert product preservative; formalin is commonly used commercially (Wojdyło et al., 2008). The formaldehyde interlinks adjacent proteins by inserting a methylene bridge (-CH2-) between the nitrogen in the amino groups. Hence, the protein is converted into a complex molecular crosslinked lattice structure, which is no longer susceptible to serving as food for bacteria or a substrate for enzymes (Wojdyło et al., 2008; The Nutrition Source, 2024). The above-mentioned process depicts a 2-step reaction that results in the Lysine residue of protein and Guanine Base of DNA.

From Table 2, it can be observed that the percentage of protein in an Apple is around 1%. Apples are widely consumed around the world due to their natural ability to combat diseases and their accessibility (Wojodylo et al., 2008). It is a very good source of fiber, phytochemicals, and vitamin C (The Nutrition Source, 2024). Apples are also rich in pectin and quercetin, both of which provide considerable health benefits. Quercetin acts as an antioxidant and has anti-inflammatory effects. Pectin, a soluble fiber, assists in resisting constipation, LDL "bad" cholesterol, and when fermented in the colon by beneficial bacteria, can help prevent chronic diseases such as certain cancers and bowel disorders.

Several studies have been conducted on the detection of formaldehyde over the years. Such as, in one of the papers, the detection of formalin is obtained by machine learning and a gas sensor (Brighty et al., 2021). However, since formalin is a colorless volatile liquid, detection by image processing should have been unrealistically difficult. In Antora et al. (2018), mango, litchi, and mushroom were treated with different concentrations of formaldehyde solutions, and the color, texture and weight loss were observed. It was observed from the research that formaldehyde does not improve post-harvest quality or shelf life (Antora et al., 2018). A variety of fruit, vegetable, milk, chicken, mutton, and meat samples were tested for naturally occurring formaldehyde (Nowshad et al., 2018). Not much work has been done on how effectively formaldehyde can improve the shelf life of fruits, even though the news of its application is circulating in the mass media in Bangladesh.

This research work demonstrated a systematic formalin detection process and measured the formalin application concentration on fruits. Formalin of different concentrations (20%, 30%, and 40%) was applied to apples. The longevity of the existence of formaldehyde was detected using an E-Nose (Datasheet4U, 2025; Baldwin et al., 2011). The validity of the readings at different stages has been ensured by the spectrophotometry and BCSIR KIT (Bangladesh Council of Scientific and Industrial Research, 2023).

Table 2
Nutrients that are present in a medium-sized apple (The Nutrition Source, 2024)

Components	In Medium Apple (in g)
Calories	95
Fat	0
Protein	1
Sugar	19

The research portrays a systematic approach to how formaldehyde can be tested and also validates that the E-Nose is a reliable and cheap method of detecting formaldehyde. Moreover, the decay period of formaldehyde has been deduced, and the hypothesis that formalin is not useful for increasing shelf life has been established. It is expected that the findings of the paper will provide actual information to researchers and consumers about the rumors surrounding formalin implementation.

MATERIALS AND METHODOLOGY

Chemical Test Kit for Formalin Detection

Figure 1. Bangladesh Council of Scientific and Industrial Research (BCSIR) kit for food formalin detection

In order to examine the existence of formalin, a Bangladesh Council of Scientific and Industrial Research (BCSIR) kit for food formalin detection was used (Islam et al., 2015). The kit comes with three different reagents, as shown in Figure 1. Fifteeen drops of each reagent are poured into the test sample, one by one. After reagent-1 is added, the solution should be stirred well and allowed to wait 30 seconds each time. The same test tube was then filled with 15 drops of reagent 2. The solution is left to stand for 30 seconds after being thoroughly stirred. Finally, the third reagent is added, stirring the solution for 30 seconds. Color changes can be observed during the process. After the third reagent is added, the color turns pinkish to reddish brown if the solution is contaminated with formaldehyde (Islam et al., 2015; Uddin et al., 2011). However, the sample does not contain formalin if the solution's color does not change.

