

Non-invasive detection of adulterants in pulse grains using microwave signals

Prodyuti Sarkar¹, Rahul Mondal², Arijit Das², Avijit Swarnakar², Piyali Basak¹, Sushanta Sarkar², Partha Pratim Sarkar^{2*}

¹*School of bio science and engineering, Jadavpur University, Jadavpur, West Bengal, India.*

^{2*}*Department of Engineering & Technological Studies, University of Kalyani, Kalyani, West Bengal, India.*

Abstract—Foodborne diseases and food poisoning are open challenges to the society and the country's economy. Incorporating appropriate techniques for detecting any type of adulterant, contaminant, or impurity in food products prior to their marketing for sale is the first step to cope up with this problem. Several traditional physical, chemical and biochemical procedures were discovered time to time for detection of any foreign particle or contaminant present in food which can pose serious health risks. But their practical implementation anytime and anywhere is difficult due to lack of simplicity, cost-effectiveness, proper infrastructure in rural and semi-urban areas and the non-availability of trained experts to perform complex chemical assays and prediction of food quality with accuracy. Moreover, most of these methods are invasive in nature i.e., they require opening of food packages and taking out samples of food before testing. Food products may get deteriorated after packaging due to improper transportation/ packaging/ storage conditions. Therefore, these procedures are not helpful to check the condition/ quality of food after packaging. The experimental procedure demonstrated here aims at reducing these challenges experienced in these existing methods. Here, microwave signal in the electromagnetic spectrum is used for detection methods. A Frequency Selective Surface (FSS) was designed accordingly to selectively transmit incident microwave signal through it at a specific frequency range. Completely non-invasive detection was observed as the closed container (kept in contact with the FSS) containing pure as well as adulterated food grains reflect the residual signal after being absorbed by the food grains. The residual signal captured by the receiving antenna is recorded in the Vector Network Analyzer (VNA). The “Reflection Co-efficient (S11) Vs. Frequency” plot indicates significant shifts in peaks at resonant frequency due to the modification of the reflection as well as transmission co-efficient of the incident microwave signal because of different dielectric constants/ properties of pure and adulterated food. Hence, the presence of adulterants if present in food can be detected by simply analysing the plots in a non-invasive manner.

Keywords: Adulterants, FSS, permittivity, non-invasive method.

1. INTRODUCTION

Nearly 600 million people worldwide which accounts for roughly 1 in every 10 people, become sick after consuming contaminated food, and 420,000 people pass away each year, according to a World Health Organization (WHO) report on the estimates of the global burden of foodborne diseases published in

2015. With 125,000 deaths annually, children under the age of five account for 40% of the burden of foodborne illness. Foodborne diseases are more prevalent in Eastern and South-east Asian countries including India [1–3] due to lack of awareness among common people regarding food safety, casualty of the food businesses and unhygienic conditions of food production, processing, packaging, transportation and storage. Food Safety and Standards Authority of India (FSSAI) established by Food Safety and Standards (FSS) Act, 2006 has taken several initiatives to enhance food safety and to create awareness regarding food safety and hygiene [4]. Food testing laboratories and quality control laboratories set up by FSSAI provides testing facilities of food samples before marketing and sale [5–8]. But, most of the laboratories are confined to metropolitan cities and urban areas, they use traditional complex chemical assays for quality checking of food which are time-consuming and require expert food analysts. The main disadvantage regarding this is that detection of contaminated or spoilt food is not possible after packaging. Presently existing techniques do not have the advantage of predicting the presence of adulterants in food in packaged conditions. Moreover, food might get spoilt even after successfully passing through all steps of processing. Food articles, when stored in retail shops for sale undergo reduction in shelf-life automatically after some days. Shelf-life of food may get reduced at a faster rate due to improper storage condition or packaging in retail shops. In this case, even if the food articles may have undergone proper testing before marketing, food spoilage cannot be detected if it occurs in retail shops after packaging. Existing techniques of detection of food quality are invasive in nature i.e., they require testing of food samples outside the package. Therefore, the problem of detecting food spoilage after packaging still exists. Some physical methods of food quality analysis discovered so far uses sophisticated experimental procedures including spectrometry, DNA barcoding, Thin Layer Chromatography (TLC), nano- sensors, 2-D gel electrophoresis technique for protein profiling, Near-infrared (NIR) reflectance spectroscopy and chemometrics, Fourier transform infrared (FTIR) spectroscopy etc. Although some of these techniques are non-invasive in nature, these are undoubtedly very costly and not readily available anywhere and anytime [9–19]. Modern innovative and emerging technology has designed portable intelligent device for rapid screening of pulse quality [20], but its practical implementation and its success in industrial application is still under process. The electromagnetic spectrum, particularly the microwave portion of the spectrum, has been used in recent studies to identify food adulteration. Non-invasive methods of detection are provided by the procedures. In order to identify adulterants in food grains, metamaterial absorbers serve as sensors [21]. When stale rice makes up more than 20% (weight/weight) of pure rice, this method can identify it. Although the method is highly innovative, it has a complicated design process and a low precision rate. The most widely used modern methods that rely on measuring the dielectric characteristics of food and predicting its quality are microwave sensing technologies. Non-destructive evaluation of food quality is made

