

Evaluating the Impact of Grinding Methods and Frequency on Iron Chip Contamination in Ground Pepper

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Abstract

Pepper is a popular spice used all over the world, and its iron-containing nutritional value is noteworthy. The iron content of pepper can be greatly impacted by the grinding process since grinding equipment can contaminate it. Because iron particles are released into the food due to wear and tear on the grinding plates, studies have shown that older attrition mills, particularly, can increase the iron content. The amount of iron in pepper may change depending on how it is ground. It is still unknown how different grinding frequencies and techniques affect iron concentration. Consequently, the purpose of this study is to examine how the iron content of ground pepper is affected by different grinding techniques (such as Burr plates, granite plates, grinding stones, and grinders) and frequencies (such as single grinds, double grinds and triple grinds). To examine the relationship between these variables, regression and Xgboost models are used. R-squared, Mean Absolute Error (MAE) and the Root Mean Square Error (RMSE) are used as the model comparison performance. The result revealed that the grinding frequency has a significant contribution to the iron content and also, both the grinding method and the frequency (number of grinding times) had a positive and direct association with the iron content of the cayenne pepper. The Xgboost feature importance result revealed that the number of times pepper is ground has a 68.32% contribution to the iron content and the grinding method 31.68%. This study provides valuable insights into the effects of grinding methods and frequency on the nutritional content of pepper, specifically iron concentration. The findings are relevant to food processors, nutritionists, and consumers interested in optimizing the nutritional value of spices. Recommendations for food processors and consumers on how to minimize iron contamination during the grinding process.

Keywords: Ground Pepper, Iron Chips, Grinding Method, Contamination, Pepper.

Introduction

Ground pepper is a versatile and essential spice that plays a significant role in global cuisines, health remedies, and cultural traditions. Its origins can be traced back thousands of years, with evidence of its use in ancient civilisations such as India, Egypt, and China. The term "ground pepper" typically refers to powdered forms of peppercorns or chilli peppers,

each with distinct flavours and characteristics. The peppercorn, derived from the *Piper nigrum* plant, is often referred to as "black gold" due to its historical value as a luxury spice. Originating in India, it became a major commodity during the spice trade, influencing exploration and commerce across continents. Chilli peppers, on the other hand, are native to the Americas and were introduced to the rest of the world following Christopher Columbus' voyages (Hancock, 2021).

Ground pepper comes in multiple forms, based on the types of pepper used: Black pepper is made from dried, unripe peppercorns. It has a robust, spicy flavour. White pepper is derived from ripe peppercorns with the outer layer removed, offering a milder taste. Cayenne pepper is made from dried and ground chilli peppers, known for their fiery heat. Paprika is a ground spice made from red bell peppers or chilli peppers, ranging from sweet to hot. Ground pepper contains active compounds like piperine (in peppercorns) and capsaicin (in chilli peppers), which have been associated with various health benefits, such as promoting digestion and stimulating appetite. It is rich in antioxidants, helping combat free radicals. It possesses anti-inflammatory properties, aids metabolism and weight management (Hancock, 2021). Khan, (2019) analyzed the nutritional composition of 35 unexplored genotypes of *Capsicum annuum* L (*chilli pepper*) to identify highly nutritive candidates for hybridization. The genotypes were categorized into three groups: thin chillies (Group I), intermediate chillies (Group II), and cherry chillies (Group III). Mineral content was assessed using atomic absorption, flame photometry, and spectrophotometry, while proximate composition was determined using AOAC methods. Group II had the highest magnesium (287.52 mg/100 g), calcium (114.0 mg/100 g), and potassium (286.30 mg/100 g), while Group III had the highest phosphorus (29.20 mg/100 g), iron (109.0 mg/100 g), copper (0.21 mg/100 g), and sodium (15.90 mg/100 g). Group I had the highest manganese (0.50 mg/100 g) and zinc (0.20 mg/100 g). Proximate analysis showed Group III had the highest lipid (2.15%), ash (8.93%), and protein (9.09%) content, while Group II had the highest moisture (11.86%) and carbohydrate (52.28%) levels. The study confirmed that chilli peppers are rich in magnesium, potassium, calcium, and iron. The grinding process can significantly affect the iron concentration in pepper due to contamination from grinding machinery. Studies have shown that older attrition mills, in particular, can increase iron content as wear and tear on the grinding plates releases iron particles into the food. Research found that pepper ground in older attrition mills had higher iron levels compared to those processed in newer mills or with alternative tools like electric blenders, wooden mortars and pestles, or grinding stones.

