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A Review of Biological Activities and Phytochemistry of *Rhus* Species

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Abstract The genus *Rhus* (family: Anacardiaceae, order: Sapindales) consists of more than 250 species distributed in the tropics, subtropics and temperate regions. Traditionally, extracts and products from *Rhus* species are regarded as important remedy and have been used extensively as part of traditional healing practices for the treatment of fungal, bacterial and protozoal infections in both humans and animals. However, scientific data to support these ethnomedicinal uses is lacking for most *Rhus* species. The aim of this study was to collate and review the fragmented information on ethnomedicinal, phytochemistry and biological activities *Rhus* species and present recommendations for future research. Peer-reviewed articles using "*Rhus*" as search term were retrieved from Scopus, Science Direct, SciFinder and Google Scholar. Various books that contained ethnopharmacological information of the plants were also consulted. In addition to anti-infective properties, *Rhus* extracts are also used to treat a wide range of ailments including abdominal pain, inflammation, stomach aches, fever and headaches, which may be a manifestation of infections. Most of the biological activities are attributed to flavonoids, phenolic and terpenoid compounds present in the various species. From the literature available it is evident that most of *Rhus* species have not been studied. Further research aimed at identification of active extracts and compounds from the plants is needed.

Keywords Rhus species, Bioactivity, Phytochemistry, Compounds

1. Introduction

The use of plants in management of infections has been practiced for several years. Traditional medicine still plays an important role in meeting the primary healthcare needs in many developing countries [1-6]. Plants have been reported to produce secondary metabolites some of which have the capacity to combat diseases [7-11]. Despite the availability of conventional drugs, continued search for novel biologically active compounds is unavoidable since most of the available drugs have limitations in terms of side effects and drug resistance [1,12]. Currently, researchers have focused on determining efficacy of medicinal plant through *in-vivo* and in-vitro experiments, and isolation and characterization of bioactive compounds [13-19]. This has led to the identification of several important biologically active compounds including terpenoids, alkaloids, steroids, flavonoids and quinones [20-24]. Such compounds represent an important source of drugs in the process of developing new pharmacologically active compounds.

The genus *Rhus* (family: Anacardiaceae, order: Sapindales) consists of more than 250 species of deciduous trees and shrubs, mainly distributed in the tropics, subtropics and temperate regions. *Rhus* species are widely used in modern and traditional medicine for management of various infections. However, the scientific data to support the ethnomedicinal uses is lacking for most *Rhus* species since only a few of the species have been subjected to scientific evaluation. The paper presents a review of *Rhus species* as potent medicinal plants by highlighting their traditional applications as well as the recent findings for novel pharmacological and clinical applications.

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2. Ethno-Medicinal Uses of *Rhus species*

Rhus species have been used for numerous applications. *Rhus chinensis* extracts are use treat coughs, diarrhea, dysentery, fever, jaundice, hepatitis, malaria, snake bite and rheumatism [25]; *R. coriaria* extracts are used to treat wounds, indigestion, anorexia, hemorrhages, hyperglycemia, stomach diseases, fever, dermatitis, diabetes, obesity, paralysis, colitis, dysentery, hemoptysis, analgesic and conjunctivitis [26-28]; *R. glabra* extracts are used to control diarrhoea, fevers, general debility, sore mouths, sore throats, rectal bleeding, uterine prolapse, vaginal discharge, burns and skin eruptions [29,30]; *R. javanica* L. extracts are used to treat dysentery, diarrhea, spermatorrhea and malaria [31]; *R. trilobata* extracts are used to treat gastrointestinal diseases and cancer [32]; *R. tripartita* is used to treat digestive

diseases, wound, inflammatory conditions, gastrointestinal and cardiovascular disorders, diarrhea and ulcers [33,34]; *R. tripartitum* is used to treat diarrhoea, dysentery and ulcers [33]; *R. succedanea L*. is used to treat diarrhoea and dysentery [26]; *R. typhina* is used to treat abdominal pain, diarrhea, infected wounds, sore throats [35] and *R. verniciflua* Stokes is used to treat abdominal disorders, obesity, allergic inflammatory, allergic contact dermatitis, swelling, angiogenesis, Parkinson's disease, Huntington's disease, and cancer [35,37]. Given the importance of the plants in traditional medicine, further research aimed at identification of the bioactive compounds is necessary.

3. Chemical Composition

Previous phytochemical studies have shown that *Rhus* species are rich in secondary metabolites such as flavonoids, urushiols, and terpenoids (Table 1). Flavonoids reported from the plants include kaempferol (**1**), 7-O-methyl isokaemferide (**2**), quercetin (**3**), 7,3′-O-dimethylquercetin (**4**), quercetin-3-O-glucoside (**5**), quercitrin (**6**), rutin (**7**), quercetin-3-O-α-L-(3″-O-galloyl)-rhamnoside (**8**), myricetin (**9**), myricetin-3-O-β-glucoside (**10**), myricetin 3-rhamnoside (**11**), fisetin (**12**), apigenin (**13**), genkwanin (**14**), apigenin dimethyl ether (**15**), luteolin (**16**), 7-O-methyl luteolin (**17**), 3', 4', 7-trihydroxyflavone (**18**) and 5,6,7-trihydroxy-2-phenyl-4H-chromen-4-one (**19**). Flavanoids reported from *Rhus* species include naringenin (**20**), 7-O-Methyl naringenin (**21**), eriodictyol (**22**), eriodictyol-7-methyl ether (**23**), eriodictyonone (**24**), 3′, 5, 5′, 7-tetrahydroxy flavanone (**25**), hesperetin (**26**), 7-O-methyl hesperetin (**27**), hesperetin 7-rutinoside (28), butin (**29**), garbanzol (**30**), fustin (**31**), taxifolin (**32**), catechin (**33**), gallocatechin (**34**), epicatechin (**35**), epicatechin-3-O-rhamnoside (**36**), epigallocatechin (**37**) and mollisacasidin (**38**). Isoflavonoids: daidzein (**39**) and orobol (**40**) were also reported. Chalcones from the plants include butein (**41**), cilicione-B (**42**), phloretin (**43**), phlorizin (**44**), rhusopolyphenol A (**45**), rhusopolyphenol B (**46**), peapolyphenol C (**47**), rhusopolyphenol D (**48**), rhusopolyphenol E (**49**), rhusopolyphenol F (**50**) and 3,4,2',4'-pentahydroxydihydrochalcone (**51**). Biflavonoids reported form the plants are volkensiflavone (**52**), morelloflavone (**53**), rhuspartin (**54**), agathisflavone (**55**), rhusflavanone (**56**), robustaflavone (**57**), masazinoflavanone (**58**), hinokiflavone (**59**), 2″,3″-dihydrohinokiflavone (**60**), amentoflavone (**61**), 3′,8-binaringenin (**62**), 2,3-dihydroame ntoflavone (**63**), 7,7″-di-O-methyltetrahydroamentoflavone (**64**), cupressuflavone (**65**), mesuaferrone-A (**66**), mesuaferrone B (**67**), 2′,4′-dihydroxychalcone-(4-*O*-5‴)-4″, 2‴,4‴-trihydroxychalcone (**68**) and rhuschalcone-1 (2′,4″,2‴-trihydroxy-4′,4‴-dimethoxy-4-O-5‴-bichalcone) (**69**). Calodenone (**70**), Rhuschromone (**71**) and 7,8,9,13-tetrahydroxy-2-(3,4-dihydroxyphenyl)-2,3-trans-3, 4-cis-2,3,10-trihydrobenzopyrano[3,4-c]-2-benzopyran-1-o ne (**72**) were also reported from *Rhus* species. Anthocyanins such as cyanidin -3-O-glucoside (**73**), cyanidin-3-O-(2″gall oyl)-galactoside (**74**), 7-O-methyl-cyanidin-3-O-galactoside (**75**), 7-O-methyl-cyanidin-3-O-(2″galloyl)-galactoside (**76**), delphinidin-3-O-glucoside (**77**), 7-O-methyl-delphinidin-3-O-(2'' galloyl)-galactoside (**78**), sumadin A (**79**) and sumadin B (**80**) have been reported. Aureusidin (**81**) and coumarins scoporone (**82**), 5-formylmellein (**83**) and 5-hydroxymethylmellein (**84**) were also reported. Xanthones reported from the plants include 2,3-dihydroxy-7-methyl xanthone (**85**), 2,3,6-trihydroxy-7-hydroxymethylene xanthone-1-carboxylic acid (**86**), 2-methoxy-4-hydroxy-7-m ethyl-3-*O*-*β*-D-glucopyranosyl xanthone-1,8-dicarboxylic acid (**87**) and 2-hydroxy-7-hydroxymethylene xanthone-1,8 -dicarboxylic acid 3-*O*-*β*-D-glucopyranosyl-(2'→3'')-3''-*O* -stigmast-5-ene (**88**).

