

Novel *N*-acyl dehydroalanine derivatives as antioxidants: Studies on rat liver lipid peroxidation levels and DPPH free radical scavenging activity

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Abstract

Oxidative stress has been implicated in the development of many neurodegenerative diseases such as Parkinson and Alzheimer's disease and is also responsible for aging, atherosclerosis, rheumatoid arthritis and carcinogenesis. Olefins such as dehydroalanines have been shown to inactivate free radicals by forming stabilized free radical adducts. Among these molecules *N*-acyl dehydroalanines react with and scavenge oxygen and hydroxyl radicals. This study describes the synthesis, characterization and *in vitro* effects on rat liver lipid peroxidation levels, and DPPH free radical scavenging activities of some *N*-acyl dehydroalanine derivatives. Compounds **c**, **f** and **j** slightly scavenged the level of DPPH radical at 10^{-3} M concentration by about 27, 46, and 56%, respectively while compounds **a**, **d**, **e**, **f**, **g**, **h** showed a strong inhibitory effect on lipid peroxidation at 10^{-3} M and 10^{-4} M concentrations and inhibition was in the range of 76–90%. The possible antioxidant mechanism of the compounds was discussed.

Keywords: Dehydroalanine, lipid peroxidation, radical scavenging, synthesis, free radical

Introduction

In disease states, the immune system produces an excess of superoxide which overwhelms the native superoxide dismutase (SOD) enzymes' ability to remove superoxide free radicals so leading to free radical-induced damage to cells and tissues. Free radical damage has been associated with a growing number of diseases and conditions, such as autoimmune diseases like rheumatoid arthritis, neurodegenerative disorders like Parkinson's disease, multiple types of cancer, complications of diabetes mellitus, stroke, heart attacks, reperfusion injury during transplants of organs, pain and inflammation [1]. Free radicals are chemically reactive species that can attack and damage several biomolecules such as DNA and enzymes. Oxidative damage to DNA by reactive oxygen species (ROS) is a continuous problem that cells must guard against to survive [2]. All amino acid

residues of proteins are susceptible to oxidative modification by one or more forms of ROS [3,4].

Dehydroamino acids represent an important class of compound as they are key intermediates in amino acid and peptide synthesis and are constituents of a variety of naturally occurring antibiotic and phytotoxic peptides including several fungal metabolites which possess antibiotic activity [5–9]. They also play an important role at the active site of some enzymes and show free radical scavenging activity [4]. It has been postulated that dehydroamino acids play an important role in giving the definite peptide conformation that is required for expression of biological activities [10]. Recently, much attention has been given to the oxidative stress theory to explain increased risks to life-threatening and chronic or degenerative diseases [11–13]. Singlet oxygen, superoxide anion, hydrogen peroxide and hydroxyl radicals often cause deleterious effects on cells and macromolecules and cause

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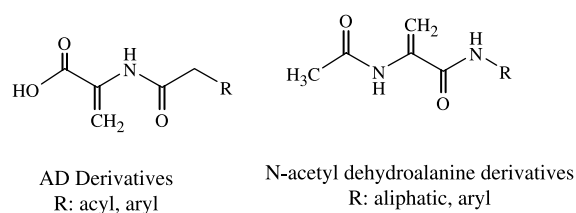


Figure 1. General structure of AD^{23,25} and *N*-acetyl DHA derivatives.

oxidative stress-induced neuronal cell death in a number of neurological disorders.

Antioxidants and antioxidant enzymes function as major protective systems in organisms against free radical attack [14–17]. Dehydro amino acids and corresponding peptides can function as radical scavengers [18–21]. Oxygen radicals are involved in tumor promotion and they are considered as the principle causative agents of the deleterious effects of ionising radiations. Wagner *et al* [22] showed that the dehydroalanyl residue can capture the 5'-deoxyadenosyl radical generated from S-adenosylmethionine by pyruvate formate-lyase-activating enzyme. *N*-(acyl-aryl)-dehydroalanine derivatives have shown inhibitory activity towards oxygen radicals [23–24]. The *o*-methoxyphenylacetyl dehydroalanine derivative, referred to as AD-20 has free radical scavenging activity and protects against the effects of ionising radiation [25] (Figure 1). *N*-substituted dehydroalanines, a class of compounds with both acceptor and donor

substituents react with and scavenge oxygen radicals. The reactivity of these compounds with hydroxyl radical is evident from their inhibition of hydroxyl radical adduct formation. ESR spin trapping studies of the species formed by reaction of the dehydroalanine derivatives with the hydroxyl radical was reported by Sipe *et al* [26]. Therefore it was of interest to investigate antioxidant ability of *N*-substituted dehydro amino acid derivatives. Eleven *N*-acetyl dehydroalanine (*N*-acetyl DHA) derivatives were synthesised to evaluate their antioxidant properties on rat liver lipid peroxidation (LP) levels and DPPH free radical scavenging activity. R groups were chosen aliphatic and cyclic chains in order to identify the possible structure antioxidant activity relationships of the compounds and to guide perspective the design of new analogues (Figure 2).