Spectrophotometer GENESYS-10S

The GENESYS-10S Spectrophotometer was used in this experiment to measure the absorbance of light in samples of solution containing different concentrations of formaldehyde (Figure 2). Ultraviolet-visible (UV-Vis) spectroscopy is a method of measuring the amount of light that is absorbed and scattered by any material once placed inside a thermal spectrophotometer. The amount of light is called the extinction, the total of absorbed and scattered light. The most basic method involves placing a sample between a light source and a photodetector and measuring the light beam's intensity before and after it passes through the sample. These values are compared at each wavelength to quantify the wavelength-dependent extinction spectrum of the sample. Usually, the absorbance data is compared against wavelength. A 500–700 nm wavelength range is used for detecting formaldehyde (Nag et al., 2021). Each spectrum is background corrected using a blank, basically, a cuvette filled

with the dispersing medium to ensure that the sample spectrum does not contain solvent-related spectral characteristics (Instrument Center, 2018; Thermo Scientific, 2010). This experiment used a sample of distilled water and a test kiwereere as a reference dispersing medium.

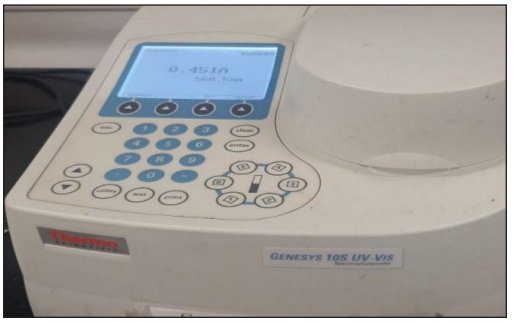

Figure 2. GENESYS-10S Spectrophotometer

Beer-Lambert's law can then be applied, which describes light intensity as it travels through a material containing chemicals that can absorb light (Nurjayadi et al., 2021). It states that A = εlc, where A is absorbance, ε is the molar extinction coefficient, c is the concentration, and l is the path length (Mäntele & Deniz, 2017). This formula can calculate the formaldehyde concentration using the absorbance values obtained from the GENESYS-10S Spectrophotometer.

Electronic Nose Sensor

The MS1100 Gas Sensor (E-nose) module is a semiconductor-type sensor used to detect the concentration of formaldehyde in a closed environment (Figure 3). It has a detection range of 0–1000 ppm for gas detection and can identify a variety of volatile organic compounds (VOCs), such as formaldehyde, toluene, benzene, and organic solvents (Thermo Scientific, 2010; Nurjayadi et al., 2021). This device can detect gases over 0.1 ppm and has high sensitivity and stability (Mäntele & Deniz, 2017). The output voltage obtained is proportional to the concentration of gas. The sensor finds its application in indoor air quality monitoring, environment monitoring, HVAC systems, smart homes and safety security systems.

Figure 3. MS1100 gas sensor

Sample Selection

Around 30 apples were collected from the local markets of Dhaka as test samples for this research. Uniformly ripe samples of the same type, free of any sort of deformation or bruises, were selected. This ensures that the naturally produced formalin will be at identical levels because its emission varies with color and breed (Nowshad et al., 2018).

Purity Test

It has been observed that MS1100 gave a reading of 40–47 ppm in room conditions. When the sensor is brought near an apple, the reading increases to a value ranging from 52–65 ppm, which agrees with the natural emission value (Brighty et al., 2021; Nowshad

et al., 2018). Purity tests on apples were performed using three different methods: (1) spectrophotometry, (2) formalin test kit, and (3) MS1100 gas sensor.

First, formalin was detected using the MS1100 sensor to see if the formaldehyde emission was more than natural. Then, the apples were placed in distilled water for 30 minutes, and 2.5 mL solutions were taken from them. The solution was added with the reagents from the test kit to observe the color change for formaldehyde detection. Third, the samples were tested with the spectrophotometer to determine the concentration.

Sample Preparation

First, three different concentrations (20%, 30%, 40%) of formaldehyde were prepared, as shown in Figure 4. Two apples were rinsed with the 20% formalin solution and kept dry.