Meghwal and Goswami, (2014) evaluated the effects of different grinding techniques and packaging materials on the quality of fenugreek and black pepper powders. They assessed factors such as colour (using a colorimeter), odour (through sensory evaluation), and moisture content (via oven drying). Powders were stored in glass jars, steel jars, plastic jars, aluminium bags, and poly bags under controlled conditions. Sensory tests after six months indicated a decline in colour, flavour, aroma, and overall acceptability, with steel and glass jars proving to be the best storage options. The study contributed to designing an improved

spice grinder (incorporating ball, hammer, rotor, and pin mills) and highlighted the importance of selecting suitable packaging to maintain spice quality over time. The grinding method significantly influences the flavour, colour, and chemical composition of black pepper (*Piper nigrum* L.). Liu *et al.*, (2018) compared ambient and cryogenic grinding, found that cryogenic grinding preserved key components such as lipids, moisture, crude protein, starch, non-volatile ether extract, piperine, and essential oils. In contrast, traditional grinding led to greater losses of these compounds, affecting the overall quality of black, white, and green peppers.

There are few studies specifically examining the effect of grinding frequency on pepper quality, even though the frequency of grinding (i.e., the number of grinding cycles or the speed of the grinder) might affect the distribution of particle sizes and heat generation during the process (Yahaya *et al.*, 2012; Bacon *et al.*, 2012). Higher grinding frequencies, on the other hand, are known to enhance heat production, which may result in increased losses of volatile chemicals and the deterioration of nutrients that are sensitive to heat. To maintain the quality of ground pepper, it is therefore essential to optimize the grinding parameters (Ghodki and Goswami, 2016). The grinding methods and the frequency of grinding have been a problem in the reduction of contamination of the amount of iron chips in ground pepper.

Pepper can be ground in various ways, including manual, mechanical, hammer mill, cryogenic, ball mill, and roller mill grinding. Manual grinding requires the use of a mortar and pestle to create coarse, irregular particles that are ideal for small-scale applications, commonly found in homes and small enterprises. Mechanical grinding produces homogeneous medium to fine particles using grinders or mills. The spice industry extensively utilizes hammer mills, which grind fine powder with high-speed revolving hammers. Cryogenic grinding preserves the essential oils and aroma of pepper by freezing it with liquid nitrogen before grinding. In specialized industries, ball mill grinding yields ultra-fine, uniform powder using revolving cylinders and grinding media. Pepper is ground in a roller mill, which produces small particles with less heat and is suitable for large-scale processing (Salim and Goswami, 2022).

Frequency of grinding in Pepper Processing is as follows: processing scales, storage and shelf life, heat generation and quality, cryogenic grinding, Market Demand, packaging and Distribution. Under the processing scale are households that grind as needed, while commercial production involves continuous grinding. Storage and shelf life require frequent grinding to preserve freshness, as pre-ground pepper degrades faster. Heat Generation and Quality entails high-speed grinding that can cause heat build-up; cryogenic grinding helps to maintain quality. Market Demand is high demand requiring frequent grinding, while some producers grind in batches. Packaging and Distribution entails frequent grinding followed by airtight packaging extends shelf life; whole peppercorns are preferred for long-term storage (Aradwad *et al.*, 2021). Samuel *et al.*, (2023) explored the solvent-free mortar-pestle grinding method for synthesizing chemical products using

sustainable, cost-effective, and eco-friendly practices. This approach minimized hazardous waste, reduced production time, and increased yield. While the method aligned with green chemistry, it also had potential applications in selecting hydrazone-based biocidal agents. Singh *et al.*, (2018) examined the impact of heating and sieve blockage on the fat content of spices during grinding. They found that temperature increases led to a significant loss of volatile oils. To counteract this, a cryogenic grinding system was developed, incorporating a precooler (with a screw conveyor, compressor, and liquid nitrogen dewar) and a grinder. Tests on cumin seeds showed that grinding below -70°C was effective, while sieve blockage occurred at higher temperatures. As grinding temperature increased from -160°C to -70°C , particle size and energy consumption rose, but the change in volatile oil content (3.30 to 3.26 ml/100 g) was not statistically significant.

Ghodki and Goswami, (2016) extensively used cryogenic grinding to produce high-quality black pepper powder and analysed its physical-chemical properties across different grinding temperatures (0°C , 40°C , 80°C , 120°C , and -40°C). They found that as grinding temperature increased, particle size and flow ability improved, while specific surface area and surface roughness decreased. SEM analysis revealed particle morphology changes. Lower grinding temperatures enhanced mineral accessibility, with potassium being the most abundant, followed by calcium and chlorine. Additionally, reducing the grinding temperature increased moisture content (10.5%), water activity (19.1%), and volatile oil content (20.1%). However, pH value and specific energy consumption for grinding and conveying dropped by 3.7% and 87.2%, respectively. The total colour difference was minimal at -40°C , while the gross calorific value showed no consistent trend.