Materials and methods

Uncorrected melting points were determined with a Büchi SMP-20 apparatus. The ¹H NMR spectra were measured with a Varian mercury 400 MHz using TMS as internal standard and DMSO-d₆ or CDCl₃. All chemical shifts were reported as δ (ppm) values. ESI Mass spectra were determined on a Waters micromass ZQ. Chromatography was carried out using Merck silica gel 60 (230–400 mesh). Cytochrome c, 2,2-diphenyl-1-picrylhydrazyl (DPPH), α-tocopherol and thiobarbituric acid (TBA) were purchased from

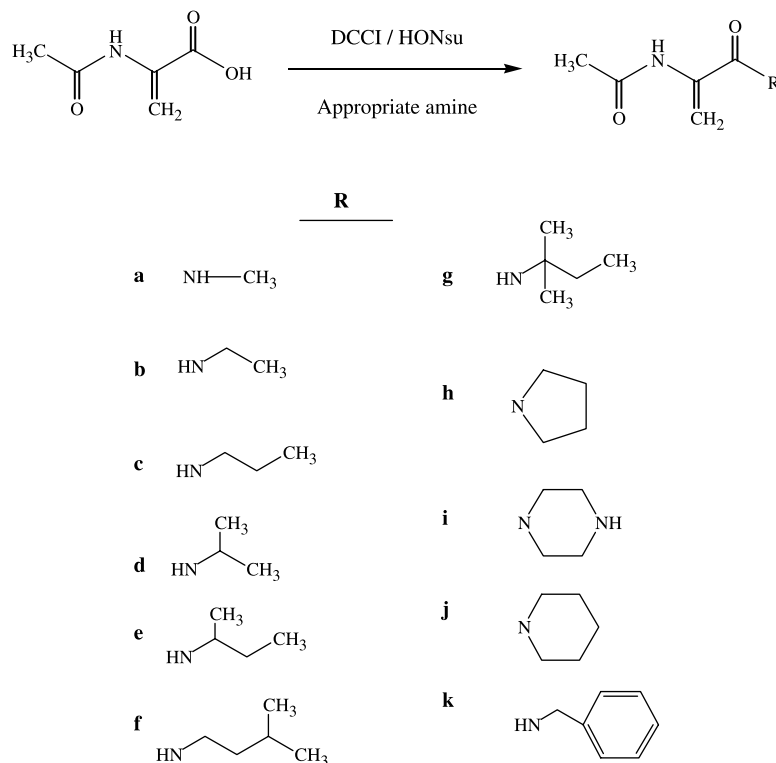


Figure 2. Synthesised *N*-Acetyl dehydroalanine derivatives.

Sigma Chemical Co. (St Louis, MO, USA). The chemical reagents used in synthesis were purchased from Sigma (Germany) and Aldrich (USA). The abbreviations used for chemicals are as follows: DCCI (1,3-dicyclohexyl carbodiimide), HONSu (N-hydroxysuccinimide). Male Wistar rats weighing 200–220 g were used for experiments. They received a standard diet. All the antioxidant experiments were performed in triplicate. Procedures involving the animals and their care conformed to Institutional guidelines, in compliance with National and International laws and guidelines for the use of animals in biomedical research.

Chemistry

For the synthesis of N-acetyl-DHA derivatives (**a–k**) the method described by Harada and Tagasaki described [31] was performed. DCCI and HONSu were used for the coupling of acetamidoacrylic acid and the appropriate amine. Synthesis and characterization of compounds **c**[27], **d**[28], and **k**[28] were published previously by our research group. Compounds **a** and **b** were characterized by Palmer *et al* [29] and Gulzar *et al*[30] respectively. The physical and spectral data of the synthesized compounds are given in Table I.

General procedure for the preparation of N-acetyl dehydroalanines

Acetamidoacrylic acid (1 mol), DCCI (1.2 mol), HONSu (1.1 mol), and appropriate amine (1 mol) in ethyl acetate were cooled at -10°C . The heterogeneous reaction mixture was then stirred at r.t for 24 h (48 h for compound **h**, **i** and **j**). At the end of the reaction the precipitated dicyclohexylurea was filtered and the filtrate was evaporated to dryness. The crude product was purified by column chromatography (ethyl acetate/petroleum spirit 60° – 80°). For compounds **g** and **h** column chromatography was applied twice for purification.