possible by monolithic microwave integrated circuits (MMIC), antenna arrays, System on Chip (SoC) Ultra-Wide Band (UWB) pulse-based time domain systems, and integration of new information and communication technologies (ICT) [22]. Although contactless measurement is made possible by these recently created revolutionary processes, there are still certain drawbacks and restrictions, such as low spatial resolution, challenges with calibration and decision-making, lengthy response times, system complexity, etc. The main motive of our research work is to minimize these challenges associated with currently existing techniques. In a previous research work in [23], a unique experimental setup was developed using pure unhusked rice grains as the food product and small stones/ pebbles and broken rice used as two different kind of adulterants. Very low quantity of adulterant such as 2% (weight/ weight) of total weight of pure rice grains if present, the system can detect it showing the high precision and accuracy of the experiment. In this research work, the same experimental setup mentioned in [23] is used and the experiment is performed with different types of food materials and different adulterants to check the versatility and the replicability of this novel procedure. As rice and pulses (dal) is the staple food in India and in most of the countries in south and south-east Asia, the food materials taken for this experiment are different types of unhusked split pulse grains. As consumed by all, pulse grains are often adulterated voluntarily by merchants and retailers with small stones/ pebbles (to increase the weight) while packaging for monetary benefit. Low-quality pulse grains like Khesari dal which is much cheaper in price than the high-quality pulse grains, widely consumed by people are also often mixed. Khesari dal (Grass pea) also known as *Lathyrus sativus*, is mainly used as a fodder crop and consumed by maximum poor people. It contains a neurotoxin called β -N-oxalyl-L, α , β -diamino propionic acid (β -ODAP) [24]. In the past, excessive consumption of khesari dal led to a disease called neurolathyrism, which causes paralysis in the lower limbs. The seed of this legume harbours this excitotoxic amino acid, held responsible for induction of spastic paraparesis (lathyrism) in those with heavy and prolonged dependence on grass pea as a dietary staple [25]. So, the detection of quality of packaged pulse grains before sale is very much essential. In this research work, three different types of unhusked split pulse grains are taken as pure food grains under test namely: (i) Arhar dal i.e., Pigeon pea (*Cajanus cajan*), (ii) Chola dal i.e., Chick pea (*Cicer arietinum*) and (iii) Matar dal i.e., Green pea (*Pisum sativum*). Two different types of adulterants namely: (i) Small stones/ pebbles and (ii) A low-quality pulse grain, Khesari dal i.e., Grass pea (*Lathyrus sativus*) is mixed separately with each of these three types of pulses and separate experimental measurements are taken. Significant modification in “Reflection coefficient (S11) Vs. Frequency” curve is noticed in presence of adulterants and while increasing the percentage of adulterants. From this modification, quality and quantity of adulterants mixed with pure pulse grains can be predetermined in packaging condition.

2. PRINCIPLE OF THE EXPERIMENT

There is a specific value of dielectric constant of a material due to which the material possesses a particular reflection/ absorption characteristic at a given frequency range when microwave signal is incident on it. The reflection as well as absorption characteristics of a material get modified due to change in its dielectric property and this change is very prominent in the microwave range of the electromagnetic spectrum. This property is exploited to detect adulterants in pulse grains. The dielectric property of pure pulse grains changes when small stones or low-quality pulse grains are mixed as adulterants, thereby changing the resonant frequency in the “Reflection Co-efficient (S11) Vs. Frequency” plot. By successively increasing the percentage of adulterants with respect to the pure pulse grains, there is a successive shift in the resonant frequency which is used to determine the quantity of adulterants present in the pure pulse grains.

3. DESIGN OF THE FSS AND SIMULATED RESULT

The Frequency Selective Surface (FSS) used in this experiment contains two-dimensional periodic metal patches on a dielectric substrate. It is designed using the CST microwave studio software's electromagnetic simulator and is fabricated using the PCB etching method. Low cost FR4 is used as dielectric substrate. The patch of the FSS comprises of a square metallic ring with eight square slots and a square patch at the centre of the unit cell. The unit cell of the FSS and the fabricated prototype of the FSS is shown in Fig. 1. The FSS is designed such that it will pass around 6 GHz to 7 GHz microwave signal through it when it is without load. The simulated Reflection Co-efficient of the FSS and empty box (without load) is plotted in Fig. 2. The box containing pulse grains is kept on top of the FSS (placed on the horizontal discontinuous wooden platform) in contact with it i.e., the FSS is placed between the wooden platform and the box. The platform holds the FSS and above the FSS the box is kept. The box lid is covered with metal sheet to prevent transmission of microwave signal outside the box. The composite structure will pass the microwave signal in the frequency range 5 GHz to 6 GHz due to loading effect on the FSS. The microwave signal is incident through the FSS into the box containing the pulse grains and is reflected back by the lid. After multiple reflections within the box, a part of the residual signal is captured by the receiving antenna.

