



Corrosive Effect of Tomato, Pepper and Onion Pulps on Selected Grinding Machine Components

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Authors' contributions

This work was carried out in collaboration among all authors. Author OJO designed the study. Author OJO supervised the project while author JOB wrote the first draft of the manuscript. Authors BFO and OJO contributed to the literature search, methods of the research and corrected the final manuscript. Authors VEO, OCA and NOO carried out the design, processing, laboratory analysis and managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

As a result of cost considerations, local grinding machine manufacturing outfits are employing non-stainless-steel components for equipment fabrication. Despite the fact that the components are known to corrode, the number of the manufacturing outfits has increased over the years. Corrosion is a major concern to the food industry because the ingestion of corroded metals can harm and affect the function of some body organs. Potentiodynamic polarization method and a weight loss approach at room temperature was used to investigate the influence of tomato, pepper, and onion pulps on the electrochemical characteristics and weight loss of mild, galvanized, and stainless steel over a period of 30 days, at 5-day intervals. The results revealed that highest corrosion rate was found in mild steel (2.95×10^{-8} mm/y) but low compared to the corrosion value obtained for galvanized steel (3.4×10^{-8} mm/y) in the hybrid medium. Consequently, the use of mild steel as a

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substitute for stainless steel is suggested, provided that it is coated, and that the machine is cleaned regularly to remove residues from the metal surface or to inhibit microbiologically induced corrosion.

Keywords: Corrosion; pulps; metals; potentiodynamic; weight loss.

1. INTRODUCTION

Corrosion is generally referred to as metal degradation by chemical effect or a metal's reaction to its surroundings [1]. It's a never-ending problem that's difficult to entirely eradicate. It is a concern in many industries, but it is especially difficult in the food processing and pharmaceutical industries, where, in addition to lost production time and the possibility of equipment failure, there is also the risk of product contamination by corrosion products, which can contribute to food contamination. Therefore, corrosion has great potential of retarding industrialization and economic advancement [2]. According to Fontana [3], stainless steels are being used as a standard in food processing machinery due to cost concerns. While stainless steel is utilized in most industrial food processing equipment, other materials such as tinned copper have been employed in the past, and the possibilities of other materials, especially for specialized situations, are worth investigating. The indigenous fabrication of food processing equipment using non-stainless-steel materials has increased in Nigeria over the years, lowering costs and making it more accessible to rural small-scale farmers and food processors. This calls for concern because amongst the detrimental effects of corrosion, vulnerable lives had been lost [2].

Tomatoes (*Lycopersicon esculentum*), is a fleshy berry regarded as very popular perishable fruit as well as vegetable grown throughout the tropical and temperate regions of the world. It was reported that tomato is one of the most important vegetable crops grown all over Nigeria after onions and pepper [4]. It is the world's largest vegetable crop after potato and sweet potato.

Peppers (hot and sweet) belong to the *Solanaceae* family, genus *Capsicum*. This genus originated from Central and South America and comprises about 30 species, of which, five are domesticated comprising *Capsicum annuum* L. (hot and sweet peppers), *Capsicum frutescens* L. or bird pepper, *Capsicum chinense* Jacq. or aromatic chili pepper, *Capsicum baccatum* L. (aji), and *Capsicum pubescens* Ruiz and Pav.

(rocoto). Pepper is often described as the "king of spices" and shares a place with salt on most tables. Onion (*Allium cepa* L.) has been valued as a food and a medicinal plant since ancient times. It is widely cultivated, second only to tomato, and is a vegetable bulb crop known to most cultures and consumed worldwide [5]. It is commonly known as "Queen of the kitchen" due to its highly valued flavor, aroma, and unique taste, and the medicinal properties of its flavor compound [6, 7].

It has been reported that anode deficiency in electrons leads to oxidation and subsequently corrosion of the metallic surface [8], and metal toxicity can harm and affect the function of organs such as the brain, kidney, lungs, liver, and blood thus necessitating the need to combat the potentials of corrosive menace [9]. Specifically, some corrosive metals can cause cancer after long-time exposure [9]. Consequently, considering the fact that metallic and environmental factors affect corrosion [10], the purpose of this study is to investigate the impacts of tomato, pepper, and onion pulps on various grinding machine components, such as stainless steel, mild steel, and galvanized steel.