Liu *et al.*, (2013, 2018) compared the effects of hammer milling and cryogenic grinding on the flavour characteristics of black, white, and green pepper. Used HS-SPME, GC/MS, sensory evaluation, and electronic nose (e-nose) analysis, they found that cryogenic grinding better preserved colour, flavour, and sensory qualities compared to hammer milling. It also retained key aroma compounds more effectively, though their concentrations decreased significantly after six months of storage at 4°C . E-nose analysis confirmed these findings, indicating that cryogenic grinding was superior for maintaining pepper's sensory attributes. However, overall flavour quality declined during storage.

Salawu and Hassan, (2021) investigated the impact of different grinding methods on the iron content of wet-ground cowpea (*Vigna unguiculata*) and pepper (*Capsicum frutescens*), assessing the biosafety of commonly used domestic grinding techniques. The study compared attrition mills with new (mill 2) and old (mill 1) plates, along with wooden mortars and pestles, grinding stones, and electric blenders. Atomic Absorption Spectrophotometry (AAS) analysis revealed that food ground in attrition mills had significantly higher iron concentrations, 30–40 times more than other methods, due to metal contamination from grinding plate wear. Pepper ground in the older attrition mill (4300 ± 474.35 mg) had higher iron content than that from the newer mill (3199 ± 281.68 mg), both exceeding recommended dietary iron intake levels. The study highlighted the risk of iron overloading

in food processed using attrition mills, with contamination increasing as grinding plates wore down.

Ionescu *et al.*, (2023) examined how fractionating blackthorn berry (*Prunus spinosa*) powder by particle size affects its chemical composition, phytochemical properties, preservation capacity, functional properties, and physicochemical characteristics. After drying and grinding, the powder was sieved into eight fractions based on mesh size. The key findings were that smaller particles improved functional properties and larger particles retained higher vitamin C content due to reduced degradation. The powder demonstrated good microbiological stability, with low moisture content (5.61%) and water activity (0.250). Sieving improved the physicochemical and functional qualities, particularly for finer particles.

The black pepper was modelled using DEM attributes by Kanakabandi and Goswami, (2019). The angle of repose and flow properties of black pepper were examined using a revolving drum device. The precise input parameters were chosen by comparing the dynamic angle of repose results from simulations and experiments. The two factors that most affect the outcomes are the coefficient of rolling friction for particle-to-wall contact and the coefficient of static friction for particle-to-particle contact. For both particle-to-particle and particle-to-wall contact, the simulations that best matched the experimental results had coefficients of static friction of 0.4 and rolling friction between particle-to-wall contact of 0.03. The study by Sandanayake *et al.*, (2017) examined the metal content in powdered and whole black pepper. While most metal levels were within safe limits, cadmium (Cd) exceeded permissible levels, likely due to agricultural practices. Ground pepper had higher iron (Fe) levels than whole pepper, possibly from milling contamination. Significant differences in Fe, Pb, Cd, and Zn suggested that contamination occurred during grinding. Potassium (K) was the most abundant metal, followed by calcium (Ca) and magnesium (Mg). Branded pepper powders had higher K and Mg levels than unbranded samples. Differences were observed between AAS and XRF analysis methods. They emphasized on the need for routine monitoring to prevent hazardous metal accumulation in the human body.

Aradwad *et al.*, (2021) analysed various spice grinding methods, including conventional (hammer, plate, pin mill), superfine (ball, jet, roller mill), and improved techniques (cryogenic, dry ice, chilled air, water jacket, stage grinding). They used attribute coding and the approach to determine critical quality retention factors. Key factors identified were grinding method, liquid nitrogen treatment, moisture content, feed rate, and sieve type. Improved grinding methods, especially cryogenic grinding, showed

Statement of the Problem

Iron toxicity is not always caused by an increase in dietary iron. Many diseases can lead to problems with iron absorption and, in turn, result in iron toxicity (Wessling-Resnick, 2014). In cases of acute iron poisoning, much of the damage to the gastrointestinal tract and liver

may stem from highly localized iron concentrations and free radical production. Without treatment, the disease can lead to organ failure. People with hemochromatosis absorb more iron than the body needs. The body has no natural mechanism to eliminate excess iron, so it is stored in body tissues, particularly in the liver, heart, and pancreas.