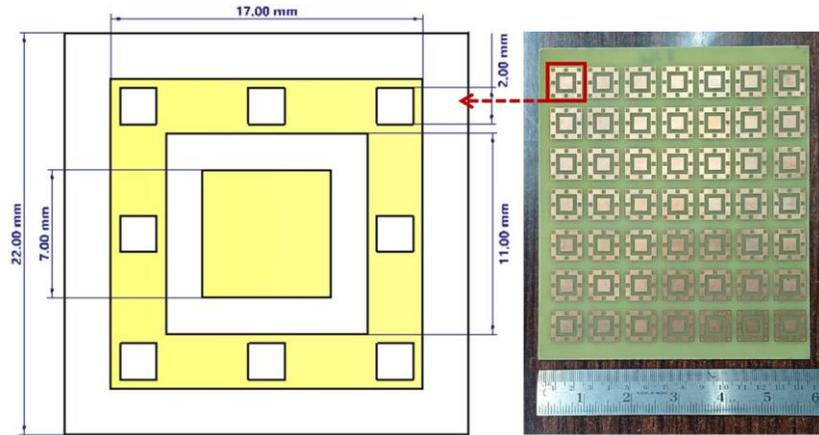


Fig. 1 Design of the FSS Prototype

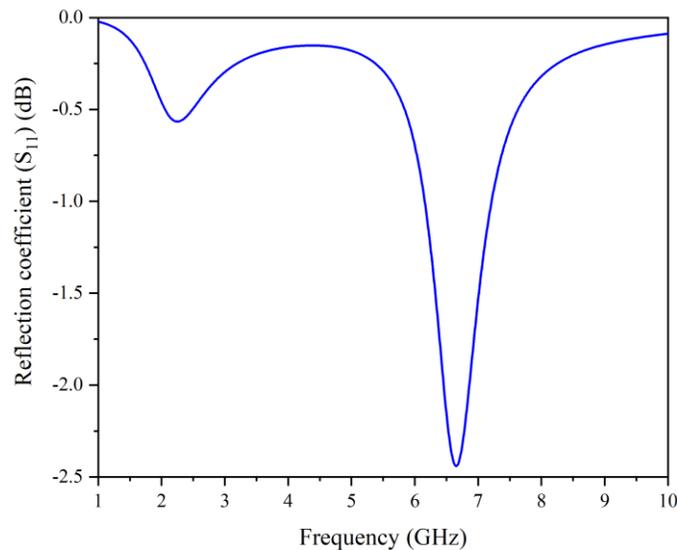


Fig. 2 Simulated Result: Characteristic curve of the composite structure containing FSS and empty box.

4. EXPERIMENTAL SET UP

The experiment is prepared with a unique arrangement. This particular experimental set up was also used in the experimental work which was published in the research paper [23]. The image of the experimental set up is shown in Fig. 3. Two vertical wooden stands that are 56 cm tall and 20.5 cm apart are constructed with a wooden base connecting them at the bottom. Each of the stands is attached to a narrow, horizontal wooden platform that is adjustable to any height using screws. The wooden platform is not continuous. A gap of 12.8 cm is left between the two horizontal wooden platforms set at same height when they are bolted to the vertical wooden stands. By using movable clamps, the platforms may support the FSS and the box filled with pulse grains at any desired height. Two sockets at the wooden base beneath the platform hold the transmitting and receiving antennae. The gap between the two wooden

platforms is kept so that the incident microwave signal from the transmitting antenna can pass through the gap, reach the FSS and the box, and then be reflected back to the receiving antenna from the box.

4.1 Vector Network Analyzer (VNA) (R&S ZNB20)

The experiment uses a Vector Network Analyzer (VNA) device to record the reflection coefficient (S_{11}) of the reflected microwave signal from the pulse grain sample stored inside the box. The microwave signal has a power range of -10 dBm to 10 dBm and a frequency range of 0.1 GHz to 20 GHz. Figure 4 displays a screenshot of the VNA.

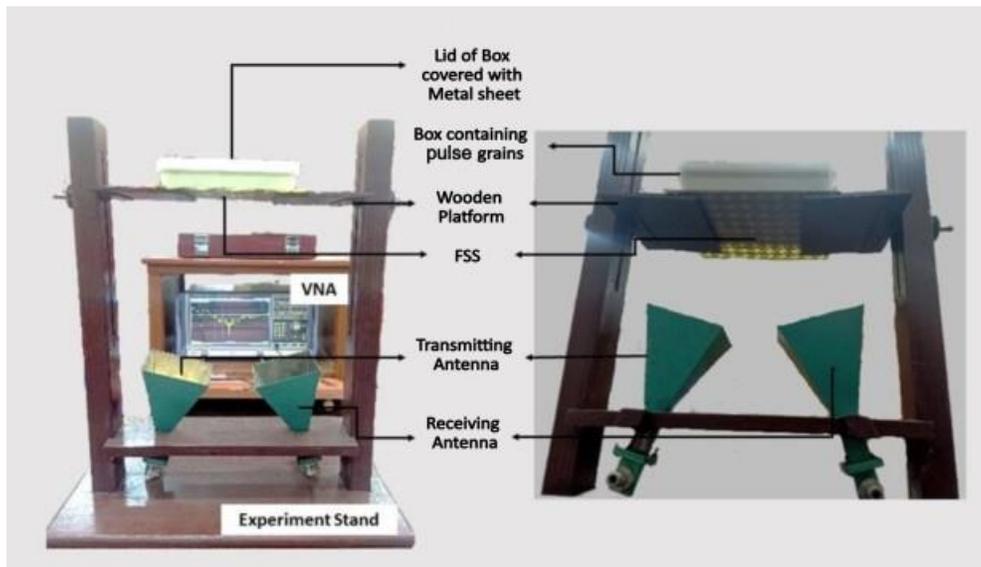


Fig. 3 Entire Experimental Set-up (2 different views).

4.2 Transmitting antenna and Receiving antenna

The VNA equipment is connected to two antennae that span the frequency range of 6 GHz to 12 GHz, as depicted in Fig. 5. One of them serves as a transmitting antenna, sending the microwave signal via the FSS to the pulse grain sample, and the other serves as receiving antenna, capturing the signal once the sample reflects it back. The two antennae are spaced 25.5 cm apart in order to keep the reflected and transmitted signals separated.



Fig. 4 Vector Network Analyzer (VNA) (R&S ZNB20).



Fig. 5 Transmitting antenna and Receiving antenna.