The other apple was kept in distilled water for 10 minutes. The solution was preserved in a test tube for further testing with the Bangladesh Council of Scientific and Industrial Research (BCSIR) food formalin detection kit. This apple was dried and placed into another zipper bag (Figure 6). The process was repeated with three different concentrations (20%,

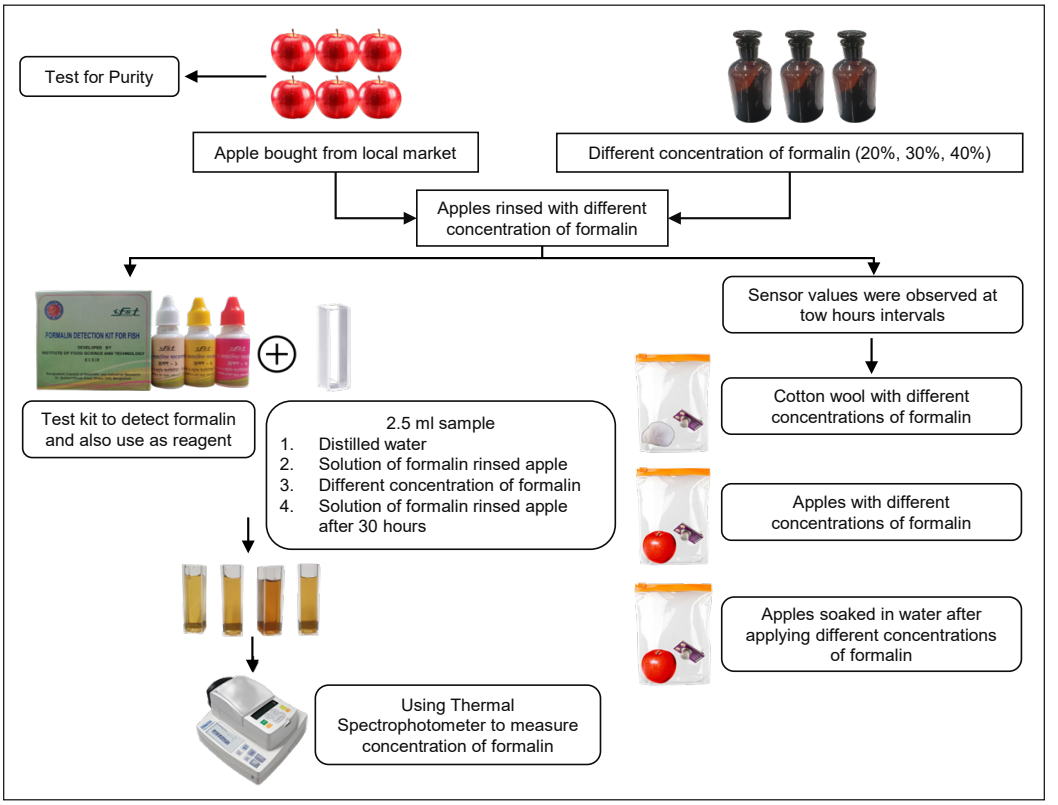

Figure 4. Methodology of the entire process, from the application of formalin on the apple to the detection One of the apples was placed inside a zipper bag to test with the E-nose sensor as a sample containing directly applied formalin, as shown in Figure 5

30%, and 40% of formalin) as shown in Figures 7 and 8. Two different apples were taken each time for different concentrations.

In order to facilitate the understanding of the methodology, we have labeled the solution samples in Table 3.

