# Pearson Correlation and Multiple Correlation Analyses of the Animal Fat S-Parameter

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***Abstract*** **– In specialised food products, the detection and identification of various sources of oils and fats are essential. Consumers are concerned about the adulteration of vegetable oils to avoid health problems and the risk of developing heart disease. There were a few cases where less expensive animal fat, in particular pork fat, was found in halal meals. The limitations of conventional methods for detecting pork in other meats can be overcome with the use of non-destructive methods. This study reveals the feasibility of using the microwave non-destructive testing method to identify animal fats. In the frequency between 8 GHz and 12 GHz, the microwave non-destructive testing method was used to obtain the S-parameters of the chicken, beef, and pork fats in the form of raw, baked, and oil. Single and multiple correlation analyses were then performed to identify the relationship between the animal fats and to differentiate them. The results of the Pearson correlation analysis show that for all animal fats, both raw and baked fat had a higher correlation value, which indicated they have the same or similar features.**

**The different correlation values obtained from the multiple correlation analysis demonstrated that animal fats have distinct features, regardless of whether they are raw, baked, or liquid forms. The multiple correlation analysis is a more suitable technique to detect animal fats compared to the Pearson correlation analysis.**

***Keywords*** **– MNDT, microwave, animal fat, Pearson's correlation, correlation, multiple correlations.**

DOI: 10.18421/TEM131-15
https://doi.org/10.18421/TEM131-15

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*Received: 09 August 2023.*
*Revised: 05 December 2023.*
*Accepted: 14 December 2023.*
*Published: 27 February 2024.*



## 1. Introduction

According to data from the Organisation for Economic Co-operation and Development-Food and Agriculture Organization of the United Nations (OECD-FAO) database, global per capita meat consumption rose from 29.5 kg in 2000 to 34 kg in 2019 [1]. The increase has been driven by economic growth, urbanization, and consumer preference. The rise in animal-based product demand has led to widespread pork adulteration in beef products for greater profit margins. Confirming the quality and purity of meat products before consumption is critical for health and religious requirements.

For Muslims, acquiring halal food is an important requirement. Therefore, authentication and verification of halal food sources are needed. Halal food pertains to food that is allowed or permissible in accordance with Islamic law. Some non-Muslims prefer cuisine without pork for health reasons [2], [3], [4], while other religions such as Hinduism and Judaism prohibit pork meat consumption [5]. The world halal market is expected to reach 2.2 billion in 2030 to serve approximately one billion Muslims in the world's population in more than 100 countries [6].

Besides that, one of the world's largest consumer markets is halal foods. Furthermore, one of the largest consumer markets globally centers around halal foods. It is estimated that the halal food industry will significantly increase reaching USD 6.4 trillion by 2030 from USD 3 trillion in 2013 [7].

There are many cases of adulteration in halal foods for example, in Malaysia pig DNA had been discovered in Cadbury's products [8], [9]. Various methods were employed in halal food and product detection which include Fourier Transform Infrared Spectroscopy, hydroxyproline analysis tool, real-time polymerase chain reaction (PCR), and others [10], [11], [12], [13], [14]. However, the approaches require combining the sample with a chemical solution to change its condition which causes the sample to be destroyed. There is a non-destructive method, but it relies on human identification, as reported by several studies [15]. The use of artificial intelligence in a non-destructive method can overcome the limitations of the conventional method [16], [17].

One of the food characterization methods that gain popularity recently is microwave nondestructive testing (MNDT). It is a method for evaluating a sample's S-parameter. MNDT employs a non-invasive approach that leaves the sample unchanged and measures it directly. MNDT is widely utilized for material testing that encompasses the development of sensors, probes, procedures, and calibration techniques for employing microwaves to find defects, fractures, and moisture content [18]. The approach has been thoroughly studied in other fields, like civil engineering, where much of the research has centered on concrete [19], [20]. Researchers in the field of food technology have used MNDT to identify fruit states and assess their freshness [21]. In other studies, liquids like oil and animal fats have been characterized using the MNDT [22], [23]. In the MNDT analysis of animal fats, the researchers look at the S-parameters of the raw and baked fats without using correlation analysis [23].

