Advanced International Journal of Material Science and Engineering
Volume.10, Number 3; July-September, 2025;
ISSN: 2837-3928 | Impact Factor: 9.50
http://zapjournals.com/Journals/index.php/aijmse
Published By: Zendo Academic Publishing

ANALYSIS OF THE INHIBITORY WORTH OF NONI (*MORINDA CITRIFOLIA)* FRUIT JUICE ON CORROSION OF COOKWARE ALUMINUM BY ITS CHEMICAL COMPONENTS

[1]T.N. Guma and Aliyu Musa
Email: tnguma@nda.edu.ng

Article Info
Keywords: Cookware aluminium, Corrosion issues, Preventive methods, Plant inhibitors, Several benefits, Noni juice, Corrosion inhibitability, Chemical components, Component analyses
DOI
10.5281/zenodo.16536576

Abstract
Corrosion of aluminum cookware has been a major issue in medical, food processing, and engineering fields. Owing to their numerous advantages and overall environmental friendliness, plant extracts are being increasingly investigated as possible corrosion inhibitors. This paper provides basic information on the inhibitory worth of pure noni fruit juice on the corrosion of aluminum cookware by analyzing the chemical species present in the juice. Chemical analysis of the juice was separately carried out using XRD, XRF, and FTIR as supplementary techniques for better results and confidence. The analysis shows that the fruit juice consists of several mineral elements and their oxides, as well as many complex organic and inorganic compounds. Most of the elements in the juice promote aluminum corrosion inhibition, and most of the oxides have high inhibitory effects on aluminum corrosion by creating or maintaining protective oxide films on its surface. Many of the chemical compounds in the juice are composed of nitrogen, sulfur, oxygen, and their heteroatoms, as well as aromatic hydrocarbons, which have corrosion-inhibiting properties on aluminum in alkaline or acidic media by effectively adsorbing onto its surface to create or maintain protective barriers. The analysis concludes that the fruit juice is highly corrosion-inhibitory on aluminum cookware. This information encourages all research interests and works aimed at developing noni fruit juice as a corrosion inhibitor of cookware aluminum.

1.0 INTRODUCTION

Cookware aluminum refers to aluminum alloys, such as AA 6061 and AA 6063, which are usually used for producing cooking utensils, such as pots and pans. [1-6]. As aluminum alloys, cookware aluminum has greater

[1] Department of Mechanical Engineering, Faculty of Engineering and Technology, Nigerian Defence Academy, Kaduna, Nigeria

strength and stability than pure aluminum, but it is less corrosion-resistant than pure aluminum. Cookware aluminum and its products are frequently processed and used in corrosive environments such as hot, chloride, acidic, and alkaline water, food, and general environments. Corrosion of aluminum cookware can be an unavoidable source of aluminum intake into the human body system along with food, resulting in health issues such as Alzheimer’s disease, organ failure, cancer, infertility, anemia, osteomalacia, dementia, and other chronic ailments. Corrosion of aluminum cookware has been a serious concern in medical, food processing, and engineering fields [1-3, 6-12]. Acidic foods, such as citrus fruits, tomatoes, and vinegar-based sauces, can cause pernicious substances from aluminum cookware to leach into food. High temperatures, improper cleaning methods, salty foods, and general environmental exposure to acidic, alkaline, and chloride conditions can also cause the cookware to leach. Discoloration, pitting, and even small holes are common indicators of corrosion of aluminum cookware [1-3, 6-12]. Several methods, including anodizing, applying protective coatings, ensuring proper cleaning and storage, and using corrosion inhibitors, are commonly used to prevent the corrosion of aluminum cookware [3, 6, 13]. These techniques help to create a barrier against corrosive elements, which reduces the rate of corrosion. The use of corrosion inhibitors that slow down or prevent corrosion of aluminum cookware can be beneficial, especially in high-exposure aqueous environments [14-15]. Organic corrosion inhibitors such as azole derivatives, mercapto compounds, quinolines, and certain organic dyes containing heteroatoms like nitrogen or sulfur can adsorb onto the aluminum surface, forming a barrier against corrosive agents. The stability of the protective aluminum oxide layer in media with various pH levels is crucial. Citric acid can act as an efficient inhibitor in alkaline environments. However, in acidic conditions, mixtures such as 3-amino-5-alkyl-1, 2,4-triazoles and aminotris(methylenephosphonic acid) can be used. Applying a protective coating, such as epoxy powder coating, provides a physical barrier against the corrosion of aluminum cookware [15-19].

Plant extracts offer several advantages as corrosion inhibitors for aluminum cookware. The advantages include eco-friendliness, renewability, biodegradability, and low cost. They are also less toxic than traditional chemical inhibitors and can be easily obtained and processed. Several plant extracts have shown promise as corrosion inhibitors for aluminum in cookware, with some demonstrating higher effectiveness than others depending on the specific environment. For example, M. oleifera extract has shown excellent corrosion inhibition in acidic solutions. Tulsi (holy basil) extract has been found to be more effective than green tea extract in alkaline solutions. Curcumin, found in turmeric, has shown promise as a green corrosion inhibitor for aluminum in food-related applications. Curcumin can significantly reduce aluminum leaching into food solutions, especially at cooking temperatures. Pomegranate peel extract, which is rich in polyphenols, has shown excellent corrosion inhibition in saline solutions. Laurus nobilis (bay leaf) extract effectively prevents aluminum corrosion in saline solutions. Green tea and tulsi (holy basil) extracts are more effective than green tea extract in alkaline solutions. A wide variety of other plant extracts, including those from sunflower seed hulls, ginkgo leaves, and others, have been explored as potential corrosion inhibitors for cookware aluminum [14-19]. When using corrosion inhibitors, including plant extracts for cookware, it is important that they do not affect food safety and do not impart any undesirable taste or odor to food [1-3, 6-8]. Differences in seasonal times and geographical location of plants, as well as the maturity or ripening stages of their parts, such as fruits, can lead to significant variations in the chemical composition of extracted juice from plant parts. In addition, different extraction methods can result in different concentrations of active compounds in the extracted juice and differences in the juices' effectiveness when used as inhibitors for protecting metals from corrosion [15-25].

Noni fruit juice is an extract from the fruit of the noni tree. The tree can grow to about 3–10 m in height, and it is common in Nigeria and other tropical regions. The leaves and fruit of the tree are traditional food in many cultures near where they grow, such as in Southeast Asia and the Pacific Islands. Fruit juice is derived from the tree and has been widely used in traditional medicine for over 40 ailments in tropical zones owing to its antibacterial, antitumor, anthelminthic, analgesic, anti-inflammatory, and immunostimulant properties [20-31]. It has increasingly become popular in many countries owing to its health benefits. Natural fermentation is the most popular traditional method of producing the fruit juice. The juice is as follows [20-31]:

i. Rich in antioxidants, which help protect cells from free radical damage.
ii. Helps to modulate the immune system.
iii. Used traditionally to manage pain associated with conditions such as arthritis.
iv. Can alleviate constipation, diarrhea, and irritable bowel syndrome symptoms.
v. Supports heart health, particularly for smokers.
vi. Curative effects on blood sugar levels, blood pressure, and cancer

The composition of noni fruit juice is chemically complex, as reported by several researchers using various analytical techniques [20-31]. However, no individual technique of chemical analysis has been found perfect or ideal for such analytical situations. Techniques may be used to complement one another for better results in chemical analyses of materials than using one technique [32-34]. X-ray diffraction (XRD), X-ray fluorescence (XRF), and Fourier transform infrared spectroscopy (FTIR) are modern, versatile, and frequently used techniques of vast importance in chemical analysis of materials [32-34]. This study aims to investigate the inhibitory worth of pure noni fruit juice produced with noni fruits from noni plants grown at various locations in Nigeria as a plant juice with numerous benefits on corrosion of cookware aluminum through the analysis of chemical components found in the juice using X-ray diffraction (XRD), X-ray fluorescence (XRF), and Fourier transform infrared (FTIR) techniques.