2. MATERIALS AND METHODS

The materials used as samples for the potentiostatic polarization study as well as the weight loss method are galvanized steel sheet, stainless steel sheet, mild steel samples and undiluted tomato, pepper, and onion pulps. The chemical composition of the test coupons were determined using an optical emission spectrometer.

2.1 Weight Loss Method

The cut stainless steel, galvanized steel and mild metallic samples were weighed and recorded using a sensitive weighing balance (Fig.1). All metal coupons were of dimension 3 cm x 2 cm each. The already washed container were filled separately with the pulps from tomato, pepper and onions (test medium) and the weighed sample coupon were immersed for a period of 30 days. Test specimens were taken out of the test

media every 5 days, washed with distilled water, rinsed in acetone, air-dried, and re-weighed with sensitive weighing balance and recorded, and then re-immersed in the test solution for continued tests during the whole experimental period as recommended by ASTM G31 [11], and readings taken in triplicates for samples kept at room temperature (31°C).

The corrosion rate (C.R), was calculated for each coupon using the initial and final weights, coupon surface area, and density of the alloy as well as exposure time as shown in eqn (1);

$$C.R = \frac{K \times W}{D \times A \times T} \quad (1)$$

Where: C.R = Corrosion rate express millimeter per year, K= constant (8.76×10^4 for unit mm/y), T = time of exposure in hours, A = area in cm^2 to the nearest 0.01cm^2 W = weight loss in g, D = density in g/cm^3 [11].

2.2 Potentiodynamic Polarization Method

The potentiodynamic polarization test was carried out in the Department of Metallurgy, Federal University of Technology Akure. The set up followed the one reported by Olayide *et al* [12]. The basic electro-chemical cell involves a working electrode, reference electrode, counter electrode and the freshly grinded tomato, pepper and onion pulp. The equilibrium potential assumed by the metal in the absence of electrical connections to the metal is rated as Open Circuit Potential, E_{oc} . Sufficient time for the E_{oc} to stabilize before the commencement of the

electrochemical experiment to ensure “steady state”. The different electrodes were connected to potentiostat which was connected to a computer-controlled system. The corrosion monitoring was done in real time in which the reading values were determined from the computer Graphics User Interface (GUI) where a plot of voltage versus time and current versus time was generated. The different readings for the current and voltage were then exported to excel for further analysis [12].

3. RESULTS AND DISCUSSION

3.1 Composition of Metal Samples

The composition of metal samples is shown in Table 1. Compositional analysis of the three different metal samples used revealed that the stainless steel sample contained 72% iron, 15% chromium, 0.096% carbon and other incidental elements in minute quantities compared with that of the Atlas steels chart for the chemical analysis of stainless steel (which include 16-18%, 0.15% for chromium and carbon respectively). The Galvanized Steel sample contained 99% iron, 0.074% carbon and other elements in minute concentrations, which is in line with the suggestion that for a steel to be galvanized it will produce acceptable coating which contain carbon proportion less than 0.25%, phosphorus less than 0.05% and manganese less than 1.3% (metalplate.com). The mild steel sample had 99.4% iron, 0.112% carbon with other elements negligibly concentrated.



Fig. 1. Test samples suspended in plastic container containing corrosion test media for 30 days