As mentioned in Table 3, we tested with 20%, 30% and 40% formalin solutions (4, 5 and 6). We also prepared solutions 1, 2, and 3, which are distilled water solutions used to soak apples that had already been rinsed with either solution 4, solution 5, or solution 6. All the solutions mentioned in Table 3 were tested with a BCSIR kit to examine the presence of formalin. The blank solution was tested with the kit to act as the control sample. The process involved collecting samples of 2.5 ml solutions and sequentially adding reagents 1, 2, and 3. At first, 15 drops of reagent 1 were poured into the solution and shaken for 30 seconds. Color changes were carefully noticed during the process. Sequentially, 15 drops of reagent 2 were added, and the solution was shaken for 30 seconds. Then, finally, 15 drops of reagent 3 were added, and the solution was shaken in the same manner. After the third reagent is added, the color change is observed to

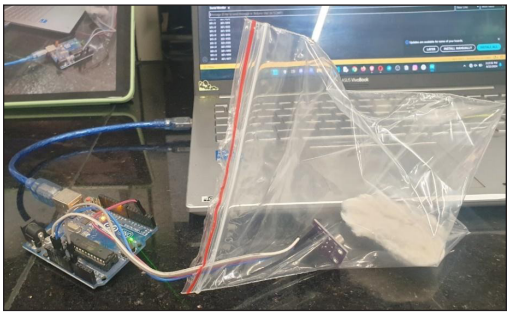

*Figure 5***.** Detection of formalin through MS1100

*Figure 6***.** Application of different concentrations of formalin on apples

Figure 7. Apple is placed inside a zipper bag

Figure 8. Application of BCSIR kit solutions on test solutions

Table 3
Analysis of constituent solutions and formalin-treated apple solutions

Solution Name	Constituent
Blank Solution	Distilled water
Solution 1	The solution from distilled water in which the 20% formalin rinsed apple was soaked
Solution 2	The solution from distilled water in which the 30% formalin rinsed apple was soaked
Solution 3	The solution from distilled water in which the 40% formalin rinsed apple was soaked
Solution 4	20% formalin solution
Solution 5	30% formalin solution
Solution 6	40% formalin solution

check if the solution was contaminated with formaldehyde. Noticeable color changes from pinkish to reddish brown were observed and noted. The color change confirms the presence of formalin.

Then, the spectrometer GENESYS-10S was used to detect the change in absorption and find out the concentration of formalin. For spectrophotometry, we require a reagent that will change the color of the solution upon reacting with formaldehyde. Thus, all the different solutions in which test kit reagents were previously added were applied to a spectrophotometer. Later on, changes in concentration of the formaldehyde were measured by using Beer-Lambert's law, $A= \varepsilon lc$, where A is absorbance, ε is the molar extinction coefficient, c is the concentration, and l is the path length. A wavelength of 568.5nm was used to measure the change in absorbance. Five samples were tested at a time.

In parallel to the spectrophotometric analysis, the apples that were kept in zipper bags were examined to observe the presence of formalin over a duration of 30 hours, as the readings stabilized after this period (Figure 9), so that a decay profile of the formalin can be observed. The data inputs were taken at every two-hour interval using the E-nose sensor. The sensor was kept on for 2 minutes to measure the input each time to reach a steady value, and the room condition readings were noted. After getting a stable reading, the zip of the zipper bag was opened slightly, and the sensor was kept inside the bag, near the apple, and new readings were recorded.

In addition to apples, cotton swabs containing soaked formalin samples of different concentrations (solutions 4, 5, and 6) were also placed in zipper bags. The sensor readings were noted for 30 hours. Eventually, decay graphs of formaldehyde were produced with the data collected.

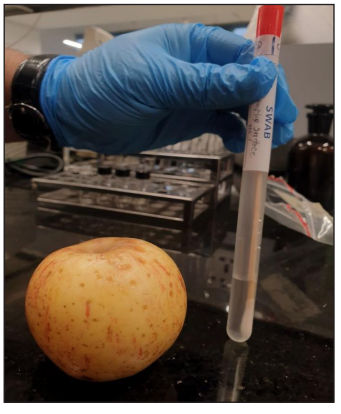

Figure 9. Apple samples were rinsed with different concentrations of formalin and rubbed with a cotton tester after 30 hours

As shown in Figure 9, the surface of the apples was rubbed with a cotton tester and dipped into 3 mL of distilled water to measure the existence of formaldehyde after 30 hours of storage. After 10 minutes, 2.5 mL samples were taken in a test tube, and the kit test was again performed. Another round of spectrophotometry was conducted with the same blank sample to get the absorbance and, eventually, the concentration.