Conventional methods had issues like high energy consumption and material instability. Cryogenic grinding, despite its advantages, requires further optimization for practical application. In conclusion, the grinding method and frequency significantly impact the quality, aroma, and usability of pepper (Siddique and Kowdley, 2012). Traditional and mechanical grinding methods are widely used, while cryogenic and roller mill grinding are preferred in industrial settings to preserve essential oils and enhance product quality. Therefore, there is a need to study the impact of grinding methods and frequency on iron chip contamination in ground pepper.

Materials and Methods

This work aims to evaluate the impact of grinding methods and frequency on iron chip contamination in ground pepper. Pepper gotten from the market was divided into two parts: one part was wet ground and the other dry ground. Each part of both wet and dry ground samples of Q1, Q2 and Q3 of 25g, 35g and 45g, respectively, was used as the quantities. Four methods of grinding considered were: grinding stone, blender, burr mill plates, granite plates and a mortar and pestle was used as a control. The granite plate was carved out of granite stone for the purpose of the research. The two granite plates replace the burr mill plates while grinding and the samples were analyzed. In this section, the data used for the study is discussed and the methods used for analysis. Regression and XGBoost models are used to study the relationship between these variables. The models used 70% of the data for training and the remaining 30% for testing.

Data

Primary data gathered from the cayenne pepper experiment served as the basis for this investigation. Data was collected on the pepper's dry and wet moisture contents. In this investigation, four distinct grinding techniques were examined. Burr plates, granite plates, grinding stones, and grinders are some of these grinding techniques. In this experiment, three different amounts of dry and wet cayenne pepper were employed. With 25g denoted as Q1, 35g as Q2, and 45g as Q3, these amounts are represented. Each quantity of cayenne pepper was ground three times, and the amount of iron present, measured in parts per million (ppm) or milligrams per kilogram, was measured at each stage of the grinding process. Determining if grinding techniques and frequency (number of grinding times) yield significant amounts of iron in pepper is the aim of this investigation.

Regression Analysis

Linear Regression is a fundamental statistical method used to model the relationship between a dependent variable y (target) and one or more independent

variables X (features). It assumes a linear relationship between the input features and the target variable, making it interpretable and widely applicable for regression tasks. The linear regression model is represented as:

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n + \epsilon$$

Where:

y is the target variable (car price).

β_0 is the intercept.

$\beta_1, \beta_2, \dots, \beta_n$ are the coefficients of the features $x_1, x_2, \dots, x_n$

ϵ is the error term, assumed to be normally distributed with mean 0 and variance σ^2 . In matrix form, the linear regression model can be expressed as:

$$y = X\beta + \epsilon$$

Where:

y is an $n \times 1$ vector of observed target values.

X is an $n \times (p+1)$ design matrix of input features (with an additional column of 1s for the intercept).

β is a $(p+1) \times 1$ vector of coefficients.

ϵ is an $n \times 1$ vector of error terms.

Ordinary Least Squares (OLS) Estimation

The goal of OLS is to find the coefficient vector β that minimizes the Residual Sum of Squares (RSS):

$$RSS = \sum_{i=1}^n (y_i - \hat{y}_i)^2 = (y - X\beta)' (y - X\beta)$$

The optimal coefficients β are obtained by solving the normal equation:

$$X'X\beta = X'y$$

Solving for β :

$$\beta = (X'X)^{-1} X'y$$

Where:

X' is the transpose of the design matrix X .

$(X'X)^{-1}$ is the inverse of the matrix product $X'X$.

Xgboost Model

XGBoost (Extreme Gradient Boosting) Regressor is a gradient-boosting model known for its high predictive accuracy and iterative error minimization (Ogundunmade *et al*, 2025). It has demonstrated superior performance in machine learning competitions and is particularly suited for structured data, making it ideal for this study's objectives.

The mathematical expression for XGBOOST model is given as:

$$\hat{y}_i = \sum_{k=1}^K f_k(x_i)$$

Where:

- $\hat{y}_i$ is the predicted value for the i-th instance.
- f_k is the k-th tree, belonging to the space of regression trees F .
- x_i is the feature vector for the i-th instance.

Each of these models will be compared and evaluated to determine the best-performing model for determining the impact of grinding frequency and methods on iron contamination content in pepper. The goal is to identify which model provides the most accurate and reliable predictions based on the features and dataset provided.

Evaluation Metrics

To evaluate the models comprehensively, multiple metrics will be used to assess their accuracy and reliability. These metrics include the R^2 score, Mean Absolute Error (MAE), and Root Mean Square Error (RMSE). Each of these metrics offers unique insights into the models' performance.