The Pearson correlation coefficient is among the most frequently utilized metrics for evaluating data relationships. The Correlation test is being employed for a broad range of research goals, including mathematics-statistics, physics, medicine, image and speech processing [11], [24], [25], [26], [27] and evaluated the resemblance of organic mass spectra using the Pearson correlation coefficient method and enhanced the mass spectrometry databases search efficiency. Mecozzi *et al.* [27] used the Pearson correlation coefficient approach to anticipate wind power combinations in the literature. They successfully mitigated the significant errors associated with conventional methods and improved the accuracy of predicting mixed wind power combinations.

In another study, Qin *et al.* [28] employed the Pearson correlation coefficient method to enhance the accuracy of line loss calculations, which is beneficial for reducing losses and improving efficiency.

This paper describes the correlation analysis of three animal fats; chicken, beef, and pork to identify their similarities and to distinguish them. The Pearson and multiple correlation analysis methods were used to compute and assess the strength of the correlation coefficients between the animal fat S parameter obtained from MNDT.

## 2. Method

The correlation coefficient between the variables is generally assessed in correlation analysis. There are two types of correlation coefficients: linear correlation coefficients and nonlinear correlation coefficients. This research primarily focuses on the linear correlation coefficient, the Pearson correlation coefficient, and the multiple correlation coefficient.

In this study, raw, baked, and oil forms of chicken, beef, and pork fats were used. The S-parameters measurement was carried out after each sample was placed in an acrylic container attached to the MNDT sample holder. The S-parameters of all animal fat samples were obtained from the S2P file generated by a Vector Network Analysis (VNA) machine. The details of the sample preparation, instrument set, and experiments were as described by [29]. A total of 30 samples were used for each chicken, beef, and pork fat. Out of the thirty samples, every 10 samples are from raw, baked, and oil fat.

### *2.1. Pearson Correlation Analysis*

The Pearson correlation coefficient is a statistical method employed to accurately measure the linear correlation between two variables, thereby indicating the extent of the relationship between them. Experiments are used to obtain two sets of data for the variables X and Y: X = $[X_1, X_2, X_3,.X_n]$ and Y = $[Y_1, Y_2, Y_3,...Y_n]$. A correlation coefficient, represented by the symbol r, quantifies the strength of the link. It is a measurement of linear association and is occasionally referred to as Pearson's correlation coefficient after its creator. A type of memory-based communitarian filtering calculation is Pearson's algorithm. The range of Pearson's connection, from +1 to -1, reflects the level of direct relationship between two elements, or the degree to which the components are connected. A connection of +1 suggests that there is a strong positive relationship between the variables, or, indicates, that the samples have fundamentally the same structure whereas a connection of -1 demonstrates a strong negative relationship or that the sample structures are different.

The level of relationship is determined by using Pearson's connection coefficients [30]. The PCC can be computed using (1).

$$P_{x,y} = \frac{E(K_x K_y) - E(K_x)(K_y)}{\sigma_x \sigma_y} \quad (1)$$

where $E(K_x K_y)$ signifies the mean value of the product of the corresponding variables in the two data sets, x, and y, $E(K_x)$ represents the sample x average value, $E(K_y)$ represents the sample y average value, $\sigma_x$ represents the sample x standard deviation, and $\sigma_y$ represents the sample y standard deviation.

In this study, the PCC was used to measure the strength and direction of the linear relationship between two animal fats, for example between chicken and beef, chicken and pork, beef and pork, and others. Here, the PCC analysis on the complex transmission coefficient ($S_{21}$) of all fat samples was carried out using Equation (1), which is available in the Statistical Package for the Social Sciences (SPSS). The degree of correlation between fat samples was determined according to the criteria outlined in Table 1.