4.3 Specially designed box containing pulse grains

A thin plastic box (as shown in Fig. 6(a)) of dimensions $17.8 \text{ cm} \times 14.2 \text{ cm} \times 3.3 \text{ cm}$ is set up above the FSS that is positioned between the two platforms. 500 grams of weight of specific pulse grains are filled inside the box up to its maximum capacity. To prevent the microwave signal from leaving the box, a metal sheet covers the upper portion of the lid (as shown in Fig. 6(b) and 6(c)).

4.4 Pulse grains and Adulterants

Three different types of unhusked split pulse grains of high quality are used for the experiment as the main food articles: (i) Arhar dal, (ii) Chola dal and (iii) Matar dal. Two different types of adulterants are used: (i) Low quality pulse grains (Khesari dal) and (ii) Small stones/ pebbles. Each type of pure pulse grains is mixed with specific proportions of each type of adulterants, thereby creating six different experimental measurements which are performed by taking all different combinations of pure pulse grains

and adulterants. Figure 7(a), 7(b) and 7(c) display the images of all three different types of unhusked pure split pulse grains. Figure 8(a) and 8(b) display the images of the two different types of adulterants. Figure 8(c) displays small stones and pebbles mixed with pure pulse grains.

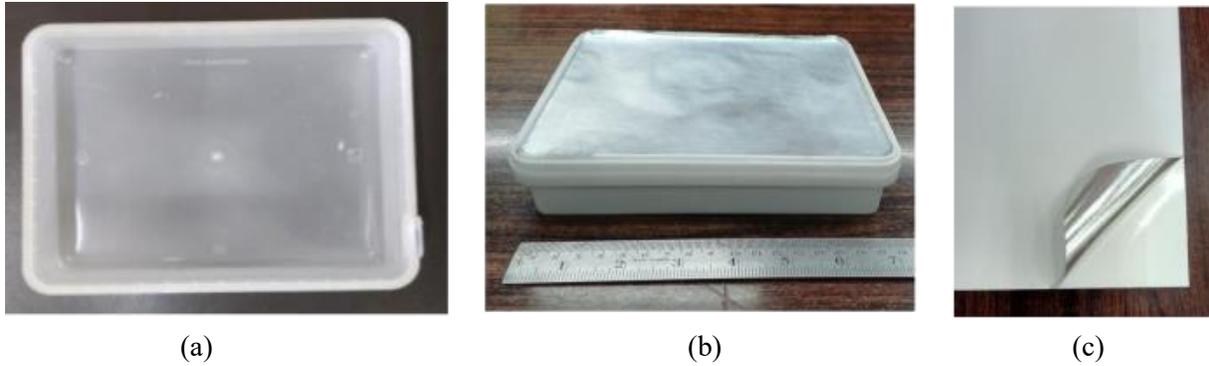


Fig. 6 Specially designed box: (a) without lid, (b) with lid and (c) Metal sheet coated on the lid of the box.

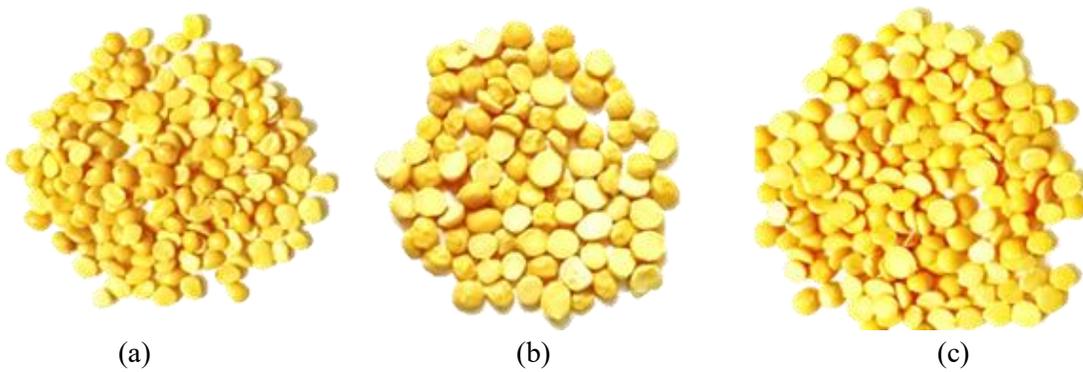


Fig. 7 (a) Arhar dal, (b) Chola dal and (c) Matar dal.

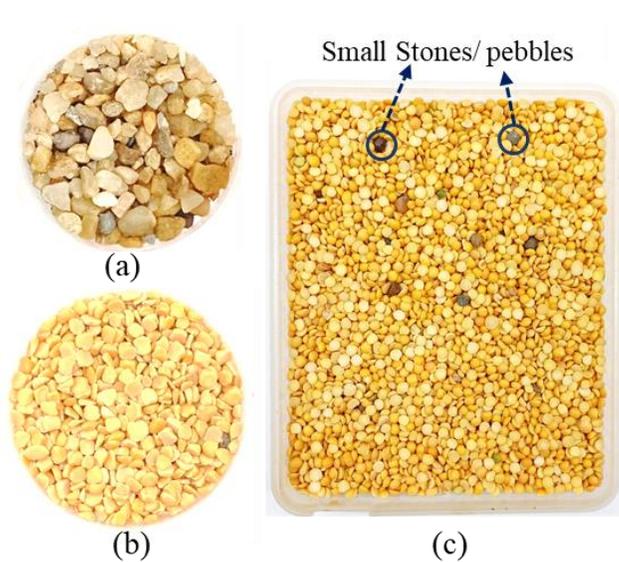


Fig. 8 (a) Small stones/ pebbles used as adulterant, (b) Khesari dal used as adulterant and (c) Small stones/ pebbles mixed as adulterant in pure pulse grains.