2.0 A LITERATURE REVIEW ON CHEMICAL COMPOSITION OF NONI FRUIT JUICE

Several different studies by researchers, such as Meng et al. [20], Youn and Chang [21], Kim et al. [22], Luján et al. [23], Samarasinghe et al. [24], Zhou and Huang [25], Ndiaye et al. [26], Wei et al. [27] , Ali et al. [28], Samoylenko et al. [29], Su et al. [30], and Shettima et al. [31] using various methods of chemical analysis such as atomic absorption spectrophotometry coupled with CCD detection, chromatographic techniques like High-Performance Liquid Chromatography (HPLC) and Gas Chromatography (GC), coupled with Mass Spectrometry (MS), etc. have reported that the noni plant is rich in various bioactive compounds, including polysaccharides, xeronin**,** scopoletin, β-D-glycopyranose pentacetate**,** vitamins, minerals, and other phytochemicals like anthraquinones, flavonoids, and phenolic compounds. Specific components in fruit juice include glucuronic acid, galactose, arabinose, rhamnose, glycosides, phenylpropanoids, terpenoids, trisaccharides, fatty acids, and their esters. The juice also contains xeronine, terpenes, essential oils, and resins. Polysaccharides include glucuronic acid, galactose, arabinose, rhamnose, glycosides, and a trisaccharide fatty acid ester. Scopoletin is a coumarin derivative with potential health benefits. Several minerals and vitamins, including magnesium, iron, manganese, potassium, phosphorus, selenium, sodium, nickel, lead, mercury, arsenic, cadmium, calcium, chromium, zinc, copper, sulfur, and vitamin C, have reportedly been found in the fruit juice. Other phytochemicals present in the fruit juice include phenolic compounds, alkaloids, steroids, resins of β-sitosterols, rubichloric acid, chrysophanol, and ursolic acid. Terpenes include asperuloside, aucubin, and asperuloside tetraacetate. Essential oils, various types and quantities of fatty and amino acids, and organic acids, such as citric acid, malic acid, and ascorbic acid, are also found in the fruit juice. The antioxidant properties of the juice are attributed to scopoletin, rutin, and other phenolic compounds. However, variations in the results of the chemical analysis of the noni juice by the researchers can be attributed to differences in the ripeness or maturity stage of the fruit used, the location where the fruits are harvested, the part of the noni tree used for the juice extraction, the chemical analysis technique used, and the juice extraction techniques, such as fermentation, pasteurization, hydro-methanolic, and hot and cold extraction techniques [20-30].

3.0 METHODOLOGY

3.1 Materials

The study used fresh noni fruits of different ripening stages harvested from 15 different parts of Nigeria and purchased from the sellers at Kaduna Central Market in Kaduna City, Nigeria. Plate I shows a view of the noni fruits purchased for the study.

Plate I: View of the purchased noni fruits

3.2 Extraction of Noni Fruit Juice from Purchased Fruits

The acquired noni fruits were thoroughly rinsed under clean running tap water to remove any dirt or debris on them. The cleaned fruits were chopped into small pieces with a clean stainless-steel knife, and placed in a clean blender and blended until a smooth pulp was formed. The pulp was then slowly poured onto a strainer with a mesh size of 200 that was properly secured in place over a sterile, clean plastic bowl. The pulp was filtered into fine particles of approximately 74 microns, and approximately two liters of the filtered juice were collected and kept in a clean glass container before chemical analysis of the juice.

3.3 Chemical Analysis of the Extracted Noni Juice

3.3.1 XRD technique

The chemical analysis of the pure noni fruit juice extract by X-ray diffraction (XRD) was conducted at room temperature at the Nigerian Institute for Chemical Research Technology (NARICT) Zaria using a Japanese-made Shimadzu 1200 model diffractometer with counter monochromatic Cu-Ka radiation from a Cu tube of wavelength 0.1406 nm in accordance with the facility's manual, sample positioning, and calibration. The voltage and current settings were set to 40 kV and 30 mA, respectively. The produced noni fruit juice was placed in a suitable quantity in the specimen-holding container of the diffractometer according to the manufacturer's instructions. The noni juice sample was examined in a continuous mode across the goniometer angle range of 2-theta (2) = 0°–60°. The scanning speed, sampling pitch, and preset time were 2-70/min, 0.02°, and 0.17 s, respectively. The diffractogram, reference peak intensities, reference high- and low-intensity peaks, performed search, match, and accept information, and analysed chemical compositions of the noni fruit juice were produced using the integral computer accessory of the diffractometer. This was repeated three times, and the consistent results at least twice were taken as the XRD-analyzed chemical composition of the noni fruit juice. Plate II shows a glass container sample of the extracted noni fruit juice used for the analysis.

Plate II shows the noni fruit juice extracted in a glass container.

3.3.2 XRF technique

The chemical analysis of the extracted noni juice using the X-ray fluorescence (XRF) technique was also conducted at the NARICT but with an XRF spectrometer made by Skyray Instruments USA Inc. The spectrometer was used to generate and focus high-energy X-rays from the spectrometer onto the noni juice sample contained in a holder in the X-ray tube of the spectrometer. This ionized the different chemical species in the noni fruit sample and caused each of them to emit secondary X-rays of distinct wavelengths and energy characteristics. The integral computer of the spectrometer automatically processed the distinct wavelength characteristics using its library of information on such wavelength and energy characteristics as stored in its memory for various chemical elements and groups. The various identified chemical groups present in the juice sample were automatically outputted, and their percentage compositions were printed. The analysis was repeated three times with different noni juice samples to account for any source of error in the analysis. Sample results that deviated from most of the rest were discarded.

3.3.3 FTIR technique

The chemical analysis of the pure noni juice extract by FTIR was conducted at the INARICT using the Shimadzu 8400-FTIR spectrometer in accordance with the facility's manual, sample positioning, and calibration requirements. When the diffractometer was properly set and operated, infrared radiation of about 10,000 to 100 cm^{-1} wave numbers was sent through the noni fruit juice sample, with some of the radiation absorbed and some passing through the sample. The absorbed radiation was set into rotational and vibrational energies by the sample molecules. The resulting energy signal at the detector is manifested as a spectrum of wave numbers, representing a sample's molecular fingerprint. Each molecule or chemical structure in noni juice produced a unique spectral fingerprint. The information was outputted and printed along with the computer's library of information on various chemical groups and their wavelengths. The printouts were used to identify the chemical compounds in the noni juice extract.

4.0 RESULTS AND DISCUSSION

4.1 Results

Table 1 and Fig. 1 show the chemical analysis results of the noni fruit juice using the XRD techniques. Tables 2 and 3 show the analysis results using the XRF technique, while the printout information from the FTIR technique is depicted in Fig. 2 and Table 4.

Table 1: Chemical components found in noni juice using XRD

S/No.	Phase name	Chemical formula	Intensity (%)
1	Bischofite	$MgCl_2.6H_20$	37.7(19)
2	Urea	CH_4N_20	19.9(13)
3	Chaoite	C	25(2)
4	Hanksite	$Na_{22}KCl\ (CO_3)_2\ (SO_4)_9$	9.2(4
5	Marialite	(Na.21 Ca0.68K0.11)	1.97(8)
6	Silicon oxide	SiO_2	6.6(6

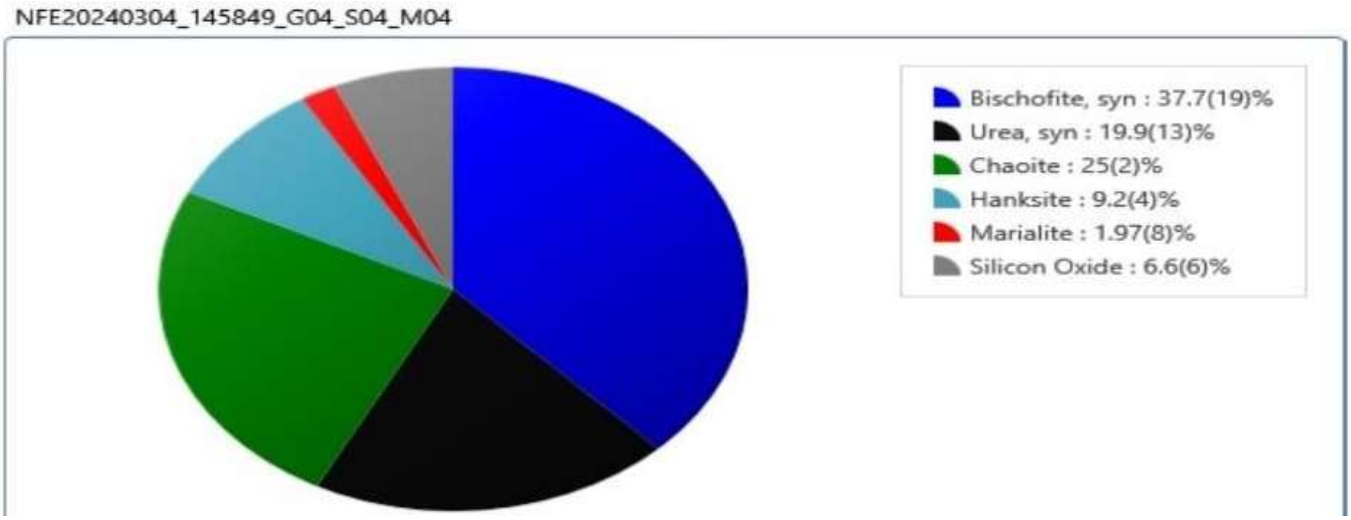


Fig. 1: Chemical analysis results of the test noni fruit juice using the XRD technique