*Table 1. Degree of correlation relationship between two variables*

| Condition | Degree of Correlation |
|---|---|
| $0.8 < P_{x,y} < 1.0$ | remarkably strong correlation |
| $0.6 < P_{x,y} < 0.8$ | strong correlation |
| $0.4 < P_{x,y} < 0.6$ | moderate correlation |
| $0.2 < P_{x,y} < 0.4$ | weak correlation |
| $0.0 < P_{x,y} < 0.2$ | remarkably weak or correlated |

### *2.2. Multiple Correlation Analysis*

A multiple correlation coefficient is a statistical measure that quantifies the degree of a linear relationship among two or more variables. The multiple linear regression equation must first be computed because it is impossible to immediately calculate multiple correlation coefficients. In the context of multiple linear regression analysis, linear regression is employed when there is a linear relationship between the dependent variable and one or more independent variables. Here, the multiple linear regression equation (2) was used in the analysis.

$$\beta_{x,y} = b_0 + b_1 x_1 + b_2 x_2 + \cdots + b_p x_p + \mu \quad (2)$$

where β represents a dependent variable, b represents regression coefficients, x represents independent variables, and μ represents random error.

When p = 1, it is called simple linear regression, and when p = 2, it is called multiple linear regression. Using the multiple linear regression equation, the values of the dependent variables were predicted from the values of the plurality of independent variables [30].

This method was used to assess the strength of the correlation between different types of fat samples and target fat samples. Like the PCC, the $S_{21}$ of all fat samples was used in the multiple correlation coefficient analysis. In this method, a value of 1 signifies a highly positive relationship, a value of -1 represents a significant negative relationship, and a value of 0 suggests the absence of a relationship.

## 3. Results and Discussion

This section discusses the relationship between chicken, beef, and pork fats obtained using the PCC and the strength of the correlation coefficients for the S parameters of animal fats through multiple correlation coefficients.

### *3.1. Pearson Correlation Coefficient*

The representational relationship between chicken, beef and pork raw fats concerning one another is depicted in the heatmap image in Figure 1. The samples were chosen from among the 10 samples that were gathered for the analysis of sample similarity. The general color of the heatmap demonstrates that all three pairs of raw fat correlations are highly connected. The Pearson correlation and pair correlation tests are incompatible.

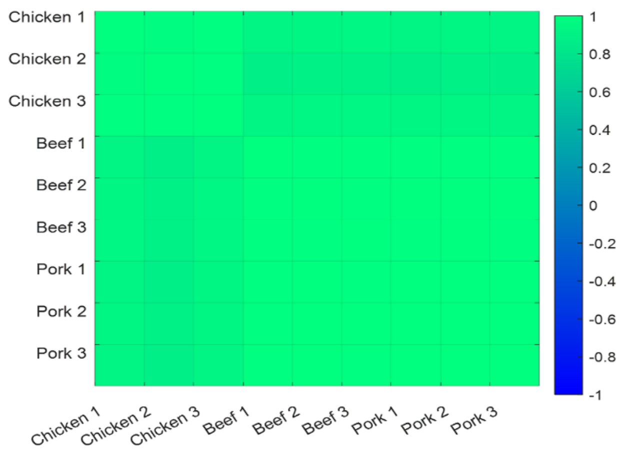


*Figure 1. Pearson correlation coefficient of raw animal fat samples*

Pearson correlation coefficient of baked samples of chicken, beef, and pork animal fat concerning one another is shown in the form of a heatmap in Figure 2. Three of ten samples have been preselected for the analysis of sample similarity.

The heatmap shows how closely related the three pairs of baked fat correlations are to one another. Since the Pearson correlation had a greater value, suggesting that all samples are comparable in terms of linearity and cannot be distinguished by correlation testing. Therefore for baked animal fat, correlation analysis cannot be used to distinguish different sources of animal fat.