The R^2 score, or coefficient of determination, measures the proportion of variance in the target variable (car price) explained by the model. Higher R^2 values indicate that the model captures more of the variability in iron concentration, providing a useful measure of model fit.

$$R^2 = 1 - \frac{\sum_{i=1}^n (y_i - \hat{y}_i)^2}{\sum_{i=1}^n (y_i - \bar{y})^2}$$

Mean Absolute Error (MAE) calculates the average absolute difference between the predicted and actual iron contamination values. It provides a straightforward interpretation of the model's average prediction error, making it easy to assess the general performance of the model.

$$MAE = \frac{1}{n} \sum_{i=1}^n |y_i - \hat{y}_i|$$

Root Mean Square Error (RMSE) is similar to MAE but penalizes larger errors more heavily. This metric is useful for identifying models that exhibit substantial variance in their predictions and helps assess models with higher error magnitudes.

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2}$$

By using these metrics, the study ensures a holistic comparison of model performance, which will aid in selecting the model that best balances accuracy.

Results and Discussions

This section provides a summary of the experiment's findings. Regression analysis is also shown to investigate how frequency and grinding techniques affect cayenne pepper's iron contamination. The iron (Fe) content of ground cayenne pepper, both wet and dry. The recorded values' mean and standard deviation are displayed in the table. According to the

FAO/WHO, the maximum amount of iron that can be found in fruits and vegetables is 425.5 mg/kg.

Exploratory Data Analysis (EDA)

Table 1: The concentration of Iron using the number of grinding times(mg/kg)

NO OF GRINDING TIMES	DRY	WET
Once	140.6±15.1	280.22±167.57
Twice	332.9±156.5	109.44±65.89
Thrice	757.3±324.2	497.39±307.72

Note: Mean ± SD

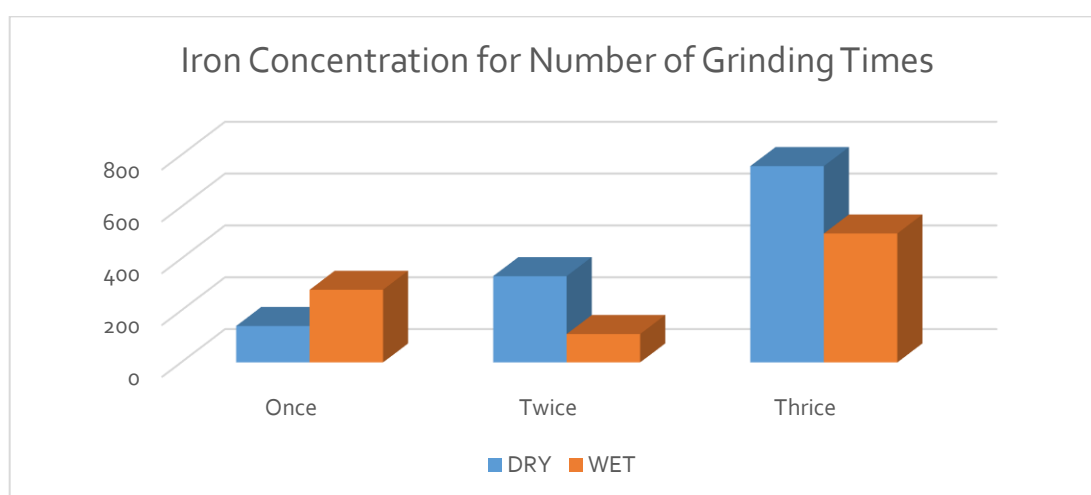


Fig 1: Bar plot showing the concentration of iron for number of grinding times for wet and dry pepper

Table 2: The concentration of Iron using the grinding methods(mg/kg)

GRINDING METHODS	DRY	WET
Grinder	129.43±14.07	141.64±139.58
Granite Plate	176.43±46.20	10.98±4.67
Burr Plate	1197.19±406.32	647.13±399.57
Grinding Stone	137.97±20.51	358.97±190.48