Table 2: Elements found in noni fruit juice using the XRF technique

S/no	Element	Ratio	Intensity(c/s)	Error(c/s)	Intensity	Conc.
1	O	None	0.000	0.000	Gaussian	43.445
2	Mg	None	1.156	3.4846	Gaussian	9.783
3	Al	None	6.579	6.2025	Gaussian	5.970
4	Si	None	140.123	12.7110	Gaussian	24.769
5	P	None	2.894	6.9998	Gaussian	0.222
6	S	None	8.116	5.4301	Gaussian	0.321
7	Cl	None	159.442	14.4533	Gaussian	4.867
8	K	None	331.641	21.3993	Gaussian	7.376
9	Ca	None	73.641	11.7344	Gaussian	1.268
10	Ti	None	27.271	8.9994	Gaussian	0.213
11	V	None	0.660	8.8648	Gaussian	0.004
12	Cr	None	3.144	10.0348	Gaussian	0.014
13	Mn	None	24.789	11.7335	Gaussian	0.085
14	Fe	None	258.618	19.4650	Gaussian	0.724
15	Co	None	3.463	13.5715	Gaussian	0.008
16	Ni	None	1.866	13.7385	Gaussian	0.004
17	Cu	None	125.933	18.2859	Gaussian	0.225
18	Zn	None	51.568	17.7940	Gaussian	0.082
19	Rb	None	42.682	23.5532	Gaussian	0.058
20	Sr	None	10.419	22.3340	Gaussian	0.016
21	Zr	None	12.344	22.4281	Gaussian	0.023
22	Nb	None	60.960	23.0249	Gaussian	0.126
23	Mo	None	22.121	21.6437	Gaussian	0.047
24	Ag	None	8.827	15.6898	Gaussian	0.197
25	Sn	None	1.260	20.3043	Gaussian	0.088
26	Ba	None	0.000	8.3857	Gaussian	0.000
27	Ta	None	6.605	19.1354	Gaussian	0.043
28	W	None	3.440	20.0044	Gaussian	0.021

Table 3: Chemical species found in noni fruit juice using XRF techniques

S/no	Chemical specie	Concentration	Error	Mole (%)	Error	Unit
1	SiO_2	52.989	4.807	52.084	4.725	wt. %
2	V2O5	0.007	0.090	0.002	0.029	wt. %
3	Cr_2O_3	0.020	0.064	0.008	0.025	wt. %
4	MnO	0.109	0.052	0.091	0.043	wt. %
5	Fe_2O_3	1.035	0.078	0.383	0.029	wt. %
6	Co_3O_4	0.011	0.043	0.003	0.011	wt. %
7	NiO	0.005	0.036	0.004	0.029	wt. %
8	CuO	0.281	0.041	0.209	0.030	wt. %
9	Nb_20_3	0.159	0.060	0.040	0.015	wt. %
10	MoO_3	0.071	0.069	0.029	0.028	wt. %
11	WO_3	0.026	0.154	0.007	0.039	wt. %
12	P2O3	0.510	1.233	0.212	0.513	wt. %
13	SO_3	0.802	0.537	0.592	0.396	wt. %
14	CaO	1.774	0.283	1.869	0.298	wt. %
15	MgO	16..221	48.888	23.769	71.635	wt. %
16	K_2O	8.885	0.573	5.571	0.359	wt. %
17	BaO	0.000	0.000	0.000	0.000	wt. %
18	Al_2O_3	11.280	10.635	6.534	6.160	wt. %
19	Ta_2O_5	0.052	0.151	0.007	0.020	wt. %
20	TiO_2	0.355	0.117	0.263	0.087	wt. %
21	ZnO	0.102	0.035	0.074	0.026	wt. %
22	Ag_2O	0.211	0.376	0.054	0.096	wt. %
23	Cl	4.867	0.441	8.107	0.735	wt. %

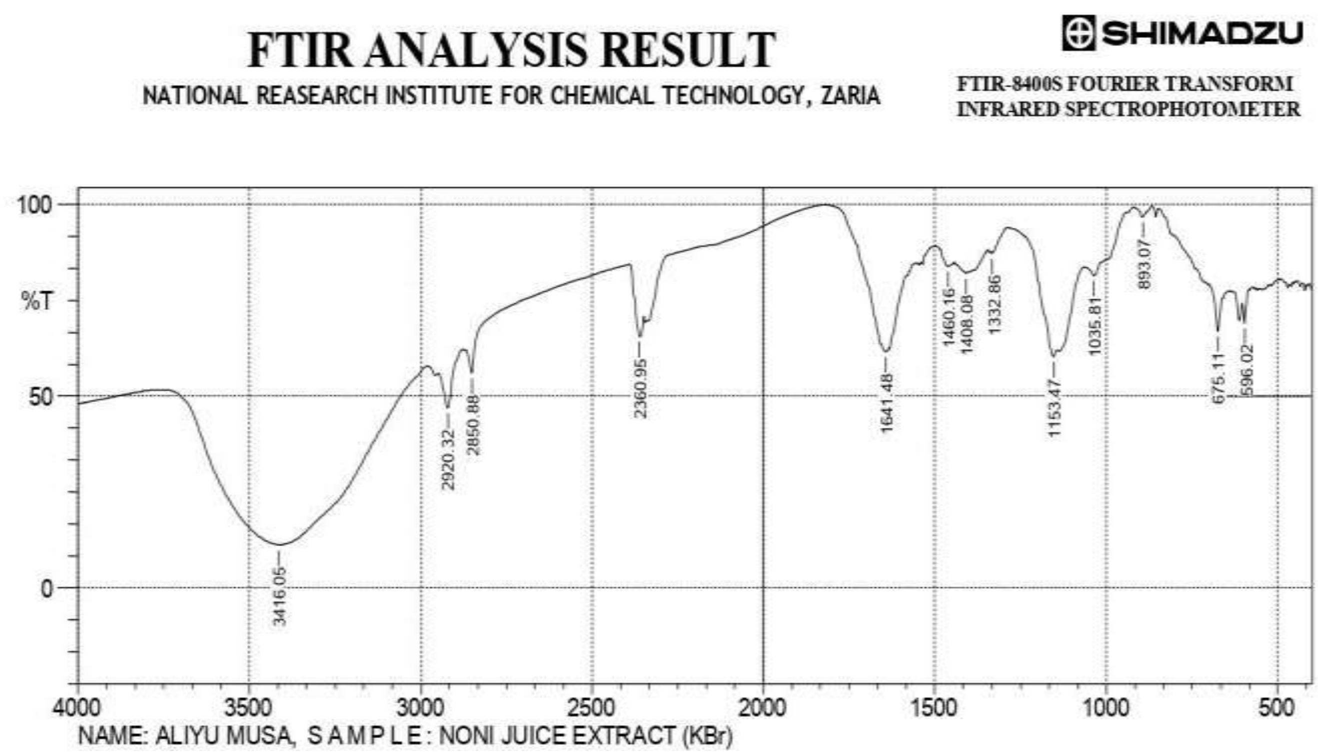


Fig. 2: Print-out wavelength pattern of chemical species in the noni fruit juice sample obtained using the FTIR technique

Table 4: Interpretative results for the FTIR technique wavelength pattern of the noni fruit juice