Figure 3 shows the heatmap of Pearson correlation between chicken, beef, and pork oils concerning one another. Ten samples were used for correlation analysis for each type of animal fat. From the heatmap, it is obvious that chicken has a low correlation value with both beef and pork samples. The correlation between beef and pork itself had a higher correlation value, indicating that both had samples equal in terms of linearity and could not be differentiated by correlation testing. Chicken samples were the opposite of both beef and pork samples in terms of linearity and can be distinguished by correlation testing.

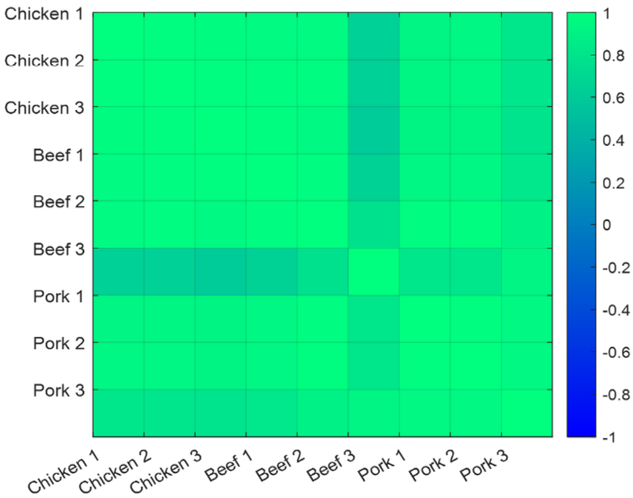


*Figure 2. Pearson correlation coefficient of baked animal fat samples*

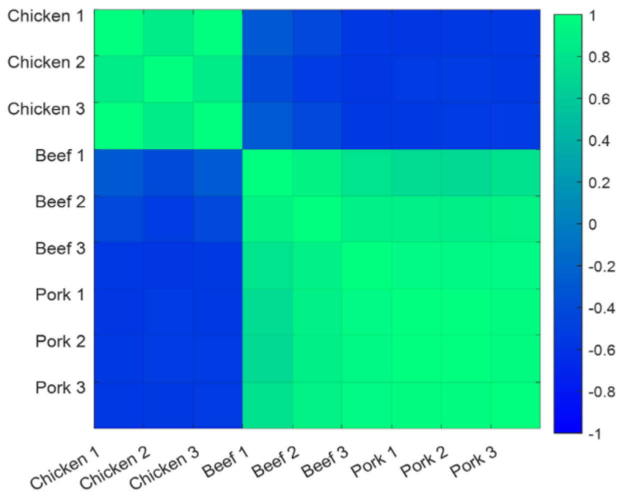


*Figure 3. Pearson correlation coefficient of animal fat oil*

### *3.2. Multiple Correlation Coefficient*

Table 2 displays the multiple correlation coefficients (MCC) between beef and pork fats as independent variables and chicken fat as a dependent variable. The MCC of three fats for three different states shows that chicken fat data can be used to differentiate sample beef and pork and that neither independent is substantially correlated with chicken fat. The beef and pork relationships with chicken raw fat showed an extremely weak (0.169) and strong correlation (0.716), respectively. While the values for both beef and pork correlation for chicken baked fat and chicken oil showed a weak (0.219) and extremely strong negative correlation (-1.017) for baked also moderately negative (-0.505) and extremely weak relationship (-0.073) for oil, respectively. This demonstrates that chicken fat in all three distinct fat states had a different relationship with both beef and pork.