Table 1. Compound from Rhus species

S/no	Name	Reference	S/no	Name	Reference
1	Kaempferol	45	**90**	Vanillin	30
2	7-O-Methyl isokaemferide	47	**91**	4-Hydroxy-3,5-dimethoxybenzaldehyde	58
3	Quercetin	30	**92**	4-Hydroxy-3,5-dimethoxybenzaldehyde	30, 58
4	7,3'-O-Dimethylquercetin	50	**93**	3,5-Dihydroxytoluene	31, 58
5	Quercetin-3-O-glucoside	53	**94**	p-Hydroxybenzyl alcohol	66
6	Quercetin-3-O-rhamnoside	43	**95**	Ficusol	58
7	Rutin	45	**96**	Catechol	41
8	Quercetin-3-O-α-L-(3''-O-galloyl)-rhamnoside	45	**97**	Pyrogallo	30
9	Myricetin	42, 39	**98**	6-Pentadecylsalicylic acid	30, 44
10	Myricetin-3-O-β-glucoside	40	**99**	Benzoic acid	30
11	Myricetin 3-rhamnoside	53	**100**	Gentisic acid	30
12	Fisetin	49, 55	**101**	2,4-Dihydroxybenzoic acid	30, 44
13	Apigenin	45	**102**	Coriariaoic acid	66
14	Genkwanin	47	**103**	Anthranilic acid	45
15	Apigenin dimethyl ether	44, 45	**104**	Vanillic acid	30
16	Luteolin	44	**105**	Vanillic acid O-glycoside	68

S/no	Name	Reference	S/no	Name	Reference
17	7-O-Methylluteolin	50	**106**	Syringic acid	30
18	3', 4', 7-Trihydroxyflavone	49, 57	**107**	Gallic acid	30
19	Trihydroxy-2-phenyl-4H-chromen-4-one	49	**108**	p-Hydroxybenzoic acid	30
20	Naringenin (4',5,7-trihydroxyflavanone)	45	**109**	Anisic acid	30
21	7-O-Methylnaringenin	47	**110**	3,4-Dihydroxybenzoic acid	55, 57
22	Eriodictyol	32, 50	**111**	4-Methoxy-3,5-dihydroxybenzoic acid	70
23	Eriodictyol-7-methyl ether	47	**112**	Methyl gallate	58
24	Eriodictyonone	47	**113**	Methyl m-digallate	42
25	3', 5, 5', 7-Tetrahydroxyflavanone	45	**114**	Methyl p-digallate	42
26	Hesperetin	51	**115**	Methyl 3,4-dihydroxybenzoate	30
27	7-O-Methyl hesperetin	47	**116**	3,5-dihydroxybenzamide	45
28	Hesperetin 7-rutinoside	51	**117**	Tyrosol	45
29	Butin	31	**118**	Cinnamic acid	30
30	Garbanzol	55	**119**	p-Coumaric acid	30
31	Fustin	56, 82	**120**	Caffeic acid	30
32	Taxifolin	59	**121**	1-Docosanoyl cafferate	65
33	Catechin	30	**122**	Alkyls caffeate	58
34	Gallocatechin	59	**123**	Alkyls caffeate	58
35	Epicatechin	24	**124**	Alkyls caffeate	58
36	Epicatechin-3-O-rhamnoside	59	**125**	Ferulic acid	30
37	Epigallocatechin	59	**126**	Methyl ferulate	58
38	Mollisacasidin (fisetinidol-4α-ol	81	**127**	Sinapic acid	30
39	Daidzein	45	**128**	chlorogenic acid	30
40	orobol	45	**129**	rosmarinic acid	30
41	Butein	45	**130**	Dimethoxy[1,4]benzoquinone	58
42	Cilicione-B	36	**131**	10′(Z)-heptadecenylhydroquinone	25
43	Phloretin	45	**132**	10'(Z),13'(E)-heptadecadienylhydroquinone	43
44	Phlorizin	45	**133**	Heptadecatrienylhydroquinone	43
45	Rhusopolyphenol A	36	**134**	3-((Z)-Heptadec-13- enyl) benzene-1,2-diol	46
46	Rhusopolyphenol B	36	**135**	2-Hydroxy-6-pentadec-8(Z)-enylbenzoic acid	58
47	Peapolyphenol C	36	**136**	Pinoresinol	58
48	Rhusopolyphenol D	36	**137**	4-Oxopinoresinol	58
49	Rhusopolyphenol E	36	**138**	Syringaresinol	55, 57
50	Rhusopolyphenol F	36	**139**	Quinic acid	68
51	Pentahydroxydihydrochalcone	36	**140**	Shikimic acid	68
52	Volkensiflavone	61	**141**	Hydroxytetramethylhexadeca-2,6,10,11-tetraenyl)-2(3H)-benzofuranone	72
53	Morelloflavone	60	**142**	Rhuscholide A	72
54	Rhuspartin	59	**143**	Betulonic acid	58
55	Agathisflavone	64	**144**	Betulinic acid	58
56	Rhusflavanone	61, 64	**145**	Betulin	58
57	Robustaflavone	60	**146**	Lupeol	48
58	Masazinoflavanone	38, 42	**147**	3β,20,25-trihydroxylupane	58, 71
59	Hinokiflavone	60	**148**	3β,22,25-trihydroxylupane	75
60	2'',3''-dihydrohinokiflavone	59	**149**	Moronic acid	58
61	Amentoflavone	63	**150**	3β-hydroxyolean-18-en-28-oic acid	58
62	3′,8-Binaringenin	40, 50	**151**	3-Oxo-6β-hydroxyolean-18-en-28-oic acid	58
63	2,3-Dihydro amentoflavone	64	**152**	3-Oxoolean-12-en-28- oic acid	58
64	7,7''-di-O-Methyltetrahydroamentoflavone	50	**153**	Oleanolic acid	58