5. PROCEDURE

One by one, the empty box, the box filled with pure high quality pulse grains, and the box filled with adulterated pulse grains are used in the experiment. The presence of impurities or adulterants alters the dielectric constant or property of the pure pulse grains, which in turn alters the reflection rate and resonant frequency and changes the “Reflection co-efficient (S11) vs. Frequency” plot. The whole experimental process commenced with a pure high quality pulse grain sample taken in the container, the lid is closed tightly and then the reflection co-efficient (S11) is recorded in the VNA. Similarly, adulterants of specific percentages are weighed and mixed with pure pulse grain sample and the data of reflection co-efficient (S11) with respect to different percentage of adulterants are recorded.

6. RESULTS OF THE EXPERIMENT

In this experiment, three types of different pure pulse grain samples (Arhar dal, Chola dal and Matar dal) and two different types of adulterants are used. At first, 500 grams of a specific type of pure pulse grain is taken and the reflection co-efficients are recorded for the pure pulse grain samples of Arhar dal, Chola dal and Matar dal. Then, 2% (weight/ weight) of small stones and pebbles are mixed homogeneously as adulterants with respect to the total weight of the pure pulse grain sample and the experimental data is recorded. The Reflection Co-efficient (S11) (dB) Vs. Frequency (GHz) plot by increasing the percentage of stones/ pebbles as adulterant in pure Arhar dal is shown in Fig.9(a). Successively, the percentage of stones/ pebbles is increased from 2% to 10% with consecutive increment of 2%, thereby five consecutive data points of resonant frequency are plotted in Fig.9(b) with respect to percentage of adulterant for better understanding. Similarly, Reflection Co-efficients and resonant frequencies of pure Chola dal and Matar dal along with by increasing the percentage of stones/ pebbles as adulterant are shown in Fig. 10(a,b) and Fig. 11(a,b), respectively.

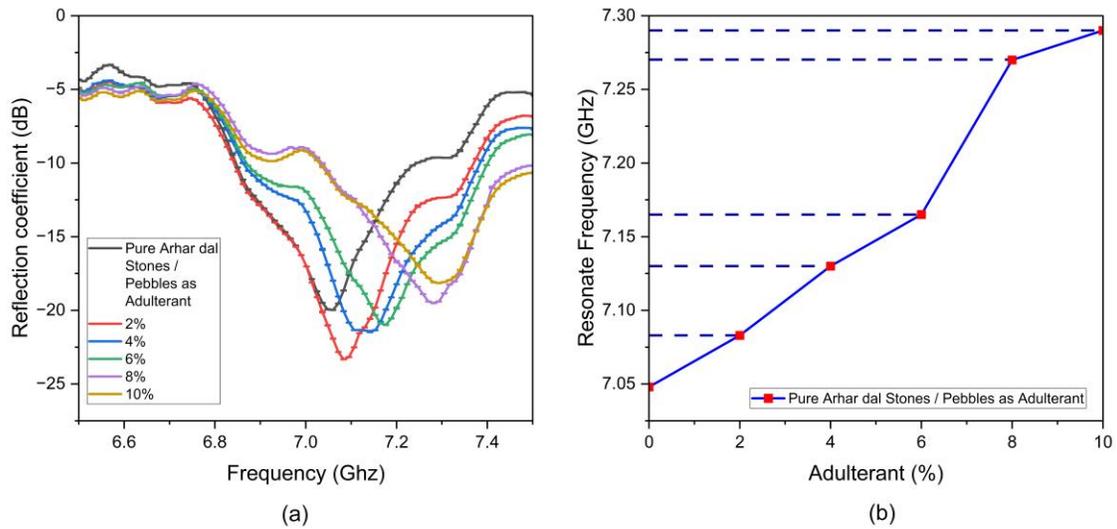


Fig. 9 (a) Reflection Co-efficient Vs. Frequency plot by increasing the percentage of stones/ pebbles as adulterant in pure Arhar dal, (b) Resonant Frequency Vs. Percentage of adulterant plot with respect to pure Arhar dal.

Table- 1: P-values and SD of the plot shown in Figure 9(a)

	Pure Arhar Dal	Percentages of Adulterants (Small stones)				
		2%	4%	6%	8%	10%
P-value	0.999	0.998	0.999	0.997	0.998	0.997
SD	4.929	5.626	5.376	5.091	4.668	4.175