Table 1. Chemical composition of the metal samples employed for this study

Element (%)	Stainless Steel Sample	Galvanized Steel Sample	Mild Steel Sample
C	0.096	0.074	0.112
Si	0.369	<0.0001	<0.0001
Mn	8.89	0.207	0.313
P	0.060	0.0020	0.011
S	0.0073	0.0033	0.018
Cr	15.50	0.0024	0.013
Ni	1.10	0.017	0.029
Mo	0.043	<0.0001	<0.0001
Al	0.0024	0.033	0.0064
Cu	1.68	0.0060	0.028
Co	0.051	0.0021	0.0022
Ti	0.0072	0.0007	0.0007
Nb	0.016	0.0064	0.0072
V	0.072	0.0026	0.0030
W	0.037	<0.0001	<0.0001
Pb	0.041	0.0056	0.0080
B	0.0027	0.0004	0.0004
Sn	0.011	0.0009	0.0013
Zn	–	0.0037	0.0009
As	0.012	<0.0001	<0.0001
Bi	<0.0015	0.0010	0.0009
Ca	0.0003	0.0002	0.0002
Ce	–	0.0060	0.0064
Zr	–	0.0016	0.0023
La	–	0.0009	0.0005
Fe	72.0	99.6	99.4
Mg	–	–	–
Sb	–	–	–
Ag	–	–	–
Be	–	–	–
Cd	–	–	–
Li	–	–	–
Na	–	–	–
Sr	–	–	–
Bg	–	–	–

3.2 Weight Loss Measurement

The various metals were found to corrode differently in the media. This is evident by the decrease in the original weight of the metal coupons by different amounts when immersed in test media at room temperature. The corrosion rate of mild and galvanized steel in pulp media are shown in Figs. 2 to Fig. 5.

In the tomato pulp, mild steel showed its highest corrosion rate at 2.32×10^{-8} mm/y for immersion time of 240 h which is low compared to

Galvanized steel, which showed high corrosion for immersion time of 120 h at 2.97×10^{-8} mm/y. The corrosion performance in pepper pulp showed that the corrosion rate of mild steel was higher at 3.1×10^{-8} mm/y in the first 120 h compared to galvanized steel which has its highest corrosion rate at 3.02×10^{-8} mm/y. In onion pulp, galvanized steel had its peak corrosion rate at 3.15×10^{-8} mm/y at 360 h which is low compared to mild steel whose peak corrosion rate was evaluated at 3.18×10^{-8} mm/y for immersion time of 240 h. Corrosion performance in the hybrid pulp, indicated that the

corrosion rate of mild steel was high at 2.95×10^{-8} mm/y in the first 120 h while galvanized steel has its own high corrosion rate at 3.4×10^{-8} mm/y at 120 h. Stainless steel immersed in the test samples did not show any noticeable weight loss throughout the experimental period, this shows it has a higher corrosion resistance to the media.

Generally, the results showed that stainless steel have the highest resistance to corrosion at the end of the experimental test followed by mild and then galvanized steel in the weight loss experiment. The decreasing trend of the corrosion rate of the galvanized steel with immersion time can be related to the formation of zinc salt of the organic acid which then reduces

the concentration of the corroding media from acidic to alkalinity [13], and thus affecting the rate at which most or all of the atoms on the individual metal surfaces are oxidized and consequently damaged [10]. Galvanized steel when in contact with acidic foods is aggressively attacked by the acid species to yield zinc salts of the organic acids present. This explains why galvanizing was quickly lost into the acidic medium of tomato pulp as well as the hybrid medium as previously reported by Olayide *et al.*, [12] and Stanley *et al.*, [13] where the rate of galvanized steel was calculated to be 1.089 mm/y and 6.99×10^{-4} mm/y respectively compared with the ones calculated for other metals.