S/no	Name	Reference	S/no	Name	Reference
65	Cupressuflavone	64	**154**	3-Oxo-6β-hydroxyolean-12-en-28-oic acid	44
66	Mesuaferrone-A	59	**155**	Friedelin	45
67	Mesuaferrone B	64	**156**	α- Amyrin	45
68	2',4'-dihydroxychalcone-(4-O-5''')-4'',2''',4'''-trihydroxychalcone	46	**157**	Lantabetulic acid	44
69	Rhuschalcone-1	62	**158**	Semimoronic acid	58
70	Calodenone	38	**159**	3-O-methyl semimoronic acid	58
71	Rhuschromone	46	**160**	Lantanolic acid	58
72	Tetrahydroxy-2-(3,4-dihydroxyphenyl)-2,3-trans-3,4-cis-2,3,10-trihydrobenzopyrano[3,4-c]-2-benzopyran-1-one	36	**161**	1,10,24,25,30-Pentahydroxysqualene	58
73	Cyanidin -3-O-glucoside	53	**162**	Lutein	47, 48
74	Cyanidin-3-O-(2''galloyl)-galactoside	35, 53	**163**	3-Oxotirucalla-7,24-dien-21-oic acid	58
75	7-O-Methyl-cyanidin-3-O-galactoside	35, 53	**164**	β-sitosterol	58
76	7-O-Methyl-cyanidin-3-O-(2''galloyl)-galactoside	35, 53	**165**	β-Sitosterol glucoside	47, 48
77	Delphinidin-3-O-glucoside	53	**166**	Stigmasterol	48
78	7-O-Methyl-delphinidin-3-O-(2'' galloyl)-galactoside	35	**167**	Stigmast-4-en-3-one	58
79	Sumadin A	35	**168**	Stigmast-4-ene-3,6-dione	58
80	Sumadin B	35	**169**	Stigmastane-3,6-dione	58
81	Sulfuretin	55	**170**	Stigmast-7-en-3-ol	58
82	Scoporone	45	**171**	Dipterocarpol	58
83	5-formylmellein	58	**172**	isofouquierone peroxide	58
84	5-hydroxymethylmellein	31, 58	**173**	fouquierone	58
85	2,3-dihydroxy-7-methyl xanthone	77	**174**	dammar-20(22),24-diene-3β,26,27−triol	76
86	2,3,6-trihydroxy-7-hydroxymethylene xanthone-1-carboxylic acid	77	**175**	3β-hydroxy-22,23,24,25,26,27-hexanordammaran-20-one	80
87	2-methoxy-4-hydroxy-7-methyl-3-O-β-D-glucopyranosyl xanthone-1,8-dicarboxylic acid	77	**176**	Semialatic acid	58
88	2-hydroxy-7-hydroxymethylene xanthone-1,8-dicarboxylic acid 3-O-β-D-glucopyranosyl-(2'→3'')-3''-O-stigmast-5-ene	77	**177**	Semialactone	58
89	4-hydroxybenzaldehyde	45			

Compounds **1**, **3**, **13**, **32**, and **33** were reported from *R. flexicaulis* [30,38], compounds **1**,**3**, **10**, **58** and **70** were reported from *R. tripartitum* [39-41]; compounds **1** and **39** were isolated from *R. copallinum* [42], compounds **1**, **3**, **6**-**8**, **13**, **16**, **26**, **33**, **39**-**44** and **82** were reported from *R. typhina* [43-45], compounds **2**, **14**, **21**, **23**, **24**, **27**, **28**, **35**, **68** and **71** were reported from *R. natalensis* [46-48], compounds **3**, **12** and **19** were reported from *R. mysorensis* [49], compounds **4**, **14**, **17**, **21**, **22** and **64** were reported from *R. retinorrhoea* [50], compounds **5**, **11**, **26**, **28**, **41**, **85** and **88** were reported from *R. coriaria* [47,51-53], compounds **12**, **18**, **29**-**32**, **38**, **41**, **42**, **45**-**52**, **72**-**80** have been reported from *R. verniciflua* [35,36,53-57], compounds **20**, **22**, **29**, **83** and **84** were reported from *R. javanica* [31,58], and compounds **29**, **32**-**37**, **54**, **60**, **62** and **66** were reported from *R. tripartita* [39,40,59]; compounds **53**, **55**-**57** and **59** were isolated from *R. succedanea* [60,61]); compounds **55**, **61** and **69** were reported from *R. pyroides* [62,63] while compounds **55**, **65**, **67** and **81** were reported from *R. parviflora* [64].

Phenolic compounds reported from *Rhus* species include 4-hydroxybenzaldehyde (**89**), vanillin (**90**), 4-hydroxy-3,5-dimethoxybenzaldehyde (**91**), 4-hydroxy-3,5-dimethoxybenzaldehyde (**91**), 3,5-dihydroxytoluene (**93**), *p*-hydroxybenzyl alcohol (**94**), ficusol (**95**), catechol (**96**), pyrogallo (**97**), 6-pentadecylsalicylic acid (**98**), benzoic acid (**99**), gentisic acid (**100**), 2,4-dihydroxybenzoic acid (**101**), coriariaoic acid (**102**), anthranilic acid (**103**), vanillic acid (**104**), vanillic acid *O*-glycoside (**105**), syringic acid (**106**), gallic acid (**107**), *p*-hydroxybenzoic acid (**108**), anisic acid (**109**), 3,4-dihydroxybenzoic acid (**110**), 4-methoxy-3,5-dihydroxybenzoic acid (**111**), methyl gallate (**112**), methyl *m*-digallate (**113**), methyl *p*-digallate (**114**), methyl 3,4-dihydroxybenzoate (**115**), 3,5-dihydroxybenzamide (**116**), tyrosol (117), cinnamic acid (**118**), *p*-coumaric