CHARACTERISTIC INFRARED ABSORPTION BANDS OF FUNCTIONAL GROUPS

Class of Compounds	Absorption, cm^{-1}	Intensity	Assignment
Alkanes and **Alkyls**	2850-3000	s	C-H stretch
	1450-1470	s	C-H bend
	1370-1390	m	CH_3 C-H bend
	1365 + 1395 (two bands)	m	$-CH(CH_3)_2$ or $-(CH_3)_3$ bend
	715-725	w	$-(CH_2)_n$ bend
Alkenes	3020-3140	w-m	=C-H stretch
	1640-1670	vw-m	C=C stretch
$RCH=CH_2$	910 + 990 (two bands)	m + s	=C-H bend
$RR'C=CH_2$	885-895	s	=C-H bend
cis-RCH=CHR'	665-730	m-s, broad	=C-H bend
trans-RCH=CHR'	960-980	s	=C-H bend
RCH=CR'R"	790-840	s	=C-H bend
Alkynes			
R-C≡C-H	3265-3335	s, sharp	≡C-H stretch
	2100-2140	m	C≡C stretch
	610-700	s, broad	≡C-H bend
R-C≡C-R'	2190-2260	vw-w	C≡C stretch
Alkyl halides			
R-F	1000-1350	vs	C-F stretch
R-Cl	750-850	s	C-Cl stretch
R-Br	500-680	s	C-Br stretch
R-I	200-500	s	C-I stretch
Alcohols	3300-3400	s, broad	O-H stretch
$C=C-CH_2-OH$	1035-1050	m-s	C-O stretch
$R-CH_2-OH$ (1°) or C=C-CH(R)-OH	1050-1085	m-s	C-O stretch
RR'CH-OH (2°) or C=C-CRR'-OH	1085-1125	m-s	C-O stretch
RR'R"C-OH (3°)	1125-1205	m-s	C-O stretch
Ar-O-H	1180-1260	m-s	C-O stretch
Ethers			
R-O-R'	1085-1150	s	C-O-C stretch
Ar-O-R	1020-1075 and 1200-1275 (two band)	m-s	=C-O-C sym. & asym. stretch
Aldehydes	2700-2725	m	H-C=O stretch
R-CH=O	1720-1740	s	C=O stretch
C=C-CH=O or Ar-CH=O	1685-1710	s	C=O stretch
Ketones			
RR'C=O	1710-1720	s	C=O stretch
C=C-C(O)-R	1665-1685	s	C=O stretch
Ar-C(O)-R	1675-1695	s	C=O stretch
four member cyclic	1770-1780	s	C=O stretch
five member cyclic	1740-1755	s	C=O stretch
six member cyclic	1710-1720	s	C=O stretch

Class of Compounds	Absorption, cm^{-1}	Intensity	Assignment
Carboxylic Acids	2500-3500	s, broad	O-H stretch
R-C(O)-OH	1710-1715	s, broad	C=O stretch
C=C-C(O)-OH or Ar-C(O)-OH	1680-1710	s	C=O stretch
Esters	aliphatic 1160-1210 acetates ~1240 aromatic 1250-1310	s-vs	O=C-O-C stretch
R-C(O)-O-R	1735-1750	s	C=O stretch
C=C-C(O)-O-R or Ar-C(O)-O-R	1715-1730	s	C=O stretch
R-C(O)-O-Ar	1760-1790	s	C=O stretch
Acyl Chlorides			
R-C(O)-Cl	1785-1815	s	C=O stretch
Ar-C(O)-Cl	1770-1800	s	C=O stretch
Anhydrides			
R-C(O)-O-C(O)-R	~1750 + ~1815	s,s	C=O symmet
Ar-C(O)-O-C(O)-Ar	~1720 + ~1775 (both two bands)	s,s	& asym. stret
Nitriles			
R-C≡N	2240-2260	m-s	C≡N stretch
C=C-C≡N or Ar-C≡N	2220-2240	s	C≡N stretch
Amines			
$R-NH_2$	~3400 + ~3500 (two bands)	w	N-H symmet & asym. stret
	1580-1650	w-m	N-H bend
RR'N-H	3310-33350	w	N-H stretch
Amides			
$R-C(O)-NH_2$	3200-3400 and 3400-3500 (two bands)	w-m	N-H symmet & asym. stret
	1650-1690	s, broad	C=O stretch
	1590-1655	m-s	N-H bend
R-C(O)-NH-R	3400-3500	w-m	N-H stretch
	1640-1690	s, broad	C=O stretch
	1510-1560	m-s	N-H bend
R-C(O)-NR'R"	1630-1680	m-s	C=O stretch
Nitro Compounds			
$R-NO_2$	~1550 and ~1370	s s	N-O symmet & asym. stret
$C=C-NO_2$ or $Ar-NO_2$	~1525 and ~1335 (both two bands)	s s	N-O symmet & asym. stret
Aromatic Compounds	3010-3100	m	Ar C-H stretc
	1450-1600 (two to four bands)	m-s sharp	ring C=C stre
monosubstituted	730-770 and 690-710 (two bands)	s s	C-H bend C-H bend
o-disubstituted	735-770	s	C-H bend
m-disubstituted	750-810 and 690-710	s s	C-H bend C-H bend
p-disubstituted	810-840	s	C-H bend

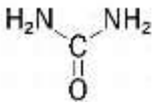
Intensity abbreviations: vw = very weak, w = weak, m = medium, s = strong, vs = very strong

4.2 Discussions

4.2.1 XRD results shown in Table 1 and Fig.1

Table 1 and Fig. 1 show that the noni fruit juice produced in this study contains bischofite, urea, chaoite, hanksite, marialite, and silicon oxide with intensities of 37.6%, 19.9%, 25%, 9.9%, 1.97%, and 6.6%, respectively, as obtained by XRD.

Bischofite ($MgCl_2.6H_2O$) can offer corrosion protection when used with some additives. For example, a 24% $MgCl_2$ bischofite solution with 0.1% KI-1M corrosion inhibitor provides 99.6% corrosion protection to industrial gas pipelines. The chemical formula of urea is CO (NH2)2, and it can also be written as CH4N2O. It is an organic compound also known as carbamide and is the main nitrogenous end product of protein metabolism in many animals.



Urea contains nitrogen and oxygen, which common elements are found in very effective organic corrosion inhibitors for aluminum and most other metals, making it potentially suitable for this purpose [35]. Urea can act as a corrosion inhibitor for aluminum under certain conditions, but its effectiveness is limited and depends on the specific environment and concentrations. Urea alone inhibits aluminum corrosion, but it is often more effective when combined with other substances, such as zinc ions [36].

Chaoite, also known as white carbon, is a disputed allotrope of carbon, and its existence has not been confirmed definitively. It is believed to have a carbyne structure, which is a linear, chain-like structure of carbon atoms, but its chemical formula is not definitively established. According to some sources, it is C, while others propose a more complex formula related to its formation environment (shock-fused graphite gneiss). It is not typically known for its corrosion-inhibiting properties on aluminum.

Hanksite is a rare mineral. Its chemical formula is $Na_{22}K(SO_4)_9(CO_3)_2Cl$. It has a hexagonal crystal structure and contains sodium (Na) and potassium (K). It also contains sulfate (SO_4), carbonate (CO_3), and chloride (Cl) ions. There is no scientific literature or research on the corrosion inhibition of aluminum by hanksite [38].

Marialite is a scapolite mineral group member with the chemical formula $Na_4Al_3Si_9O_{24}Cl$ as a pure endmember, or $Na_4 (AlSi_3O_8)_3(Cl_2,CO_3,SO_4)$ with increasing meionite (Ca-rich scapolite) content. It is a tectosilicate with a framework structure composed of interconnected [SiO_4] and [AlO_4] tetrahedra, with the spaces occupied by the framework occupied by sodium and chloride ions. Marialite is not typically associated with aluminum corrosion inhibition [39].

Silicon dioxide has the chemical formula of SiO_2. It is the major constituent of sand in many parts of the world and is commonly found as quartz in nature. It enhances the corrosion resistance of aluminum by forming a protective layer similar to that of naturally occurring aluminum oxide and acts as a barrier against corrosive agents in the environment. Therefore, the presence of silicon, either as a component of the aluminum alloy or as an environmental component, can promote the formation of a more robust and stable oxide layer on an aluminum metal surface, thereby improving its corrosion resistance [40].