RESULT AND ANALYSIS

Results Graphs Obtained from E-nose Sensor

As stated, the E-nose sensor reading in room conditions varied from 40 to 47 ppm, and the pure apple formaldehyde reading ranged from 6 to 23 ppm. So, at room conditions, in the presence of a pure apple, the readings are around 60–70 ppm. Figure 10 depicts how the reading of the MS-1100 sensor varied at regular time intervals when cotton swabs were soaked with formalin solution of different concentrations (solutions 4, 5, and 6). Results indicate that sensor values became constant after 18–20 hours in the three cases. In order to get a constant value, multiple readings were taken from the sensor until a constant value was reached. It takes around 2–3 minutes to reach a constant reading. A gradual decline in the sensor reading can be observed in each of the three cases. Cotton swabs with 20% formalin solution had readings gradually declining from 465 ppm to 315 ppm, whereas the readings decreased from 495 ppm to 345 ppm in the case of 30% formalin. Finally, as expected, the highest reading was observed in the case of 40% formalin, the variation being from 540 ppm to 412 ppm. The results clearly show that higher concentrations of formaldehyde solution lead to greater releases of formaldehyde gas, as detected by the

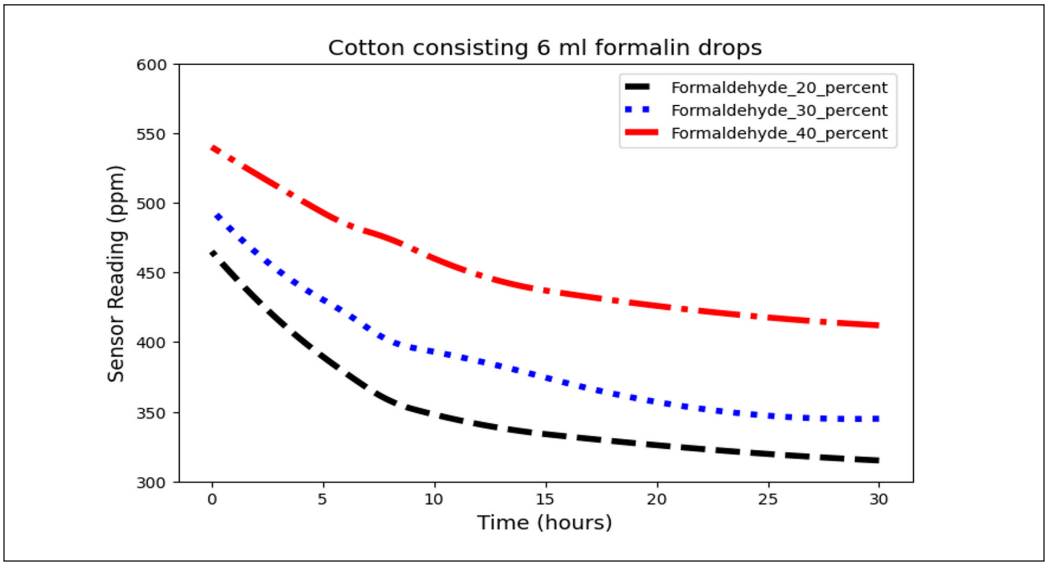

Figure 10. Sensor data from the E-nose sensor detecting formaldehyde in the cotton sample

sensor. This occurs because formaldehyde is a volatile organic compound (VOC), which easily evaporates from the solution and becomes a gas at normal temperatures (Li et al., 2023; Ali et al., 2020; Minnesota Department of Health, 2024).

Figure 11 shows how the readings of the E-nose sensor varied when apples rinsed with different concentrations of formalin (solutions 4, 5, and 6) were inserted in zipper bags. While the readings were taken every 2-hour intervals, the trend shows an exponential decline, becoming almost equal to room conditions at around 23–24 hours. This explains that formalin sprayed on a fruit like an apple stays on the surface level of the apple for a maximum period of 23–24 hours. The lower the concentration of formalin, the lower the time it takes for the reading to level off. Apples that contain formalin concentrations of 40%, 30% and 20% took around 23 hours, 20 hours, and 15 hours, respectively, highlighting the fact that higher concentrations of formalin usually level off at a faster rate, indicating a higher amount of release of formaldehyde gases. This data also means that it is impossible to detect the presence of formalin via sensors after 25 hours have elapsed, as the readings become very close to room condition values.