acid (**119**), caffeic acid (**120**), alkyls caffeates (**121-124**), ferulic acid (**125**), methyl ferulate (**126**), sinapic acid (**127**), chlorogenic acid (**128**), rosmarinic acid (**129**), 2,6-dimethoxy[1,4]benzoquinone (**130**), 10′(*Z*)-heptadeceny lhydroquinone (**131**), 10'(Z),13'(E)-heptadecadienylhydroq uinone (**132**), 10'(Z),13'(E),15'(E)-heptadecatrienylhydroq uinone (**133**), 3-(*Z*)-heptadec-13- enyl) benzene-1,2-diol (**134**), 2-hydroxy-6-pentadec-8(*Z*)-enylbenzoic acid (**135**), pinoresinol (**136**), 4-oxopinoresinol (**137**), syringaresinol (**138**), quinic acid (**139**) and shikimic acid (**140**). Benzofuranones: 5-hydroxy-7-(3, 7, 11, 15-tetramethylhexa deca-2, 6, 10, 11-tetraenyl)-2(3H)-benzofuranone (**141**) and rhuscholide A (**142**) have also been reported. Compounds **89**, **103**, **107**, **112**, **115-117** and **120** were reported from *R. typhina* [44,45]; compounds **90**, **91**, **97-100**, **104**, **106-109**, **118-120** and **125-129** were reported from *R. flexicaulis* [30,44]; compounds **90-93**, **95**, **97**, **112**, **121-124**, **126**, **130** and **135-137** were isolated from *R. javanica* [31,58,65]; compounds **94**, **102**, **107** and **112** were isolated from *R. coriaria* [27,66,67]; compounds **101**, **107**, **110**, **112**, **120** and **138** were reported from *R. verniciflua* [55,57]; compounds **105** and **107** were reported from *R. virens* [68]; compounds **107**, **112-114** were reported from *R. copallinum* [42,69]; compounds **107**, **112**, **141** and **142** were reported *R. chinensis* [60]; compounds **107**, **139** and **140** were reported from *R. pachyrrhachis*m[68]), compounds **111** and **112** were isolated from *R. glabra* [70]; compounds **131-133** were reported from *R. succedanea* [25] while compounds **96** and **134** were reported from *R. tripartita* and *R. natalensis* respectively [41,46,71].

Triterpenoids isolated from the plants include betulonic acid (**143**), betulinic acid (**144**), botulin (**145**), lupeol (**146**), 3*β*,20,25-trihydroxylupane (**147**), *3β*,22,25-trihydroxylupan e (**148**), moronic acid (**149**), 3β-hydroxyolean-18-en-28-oic acid (**150**), 3-oxo-6β-hydroxyolean-18-en-28-oic acid (**151**), 3-oxoolean-12-en-28- oic acid (**152**), oleanolic acid (**153**), 3-oxo-6β-hydroxyolean-12-en-28-oic acid (**154**), friedelin (**155**), α-amyrin (**156**), lantabetulic acid (**157**), semimoronic acid (**158**), 3-*O*-methyl semimoronic acid (**159**), lantanolic acid (**160**), tetrahydroxysqualene (**161**) and lutein (**162**). Steroids from the plants include 3-oxotirucalla-7,24-dien-21 -oic acid (**163**), β-sitosterol (**164**), β-sitosterol glucoside (**165**), stigmasterol (**166**), stigmast-4-en-3-one (**167**), stigmast-4-ene-3,6-dione (168), stigmastane-3,6-dione (**169**), stigmast-7-en-3-ol (170), dipterocarpol (**171**), isofouquierone peroxide (**172**), fouquierone (**173**), dammar-20(22),24-diene-3β,26,27−triol (**174**), 3β-hydroxy-22,23,24, 25,26,27-hexanordammaran-20-one (**175**), semialatic acid (**176**) and semialactone (**177**). Compounds **143-145**, **147**, **149-153**, **158-164**, **167-173**, **175-177** were isolated from *R. javanica* [58,71] compounds **143**, **145**, **149** and **154** were reported from *R. chinensis* [72,73]; compounds **144** and **153** were reported from *R. copallinum* L. [42]; compounds **146**, **164-166** were reported from *R. natalensis* [47,48]; compounds **153** and **155** were reported from *R. typhina* L [45]; compound **155** was reported from *R. alata* [74]; compounds **148**, **161** and **174** were reported from R. taitensis [75,76]; compound **165** was isolated from *R. coriaria* [77] while compound **165** was reported from *R. tripartita* [39].

4. Biological Activities and Bioactive Compounds

Previous biological activity studies on *Rhus* species have focused majorly on the fruits because of their widespread use as a dried spice. Most of the studies have used either ethanol or water based extracts [27,47]. Biological activities reported from extracts from the plant species include antimicrobial, cytotoxicity, anticancer, antioxidant, antiviral, anti-inflammatory and antimalarial activities. However, in most cases the bioactive principles are not known as most studies end after determination of bioactivities to the extracts. Extracts from *Rhus* species have been reported to have antimicrobial activity against a wide range of pathogenic microbes including *Aeromonas hydrophila, Aspergillus flavus, A. fumigatus, A. Niger, Bacillus cereus, B. subtilis, Candida albicans, Enterobacter aerogenes, Enterococcus faecalis, Escherichia coli, Klebsiella pneumoniae, Listeria monocytogenes, Microsporum gypsum, Mycobacterium tuberculosis, Penicillium notatum, Propionibaterium acnes, Proteus vulgaris, Pseudomonas aeruginosa, P. syringae, Ralstonia solanacearum, Salmonella enteric, S. typhi, Shigella dysentariae, Staphylococcus aureus, S. epidermidis, S. faecalis, Streptococcus mutans, S. pyogenes, Trichophyton mentagrophytes, T. rubrum, Xanthomonas axonopodis X. oryzae and Yersinia enterocolitica* [48,78]. The antimicrobial compounds reported from the plants are 2',4'-dihydroxychalcone-(4-*O*-5''')-4'',2''',4'''-trihydroxy chalcone (**68**), rhuschromone (**71**) and 3-(*Z*)-heptadec-13-enyl) benzene-1,2-diol (**134**) from *R. natalensis* root bark [46]; epicatechin (**35**), lupeol (**146**), β-sitosterol (**164**), β-sitosterol glucoside (**165**) and stigmasterol (**166**) from *R. natalensis* root bark [48]; 2,3-dihydroxy-7-methyl xanthone (**85**), 2,3,6-trihydroxy-7-hydroxymethylene xanthone-1-car boxylic acid (**86**), 2-methoxy-4-hydroxy-7-methyl-3-*O*-*β*-D -glucopyranosyl xanthone-1,8-dicarboxylic acid (**87**) and 2-hydroxy-7-hydroxymethylene xanthone-1,8-dicarboxylic acid 3-*O*-*β*-D-glucopyranosyl-(2'→3'')-3''-*O*-stigmast-5-e ne (**88**) from *R. coriaria* L. seeds (Singh et al 2011); methyl gallate (**112**) from *R. verniciflua* [57]; 7-O-methylnaringenin (**21**) from *R. retinorrhoea* [50]; fisetin (**12**), 3', 4', 7-Trihydroxyflavone (**18**) and gallic (**107**) from *R. verniciflua* [79]; and 1,10,24,25,30-pentahydroxysqualene (**161**) and dammar-20(22),24-diene-3β,26,27−triol (**174**) isolated from *R. taitensis* [76].