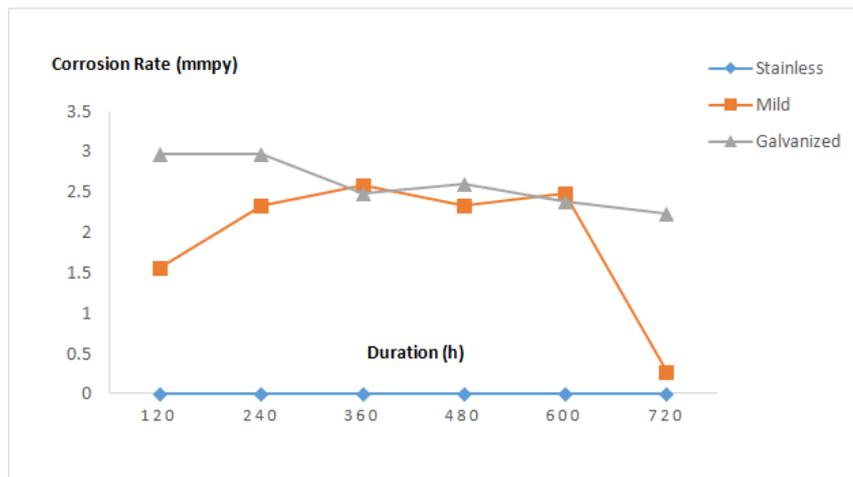


Fig. 2. Corrosion rate against time of immersion for stainless, mild, and galvanized steel in tomato juice

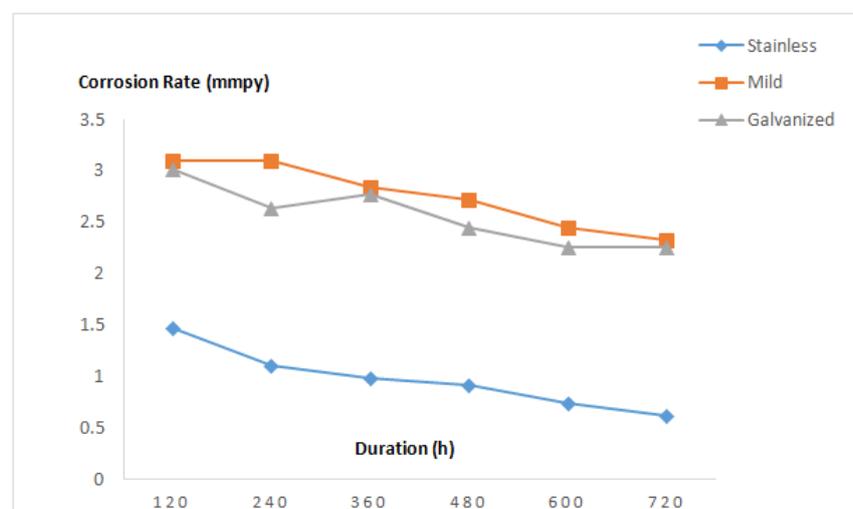


Fig. 3. Corrosion rate against time of immersion for stainless, mild, and galvanized steel in pepper juice

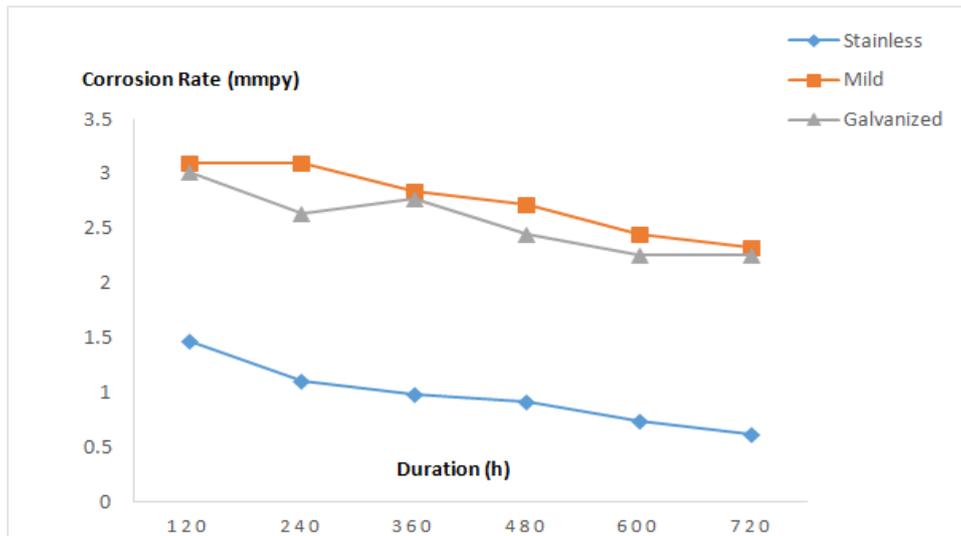


Fig. 4. Corrosion rate against time of immersion for stainless, mild, and galvanized steel in onion juice