Figure 12 shows how the reading varied in the case of apples soaked in distilled water after rinsing with formalin solution (solutions 1, 2, and 3). This is done to imitate the fact that several shopkeepers soak formalin-adulterated apples in water for some time before selling them (Panghal et al., 2018). Graphs show the gradual decline and level off within 15 hours in all three different cases. After 30 hours, all the readings reached very close to the room condition readings. What can be noted is that the formalin level at the surface almost neutralizes to zero around 20 hours, thus invalidating the fact that formalin enhances shelf life.

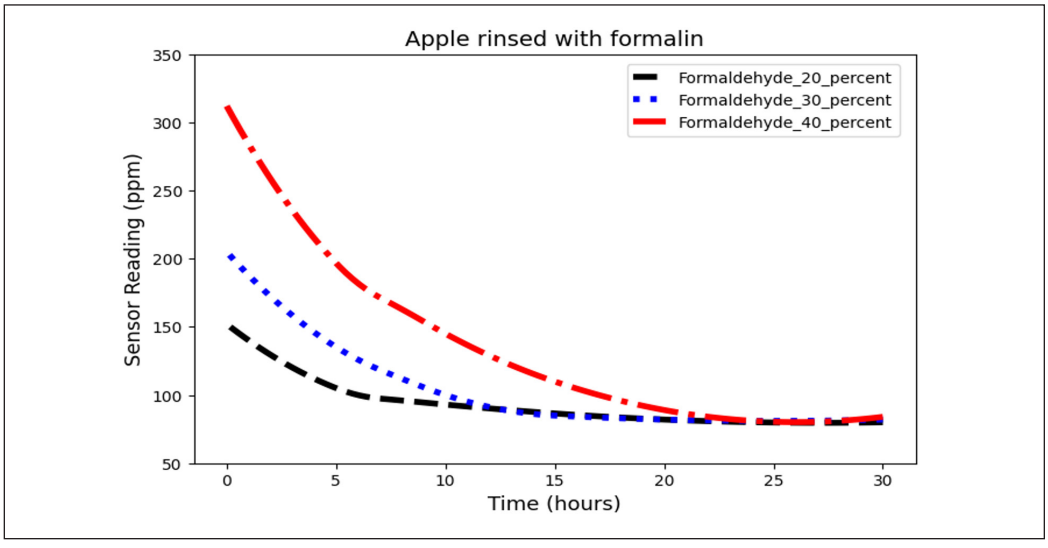

Figure 11. Sensor readings of the E-nose sensor when apples were rinsed with formalin