Antioxidant activity studies

DPPH free radical scavenging activity. The free radical scavenging activity of N-acetyl DHA derivatives was tested by their ability to bleach the free radical 2,2-diphenyl-1-picrylhydrazyl (DPPH) [32]. Because of its odd electron, DPPH gives a strong absorption band at 517 nm in visible spectroscopy. The reaction mixture contained $100\mu\text{M}$ DPPH in methanol and different concentrations of synthesized compounds. Absorbance at 517 nm was determined after 30 min at 37°C and the scavenging activity were calculated as a percentage of the radical reduction. Each experiment was performed in triplicate. α -Tocopherol was used as a reference compound. The radical scavenging activity

was obtained from the equation: Radical scavenging activity % : $\{(\text{OD}_{\text{control}} - \text{OD}_{\text{sample}})/\text{OD}_{\text{control}}\} \times 100$

Assay of lipid peroxidation. The effect of the N-acetyl DHA derivatives on rat liver homogenate induced with FeCl_2 -ascorbic acid was determined. LP was examined by the method of Mihara [33]. Animals were starved for 24 h. prior to sacrifice and then sacrificed by decapitation. The livers were immediately removed and washed in ice-cold distilled water, then immediately homogenized with a Teflon homogenizer. LP was measured spectrophotometrically by estimation of thiobarbituric acid reactants (TBARS). A typical optimized assay mixture contained 0.5 ml of liver homogenate, 0.1 ml of Tris-HCl buffer (pH 7.2), 0.05 ml of 0.1 mM ascorbic acid, 0.05 ml of 4 mM FeCl_2 and 0.05 ml of various concentrations of N-acetyl DHA derivatives or α -tocopherol, and was incubated for 1 h at 37°C . After incubation, 3.0 ml of H_3PO_4 and 1 ml of 0.6% TBA were added, the mixture shaken vigorously and then boiled for 30 min. After cooling the mixture to room temperature the absorbance of the supernatant was read at 532 nm against a blank, which contained all reagents except liver the homogenate.

Results

Eleven N-acetyl-DHA derivatives were synthesized, characterized and their *in vitro* antioxidant activity tested on rat liver lipid peroxidation levels and DPPH free radical scavenging activity. The scavenging effects of the compounds are shown in Table II. Compounds **c**, **f** and **j** slightly scavenged the level of DPPH radical at 10^{-3} M concentration by about 27, 46, and 56%, respectively. However compounds **a**, **d**, **e**, **f**, **g**, **h** showed a strong inhibitory effect on LP at 10^{-3} M and 10^{-4} M concentrations and the inhibition was in the range 76–90%. Compounds **b**, **c** and **i** also inhibited LP by about 54%, 58% and 66%, respectively but compounds **j** and **k** had no inhibitory LP activity at the same concentrations.

The superoxide anion radical scavenging activity was measured by the inhibition of cytochrome c reduction according to the modified method of Mc Cord *et al*[34]. The assay was also adapted to assess the capacity of antioxidants to react with superoxide anion radical. However none of the compounds at final concentrations of 10^{-3} and 10^{-4} M showed any significant ability to scavenge O_2^- (data not shown).

Discussion

The synthesized N-acetyl DHA derivatives had strong effects on LP while having no significant activity on

Table I. Physical and spectral data of synthesised compounds.