Note: Mean ± SD

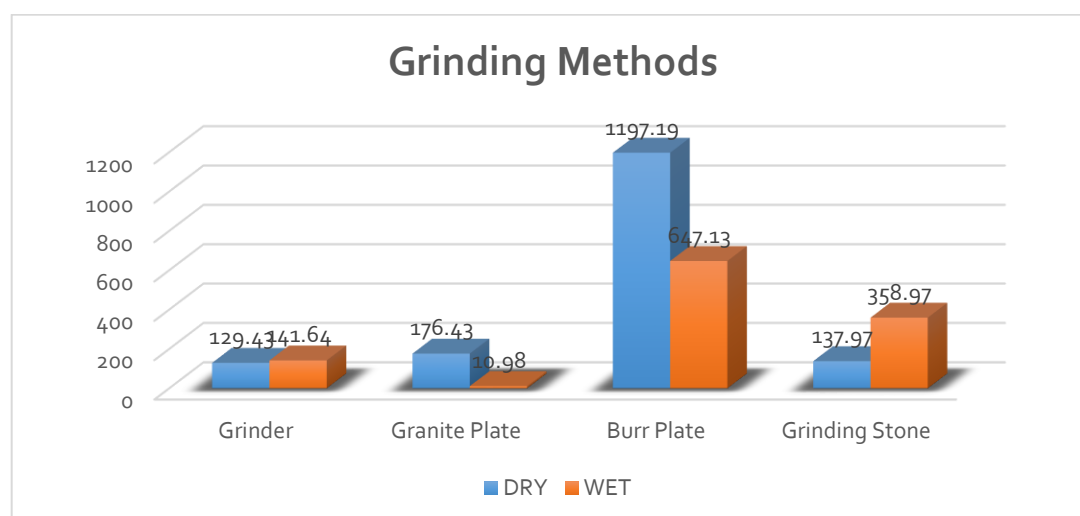


Fig 2: Bar plot for the concentration of iron grinding methods for the wet and dry pepper

The iron content of cayenne pepper is displayed in Tables 1 and 2, which are grouped according to the grinding methods and the number of times the pepper was ground. Following the once, twice, and three times, the iron concentrations tested are, on average, 140.6, 332.9, and 757.3 for the dry pepper and 280.22, 109.44, and 497.39 for the wet pepper sample, according to Table 1. Table 2 shows the average iron content of cayenne peppers classified by various grinding techniques. The results for the grinding methods of grinder, granite plate, burr plate, and grinding stone are 129.43, 176.43, 1197.19, and 137.97, respectively. In comparison with the FAO/WHO maximum amount of iron that can be found in fruits and vegetables which is 425.5 mg/kg, grinding the pepper after twice can make the iron content higher than the 425.5kg and also, using burr plate for grinding can also produce the same.

Regression Analysis

The summary of the regression iron concentration for the dry sample indicates that the Multiple R value is 0.376975, R-squared 0.14211, Adjusted R-squared 0.090117, Standard Error 712.4989, and the observation number is 36. The result from Table 3 also shows that grinding methods have a non-significant p-value of 0.33 with a positive contribution to the iron contamination in pepper, while the number of times the pepper is ground has a significant p-value of 0.042 with a direct relationship with the quantity of iron contamination in pepper.

Table 3: Regression results for Dry Sample

<i>Regression Statistics</i>	
Multiple R	0.376975
R Square	0.14211
Adjusted R Square	0.090117
Standard Error	712.4989
Observations	36

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	-468.10	411.36	-1.14	0.26	-1305.02	368.82	-1305.02	368.82
Grinding Method	104.64	106.21	0.99	0.33	-111.45	320.73	-111.45	320.73
Number of Times	308.38	145.44	2.12	0.042	12.48	604.28	12.48	604.28

Table 4: Regression results for Wet Sample

<i>Regression Statistics</i>	
Multiple R	0.236527
R Square	0.055945
Adjusted R Square	-0.00127
Standard Error	709.6052
Observations	36

<i>ANOVA</i>					
	<i>Df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	2	984715.9	492357.9	0.977794	0.386773
Residual	33	16616805	503539.6		
Total	35	17601521			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	-231.53	409.69	-0.57	0.576	-1065.05	601.99	-1065.05	601.99
Grinding Method	128.82	105.78	1.22	0.232	-86.39	344.03	-86.39	344.03
Number of Times	99.58	144.85	0.69	0.497	-195.11	394.28	-195.11	394.28

The regression model summary for the wet sample shows that the Multiple R is 0.236527, the R Square is 0.055945, the adjusted R Square is -0.00127, the Standard Error is 709.6052,

and the observation is 36. Table 4 results also indicate that grinding techniques have a non-significant p-value of 0.232, which indicates a positive contribution to pepper's iron contamination, and that the frequency of pepper grinding has a non-significant p-value of 0.497, which indicates a direct correlation with pepper's iron contamination levels.

The XGBOOST Model Summary

The Xgboost model analysis results for the dry and wet outputs are displayed in Tables 5 and 6, respectively. For Xgboost results outputs, the tables display the R-squared, mean absolute error (mae), and root mean square error values.