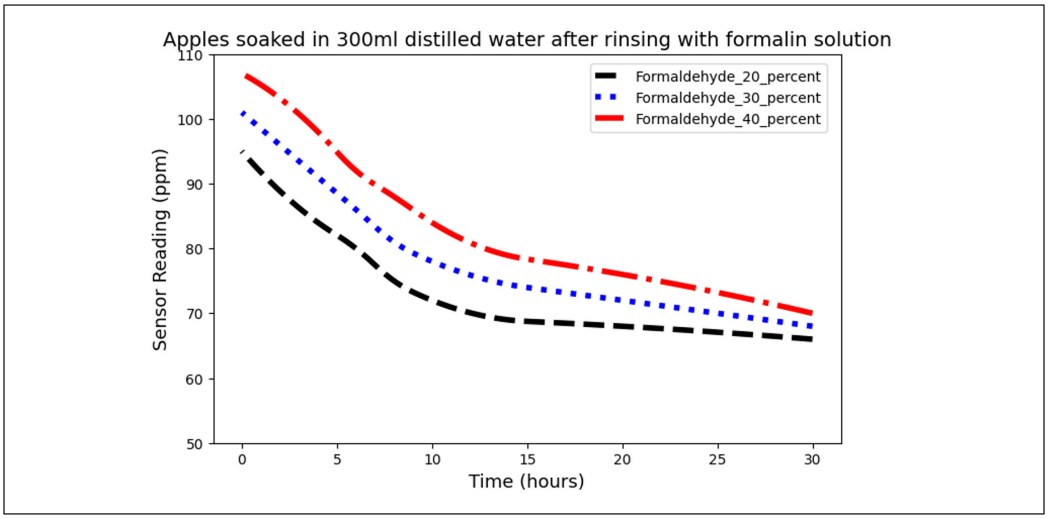

Figure 12. Sensor readings of the E-nose sensor for apples soaked in water after rinsing with formalin solution

Color Testing Reagent (BCSIR kit)

Figure 13 shows that the test kit from BCSIR showed slight color variance depending on the concentration of formalin present in the solution. The color observed varied from pale-yellowish to reddish-brown with increasing concentrations of formalin present in the solution, as shown in Table 4. As expected, the blank solution (distilled water) was pale yellow. A yellow solution

Figure 13. Different colors were observed when the test kit was applied to the solutions

Table 4
The color observed with the BCSIR kit

Solution Name	Constituent	Color Observed with BCSIR kit
Blank Solution	Distilled water	Pale-yellow
Solution 1	The solution from distilled water in which the 20% formalin-rinsed apple was soaked	Yellow
Solution 2	The solution from distilled water in which the 30% formalin-rinsed apple was soaked	Golden yellow
Solution 3	The solution from distilled water in which a 40% formalin-rinsed apple was soaked	Golden yellow
Solution 4	20% formalin solution	Deep golden yellow
Solution 5	30% formalin solution	Reddish brown
Solution 6	40% formalin Solution	Reddish brown

was observed in the case of solutions of distilled water in which a 20% formalin-rinsed apple was soaked (solution 1). A golden yellow color was observed in solutions of distilled water in which 30% and 40% formalin rinsed apples were soaked (solutions 2 and 3). Deep golden yellow and reddish brown color was observed for 20%, 30 %, and 40% concentration solutions of formalin (solutions 4, 5, and 6).

Concentration and Absorbance from Spectrophotometer

Thermal spectrophotometric measurements show an upward trend in absorbance value, highlighting the fact that higher concentrations of formalin result in higher values of absorbance, in accordance with Beer-Lambert's law, $A = \varepsilon lc$, where A is absorbance, ε is the molar extinction coefficient, c is the concentration, and l is the path length.

One factor that influences a sample's absorbance is its concentration. Since the amount of light absorbed depends on the number of molecules it interacts with, more radiation should be absorbed as the concentration rises. Hence, there is a direct proportionality between the concentration and absorbance, as shown in Table 5.

The concentration of the sample containing 20% formalin and distilled water was 38 M. The concentration value for 40% formalin and distilled water was 538 M. The sample consisting of 40% formalin had the highest absorbance and concentration values, 0.448 A and 17230 M, respectively.

As already mentioned above, spectrophotometry was also carried out with apples that were stored for 30 hours after being rinsed with solutions 1, 2, 3, 4, 5, and 6. The surface of the apple was rubbed with a cotton swab, and then the cotton swab was soaked in distilled water. The sample was then tested with the BCSIR kit and spectrophotometry. The results were very close to the results we got for the blank solution, indicating that the level of formalin on the surface has almost dropped to zero.

Table 5
Concentration and absorbance measurements from the spectrophotometer

Spectrophotometry Measurements	Spectrophotometer Absorbance Value at 568.5 nm	Concentration (M)
Distilled water	-0.006A	230.7692308
20% Formalin Apple + Distilled water	0.001A	38.46153846
30% Formalin Apple + Distilled water	0.004A	153.4615385
40% Formalin Apple + Distilled water	0.014A	538.4615385
20% Formalin	0.101A	3884.615385
30% Formalin	0.176A	6769.230769
40% Formalin	0.448A	17230.76923
Apples were rinsed with solutions 1–6 (stored for 30 hours) and rubbed with a cotton swab. Consequently, the swab was soaked in distilled water.	0.0053A-0.0059A	203.8461538-226.923076

Samples of Apples After 30 Hours

The samples were observed after 30 hours (Figure 14). The left column consists of apples to which no formalin was added, and the right column consists of apples to which artificial formalin was added.