No	Formula	Yield (%)	m.p. ^o C	¹ H NMR Data (δ ppm)	Mass Data
c	C ₈ H ₁₄ N ₂ O ₂	48	75–78	CDCl ₃ : 0.95 (t, 3H, CH ₂ -CH ₃), 1.57 (m, 2H, CH ₂), 2.14 (s, 3H, COCH ₃), 3.31 (q, 2H, NHCH ₂), 5.18 (s, 1H, = CH), 6.26 (brs, NH), 6.43 (s, 1H, = CH), 8.18 (brs, NH)	209 (M + K, 18.20), 194 (M + 1 + Na, 16.15), 193 (M + Na, 100), 150 (12.26), 129 (39.64)
e	C ₉ H ₁₆ N ₂ O ₂	27	92–94	CDCl ₃ : 0.94 (t, 3H, CH ₂ -CH ₃), 1.19 (d, 3H, CHCH ₃), 1.59 (m, 2H, CH ₂), 2.14 (s, 3H, COCH ₃), 3.37 (m, 1H, CH), 5.14 (s, 1H, = CH), 5.86 (brs, NH), 6.43 (s, 1H, = CH), 8.01 (brs, NH)	223 (M + K, 17.32), 208 (M + 1 + Na, 19.80), 207 (M + Na, 100), 185 (M + 1, 97.01), 186 (M + 2, 12.17), 169 (25, 63), 147 (22.58)
f	C ₁₀ H ₁₈ N ₂ O ₂	25	82–85	d ₆ -DMSO: 0.89 (d, 6H, (CH ₃) ₂), 1.35 (m, 2H, CH ₂ -CH), 1.57 (m, 1H, CH), 2.00 (s, 3H, COCH ₃), 3.15 (t, 2H, NHCH ₂), 5.32 (s, 1H, = CH), 6.01 (s, 1H, = CH), 8.27 (brs, NH), 9.02 (brs, NH)	237 (M + K, 12.10), 221 (M + Na, 100), 199 (M + 1, 28.76), 157 (59.05), 155 (11.18), 147 (14.14)
g	C ₁₀ H ₁₈ N ₂ O ₂	18	Oily	CDCl ₃ : 0.81 (t, 3H, CH ₂ CH ₃), 1.18-1.28 (m, 8H, (CH ₃) ₂ CH ₂), 2.04 (s, 3H, COCH ₃), 5.02 (s, 1H, = CH), 5.85 (brs, NH), 6.33 (s, 1H, = CH), 8.02 (brs, NH)	237 (M + K, 13.29), 225 (100) (M + Na, 35.67), 199 (M + 1, 17.52), 169 (18.95), 147 (13.35)
h	C ₉ H ₁₄ N ₂ O ₂	15	Oily	d ₆ -DMSO: 1.79 (m, 4H, N(CH ₂ -CH ₂) ₂), 1.89 (s, 3H, COCH ₃), 3.25 (m, 4H, N(CH ₂ -CH ₂) ₂), 4.65 (s, 1H, = CH), 5.28 (s, 1H, = CH), 9.56 (brs, NH), second NH not observed	205 (M + Na, 7.38), 183 (M + 1, 9.55), 169 (29.85), 147 (49.59) 137 (24.36)
i	C ₉ H ₁₅ N ₃ O ₂	20	Decomp. at 40	d ₆ -DMSO: 1.73 (m, 4H, CH ₂) ₂ NH), 1.96 (s, 3H, COCH ₃), 3.10 (m, 4H, N(CH ₂) ₂), 5.27 (s, 1H, = CH), 6.01 (s, 1H, = CH), 8.18 (brs, NH), 9.05 (brs, NH)	236 (M + K, 11.02), 225 (100), 221 (M + 1 + Na, 19.89), 174 (33.56), 166 (21.16), 143 (62.75), 139 (14.25), 125 (28.61)
j	C ₁₀ H ₁₆ N ₂ O ₂	31	80–83	d ₆ -DMSO: 1.33-1.58 (m, 10 H, cyclic-H), 1.89 (s, 3H, COCH ₃), 5.15 (s, 1H, = CH), 5.90 (s, 1H, = CH), 8.80 (brs, NH), 9.78 (brs, NH)	235 (M + K, 23.27), 225 (100), 219 (M + Na, 58.61), 165 (19.37), 141 (47.32), 112 (28.15)

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Table II. Effects of the compounds **a-k**, on LP levels and scavenging activity of DPPH radical^a.

Compound No	Concentration in incubation medium (M)	LP (Percent of control)	DPPH free radical scavenging activity (percent of control)
Control ^b DMSO-EtOH		100	100
a	10 ⁻³	10 ± 1	103 ± 1
	10 ⁻⁴	17 ± 2	101 ± 1
b	10 ⁻³	46 ± 3	102 ± 2
	10 ⁻⁴	93 ± 1	100 ± 1
c	10 ⁻³	42 ± 1	73 ± 1
	10 ⁻⁴	102 ± 2	99 ± 2
d	10 ⁻³	24 ± 2	98 ± 1
	10 ⁻⁴	40 ± 1	102 ± 2
e	10 ⁻³	15 ± 3	95 ± 3
	10 ⁻⁴	88 ± 2	97 ± 1
f	10 ⁻³	10 ± 1	54 ± 2
	10 ⁻⁴	25 ± 1	101 ± 2
g	10 ⁻³	11 ± 1	91 ± 1
	10 ⁻⁴	40 ± 2	100 ± 3
h	10 ⁻³	18 ± 2	103 ± 2
	10 ⁻⁴	43 ± 1	104 ± 1
i	10 ⁻³	34 ± 2	90 ± 1
	10 ⁻⁴	91 ± 1	100 ± 2
j	10 ⁻³	202 ± 3	44 ± 2
	10 ⁻⁴	240 ± 4	99 ± 2
k	10 ⁻³	203 ± 2	90 ± 2
	10 ⁻⁴	168 ± 4	99 ± 2
α-tocopherol	10 ⁻³	5 ± 1	10 ± 2
	10 ⁻⁴	10 ± 1	13 ± 2