4.2.2 XRF results shown in Tables 2 and 3

Table 2 shows that the noni fruit contains 28 chemical elements of various quantities, 27 of which, except oxygen, are minerals. Mineral elements, particularly in their ion forms, have been shown to have a substantial impact on the corrosion of aluminum metal by either promoting or assisting its inhibition, depending on their kinds, quantities, and particular conditions. Chromium, molybdenum, and tungsten, for instance, are known for effectively limiting the corrosion of aluminum metals in various environments [41-45]. Iron and magnesium aid in increasing the corrosion resistance of aluminum metal. The corrosion resistance of aluminum metal is improved by potassium in the form of a majority of compounds, such as potassium permanganate ($KMnO_4$) and potassium sorbate, but it is reduced when potassium is present in the form of hydroxides and chlorides. Copper generally decreases the corrosion resistance of aluminum and makes it susceptible to intergranular corrosion under certain conditions. Zinc increases the corrosion resistance of aluminum metal, but it sometimes leads to less corrosion resistance of the metal due to the formation of zinc-rich phases, which are more corrosion-prone sites. In general, vanadium increases the corrosion resistance of aluminum alloys by refining their grains and improving their passive films. Titanium enhances the corrosion inhibition of aluminum alloys by increasing their anodic stability in certain electrolytes. Molybdenum can act as a corrosion inhibitor of aluminum alloys in corrosive media with different pH levels. Silicon can improve the corrosion resistance of aluminum by promoting continuous passivation. By encouraging constant passivation, silicon can increase the corrosion resistance of aluminum alloys. Tin inhibits the corrosion of aluminum alloys by reducing the number of precipitate-free zones and refining the grain boundaries on the alloys. It can also form tin-accumulated layers between passive films and aluminum alloys, which inhibit cathodic reactions on the alloys. Nickel inhibits the general corrosion of certain aluminum alloys by improving the microstructure and even distribution of intermetallic particles, promoting the development of protective corrosion layers, and slowing down the corrosion reaction rates. In some aluminum alloys, sulfur is commonly linked to the formation of toxic phases, such as sulfides, which may increase the alloys' corrosion susceptibility. Sulfur is also frequently associated with the development of harmful phases, such as sulfides, which may increase the corrosion proneness of certain aluminum alloys. Phosphorus functions as an impurity in most metals and can reduce the resistance of an aluminum alloy to corrosion [41-45]. It is evident from the foregoing discussion that the majority of minerals in noni fruit juice can greatly contribute to its impact as a corrosion inhibitor of cookware aluminum under most conditions.

Table 3 shows that the noni fruit juice contains 23 oxides, most of which are oxides of different mineral contents. Although aluminum metal can naturally form a protective aluminum oxide (Al_2O_3) film, the presence of certain mineral oxides and related compounds can further enhance or modify its protection, particularly under aggressive environmental conditions where the natural oxide layer may be compromised. Some of the oxides in the noni fruit juice are components of chromate, molybdate, phosphates, tungstate, etc., which are well known for their high inhibitory effect on the corrosion of aluminum metal by forming protective oxide films on the metal surface or influencing the stability of any protective oxide film on the metal. Some of the oxides can also be part of more complex chemical components that are composed of nitrogen, sulfur, oxygen, and their heteroatoms, as well as aromatic hydrocarbons, which have corrosion-inhibiting properties on aluminum in alkaline or acidic media by effectively adsorbing onto its surface to create or maintain protective

Barriers [46]. A more detailed analysis of the oxides in noni fruit juice from relevant literature shows that

Cr_2O_3 contributes to the formation of a protective, passive chromium oxide layer on the aluminum surface that acts as a barrier against corrosive substances, such as water and oxygen, to slow down the corrosion process [46, 47].

Titanium dioxide (TiO_2) can inhibit aluminum corrosion primarily by forming a protective layer on the metal's surface and modifying the surface properties. This protective layer, often an oxide film, can prevent corrosive agents from reaching the aluminum and initiating corrosion [46, 48].

Vanadium pentoxide (V_2O_5) can inhibit aluminum corrosion by forming a protective film on the metal's surface, especially in acidic environments. This film, which is composed of vanadium-containing compounds, inhibits both the anodic dissolution of aluminum and the cathodic reactions involved in corrosion [46-49].

Silver oxide (Ag_2O) can have an inhibitory effect on aluminum corrosion through the formation of a protective layer on the metal surface that is composed of silver oxide and acts as a barrier that prevents the ingress of corrosive substances from reaching the aluminum to corrode it further [47-50].

Zinc oxide (ZnO) can be an effective corrosion inhibitor of aluminum, particularly in alkaline and acidic environments, by depositing a protective layer on the aluminum surface that inhibits the corrosion process [47-51].

Cobalt oxide (Co_3O_4) can act as a corrosion inhibitor for aluminum, thereby protecting aluminum from corrosion. This protection is achieved by forming a protective layer on the aluminum surface, which can reduce the corrosion rate [48-52].

While aluminum is known for its natural corrosion resistance due to the protective aluminum oxide film, iron oxide (Fe_2O_3) is not typically used as a corrosion inhibitor for aluminum and can even accelerate corrosion under certain conditions. Iron ions (Fe^{3+}) can promote aluminum corrosion [47-51].

Phosphorus trioxide (P_2O_3) is not a known corrosion inhibitor of aluminum. It can be corrosive to aluminum under certain conditions, particularly in the presence of moisture.

Chloride ions (Cl^-) can accelerate aluminum corrosion by penetrating and dissolving the protective oxide layer on its surface, leading to pitting and other forms of corrosion. Corrosion inhibitors, which are often organic compounds with specific functional groups, can be used to mitigate this effect by adsorbing onto the aluminum surface and hindering the access of chloride ions to the metal [1-3].

Sulfur trioxide (SO_3) is generally not a corrosion inhibitor of aluminum. It can even cause aluminum corrosion, particularly in humid environments, by reacting with water to form sulfuric acid, which is corrosive to aluminum and can disrupt its protective layer [47-52].

Manganese oxide (MnO) acts as a corrosion inhibitor for aluminum, particularly in alkaline environments, by forming a protective layer on the aluminum surface. This protective layer, often an oxide, can hinder the corrosive attack of aluminum [48-53].

NiO (nickel oxide) acts as a corrosion inhibitor for aluminum, primarily by forming a protective oxide layer on the aluminum surface and by adsorbing onto the aluminum surface, hindering corrosive attack. This protective layer can significantly reduce the corrosion rate of aluminum in various environments [48-53].

Copper oxide (CuO) can act as a corrosion inhibitor for aluminum and its alloys, with its effectiveness depending on factors such as concentration, dispersibility, and the specific corrosive environment [48-53].

Niobium oxide (Nb_2O_5) can prevent the corrosion of aluminum by creating a natural protective layer on the metal when it is exposed to air or certain harmful substances or by forming a layer on the metal surface through the adsorption of Nb_2O_5 or its compounds [48-53].

Molybdenum trioxide (MoO_3) can inhibit aluminum corrosion, particularly when incorporated into coatings or used as a conversion coating. It is usable in various forms, such as a pigment in coatings, a component in pretreatments, or as a conversion coating [49-54].

WO_3 (tungsten trioxide) can inhibit aluminum corrosion by forming a WO_3 protective surface layer on the metal surface, which hinders the corrosive effects of some environments.

Calcium oxide (CaO) can inhibit aluminum corrosion, particularly in alkaline solutions, by forming a protective layer on the aluminum surface, which reduces the corrosion rate by limiting the access of corrosive agents to the aluminum surface [50-55].

+-MgO can aid in the corrosion inhibition of aluminum metal by improving the metal's resistance to corrosion in certain environments by aiding the formation of a protective layer, often a composite with aluminum oxide that reduces the interaction between the aluminum and the corrosive medium [48-53].

Potassium oxide (K_2O) can help in the corrosion protection of aluminum, especially in alkaline conditions, by encouraging the development of a protective oxide layer that prevents additional corrosion on the aluminum surface. However, by making the solution more alkaline, which dissolves the protective coating of aluminum oxide, K_2O can actually speed up corrosion in acidic conditions [50-55].

Barium oxides, particularly barium metaborate, can act as corrosion inhibitors for aluminum and its alloys, enhancing their corrosion resistance in various media. They form a protective barrier on the metal surface or influence the formation of a protective oxide layer [53-55].