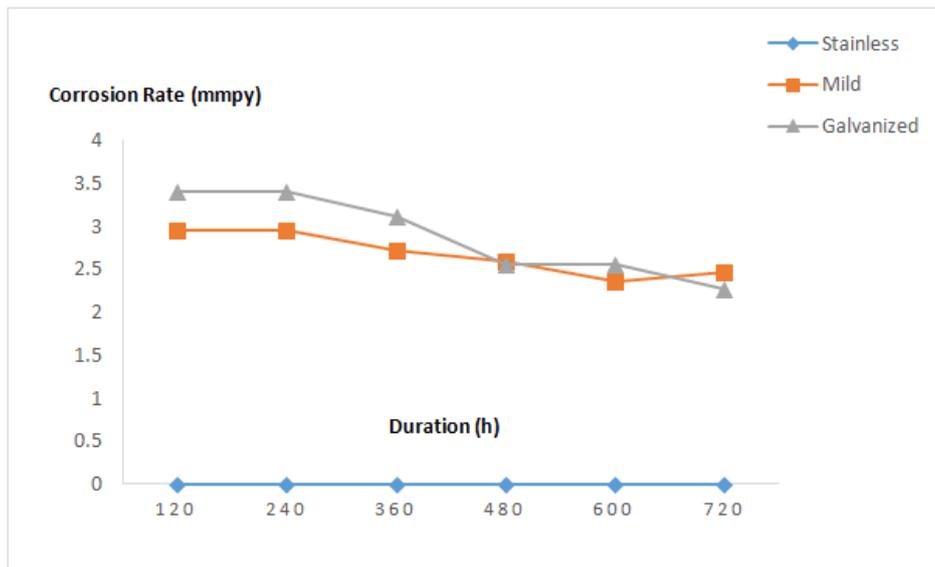


Fig. 5. Corrosion rate against time of immersion for stainless, mild, and galvanized steel in hybrid/blend juice

3.3 Potentiodynamic Polarization Measurements

The potentiodynamic polarization measurement of pulp is shown in Tables 2 to 5. For tomato pulp known to citric and malic acids, the galvanized steel electrode potential measured was -481.877 mV, the corrosion current density as 18.902 $\mu\text{A}/\text{mm}$ and the corrosion rate measured as 0.21933mm/y, which is much higher than that obtained for stainless steel and mild steel. This

agrees with the trend reported by Olayide *et al.*, [12] which shows that galvanized steel has a higher corrosion rate in the tomato medium at 0.0113mm/y compared to brass value of 0.003mm/y. For pepper pulp known to contain capsaicin and ascorbic acids, the Mild steel electrode potential measured was -545.947mV, the corrosion current density as 3.097 $\mu\text{A}/\text{mm}$ and corrosion rate measured as 0.035941mm/y which is much higher than that of galvanized and stainless steel. For onion pulp, Mild steel

electrode potential measured was -605.45mV, the corrosion current density as 30.141 $\mu\text{A}/\text{mm}^2$ and corrosion rate measured as 3.4975mm/y indicating active corrosion behaviour of mild steel in onion pulp known to contain acids such as sulfenic, glutamic, citric and malic, is much higher than that of galvanized and stainless steel. Mild steel also showed a high corrosion rate measured at 0.63952mm/y in the blend medium compared with its counterpart (galvanized and stainless steel).

The high corrosion current density obtained for galvanized steel and especially Mild steel is because oxygen is reduced and partly due to the

fact that, the metal surface allows a vast amount of current to flow around the system [12,14].

The mild steel used in this study was uncoated while the galvanized steel was coated with zinc, thus suggesting that mild steel is most corroded probably because in the electrochemical series, zinc is found to be resistant to corrosion. However, corrosion test overtime is mostly based on the gravimetric test (weight loss) because it is controllable to a reasonable degree unlike the potentiodynamic test which can be influenced by the condition of the electrode as at the time of the experiment.