Cytotoxic compounds reported from *Rhus* species are myricetin-3-O-glucopyranoside (**10**), epicatechin (**35**), mesuaferrone-A (**66**), and 2″3″-dihydrohinokiflavone (**60**) from stem bark of *R. tripartita* [59]; and 4-(2,6-dihydroxy-4-methoxyphenyl)-4-oxobutanoic acid, trichocarpol A, trichocarpol B, trichocarpol C, trichocarpol D and trichocarpol E, from *R. trichocarpa* roots [80]. Anticancer compounds reported include kaempferol (**1**), quercetin (**3**),

myricetin (**9**), methyl *m*-digallate (**113**), methyl *p*-digallate (**114**), and betulinic acid (**144**) from *R. copallinum* fruit [42]; fustin (**31**) and sulfuretin (**81**) from *R. verniciflua* [81] agathisflavone (**55**), succedaneaflavanone (**58**), cupressuflavone (**65**), mesuaferrone A (**66**) and from *R. Parviflora* fruits [64]; and cilicione-b (**42**) and α,3,4,2',4'-pentahydroxydihydrochalcone (**51**) from *R. verniciflua* bark [36].

Antioxidant compounds isolated from the plants are epicatechin-3-O-rhamnoside (**36**) and rhuspartin (**54**) from stem bark of *R. tripartita* (Alqahtani et al 2019); 7-O-methyl isokaemferide (**2**), rutin (7), genkwanin (**14**), 7-O-methyl naringenin (**21**), eriodictyol-7-methyl ether (**23**), eriodictyonone (**24**), 7-O-methyl hesperetin (**27**) and hesperidin (**28**) from aerial parts of *R. natalensis* [47]; *Myricetin-3-O-β-glucoside* (13), taxifolin (**32**) from *R. tripartita* [40,59]; quercetin (**3**) from *R. verniciflua* [58]; hesperetin from R. coriaria [51]; butin (**29**) from *R. verniciflua* [55]; fustin (**31**) from *R. verniciflua* [82] and sulfuretin (**81**) from *R. verniciflua* [83]. Antiviral compounds isolated from the plants include 5-hydroxy-7-(3,7,11,15-tetramethylhexadeca-2,6,10,11-tetr aenyl)-2(3H)-benzofuranone (**141**) and 5-hydroxy-3-(propan-2-ylidene)-7-(3,7,11,15-tetramethylhexadeca- 2,6,1 0,11-tetraenyl)-2(3H)-benzofuranone (**142**), betulonic acid (**143**), Moronic (**149**), and3-oxo-6β-hydroxyolean-18-en-28 -oic acid (**151**) from *R. chinensis* [72,73]; butin (**29**), fisetin (**12**), sulfuretin (**81**) and methyl gallate (**112**) from *R. verniciflua* [55,84]; agathisflavone (**55**), robustaflavone (**57**) and succedaneaflavanone (**58**) from *R. succedanea* [60]; amentoflavone (**61**) from *Rhus pyroides* [63] and 2'',3''-dihydrohinokiflavone (**60**) from *R. tripartita* stem bark [59]. Anti-inflammatory compounds reported from *Rhus* species are 5,6,7-trihydroxy-2-phenyl-4*H*-chromen-4-one (**19**) and quercetin (**3**) from R. *mysorensis* leave [49]; myricetin-3-O-β-glucoside (**10**), taxifolin (**32**) from *R. tripartita* [40]; fisetin (**12**) from *R. mysorensis leaves* [49] and 1-docosanoyl cafferate (**112**) from *R. verniciflua* stem bark [65]. Antimalarial reported from the plants are genkwanin (**14**), 7-O-methylluteolin (**17**), 7-O-methylna ringenin (**21**) and eriodictyol (**22**) from *R. retinorrhoea* leaves [31,50].

5. Conclusions

Whereas the genus *Rhus* consists of more than 250 species, only a few of the plants have been subjected to phytochemical investigation. The few species that have been studied include *R. alata, R. chinensis, R. copallinum, R. coriaria, R. cotinus, R. flexicaulis, R. glabra, R. javanica, R. leptodictya, R. leptodictya, R. mysorensis, R. natalensis, R. pachyrrhachis, R. parviflora, R. pyroides, R. retinorrhoea, R. succedanea,* R. taitensis,, *R. tripartita, R. tripartitum, R. typhina, R. verniciflua* and *R. virens.* Given the important role of *Rhus* species in modern and traditional medicine, further phytochemical investigation of the unstudied species is necessary to identify bioactive compounds. It is also necessary to determine the bioactivity of the already identified compounds.

REFERENCES

[1] World Health Organization, WHO (2014). 'Traditional Medicine Strategy 2014-2023'.

[2] Jeruto P., Arama P., Anyango B., Nyunja R.A., Taracha C., Opiyo S.A. (2017). 'Morphometric study of *Senna didymobotrya* (Fresen.) H. S. Irwin and Barneby in Kenya'. Journal of Natural Sciences Research 7 (6): 54-69.

[3] Kuria K.M., Opiyo S.A. (2020). 'Characterization of immunogenic soluble crude proteins from *Biomphalaria Pfeifferi* against *Schistosoma mansoni'*. Journal of Natural Sciences Research 10(12): 28-34.

[4] Ndirangu E.G., Opiyo S.A., Ng'ang'a M.W. (2020a). 'Chemical composition and repellency of *Nigella sativa* L. seed essential oil against *Anopheles gambiae* sensu stricto'. Trends in Phytochemical Research 4(2): 77-84.

[5] Opiyo S.A. (2019). 'A review of ^{13}C NMR spectra of drimane sesquiterpenes'. Trends in Phytochemical Research 3(3): 147-180.

[6] Opiyo S.A. (2020a). 'Evaluation of *Warburgia ugandensis* extracts and compounds for crop protection against *Prostephanus truncates'.* Advances in Analytical Chemistry 10(2), 15-19.

[7] Makenzi A.M., Manguro L.A.O., Owuor P.O., Opiyo S.A. (2019a). 'Chemical constituents of *Ocimum Kilimandscharicum* Guerke acclimatized in Kakamega Forest, Kenya'. Bulletin of the Chemical Society of Ethiopia 33(3): 527-539.

[8] Ochieng C.O., Ishola I., Opiyo S.A., Manguro L.O.A., Owuor P.O., Wong K.C. (2013). 'Phytoecdysteroids from the stem bark of *Vitex doniana* and their anti-inflammatory effects'. Planta Medica 79: 52-59.