Aluminum oxide (Al_2O_3), naturally formed on aluminum surfaces, acts as a corrosion inhibitor by creating a protective barrier against further oxidation. This passive layer prevents water and oxygen from reaching the underlying aluminum, thereby hindering corrosion. [1-3, 6-8]

Tantalum pentoxide (Ta_2O_5) can act as a corrosion inhibitor for aluminum, enhancing its degradation.

4.2.3 FTIR results shown in Fig. 2

The print results of the chemical analysis of the noni fruit juice using the FTIR technique are depicted in Fig. 2 with various vibration frequency values of the critical chemical components or functional groups encountered in the noni fruit juice, alongside Table 4 for use in interpreting the printed results to know the particular chemical components or functional groups of the fruit juice. It can be observed from Fig. 2 and Table 4 that the vibration frequency of 3416.05 cm^{-1} represents an alkyl (O-H) stretch, indicating the presence of the hydroxyl (OH) group from various chemical groups such as alcohol or phenol. The presence of hydroxyl (OH) groups is known to either promote or inhibit aluminum corrosion, depending on the specific environmental conditions in which the OH group is part. of. In some cases, it can contribute to forming a protective layer, while in others, it can contribute to dissolving the aluminum surface [56]. The 2920.32 cm^{-1} vibration frequency indicates alkane (C-H) stretch and the presence of saturated hydrocarbons such as methylene ($-CH_2$) or methyl ($-CH_3$) groups. Alkanes, methylene (-CH2-), and methyl (-CH3) groups are known to be influential in the corrosion inhibition of aluminum by facilitating adsorption onto the aluminum surface that forms protective layers against corrosive species, depending on their concentrations, positions, and the presence of other functional groups within their molecules [56, 57]. The 2850.88 cm^{-1} vibration frequency is that of alkane (C-H) stretch, further indicating the presence of saturated hydrocarbons. These hydrocarbons are known to assist in the corrosion inhibition of Al by creating a barrier that resists the ingress of corrosive agents [56-58]. The 2260.95 cm^{-1} vibration frequency is that of alkyl (C-N) stretch, indicating cyano (-CN) or isocyanide (-NC) groups. Cyano (-CN) and isocyanide (-NC) groups can also inhibit the corrosion of aluminum by adsorbing or forming a protective barrier against corrosion on the metal surface [57-59]. The vibration frequency of 1641.48 cm^{-1} is that of the alkene (C=C) stretch, indicating the presence of unsaturated hydrocarbons, such as alkenes or alkynes. These hydrocarbons can adsorb on the metal surface and create a barrier that reduces the contact between the aluminum surface and the corrosive environment [57-60]. The vibration frequency of 1469.16 cm^{-1} is that of the amide (C-N) stretch, indicating the presence of amide ($C-CONH_2$) or amine ($-NH_2$) groups. Both amides and amines assist in the corrosion inhibition of aluminum by forming a protective film or adsorbent, respectively, on the metal surface with their nitrogen atoms. [58-60] The vibration frequency of 1408.98 cm^{-1} is that of fluoride (C-F) stretch, indicating the presence of fluorine-containing compounds. Fluorine-containing compounds can aid in forming a protective layer of aluminum fluoride compound on the metal surface that prevents the ingress of various corrosive agents, such as salt water and acidic solutions [49-55]. The vibration frequency of 1332.98 cm^{-1} is that of the amine (C-N) stretch, indicating amine groups. The vibration frequency of 1153.47 cm^{-1} is that of the carboxylic acid (C-O) stretch, indicating the presence of carboxyl (-COOH) groups. Carboxylic acid groups (-COOH) are known to inhibit aluminum corrosion in alkaline and other environmental conditions by binding and forming a protective layer on the aluminum surface that prevents or reduces corrosion. The vibration frequency of 1035.81 cm^{-1} is that of the sulfonyl chloride (S-O) stretch, indicating sulfonyl chloride ($-SO_2Cl$) groups. Sulfonyl chloride (-SO2Cl) groups are not typically corrosion inhibitors for aluminum; however, they can act as corrosion inhibitors by adsorbing onto the aluminum surface when they are part of larger molecules that form a protective film that blocks corrosive agents [50, 51]. The vibration frequency of 679.11 cm^{-1} is that of chloride (C-Cl) stretch, indicating the presence of chlorine-containing compounds. Chlorine-containing compounds can aggravate aluminum corrosion because chloride ions can greatly attack the metal surface, especially pits, including its protective oxide layer [1-3, 6-8]. The vibration frequency of 596.02 cm^{-1} is that of the bromide (C-Br) stretch, indicating the presence of bromine-containing compounds. Bromine-containing compounds inhibit aluminum corrosion in acidic environments by adsorbing onto the aluminum surface to form protective barriers that reduce the corrosion rate, depending on the concentration, temperature, and specific bromine compounds present [51, 60, 61].

5.0 CONCLUSION

The inhibitory worth of noni fruit juice produced with noni fruits from plants grown at various locations in Nigeria on the corrosion of cookware aluminum has been rudimentarily investigated by chemical analysis and assessment of chemical components found in the juice using X-ray diffraction (XRD), X-ray fluorescence (XRF) and Fourier transform infrared (FTIR) as supplementary techniques for better results and information. The results show that the noni fruit juice is chemically complex, consisting of almost all known elements, especially minerals and their various oxides, as well as organic compounds such as urea and inorganic compounds that include bischofite, hanksite, marialite, and silicon oxide. A detailed analysis of the corrosion inhibitory capabilities of the chemical species indicates that fruit juice has a very high inhibitory effect on the corrosion of aluminum cookware. Most of the element contents and their various oxides, as well as chemical compounds present in the juice, have the potential to inhibit the corrosion of cookware aluminum. Most of its chemical compounds, such as bischofite, urea, chaoite, hanksite, and marialite, contain nitrogen, oxygen, sulfur, and their heteroatoms, as well as aromatic hydrocarbons that can effectively inhibit the corrosion of cookware aluminum by adsorbing onto the metal surface in various aqueous media. Most of the oxides in fruit juice are components of chromate, molybdate, phosphates, tungstate, and other chemical groups, which are well known for having a high inhibitory effect on the corrosion of aluminum metal by forming protective oxide films on the metal surface or influencing the stability of any protective oxide film on the metal. The nitrogen, oxygen, and sulfur contents of the noni fruit juice were also found to be appreciable, indicating the presence of nitrogen-containing compounds, such as amines and azoles; oxygen-containing compounds, such as carboxylic acids, such as maleic, malic, and citric acids; and sulphur-containing compounds, such as mercapto compounds, which exhibit good corrosion-inhibiting properties for aluminum in acidic or alkaline media.

References

Guma, T.N. and Durami, J.A. Assessment of alkaline food environment corrosion with some menus at a cadet mess on the tensile strength of aluminum 6063 alloy. International Journal for Research in Applied Science & Engineering Technology (IJRASET), 2019, 7(1), 621-630.

Guma, T.N., Sukuntuni, S.A. Effects of Acidic Food Environment Corrosion on Impact Strength of Aluminum 6061 Alloy: A Case Study with some Menus at a Cadets' Mess. International Journal of Engineering Trends and Technology, 67(7), No. 3., 2019, 70-78.

Guma, T. N., and Aliyu, J. Effects of Food Chloride Environment at a Canteen on Aluminum Cookware Corrosion, Hardness Integrity, and Food Safety. Nigerian Journal of Engineering, Vol. 28 No. 3, 2021, 50-55.

Guma, T.N., Uche, O.L. A Typification of Foundry Practices for Correct Artisanal Sand Casting of Aluminum Pots. International Journal of Engineering Sciences and Applied Technology, 4(4), 2019, 169-178.

Guma, T. N. & Abdulsalam, H.A. Statistical Analysis of Defective Artisanal Sand-Cast Aluminum Pots at Panteka Tudunwada in Kaduna Metropolis, Nigeria. Afe Babalola University Ado-Ekiti Journal of Engineering Research and Development (AJERD), 2020, 3(2), 86-93

Guma, T. N., & Maikudi, M. M. Corrosion of Aluminum Metal in Food Environments and its Associated Health Risk Issues: A Review. Arid Zone Journal of Engineering, Technology and Environment, 2023, 19(1), 71-84. https://azojete.com.ng/index.php/azojete/article/view/703

Ogidi, M., Sridhar, M. K. C., & Coker, A. O. (2017). A Follow-Up Study Health Risk Assessment of Heavy Metal Leachability from Household Cookwares. Journal of Food Science and Toxicology, 1(1); 3, pp. 1-9.