^a Each value represents the mean ± SE of 2–4 independent experiments

^b DMSO, control for compounds and α-tocopherol

the DPPH radical. The scavenging effects of the compounds on the DPPH radical and inhibitory effect on LP were not similar. Since the mechanisms of these methods are different it is possible to observe different effects [35–38].

Non-proteinogenic amino acids constitute an important group of compounds in the field of peptide chemistry. These compounds have several applications, either as biologically active substrates or as individual structural components. Among these amino acids are α,β-dehydroamino acids and β-substituted alanines [39]. There is still speculation as to the role of the dehydro units in biologically active compounds. Certainly, they have an influence as a conformational constraint due to their sp² hybridized carbon structure, however, they could well have the ability to add on nucleophiles via Michael type conjugative addition, as recently proven in a set of model experiments [39,40]. Wagner *et al* [22] stated that the free radical scavenging mechanism of the dehydroalanyl residue appeared to involve addition of the nucleophilic radical to the electrophilic carbon-carbon double bond. DHA type compounds behave as highly effective trapping agents of free radicals which add covalently to the olefinic β-carbon. Also another finding was established by Garrison [41] that the oxidation of protein by ROS can possible lead to the cleavage of peptide chains, called the α-amidation pathway. Since the *N*-acyl DHA derivatives contain

a carbon-carbon double bond and a peptide bond, an addition to the double bond [42] and/or cleavage reactions may happen during their antioxidant process (Figure 3). *N*-acetyl DHA derivatives most probably follow route(b) depending on our studies on dehydrothreonine derivatives [42].

N-Acyl dehydroalanines have shown free radical scavenging activity [23,25]. They react by scavenging mainly hydroxyl radical. Olefins such as DHA derivatives by offering a reactive site may inactive free radicals of different polarities. In DHA derivatives, free radicals are most probably attached to the carbon-carbon double bond, and the resulting radical adduct is formed easily by the effect of both electron donating groups. According to our results in the LP assay the most active compounds have electron donating aliphatic side chains. An interesting result was obtained from compound **k** which had no LP inhibitory activity, the aromatic ring did not scavenge hydroxyl radical to give the hydroxylated aromatic derivative. Buc-Calderon *et al* [23,25] have stated that *N*-acyl and aryl dehydroalanines were effected superoxide anion scavengers. Contrary to some of their findings we found no scavenging effect on superoxide anion with the synthesized DHA derivatives, (data was not shown). This may be due to the differences between the substituents of the compounds.

In conclusion, this study has shown that *N*-acetyl DHA derivatives which are substituted with aliphatic

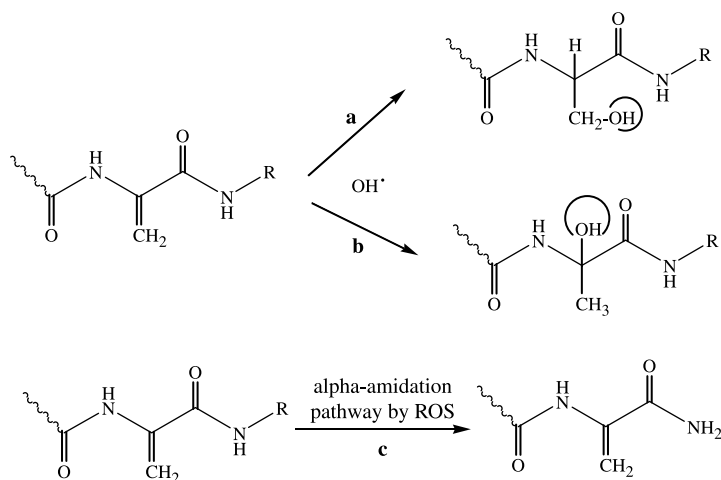


Figure 3. Possible antioxidant mechanisms of *N*-acetyl DHA derivatives.

(up to 3 or 4 carbons) and cyclic side chains (5 membered) have significant hydroxyl radical scavenging activity.

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