[9] Ochung A.A., Manguro L.A.O., Owuor P.O., Jondiko I.O., Nyunja R.A., Akala H., Mwinzi P., Opiyo S.A. (2015). 'Bioactive carbazole alkaloids from *Alysicarpus ovalifolius* (Schumach)'. Korean Society for Applied Biological Chemistry 58(6): 839-846.

[10] Opiyo S.A., Manguro L.O.A., Okinda-Owuor P., Ateka E.M., Lemmen P. (2011a). '7-alpha Acetylugandensolide and antimicrobial properties of *Warburgia ugandensis* extracts and isolates against sweet potato pathogens'. Phytochemistry Letters 4: 161-165.

[11] Opiyo S.A., Manguro L.O.A., Owuor P.O., Ochieng C.O., Ateka E.M., Lemmen P. (2011b). 'Antimicrobial compounds from. *Terminalia brownii* against sweet potato pathogens'. Natural Products 1: 116-120.

[12] Opiyo S.A., Manguro L.O.A., Ogur J.A., Wagai S.O. (2010). 'Bioactive constituents of *Conyza floribunda'.* Research Journal of Pharmacology 4 (3): 55-59.

[13] Manguro L.O.A., Opiyo S.A., Herdtweck E., Lemmen P. (2009). 'Triterpenes of *Commiphora holtziana* oleogum

resin'. Canadian Journal of Chemistry, 87: 1173-1179.

[14] Opiyo S.A., Manguro L.A.O., Akinyi D., Ochung A.A., Ochieng C.O. (2015). 'Biopesticidal extractives and compounds from *Warburgia ugandensis* against maize weevil (*Sitophilus zeamais*)'. Natural Products 5(4): 236-243.

[15] Opiyo S.A., Manguro L.A.O., Owuor P.O., Ateka E.M. (2017). 'Triterpenes from *Elaeodendron schweinfurthianum* and their antimicrobial activities against crop pathogens'. American Journal of Chemistry 7 (3): 97-104.

[16] Makenzi A.M., Manguro L.O.A, Owuor P.O., Opiyo S.A. (2019b). 'Flavonol glycosides with insecticidal activity from methanol extract of *Annona mucosa* Jacq. Leave'. Trends in Phytochemical Research 3(4): 287-296.

[17] Ndirangu E.G., Opiyo S.A., Ng'ang'a M.W. (2020b). 'Repellent Properties of Compounds and Blends from *Nigella sativa* Seeds against *Anopheles gambiae*'. Basic Sciences of Medicine 9(1): 1-7.

[18] Opiyo S.A. (2020b). 'Evaluation of *Warburgia ugandensis* extracts and compounds for crop protection against *Prostephanus truncates*'. Advances in Analytical Chemistry 10(2): 15-19.

[19] Opiyo S.A. (2020c). 'Insecticidal activity of *Elaeodendron schweinfurthianum* extracts and compounds against *Sitophilus zeamais* Motschulsky'. American Journal of Chemistry 10(3): 39-44.

[20] Manguro L.O.A., Opiyo S.A., Asefa A., Dagne E., Muchori W.P. (2010). 'Chemical constituents of essential oils from three *Eucalyptus* species acclimatized in Ethiopia and Kenya'. Journal of Essential Oil Bearing Plants 13(5): 561-567.

[21] Opiyo S.O., Ogur J.A., Manguro L.O.A., Itietze, L.F., Schuster H. (2009). 'A new sterol diglycoside from *Conyza floribunda*'. South African Journal of Chemistry, 62 (4): 9-13.

[22] Ochieng C.O., Opiyo S.A., Mureka E.W., Ishola I.O. (2017). 'Cyclooxygenase inhibitory compounds from *Gymnosporia heterophylla* aerial parts'. Fitoterapia 119: 168-174.

[23] Ochung A.A., Owuor P.O., Manguro L.A.O., Ishola O.I., Nyunja R.A., Ochieng C.O., Opiyo S.A. (2018). 'Analgesics from *Lonchocarpus eriocalyx* Harms'. Trends in Phytochemical Research 2(4): 253-260.

[24] Njoroge P.W., Opiyo S.A. (2019a). 'Antimicrobial activity of root bark extracts of *Rhus natalensis* and *Rhus ruspolii*'. Basic Sciences of Medicine 8(2): 23-28.

[25] Chen J.C., Ho T.Y., Chang Y.S., Wu S.L., Li C.C., Hsiang C.Y. (2009). 'Identification of *Escherichia coli* enterotoxin inhibitors from traditional medicinal herbs by *in silico*, *in vitro*, and *in vivo* analyses'. J Ethnopharmacol 121: 372-378.

[26] Kirtikar K.R., Basu B.D. (2000). 'Indian Medicinal Plants'. Delhi: Satguru Publications.

[27] Asgarpanah J., Saati S. (2014). 'An overview on phytochemical and pharmacological properties of *Rhus coriaria* L'. Res. J. Pharmacogn 1: 47-54.

[28] Ahmadi R., Eskandani M.A., Saadati D. (2017). 'Evaluation of antimicrobial effect of Iranian Sumac on *Bacillus cereus* in a commercial barley soup'. Slovenian Vet. Res. 54(2): 65-69.

[29] Moerman D. **(**1998). **'**Native American Ethnobotany', Timber Press. Oregon.

[30] Abdel-Mawgoud M., Khedr F.G., Mohammed E.I. (2019). 'Phenolic compounds, antioxidant and antibacterial activities of *Rhus flexicaulis* Baker'. Jordan J. Biol. Sci 12 (1): 17-21.

[31] Ouyang M.A., Chang C.I., Wein Y.S., Kuo Y.H. (2008). 'New phenol glycosides from the roots of *Rhus javanica* var. *roxburghiana*'. J Chin Chem Soc 55: 223-227.

[32] Varela-Rodríguez L., Sánchez-Ramírez B., Rodríguez-Reyna I.S., Ordaz-Ortiz J.J., Chávez-Flores D., Salas-Muñoz E., Osorio-Trujillo J.C., Ramos-Martínez E., Talamás-Rohana P. (2019). 'Biological and toxicological evaluation of *Rhus trilobata* Nutt. (*Anacardiaceae*) used traditionally in Mexico against cancer'. BMC Complement Altern Med 19: 153.

[33] Abbassi F., Hani K. (2012).' In vitro antibacterial and antifungal activities of *Rhus tripartitum* used as antidiarrhoeal in Tunisian folk medicine'. Natural Product Research 26 (23): 2215-2218.

[34] Alimi H., Mbarki S., Barka Z.B., Feriani A., Bouoni Z., Hfaeidh N., Sakly M., Tebourbi O., Rhouma K.B. (2013). 'Phytochemical, antioxidant and protective effect of *Rhus tripartitum* root bark extract against ethanol-induced ulcer in rats'. Gen Physiol Biophys 32(1): 115-127.