Al Juhaiman, L. A. (2012). Estimating aluminum leaching from aluminum cookware in different vegetable extracts. Int J Electrochem Sci 7:7283–7294.

S.A. Ali Sultan, F. Ahmed Khan, A. Wahab, B. Fatima, H. Khalid, A. Bahader, S.Z. Safi, C. Selvaraj, A. Ali, S.Y. Alomar, M. Imran Assessing Leaching of Potentially Hazardous Elements from Cookware during Cooking: A Serious Public Health Concern. Toxics. 2023 Jul 24;11(7):640. Doi: 10.3390/toxics11070640. PMID: 37505605; PMCID: PMC10386729.

Jabeen, J., Ali, B., Khan, M. A., Khan, M. B., & Hasan, S. A. (2016). Aluminum Intoxication through Food Leaching. Alexandria Science Exchange Journal, 37(4): 618-626.

Mohammad, F. S., Al Zubaidy, E. A. H., & Bassioni, G. (2019). Effect of aluminum leaching process of cooking wares on food. International Journal of Electrochemical Science, 6, 222–230 (2011).

Bondy SC. Low levels of aluminum can lead to behavioral and morphological changes associated with Alzheimer's disease and age-related neurodegeneration. Neurotoxicology. 2016 Jan; 52:222-9. Doi: 10.1016/j.neuro.2015.12.002. Epub December 12, 2015 PMID: 26687397.

Guma, T. N., Atiku, S. A., and Abdullahi, A. A. Corrosion Management and Control: Entrepreneurial Opportunities and Challenges in Nigeria, International Journal of Engineering Research and Application, 7(10), 2017, 14-23. DOI: 10.9790/9622-0710061423

Faraj, L., & Khan, G. M. Application of natural product extracts as green corrosion inhibitors for metals and alloys in acid pickling processes: a review. Int J Electrochem Sci 2015; 10:6120-6134.

Obot, I. B., & Obi-Egbedi, N. O. (2008). Fluconazole as an aluminum corrosion inhibitor in 0.1M HCl Colloids and Surfaces A: Physicochemical and Engineering Aspects, 330 (2-3), 207-212, https://doi.org/10.1016/j.colsurfa.2008.07.058

Al Juhaiman, L. (2016). Green Curcumin Extract as a Green Leaching Inhibitor from Aluminum Cookware under Quasi-Cooking Conditions. Green and Sustainable, Chemistry, 6; 57-70, Doi: 10.4236/gsc.2016.62005.

Angel, P., Raja, A.S., Sathiyabama, J., Prathipa, V. and 2014. Vitex Negundo Extract as a Green Corrosion Inhibitor for Carbon Steel in Well Water. International Journal of Chemical Studies, 2014, 2(1): 31-37.

Rani, B.E.A and Basu, B.B.J. (2012) Green inhibitors for corrosion protection of metals and alloys: an overview. International Journal of Corrosion Vol. 2012, 380217, pp. 1-15, Doi:10.1155/2012/380217

Oguzie, E. E. Corrosion inhibition of aluminum in acidic and alkaline media by S. trifasciata extract Corrosion Science, 49(3), 2007, 1527-1539, https://doi.org/10.1016/j.corsci.2006.08.009.

Meng, Y-Q., Zhang, B., Zhang, D-H., Yu, Z-X., Long, C-H., Li, S.R., Zhang, X-N., Li, X-B., and Chen, G-Y. (2019). Chemical constituents from noni (Morinda citrifolia L.) fruit juice and their chemotaxonomic significance, Biochemical Systematics and Ecology, Volume 117, 2024, 104910, https://doi.org/10.1016/j.bse.2024.104910.

U.J. Youn, L.C. Chang Chemical Constituents of Fermented Noni (Morinda citrifolia) Juice Exudates and Their Biological Activity Natural Product Sciences 23(1): 16-20 (2017). https://doi.org/10.20307/nps.2017.23.1.16.

Kim, Y., Pyeon, J., Lee, J.Y., *et al.* Chemical fingerprint analysis of M. *citrifolia* L. (Noni) juice by UHPLC Q-TOF/MS combined with chemometric analysis. Appl Biol Chem 67, 59 (2024). https://doi.org/10.1186/s13765-024-00910-w

Luján, L., Maríam, L., Assanga I, Bernard S, et al. Nutritional and Phenolic Composition of Morinda Citrifolia L. (Noni) Fruit Harvested in Nayarit, Mexico, at Different Ripeness Stages and Seasonal Patterns International Journal of Nutrition and Food Sciences, 2014, 3(5), 421-429. Doi: 10.11648/j.ijnfs.20140305.19

Samarasinghe, H.G.A.S., Gunathilake, K.D.P.P. and Illeperuma, D.C.K. Proximate composition, bioactive constituents, and therapeutic potentials of pasteurized Noni juice derived from Morinda citrifolia (L.) growing in Sri Lanka, Ceylon Journal of Science 53 (1) 2024: 87-96. https://doi.org/10.1016/j.cey.2024.07.016 DOI: http://doi.org/10.4038/cjs.v53i1.8141

Zhou, S., Huang, G. The chemical composition and pharmacological activities of *Morinda citrifolia*. *Appl Biol Chem*. 2024; 67:104. https://doi.org/10.1186/s13765-024-00960-0

Ndiaye, N., Mbaye, M., Niang, L., Dieng, M., Ayessou, N., & Touré, N. (2024). Assessment of some secondary metabolites, minerals and alcohol content of noni juice obtained by fermentation of *Morinda citrifolia* L. Fruit from Senegal *American* Journal of Plant Sciences**,** 15, 577-588, Doi: 10.4236/ajps.2024.157039.

Wei, G. J., Ho, C. T., & Huang, A. N. S. (2011). Analysis of volatile compounds in noni fruit (Morinda citrifolia L.) juice by steam distillation-extraction and solid phase microextraction coupled with GC/AED and GC/MS," Journal of Food and Drug Analysis: Vol. 19: Issue. 1, Article 7, https://doi.org/10.38212/2224-6614.2187

Ali, M., Kenganora, M. and Manjula, S.N. Health Benefits of Morinda citrifolia (Noni): A Review, Pharmacognosy Journal, 89(4), 2016, 321-334.

Samoylenko, V., Zhao, J., Dunbar, D. C., Khan, I. A., Rushing, J. W., and Muhammad, I. New Constituents from Noni (Morinda citrifolia) Fruit Juice Journal of Agricultural and Food Chemistry, American Chemical Society, 54(17), 2006, 6398-6402, Doi: 10.1021/jf060672u

Su, B. N., Pawlus, A. D., Jung, H. A., Keller, W. J., McLaughlin, J. L., & Kinghorn, A. D. Chemical Constituents of the Fruits of Morinda citrifolia (Noni) and Their Antioxidant Activity, J. Nat. Prod. Am. Chem. Soc., 68(4), 2005, 592-595, Doi: 10.1021/np0495985

Shettima, S. A., Madu, B. A., Baffa, A. A., Akinlabi, A. K. and Abdulkadir, A. S. Investigation into the Bioavailability of Some Essential Health Based Elements in Ripe and Unripe Noni Fruits (Morinda citrifolia), ncr, 28(2) 2023, 088-099, https://dx.doi.org/10.4314/njcr.v28i1

Guma, T.N., Madakson, P.B., Yawas, D.S., Aku, S.Y. X-ray diffraction analysis of the microscopies of some corrosion-protective bitumen coatings. Int. J. Mod. Eng. Res. (IJMER) 2(6), 2012, pp-4387-4395.

Guma, T. N., &Abubakar, A. A. (2020). Analysis of Steel-Corrosive Chemical Species in Nigerian Defence Academy Soil in Kaduna Metropolis Using X-Ray Fluorescence and Diffraction Techniques Uniport Journal of Engineering and Scientific Research (UJESR). Vol. 5, Special Issue, 2020, pp.140-147, http://www.ujesr.org/index.php/about/about-ujesr

Guma, T.N. and Maikudi**,** M.M**.** X-Ray diffraction and Fourier transform analyses of corrosive components of crude oils used by Kaduna refinery for corrosion control. International Journal of Engineering and Applied Physics, 2023, 3(3), 823-830, http://ijeap/article/view/164/136

Ushak, S., Marín, P., Galazutdinova, Y., Cabeza, L.F., Farid, M.M. and Grágeda, M. Compatibility of materials for macroencapsulation of inorganic phase change materials: Experimental corrosion study, Applied Thermal Engineering, Vol. 107, 2016, pp. 410-419,

https://doi.org/10.1016/j.applthermaleng.2016.06.171.