Figure 14. Comparison of physical observations of untreated and formalin-treated apples after 30 hours

As we can see, the texture of the apples where formalin was added is more porous than those in which nothing was added. The skin texture also looks a bit dull. The dullness can be attributed to formaldehyde crosslinking cellulose, which weakens structural integrity and modifies pectin, leading to altered cell wall porosity (Altartouri et al., 2019; Marsh, 2008). Certainly, this does not make formalin-applied apples look fresher than non-applied apples, which agrees with the findings of Antora et al. (2018). Since, after 30 hours, the formalin level on the surface of apples almost declines to natural levels, formalin cannot achieve the desired or the speculated objective, that is, to increase the shelf life of apples. The findings align with those of previous studies conducted by Reza et al. (2023). From our investigation, we have observed that several studies have been conducted on detecting formalin with varied methods. However, little work has been done on how it generally affects the shelf life of apples or fruits.

The shelf life of fruits can be assessed using various methods that primarily focus on physical, chemical, microbiological, and sensory changes over time (Wertalik, 2024). Physical evaluation includes texture, color, and weight loss of the fruits. Chemical-based shelf life stability is attained by monitoring the nutrient degradation, sugar content and pH shifts. Microbiological assessments identify the spoilage organisms and pathogens, ensuring food safety. The sensory evaluation of fruit encompasses various attributes, including appearance, texture, taste, and aroma, which play a crucial role in consumer satisfaction (Lozano & Echeverria, 2022). Also, AI-driven tools have been used recently. In our research, we have employed chemical and sensory evaluation for formalin detection.

CONCLUSION

In this research, we have added formalin of three different concentrations (20%, 30%, 40%) to apples. The presence of formalin on the surface of the apples was studied using three different methods: (1) spectrophotometry, (2) a formalin test kit developed by the Bangladesh Council of Scientific and Industrial Research (BCSIR), and (3) an MS1100 gas sensor. Formalin's presence and concentration on the apple were detected using spectrophotometry and test kit detection. The MS1100 sensor can infer the formalin decay profile on the apple's surface.

Measurements with varying concentrations of formaldehyde applied to cotton showed significantly high emissions after 30 hours. However, in the case of apples rinsed with formalin for the same period, the readings revealed that the formalin level had dropped drastically to its natural state of 60–70 ppm. From the research, it can be stated that formalin does not improve the shelf life of apples and, in fact, it decreases the freshness of the fruit. Since formalin is able to preserve objects or bodies with higher protein content, the conclusion aligns with the theory, as apple has only 1% protein. In pursuit of concluding this observation, we have used three methods of formaldehyde detection. The methods include the MS1100 sensor working as an E-nose, the BCSIR test Kit, and spectrophotometry. It can be concluded that the results attained through the E-nose matched the results of the test kit and the spectrophotometry. These results confirm that the E-nose (MS1100) can detect formaldehyde effectively and effortlessly. Alternate typical detection methods include formaldehyde BCSIR kit, test strip, reagent paper, portable spectrophotometers, immunoassays, and fluorescence.

However, the drawbacks of these methods are that they require considerable time and are complex for consumers to use. In contrast, the E-nose offers a simple, easy-to-implement, reusable solution and fast detection time. However, using it to detect formaldehyde application on fruits will not work since the formaldehyde loses its existence after a few days. It will only detect the emission of naturally produced formaldehyde from the apple. Nevertheless, even though the apple stopped emitting formalin at a level above the natural level after 30 hours, the cotton wool kept on emitting formaldehyde. This indicates that formaldehyde reacts with apples somehow, which could be a topic for further research. The experiments also established that putting the apples for 30 minutes in water can significantly remove the presence of formaldehyde on apples.

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