The MCC between beef fat as a dependent variable and two independent variables, chicken and pork is shown in Table 3. The MCC of three fats for three separate states demonstrates that beef fat data can be used to distinguish sample chicken and pork and that both independent are not substantially related to beef fat. Extremely strong and extremely weak correlation coefficients (0.982 and 0.012) respectively were shown between raw pork and chicken and beef fat. The correlation coefficients for both pork and chicken, baked and oil are, respectively, extremely strong and weak (1.016 and 0.209) for baked and strong and extremely weak (0.779 and -0.171) for oil. This illustrates that the relationships between pork, chicken, and beef fat in each of the three different fat states varied.

*Table 2. Multiple correlation coefficients relationship between different types of beef and pork fats with chicken fat as a dependent variable*

| Dependent variable: chicken fat | | |
|---|---|---|
| **Type** | **Independent variable** | **Coefficient** |
| Raw | Beef fat | 0.169 |
| | Pork fat | 0.716 |
| Baked | Beef fat | 0.219 |
| | Pork fat | -1.017 |
| Oil | Beef fat | -0,505 |
| | Pork fat | -0.073 |

*Table 3. Multiple correlation coefficients between different types of pork fat and chicken fat with beef fat as a dependent variable*

| Dependent variable: beef fat | | |
|---|---|---|
| **Type** | **Independent variable** | **Coefficient** |
| Raw | Pork fat | 0.982 |
| | Chicken fat | 0.012 |
| Baked | Pork fat | 1.016 |
| | Chicken fat | 0.209 |
| Oil | Pork fat | 0.779 |
| | Chicken fat | -0.171 |

Table 4 showcases the multiple correlation coefficient (MCC) for pork as the dependent variable, and chicken and beef as the two independent variables. The MCC of three fats for three different states shows that pork fat data can be utilized to differentiate between sample chicken and beef and that neither independent is significantly associated with pork fat. Relationships between beef, chicken, and pork raw fat are shown by extremely strong correlation (0.951) and extremely weak (0.048), respectively. Pork-baked fat and pork oil for the association between beef and chicken are moderately correlated (0.522) and moderately negatively correlated (-0.501) for baked and extremely strong (0.851) and extremely weak correlated (-0.027) for oil, respectively. Similarly, this illustrates that the relationships between beef, chicken, and pork fat in each of the three different fat states varied.

*Table 4. Multiple correlation coefficients between different types of beef fat and chicken fat with pork fat as a dependent variable*

| **Dependent variable: pork fat** | | |
|---|---|---|
| **Type** | **Independent variable** | **Coefficient** |
| Raw | Beef fat | 0.951 |
| | Chicken fat | 0.048 |
| Baked | Beef fat | 0.522 |
| | Chicken fat | -0.501 |
| Oil | Beef fat | 0.851 |
| | Chicken fat | -0.027 |

## 4. Conclusion

The PCC analysis showed that there is a high correlation coefficient between raw and baked fat samples for chicken, beef, and pork. These raw and baked fats contain many co-variation components, which explains why there is such a significant resemblance between them. It is possible to evaluate the S-parameter amplitude alone using the Pearson correlation coefficient method. However, for the Pearson correlation, it is preferable to suggest new data representations for correlation analysis, such as obtaining the same sample's dielectric properties to strengthen the results.

Using the multiple correlation analysis, the raw, baked and oil fats of the three animals can be distinguished, demonstrating that animal fat samples could be characterized. Pearson's correlation analysis makes no distinction between raw and baked for all three species (chicken, beef, and pork). The discrepancies from the Pearson correlation demonstrate unclear differences, however, when the same data was analyzed with multiple correlations, differences between correlations were obtained.

Therefore, it is recommended that multiple correlation analysis is used as an analytical tool for interpreting MNDT results to distinguish between different types of fat and sources of animal fat samples.

**Acknowledgements**

*This research is funded by the Malaysia Institute of Transport (MITRANS), Universiti Teknologi MARA (UiTM) Malaysia, under grant RS12020GRN18RN004. The authors express their gratitude to MITRANS for their support in the form of a research grant and to the Microwave Research Institute (MRI), UiTM for providing the necessary equipment for this study.*

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