[35] Kirby C.W., Wu T., Tsao R., McCallum J.L. (2013). 'Isolation and structural characterization of unusual pyranoanthocyanins and related anthocyanins from Staghorn sumac (*Rhus typhina* L.) via UPLC–ESI-MS, 1H, 13C, and 2D NMR spectroscopy'. Phytochemistry 94: 284-293.

[36] Kim K.H., Moon E., Choi S.U., Kim S.Y., Lee K.R. (2013). 'Polyphenols from the bark of Rhus verniciflua and their biological evaluation on antitumor and anti-inflammatory activities'. Phytochemistry 92: 113-121.

[37] Choi N.H., Jang J.Y., Choi G.J., Choi Y.H., Jang K.S., Nguyen V.T., Min B.S., Le Dang Q., Kim J.C. (2017). 'Antifungal activity of sterol and dipsacussaponins isolated from *Dipsacusasper* root against phytopathogenic fungi'. Pest Biochem Physiol 141: 103-108.

[38] Mahjoub M.A., Ammar S., Mighri Z. (2005). 'A new biflavonoid and an isobiflavonoid from *Rhus tripartitum*'. Nat Prod Res 19: 723-729.

[39] Mohammed A.E.I. (2015). 'Phytoconstituents and the study of antioxidant, antimalarial and antimicrobial activities of *Rhus tripartita* growing in Egypt'. J Pharmacogn Phytochem 4: 2762-2781.

[40] Shahat A.A, Ibrahim AY, Al-Ghamdi A.A.M., Alsaid S.M. (2016). 'Phytochemical investigation of *Rhus tripartita* and its activity against cyclooxygenases and acetylcholinesterase'. Trop J Pharm Res 15(8): 1697-1706.

[41] Miled H.B, Saada M., Jallali I., Barka Z.B., Tlili M., Alimi H., Sakly M., Rhouma K.B., Abderrabba M, Abdelmelek H., Tebourbi O., Ksouri R. (2017). 'Variability of antioxidant and biological activities of *Rhus tripartitum* related to phenolic compounds'. EXCLI Journal, 16: 439-447.

[42] Ma H., Yuan T., González-Sarrías A., Li L., Edmonds M.E.,

Seeram N.P. (2012). 'New galloyl derivative from winged Sumac (*Rhus copallinum*) fruit'. Natural Product Communications 7 (1): 45-46.

[43] Wu T., McCallum J.L., Wang S., Liu R., Zhu H., Tsao R. (2013). 'Evaluation of antioxidant activities and chemical characterisation of staghorn sumac fruit (*Rhus hirta* L.)'. Food Chemistry 138: 1333-1340.

[44] Wang L., Xu M.N., Guo L.J., Liu J., Wang L.S. (2015). **'**Antioxidant activities and phenolic compounds of various extracts of *Rhus typhina* fruits and leave'. Advance Journal of Food Science and Technology 7(4): 223-229.

[45] Qiu D.R, Wang D.C., Yang S.X., Zhang Y.M., Wei D.S., Zhang M.Z., Sun J.Z., Guo J., He S.L., Qin J.C. (2016). 'Chemical constituents from the fruits of *Rhus typhina* L. and their chemotaxonomic significance'. Biochem Syst Ecol 69: 261-265.

[46] Mwangi H.M., Mabusela W.T., Abegaz B.A., Onani M.O. (2013). 'Antimicrobial activities of a novel biflavonoid and other constituents from *Rhus natalensis*'. J. Med. Plants Res 7(10): 619-623.

[47] Alqasoumi S.I, Basudan O.A., Alam P., Abdel-Kader M.S. (2016). 'Antioxidant study of flavonoid derivatives from the aerial parts of *Rhus natalensis* growing in Saudi Arabia'. Pak. J. Pharm. Sci 29(1): 97-103.

[48] Njoroge P.W., Opiyo S.A. (2019b). 'Antimicrobial activity of root bark extracts of *Rhus natalensis*a and *Rhus ruspolii*'. Basic Sci Med 8(2): 23-28.

[49] Rani G.R., Singara C.M.A., Viswanadham M., Thupurani M.K., Gorripati S., Rajashekar K., (2016). 'Phytochemical analysis and antimicrobial activities of *Rhus mysorensis*'. Int. J. of Adv. Res 4: 503-515.

[50] Ahmed M.S., Galal A.M., Ross S.A., Ferreira D., El Sohly M.A., Ibrahim A.R.S., El-Feraly F.S. (2001). 'A weakly antimalarial biflavanone from *Rhus retinorrhoea*'. Phytochem 58(4): 599-602.

[51] Cho J.Y., Prak S.C., Kim T.W., Kim K.S., Song J.C., Kim S.K., Lee H.M., Sung H.J., Park H.J., Song Y.B., Yoo E.S., Lee C.H., Rhee M.H. (2006). 'Radical scavenging and anti-inflammatory activity of extracts from *Opuntia humifusa* Raf'. J Pharm Pharmacol 58: 113-119.

[52] Abu-Reidah I.M., Ali-Shtayeh M.S., Jamous R.M., Arráez-Román D., Segura-Carretero A., (2015). 'HPLC–DAD–ESI-MS/MS screening of bioactive components from *Rhus coriaria* L. (Sumac) fruits'. Food Chem 166: 179-191.

[53] Romeo F.V., Ballistreri G., Fabroni S., Pangallo S., Nicosia M.G.L.D., Schena L., Rapisarda P. (2015). 'Chemical characterization of different sumac and pomegranate extracts effective against *Botrytis cinerea* Rots'. Molecules 20: 11941-11958.

[54] Kim J.H., Shin Y.C., Ko S.G. (2014). 'Integrating traditional medicine into modern inflammatory diseases care: multitargeting by *Rhus verniciflua* Stokes'. Mediators Inflamm. 2014: 154561.

[55] Jang J.Y., Shin H., Lim J.W., Ahn J.H., Jo Y.H., Lee K.Y., Hwang B.Y., Jung S.J., Kang S.Y., Lee M.K. (2018). 'Comparison of antibacterial activity and phenolic constituents of bark, lignum, leaves and fruit of *Rhus verniciflua*'. PLoS ONE 13, e0200257.

[56] Lee S.O., Kim S.J., Kim J.S., Ji H., Lee E.O., Lee H.J. (2018). 'Comparison of the main components and bioactivity of *Rhus verniciflua* Stokes extracts by different detoxification processing methods'. BMC Complement. Altern Med 18: 242.

[57] Yang J., Kwon Y.S., Kim M.J. (2018). 'Antimicrobial activity and active compounds of a *Rhus verniciflua* Stokes extract'. Z Naturforsch C. J. Biosci 73: 457-463.

[58] Lee T.H, Chiou J.L., Lee C.K., Kuo Y.H. (2005). 'Separation and determination of chemical constituents in the roots of *Rhus javanica* L. var. roxburghiana'. J. Chin. Chem. Soc 52: 833-841.