Table 2. Current density (I_{corr}), open circuit potential (E_{cor}) and the corrosion penetration rate for stainless steel, galvanized steel and mild steel in the tomato pulps as obtained from the computer Graphics User Interface

Tomato Pulp				
Sample	Area (mm^2)	$E_{\text{cor}}(\text{mV})$	$I_{\text{corr}} (\mu\text{A}/\text{mm}^2)$	CR (mm/y)
Stainless Steel	100	-988.517 ^c	2.151 ^b	0.02496 ^b
Galvanized Steel	100	-481.877 ^a	18.902 ^c	0.21933 ^c
Mild Steel	100	-544.996 ^b	1.719 ^a	0.01995 ^a

Values represent means of triplicate readings; Means within the same row with different superscripts are significantly different ($p \leq 0.05$)

Table 3. Current density (I_{corr}), open circuit potential (E_{cor}) and the corrosion penetration rate for stainless steel, galvanized steel and mild steel in the pepper pulps as obtained from the computer Graphics User Interface

Pepper Pulp				
Sample	Area (mm^2)	$E_{\text{cor}}(\text{mV})$	$I_{\text{corr}} (\mu\text{A}/\text{mm}^2)$	CR (mm/y)
Stainless Steel	100	-625.403 ^b	0.008 ^a	0.00931 ^b
Galvanized Steel	100	-796.267 ^a	2.864 ^b	0.03324 ^c
Mild Steel	100	-545.947 ^c	3.097 ^c	0.03594 ^a

Values represent means of triplicate readings; Means within the same row with different superscripts are significantly different ($p \leq 0.05$)

Table 4. Current density (I_{corr}), open circuit potential (E_{cor}) and the corrosion penetration rate for stainless steel, galvanized steel and mild steel in the Onion pulps as obtained from the computer Graphics User Interface

Onion Pulp				
Sample	Area (mm^2)	$E_{\text{cor}}(\text{mV})$	$I_{\text{corr}} (\mu\text{A}/\text{mm}^2)$	CR (mm/y)
Stainless Steel	100	-766.682 ^a	1.785 ^a	0.02072 ^a
Galvanized Steel	100	-576.773 ^c	4.006 ^b	0.04649 ^b
Mild Steel	100	-605.452 ^b	30.141 ^c	3.49750 ^c

Values represent means of triplicate readings; Means within the same row with different superscripts are significantly different ($p \leq 0.05$)

Table 5. Current density (I_{corr}), open circuit potential (E_{corr}) and the corrosion penetration rate for stainless steel, galvanized steel and mild steel in the hybrid pulps as obtained from the computer Graphics User Interface

Sample	Area (mm ²)	Hybrid Pulp		
		E_{corr} (mV)	I_{corr} (μ A/mm ²)	CR (mm/y)
Stainless Steel	100	-940.508 ^a	0.001 ^a	0.00155 ^a
Galvanized Steel	100	-489.580 ^c	4.496 ^b	0.05218 ^b
Mild Steel	100	-556.701 ^b	55.113 ^c	0.63952 ^c

Values represent means of triplicate readings; Means within the same row with different superscripts are significantly different ($p \leq 0.05$)

4. CONCLUSION

The results showed that the use of galvanized steel for fabricating food processing equipment is not advisable from a corrosion point of view, as it suffered more corrosion attack than mild steel. The corroded surface in the samples is an indication of tendency of skewing up microbiologically induced corrosion on the machine during subsequent uses, and this make human to be more prone to microbial contaminations. This may also result into low flow or stagnant conditions which can make the grinding machine more susceptible to microbial growth. Mild steel is known to possess better corrosion resistance than galvanized steel in the Nigerian food processing environments; however, mild steel used in the fabrication of local grinding machine must be coated with zinc primer due to their high corrosion protection performance.

Also, the local operator of the grinding machine should be sensitized on the need to regularly clean the grinding machine in order to remove residues of these condiments after grinding to prevent it from reacting with the surface of the metal to trigger corrosion or enhance microbiologically induced corrosion.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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