Table 5: XGBOOST Result Dry Output

Measures	Values
R-squared	0.3258
MAE	0.2740
RMSE	0.4403

Table 6: XGBOOST Result Wet Output

Measures	Values
R-squared	0.3063
MAE	0.1134
RMSE	0.2238

The Xgboost results for the dry and wet samples are displayed in Tables 5 and 6, respectively. According to the results, the dry output's R-square, MAE, and RMSE are 0.3258, 0.2740, and 0.4403, respectively, whereas the wet outputs are 0.3063, 0.1134, and 0.2238.

Table 7: Feature Importance using Xgboost model

Variable	Relative Importance
Number of grinding times	68.32
Grinding method	31.68

The relative importance result in Table 7 shows that the number of times pepper is ground has a 68.32% contribution to the iron content and the grinding method contributes 31.68%.

Model Performance Result

The performance comparison of the Xgboost and linear regression models is displayed in Table 8. The outcome demonstrates how well these models work with both dry and wet outputs. According to the table, Xgboost has R-square, MAE, and RMSE values of 0.3258, 0.2740, and 0.4403 for the dry sample result, while linear regression has these values of 0.1421, 0.3001, and 0.5402 correspondingly. Additionally, the wet sample result indicates

that Xgboost has 0.3063, 0.1134, and 0.2238 for R-square, MAE, and RMSE, respectively, while linear regression has 0.0559, 0.1080, and 0.2094 for the same metrics.

Table 8: Model Performance Comparison Result

Model	R-sq value	MAE	RMSE
Dry Sample			
Linear Regression	0.1421	0.3001	0.5402
XGBOOST	0.3258	0.2740	0.4403
Wet Sample			
Linear Regression	0.0559	0.1080	0.2094
XGBOOST	0.3063	0.1134	0.2238

Conclusion

The iron content in cayenne pepper was discussed, which is grouped according to the grinding methods and the number of times the pepper was ground. The average iron concentrations for the dry pepper and wet pepper samples are shown after the once, twice, and three times. Also, the average iron content of the cayenne pepper was classified according to the various grinding techniques. The results showed that grinding the pepper twice can increase its iron content above the FAO/WHO maximum of 425.5 mg/kg found in fruits and vegetables. Using a burr plate to ground it can also yield the same amount of iron. Regression and Xgboost models were both utilized to investigate the effect of the number of grinding times and techniques on the iron contamination chip on ground pepper. The result revealed that both the grinding techniques and the number of grinding times had a positive and direct association with the iron content of cayenne pepper, according to Tables 3 and 4. By changing the size and distribution of the particles, grinding techniques may have an impact on the iron content of pepper. A more uniform distribution of iron, for example, may result from finer grinding, which increases the pepper particles' surface area. The results show that the frequency of grinding directly affects the amount of iron present. More frequent grinding of pepper exposes it to light, moisture, and oxygen, which can alter the stability and bioavailability of iron.

Additional factors, such as grinding method, particle size, storage conditions, and iron analysis methods, can be taken into consideration for future research. In addition to grinding methods and frequency, other factors that can affect iron concentration in pepper include pepper variety, growing conditions, processing, and handling practices.

Recommendation

Further research should be carried out on the materials to replace the burr mill plates or the number of times grinding be done should not be more than twice to reduce iron contamination or toxicity.

Conflict of Interest

No conflict of interest.