[59] Alqahtani A.S., Abdel-Mageed W.M., Shahat A.A., Parvez M.K., Al-Dosari M.S., Malik A., Abdel-Kader M.S., Alsaid M.S. (2019). 'Proanthocyanidins from the stem bark of *Rhus tripartita* ameliorate methylgloxal-induced endothelial cell apoptosis'. Journal of Food and Drug analysis 27: 758-765.

[60] Lin Y.M., Anderson H., Flavin M.T., Pai Y.S.H. (1997). 'In vitro anti-HIV activity of biflavonoids isolated from Rhus succedanea and Garcinia multiflora'. J. Nat. Prod 60: 884-888.

[61] Lin Y.M., Flavin M.T., Schure R., Chen F.C., Sidwell R., Barnard D.L., Huffman J.H., Kern E.R. (1999). 'Antiviral activities of biflavonoids'. Planta Med 65(2): 120-125.

[62] Masesane I.B., Yeboah S.O., Liebscher J., Mügge C. Abegaz B.M. (2000). 'A bichalcone from the twigs of *Rhus pyroides*'. Phytochemistry 53(8): 1005-1008.

[63] Svenningsen A.B., Madsen K.D., Liljefors T., Stafford G.I., Staden J.V., Jager A.K. (2006). 'Biflavones from *Rhus* species with affinity for the GABAA/ benzodiazepine receptor'. Journal of Ethnopharmacology 103(2): 276-280.

[64] Shrestha S., Park J.H.., Lee D.Y. (2012). 'Cytotoxic and neuroprotective biflavonoids from the fruit of *Rhus parviflora*'. J Korean Soc Appl Biol Chem 55: 557-562.

[65] Lee J.W., Cheong I.Y., Kim H.S., Lee J.J., Lee Y.S., Kwon Y.S., Kim M.J., Lee H.J., Kim S.S., Chun W. (2011). 'Anti-inflammatory activity of 1-docosanoyl cafferate isolated from Rhus verniciflua in LPS-stimulated BV2 microglial cells'. Korean J Physiol Pharmacol 15: 9-15

[66] Onkar S., Mohammed A., Nida A. (2011). 'New antifungal aromatic compounds from the seeds of *Rhus coriaria* L'. International Research Journal of Pharmacy 2(1): 188-194.

[67] Kacergius T., Abu-Lafi S., Kirkliauskiene A., Gabe V., Adawi A., Rayan M. (2017). 'Inhibitory capacity of *Rhus coriaria* L. extract and its major component methyl gallate on *Streptococcus mutants* biofilm formation by optical profilometry: potential applications for oral health'. Mol Med Rep 16(1): 949-56.

[68] Juárez-Aragón C.M., Moreno-Ramírez Y.R., Guerra-Pérez A., Mora-Olivo A., Olazarán-Santibáñez F.E., Torres-Castillo J.A. (2019). 'Drying effects on phenolics and free radical-scavenging capacity of *Rhus pachyrrhachis* and *Rhus virens* used in traditional medicine'. Molecules 24: 1438-1442.

[69] Djakpo O., Yao W.R. (2010). '*Rhus chinensis* and *Galla chinensis*-folklore to modern evidence: review'. Phytother

Res 24: 1739-1747.

[70] Saxena G., McCutcheon A.R., Farmer S., Towers G.H., Hancock R.E. (1994). 'Antimicrobial constituents of *Rhus glabra*'. J. Ethnopharmacol 42(2): 95-99.

[71] Lee I.S., Oh S.R., Ahn K.S., Lee H.K. (2001). 'Semialactone, isofou-quierone peroxide and fouquierone, three new dammarane triterpenes from *Rhus javanica*'. Chem. Pharm. Bull (Tokyo) 49: 1024-1026.

[72] Gu Q., Wang R.R., Zhang X.M. (2007). 'A new benzofuranone and anti-HIV constituents from the stems of Rhus chinensis'. Planta Med 73: 279-282.

[73] Wang R.R., Gu Q., Wang Y.H. (2008). 'Anti-HIV-1 activities of compounds isolated from the medicinal plant *Rhus chinensis*'. J Ethnopharmacol 117: 249-256.

[74] Parveena M., Basudan O.A., Mushfiq M., Ghalib R.M. (2008). 'A new benzofuranic acid from the leaves of *Rhus alata*'. Nat Prod Res 22: 371-382.

[75] Noro J., Barrows L.R., Gideon J. (2008). 'Tetrahydroxysqualene from Rhus taitensis shows antimycobacterial activity against Mycobacterium tuberculosis'. J Nat Prod 71: 1623–1624.

[76] Jadulco R.C., Koch M., Van Wagoner R.M., Pond C., Gideon O.G., Matainaho T., Piskaut P., Barrows L.R. (2011). 'New antimycobacterial triterpenoids from *Rhus taitensis*'. Planta Medica 14: 1651-1654.

[77] Singh O., Ali M, Akhtar N. (2011). 'New antifungal aromatic compounds from the seeds of *Rhus coriaria* L'. Int Res J Pharm. 2(1): 188-194.

[78] Mahdavi S., Hesami B., Sharafi Y. (2018). 'Antimicrobial and antioxidant activities of Iranian sumac (*Rhus coriaria* L.) fruit ethanolic extract'. J. Appl. Microbiol. Biochem 2: 1-5.

[79] Kim J.S., Yang J., Kim M.J. (2011). 'Alpha glucosidase inhibitory effect, anti-microbial activity and UPLC analysis of *Rhus verniciflua* under various extract conditions'. Journal of Medicinal Plant Research 5(5): 778-783.

[80] Lee E.J., Lee G.H., Sohn S.H., Bae H.S. (2016). 'Extract of *Rhus verniciflua* Stokes enhances Th1 response and NK cell activity'. Mol. Cell. Toxicol 12: 399-407.

[81] Park K.Y., Jung G.O., Lee K.T., Choi J., Choi M.Y., Kim G.T., Jung H.J., Park H.J. (2004). 'Antimutagenic activity of flavonoids from the heartwood of *Rhus verniciflua*'. J Ethnopharmacol 90(1): 73-79.

[82] Nam T.G., Lee B.H., Choi H.K., Mansur A.R., Lee S.G., Kim D.O. (2017). '*Rhus verniciflua* Stokes extract and its flavonoids protect PC-12 cells against H_2O_2-induced cytotoxicity'. J. Microbiol. Biotechnol 27 (6): 1090-1097.

[83] Lee J.C., Lim K.T., Jang Y.S. (2002). 'Identification of *Rhus verniciflua* Stokes compounds that exhibit free radical scavenging and anti-apoptotic properties'. Biochim Biophys Acta 1570: 181-191.

[84] Kang S.Y., Kang J.Y., Oh M.J. (2012). 'Antiviral activities of flavonoids isolated from the bark of *Rhus verniciflua* stokes against fish pathogenic viruses *in vitro*'. J. Microbiol. 50: 293-300.