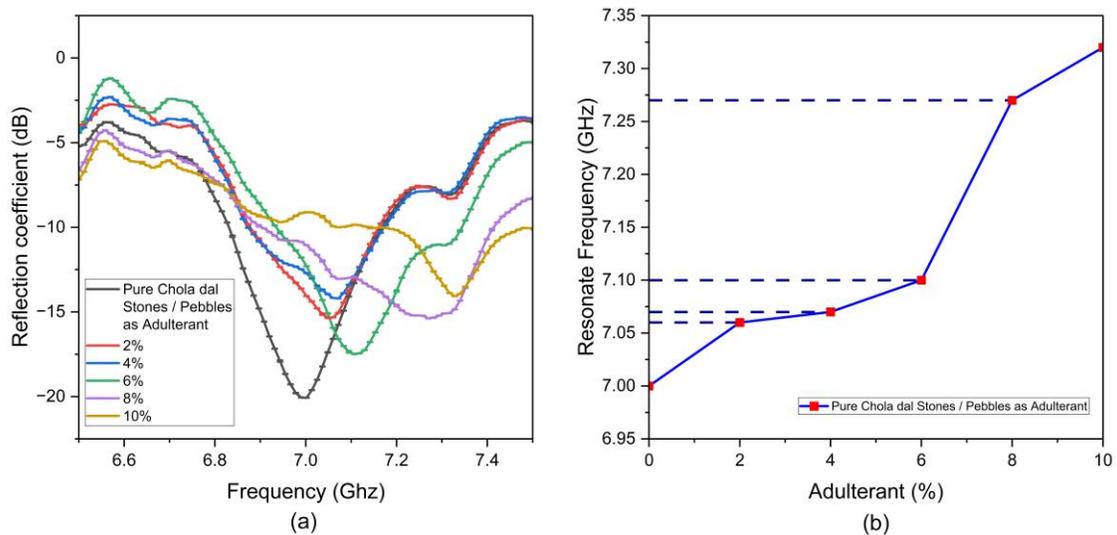


Fig. 10 (a) Reflection Co-efficient Vs. Frequency plot by increasing the percentage of stones/ pebbles as adulterant in pure Chola dal, (b) Resonant Frequency Vs. Percentage of adulterant plot with respect to pure Chola dal.

Table- 2: P-values and SD of the plot shown in Figure 10(a)

	Pure Chola Dal	Percentages of Adulterants (Small stones)				
		2%	4%	6%	8%	10%
P-value	0.999	0.998	0.999	0.996	0.998	0.996
SD	5.022	3.931	3.739	4.926	3.505	2.330

Similar experiments are done with these three types of pulse grains and using a low- quality pulse grain (Khesari dal) as the adulterant. The reflection co-efficient (S11) with respect to different frequencies is recorded. Since pure pulse grains have specific dielectric constant values and the box containing the adulterated pulse grains is kept in direct contact with the FSS, the rate of absorption as well as reflection of microwave signal by the FSS is expected to vary which is evident from the recorded reflection co-efficient. The Reflection co-efficients (S11) are examined for variation and deviation in relation to the quality and quantity of adulterants. Reflection Co-efficients and resonant frequencies of pure Arhar dal, pure Chola dal and Matar dal along with by increasing the percentage of Khesari dal as adulterant are shown in Fig. 12(a,b), Fig. 13(a,b) and Fig. 14(a,b), respectively.

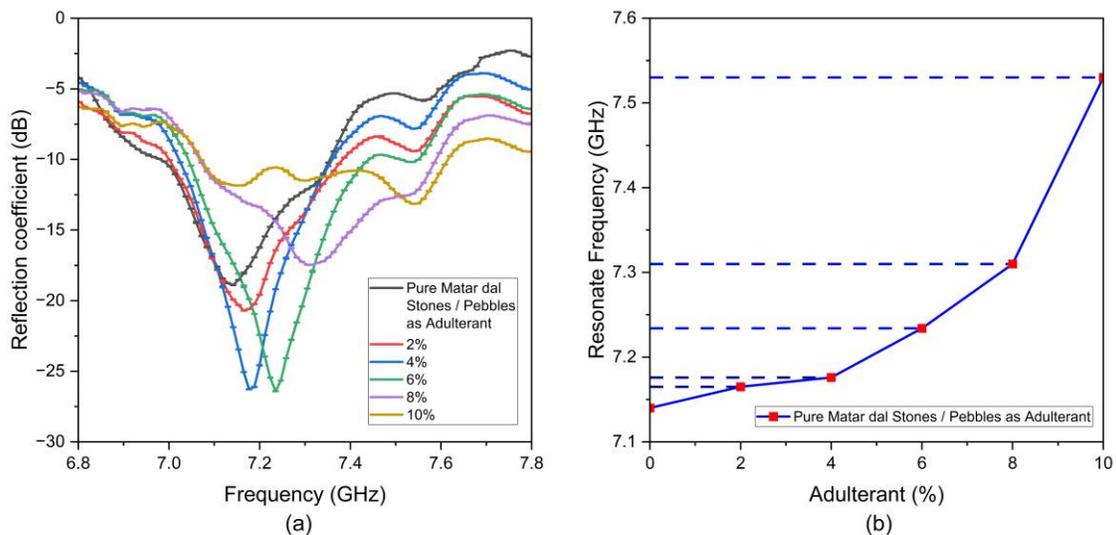


Fig. 11 (a) Reflection Co-efficient Vs. Frequency plot by increasing the percentage of stones/ pebbles as adulterant in pure Matar dal, (b) Resonant Frequency Vs. Percentage of adulterant plot with respect to pure Matar dal.

Table- 3: P-values and SD of the plot shown in Figure 11(a)

	Pure Matar Dal	Percentages of Adulterants (Small stones)				
		2%	4%	6%	8%	10%
P-value	0.999	0.997	0.998	0.998	0.999	0.996
SD	4.896	4.452	6.049	5.924	3.838	1.933