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References

- Aradwad, P. P., T V, A. K., Sahoo, P., and Mani, I. (2021). Key issues and challenges in spice grinding. *Cleaner Engineering and Technology*, 5, 100347. <https://doi.org/10.1016/j.clet.2021.100347>
- Bacon, B. R., Adams, P. C. Kowdley, K. V., Powell, L. W and Tavill, A. S. (2011). Diagnosis and management of hemochromatosis: 2011 practice and guideline by the American Association for the Study of Liver Diseases. AASLD Practice Guideline. *J. Hepatol.* 54(1): 328-343.
- Hancock, J. (2021). *Pepper*. *World History Encyclopedia*. Retrieved from <https://www.worldhistory.org/Pepper/>
- Hassan, A. A and M. A. Salawu (2014) Raised Iron Levels in Wet-ground *Vigna unguiculata* and *Capsicum frutescens* using Domestic Grinding Techniques. *African. Journal of Biomed. Res.* Volume 17, 173-179.
- Ionescu, A., Ferdeş, M., Voicu, G., Ipate, G., Constantin, G., Ştefan, E., and Begea, M. (2023). Effect of Grinding and Successive Sieving on the Distribution of Active Biological Compounds in the Obtained Fractions of Blackthorn Berries. *Applied Sciences*, 14(16), 7133. <https://doi.org/10.3390/app141671335>
- Liu, H., Zheng, J., Zheng, F and Liu, P. (2018). Pulverizing processes affect the chemical quality and thermal properties of black, white, and green pepper (*Piper nigrum* L.). *Journal of Food Science and Technology*. **55**, 2130–2142. <https://doi.org/10.1007/s13197-018-3128-8>
- Liu, H., Zeng, F., Wang, Q., Ou, S., Tan, L., and Gu, F. (2013). The effect of cryogenic grinding and hammer milling on the flavour quality of ground pepper (*Piper nigrum* L.). *Food Chemistry*, 141(4), 3402-3408. <https://doi.org/10.1016/j.foodchem.2013.06.052>
- Ghodki, B. M., and Goswami, T. (2016). Effect of grinding temperatures on particle and physicochemical characteristics of black pepper powder. *Powder Technology*, 299, 168-177. <https://doi.org/10.1016/j.powtec.2016.05.042>
- Khan, N (2019). Comparative analysis of mineral content and proximate composition from chilli pepper (*Capsicum annuum* L.) germplasm. *Pure and Applied Biology*. Volume. 8, Issue 2, <http://dx.doi.org/10.19045/bspab.2019.80075>
- Meghwal M, and Goswami T K. (2014). Effect of different grinding methods and packaging materials on fenugreek and black pepper powder quality and quantity under normal storage conditions. *Int J Agric & Biol Eng*, 2014; 7(4): 106–113. DOI: 10.3965/j.ijabe.20140704.012
- Ogundunmade, T.P., Adepoju, A.A., and Edet, I.C. (2024). Prediction of Diabetes Occurrence Using Machine Learning Models with Cross-Validation Technique. In: Awe, O.O., A. Vance, E. (eds) Practical Statistical Learning and Data Science Methods. STEAM-H: Science, Technology, Engineering, Agriculture, Mathematics & Health. Springer, Cham. https://doi.org/10.1007/978-3-031-72215-8_25
- Salim R, and Goswami T.K. (2022). Determination of medicinal properties of black pepper: effect of mortar and pestle crushing, normal grinding and cryogenic grinding. *Journal of Nutritional Health Food Engineering*. 12(3):79-85. DOI: [10.15406/jnhfe.2022.12.00360](https://doi.org/10.15406/jnhfe.2022.12.00360)

- Samuel, T. Dafa, Moses S. Iorungwa, Raymond A. Wuana, Esther N. Iornumbe, Ungwanen J. Ahile and Newton V. Akoso (2023): A Review on Mortar-Pestle Grinding Synthesis and Thermal Profiling of Hydrazone Based Complexes as Biocidal Agents <http://www.unn.edu.ng/nigerian-research-journal-of-chemical-sciences/234>
- Singh, S.S., Ghodki, B.M. and Goswami, T.K. (2018). Effect of grinding methods on powder quality of king chilli. *Food Measure* **12**, 1686–1694. <https://doi.org/10.1007/s11694-018-9784-6>
- Salawu M. A, and Hassan A. A. (2014). Raised iron levels in wet-ground Vigna unguiculata and Capsicum frutescens using domestic grinding techniques. *African Journal of Biomedical Research*. 17 (3):173–79.
- Sandanayake, P. T., Wickramasinghe, I., Rajanayake, R., and Bamunuarachchi, A. (2017). Analysis of Metal Content in Black Pepper Powder Available in the SRI LANKAN Market. *International Journal of Engineering Science & Research Technology*, 6(10), 66-81. CODEN: IJESS7 DOI: [10.5281/zenodo.1002640](https://doi.org/10.5281/zenodo.1002640).
- Wessling-Resnick M. (2014). Iron. In: Ross AC, Caballero B, Cousins RJ, Tucker KL, Ziegler RG, eds. *Modern Nutrition in Health and Disease*. 11th ed. Baltimore, MD: Lippincott Williams & Wilkins; 176-188.
- Yahaya, D. B., Aremu, D. A. and Abdullahi, I. (2012). Investigation of metal contaminants in locally ground foods (Beans and tomatoes). *Journal of Emerging trends in Engineering and Applied Sciences*. 3(1): 339-343.
- Siddique A, and Kowdley KV. Review article: the iron overload syndromes. *Aliment Pharmacol Ther*. 2012 Apr;35(8):876-93. doi: [10.1111/j.1365-2036.2012.05051.x](https://doi.org/10.1111/j.1365-2036.2012.05051.x).