Olufunmilayo O. Joseph and Olakunle O. Joseph 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1107** 012170**DOI** 10.1088/1757-899X/1107/1/012170

Okeke, P. Electrochemical Investigation of the Corrosion Inhibition of Aluminum in KOH by Urea with KI as A Synergistic Agent. IOSR J Appl Chem 2020; 13:55-61, DOI: 10.9790/5736-1312015561

Zhang Z, Wang X, Ma X, Zheng Y, Li Y. Effect of Ga content on corrosion behavior of Mg–Zn-Ga alloys in Hank's solution, Progress in Natural Science: Materials International, 33(6), 2023, 954-964, https://doi.org/10.1016/j.pnsc.2024.01.011.

Zhou, W., Xue, F., & Li, M. (2025). Corrosion Behavior of Al-Mg Alloys with Different Alloying Element Contents in 3.5% NaCl Solution *Metals*, *15*(3), and 327. Doi: 10.3390/met15030327

Xijing, L. and Yong, C. Effect of SiO2 nanoparticles on the hardness and corrosion resistance of NiW/SiO2 nano composite coating prepared by electrodeposition, Int J Electrochem Sci, (18)6, 2023, 100138, https://doi.org/10.1016/j.ijoes.2023.100138.

Sukiman, N. L., Zhou, X., Birbilis, N., Hughes, A. E., Mol, J. M. C., Garca, S. J., Zhou, X., & Thompson, G. E. (2012). Durability and corrosion of aluminum and its alloys: Overview, property space, techniques and developments, Intech, Doi: 10.5772/53752

Idu, H. K. (2024). Effects of Si addition on the corrosion susceptibility of aluminum alloys in different concentrations of NaOH, and NaCl solutions. *Nigerian Journal of Physics*, *33*(4), 32-38. https://doi.org/10.62292/njp.v33i4.2024.312

Gabalcová, Z., Gogola P, Kusý M, Suchánek H. The Effect of Sn Addition on Zn-Al-Mg Alloy; Part II: Corrosion Behavior. Materials (Basel). 2021 Sep 14;14(18):5290. Doi: 10.3390/ma14185290. PMID: 34576521; PMCID: PMC8469453.

Xavier, M. G. C., Freitas, B. J. M., Koga, G. Y., and Spinelli, J. E. (2022). Effects of Ni and Co on the corrosion resistance of Al-Si-Cu-Zn-Fe Alloys in NaCl solution. *Metals*, *12*(4), 645. https://doi.org/10.3390/met12040645

Umoru L. and Ige O. Effects of Tin on Aluminum–Zinc–Magnesium Alloy as Sacrificial Anode in Seawater," *Journal of Minerals and Materials Characterization and Engineering*, 7(2), 2008, pp. 105-113, 2008. Doi: 10.4236/jmmce.2008.72009.

Xhanari, K. and Finšgar, M. Organic corrosion inhibitors for aluminum and its alloys in chloride and alkaline solutions: A review, Arab J Chem, 12(8), 2019, pp. 4646-4663,

https://doi.org/10.1016/j.arabjc.2016.08.009.

Kendig, M. and Buchheit, R. G. Corrosion Inhibition of Aluminum and Aluminum Alloys by Soluble Chromates, Chromate Coatings, and Chromate-Free Coatings, Corrosion 59(5), 2003, 379- 399, DOI: 10.5006/1.3277570

Z. Han, Y. Zuo, P. Ju, Y. Tang, X. Zhao, J. Tang The preparation and characteristics of a rare earth/nano-TiO2 composite coating on aluminum alloy by brush plating, Surface Coatings Techno., 206 (14), 2012, pp. 3264-3269, https://doi.org/10.1016/j.surfcoat.2012.01.027.

Zhao Q, Tang T, Dang P, Zhang, Z., & Wang, F. (2017). Corrosion Inhibition Effect of Triazinedithiol Inhibitors on Aluminum Alloys in a 1 M HCl Solution *Metals*, *7*(2), 44. Doi: 10.3390/met7020044

Fayomi, O. S. I., Anawe, P. A. L., & Daniyan, A. (2018). The Impact of Drugs as Corrosion Inhibitors on Aluminum Alloy in Coastal-Acidified Medium Doi: 10.5772/intechopen.72942

Raviprabha K, Bhat RS, Bhat SI, Nagaraj P, Jyothi K. Corrosion inhibition study of 6061 aluminium alloy in the presence of ethyl 5-methyl-1-(4-nitrophenyl)-1H-1,2,3-triazole-4-carboxylate (NTE) in hydrochloric acid Heliyon. 2023;9(5): e16036. Doi: 10.1016/j.heliyon. 2023. e16036. PMID: 37215842

Wang, X., Wang, J.M., Shao, H.B., Zhang, J.O. and Cao, C.N. Influences of zinc oxide and an organic additive on the electrochemical behavior of pure aluminum in an alkaline solution, Journal of Applied Electrochemistry 35(2), 2005, :213-216, DOI: 10.1007/s10800-004-6204-x

Fu, J., Cui, K. Effect of Mn content on the microstructure and corrosion resistance of Al-Cu-Mg-Mn alloys, J. Alloys Compounds, 896, 2022.162903, https://doi.org/10.1016/j.jallcom.2021.162903.

Milošev, I. Corrosion inhibition of aluminum alloys by molybdate ions: A critical review of the chemistry, mechanisms and applications, Corr Sci 229, 2024, 111854, https://doi.org/10.1016/j.corsci.2024.111854.

Yang, J., Zhang, D., Lin, T., Zhang, W., Li, C., and Gao, L. Effect of quinoline-8-sulfonic acid and CaO as hybrid electrolyte additives on microstructure and property of AA5052 alloy anode for aluminum-air battery, J. Taiwan Inst. Chem. Eng., 2022, 131, 104150. https://doi.org/10.1016/j.jtice.2021.11.017.

Ryl, J., Brodowski, M., Kowalski, M., Lipinska, W., Niedzialkowski, P., Wysocka, J., 2019. Corrosion Inhibition Mechanism and Efficiency Differentiation of Dihydroxybenzene Isomers Toward Aluminum Alloy 5754 in Alkaline Media. *Materials*, *12*(19), 3067. https://doi.org/10.3390/ma12193067

L. Tan, J. Li, X. Zeng Revealing the Correlation between Molecular Structure and Corrosion Inhibition Characteristics of N-Heterocycles in Terms of Substituent Groups. Materials (Basel). 2023 Mar 7;16(6):2148. Doi: 10.3390/ma16062148. PMID: 36984028; PMCID: PMC10052306.

Raviprabha K, Bhat RS, Bhat SI, Nagaraj P, Jyothi K. Corrosion inhibition study of 6061 aluminium alloy in the presence of ethyl 5-methyl-1-(4-nitrophenyl)-1H-1,2,3-triazole-4-carboxylate (NTE) in hydrochloric acid Heliyon. 2023;9(5):e16036. Doi: 10.1016/j.heliyon. 2023.e16036. AKENES

Malinowski S, Wróbel, M., & Woszuk, A. (2021). Quantum Chemical Analysis of the Corrosion Inhibition Potential by Aliphatic Amines. *Materials*, *14*(20), 6197. https://doi.org/10.3390/ma14206197

Alam, M. A.; Jahan, A.; Suzuki, E.; Yashiro, H. Fluoride Ions Effect on the Corrosion Behavior of Pure Aluminum in Deaerated 0.05 M Sulfuric Acid Solutions, Chem. Europe, 8(24), 2023, https://doi.org/10.1002/slct.202300379

Wysocka J, Cieslik M, Krakowiak S, Ryl J. Carboxylic acids as efficient corrosion inhibitors of aluminum alloys in alkaline media, Electrochimica Acta, Vol. 289, 2018, pp. 175-192, https://doi.org/10.1016/j.electacta.2018.08.070.