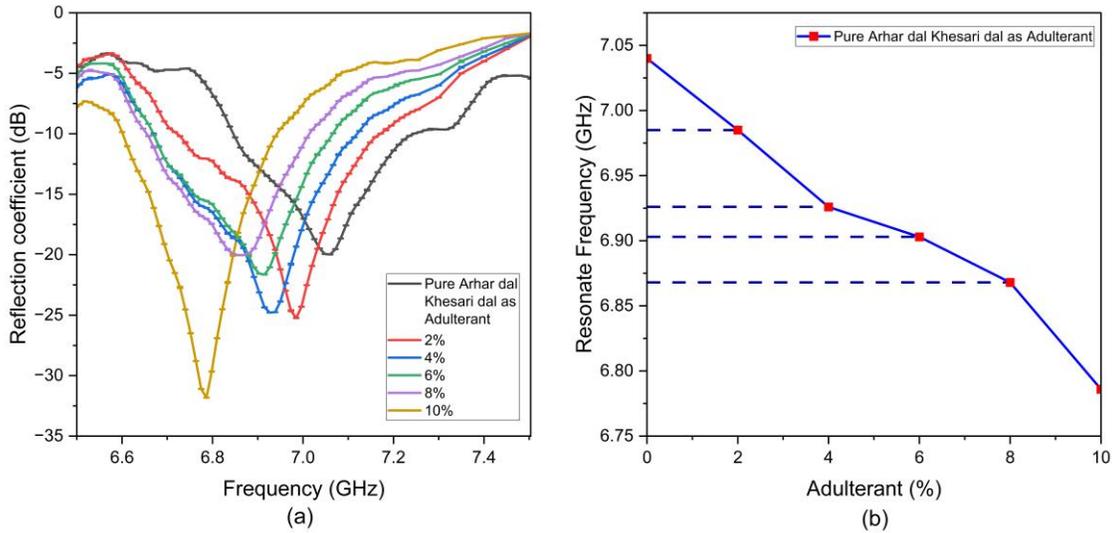


Fig. 12 (a) Reflection Co-efficient Vs. Frequency plot by increasing the percentage of Khesari dal as adulterant in pure Arhar dal, (b) Resonant Frequency Vs. Percentage of adulterant plot with respect to pure Arhar dal.

Table- 4: P-values and SD of the plot shown in Figure 12(a)

	Pure Arhar Dal Khesari	Percentages of Adulterants (Small stones)				
		2%	4%	6%	8%	10%
P-value	0.999	0.998	0.997	0.999	0.999	0.999
SD	4.930	5.965	6.109	5.605	5.462	8.022

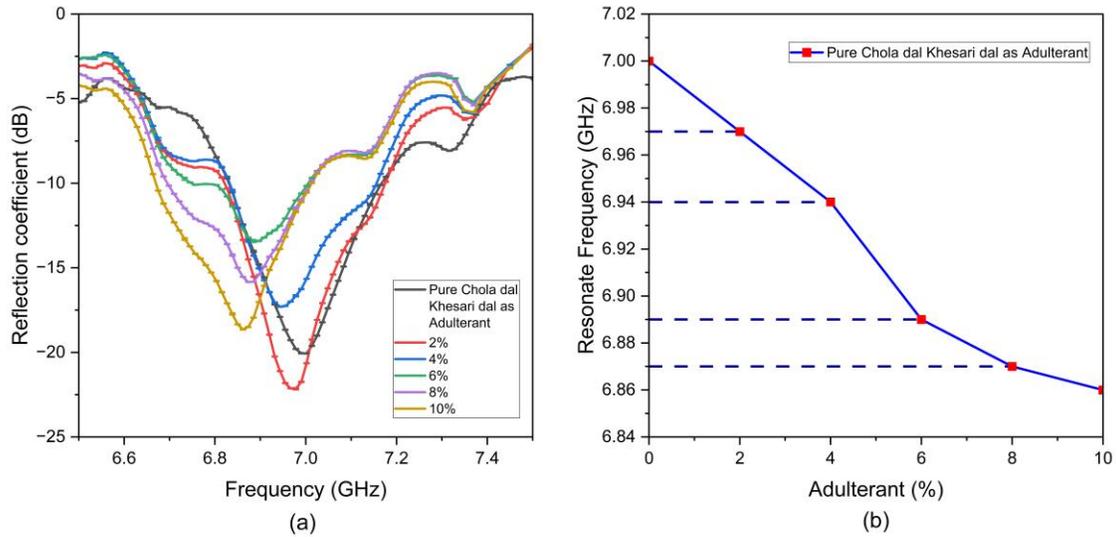


Fig. 13 (a) Reflection Co-efficient Vs. Frequency plot by increasing the percentage of Khesari dal as adulterant in pure Chola dal, (b) Resonant Frequency Vs. Percentage of adulterant plot with respect to pure Chola dal.

Table- 5: P-values and SD of the plot shown in Figure 13(a)

	Pure Chola Dal Khesari	Percentages of Adulterants (Small stones)				
		2%	4%	6%	8%	10%
P-value	0.999	0.998	0.998	0.998	0.998	0.998
SD	5.022	5.646	4.524	3.473	4.007	4.647

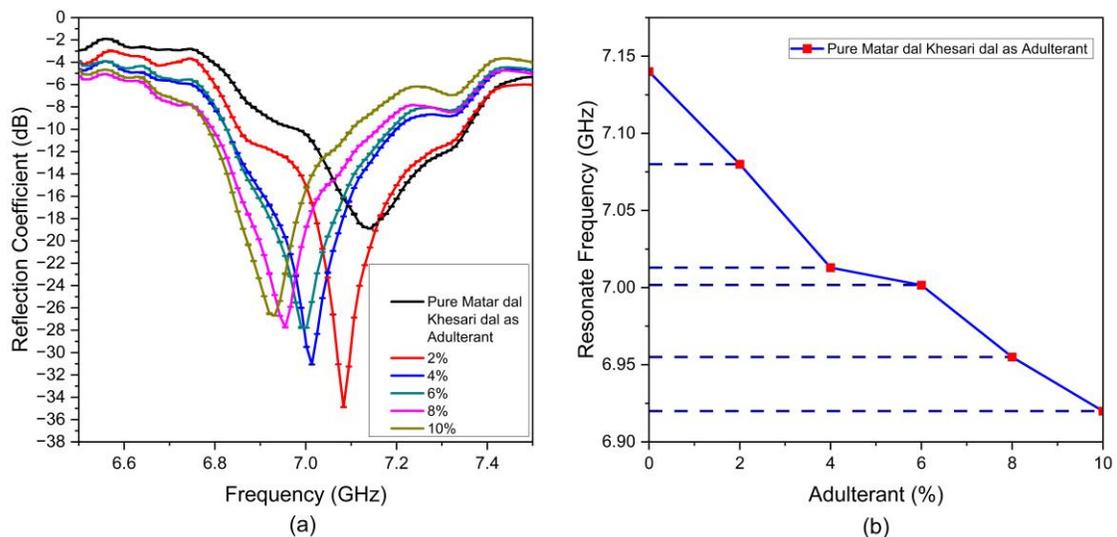


Fig. 14 (a) Reflection Co-efficient Vs. Frequency plot by increasing the percentage of Khesari dal as adulterant in pure Matar dal, (b) Resonant Frequency Vs. Percentage of adulterant plot with respect to pure Matar dal.

Table- 6: P-values and SD of the plot shown in Figure 14(a)

	Pure Matar Dal Khesari	Percentages of Adulterants (Small stones)				
		2%	4%	6%	8%	10%
P-value	0.989	0.999	0.999	0.996	0.999	0.998
SD	5.231	7.221	6.637	6.338	5.835	6.027

7. ANALYSIS AND DISCUSSION

For any thin Frequency Selective Surface (FSS), let the resonant frequency is f_r . If it is loaded with some material, the new or modified resonant frequency will be [26]

$$f_r^{new} = \frac{f_r}{\sqrt{\frac{\epsilon_r + 1}{2}}}$$

where, ϵ_r = Effective dielectric constant of the loaded material.

As Arhar dal, Chola dal and Matar dal each has dielectric constant much more than 1, due to loading effect of the pulse (dal) grains, the f_{new} will be decreased. Now, when stones/ pebbles are added with three types of pure pulse grains, effective dielectric constant, ϵ_r will be less than the dielectric constants of the pure pulse grains as dielectric constant of stones is much less than pulse grains [27]. So, resonant frequency of adulterated pulse grains with stones will decrease as of pure pulses. Khesari dal has dielectric constant slightly greater than pure Arhar, Chola and Matar dal [28–30]. So, when Khesari dal is added as an adulterant with these three types of pure pulse grains, effective dielectric constant, ϵ_r of adulterated dal with Khesari dal as the adulterant will be increased. As a result, the resonant frequency of adulterated dal will increase as of pure pulse grains.

STATISTICAL ANALYSIS OF P-VALUES AND ITS SIGNIFICANCE IN DETERMINING THE PRECISION RATE OF MEASURED DATA

Same electromagnetic radiation is incident on the total surface area of the box containing food grains in each and every case. During every experiment, the box has been placed on the same surface area marked by pencil on the horizontal wooden platform and the transmitting and receiving antennae have been fixed in the same positions. The weight of the food grains as well as the specific adulterants is also same each time. Therefore, even after reloading and remixing the respective food grains and adulterants while repeating the experiments, there will not be any significant modification in the respective recorded Reflection Co-efficient (S_{11}) at the same frequency range.

Accordingly, our hypothesis is that there is no difference between the measured mean data and the maximum deviated data from the mean. Hence, if deviation is minimum, P-value (the probability of occurrence of the measured data within the same chosen range) will be maximum i.e., close to the value of 1. If deviation is maximum, P-value will be minimum i.e., close to the value of 0 [31,32].

In the results shown above, all the respective P-values of the measured data are shown in the respective tables. In all cases, the P-value is greater than 0.99 i.e., close to the value of 1. At 0.05 (5%) significance level, or even at 0.01 (1%) significance level, it is clear that the two data sets (the mean data set and the maximum deviated data set) are not random in nature. In other words, if the significance level is set as 0.01 (1%), it means that the probability of the measured data to lie in the same range is more than 99%. Therefore, the two data set are almost similar. Acceptance of low deviation and rejection of randomness is proved here.

8. CONCLUSION

This method successfully detects adulterants in trace amounts in pulse grains by analysing the change in resonant frequencies while sending a microwave signal through materials with different dielectric properties. As a result, the innovative experimental setup and process described in [23] work well for solid food ingredients other than rice. This method accurately detects adulterants such as tiny stones/pebbles and low-quality Khesari dal (cheaper in price) that are present in trace amounts in high-quality pure pulse grains with a high degree of precision. Thus, the effectiveness of this approach and its benefit over earlier approaches are once more shown. It prevents food loss by offering non-invasive food quality detection without opening the food packet. Once the resonant frequency range at which the prominent result is obtained is known, anyone can easily determine the amount of adulterant, contaminant, or impurity in food by evaluating the rise, fall, or shift in peaks at a specific range of frequency and comparing with previous experimental results. Expert food analysts are not needed for this process. The experiment's accuracy and precision can be increased by changing, enlarging, or narrowing the permitted frequency range of a microwave signal traveling through a frequency selective surface (FSS). Other solid foods and a wide variety of adulterants can also be processed using this method. It is even possible to conduct an experiment to find contaminants in drinking water or liquid food. In addition to food, this technique can be investigated for qualitative and quantitative examination of mixture constituents in industries, medical facilities, and diagnostic labs.

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