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Research Article

DFT and QTAIM based investigation on the structure and antioxidant behavior of lichen substances Atranorin, Evernic acid and Diffractaic acid

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ABSTRACT

In this study, the structural and antioxidant behavior of the three lichen-derived natural compounds such as atranorin (AT), evernic acid (EV) and diffractaic acid (DF) has been investigated in the gas and water phase using both B3LYP and M06-2X functional level of density functional theory (DFT) with two different basis sets 6-31 + G (d, p) and 6-311 + + G (d, p). The intramolecular H–bonds (IHB) strength, aromaticity and noncovalent interactions (NCI) have been computed with the help of the quantum theory of atoms in molecules (QTAIM). This calculation gives major structural characteristics that indirectly influence the antioxidant behavior of the investigated compounds. The spin density (SD) delocalization of the unpaired electron is found to be the main stabilizing factor of neutral and cationic radical species. The main mechanisms, recommended in the literature, for the antioxidant action of polyphenols as radical scavengers such as hydrogen atom transfer (HAT), single electron transfer followed by proton transfer (SET-PT), and sequential proton loss electron transfer (SPLET), were examined. The result shows that the HAT and SPLET mechanism are the most conceivable one for the antioxidant action of this class of compounds in gas and water phase respectively. Preference of SPLET over HAT in water phase is due to the significantly lower value of proton affinity (PA) compared to the bond dissociation enthalpy (BDE) value. This study reveals that O_2-H_3, O_9-H_{26} and O_4-H_{45} respectively are the most favored site of AT, EV and DF for homolytic as well as heterolytic O—H bond breaking.

1. Introduction

Overproduction of reactive oxygen species (ROS) including free radicals can cause oxidative damage to several cellular components like cell membranes, lipids, lipoproteins, and DNA. The shift in the balance between oxidants and antioxidants in favor of oxidants is termed “oxidative stress” (Birben et al., 2012). This type of injured cell or tissue often leads to many pathophysiological conditions in the body such as atherosclerosis, carcinogenesis, cardiovascular and Alzheimer’s diseases (Huang et al., 2016). Preventing or minimizing these oxidation-related diseases may involve the use of antioxidant that protects the body from damage caused by ROS. These protective mechanisms involve either scavenge or detoxify ROS, block their production, or preventing the metal-catalyzed peroxidation (Pisoschi and Pop, 2015).

The antioxidant activity of the compound is associated with their chemical structure. It has been reported that the scavenging activity of phenolic antioxidants is related to the phenolic O—H bond dissociation enthalpy (BDE), ionization potential (IP), proton dissociation enthalpy (PDE), proton affinity (PA) and electron transfer enthalpy (ETE) (Alov et al., 2015). Each of these descriptors plays a significant role in different radical scavenging mechanism. By analyzing the value of each descriptor, one can arrive at the probable mechanism that a molecule might follow as a scavenger (Rimarčík et al., 2010). Computational study of the electronic and molecular properties and reactivity that has a unique connection to the antioxidant action of the compounds is of top-notch importance. Recently, theoretical methods especially DFT method, have been successfully utilized to elucidate the antioxidant mechanism of several polyphenols derived from phytochemicals such as flavonoids, chalcones and resveratrol (Benayahoum et al., 2013; Kozlowski et al., 2007; Rajan et al., 2018a, 2018b; Rajan and Muraleedharan, 2017). However, studies on the antioxidant nature of other natural product which has different parental skeleton are somewhat limited, and the search for new chemical entities with antioxidant activity remains an expanding field. In this scenario, the theoretical exploration of the structural characteristics of other natural products which are reported to have antioxidant activity is more critical to conceptualizing new antioxidant structural features. In this context, the computational investigation of the radical scavenging behavior of lichens secondary metabolites also known as lichen acids is of great importance.

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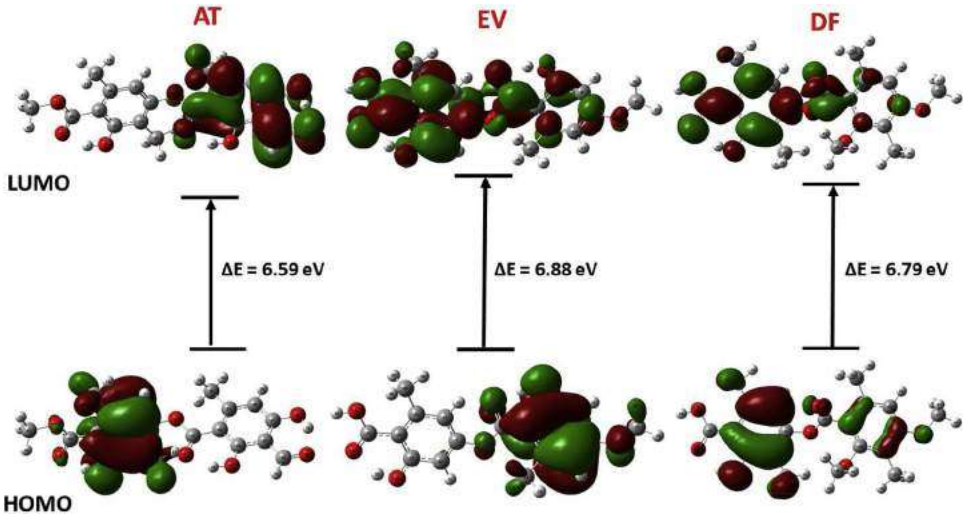

Fig. 8. FMOs of AT, EV and DF in the gas-phase at M06-2X/6-311 + + G (d, p) level of theory.

correlated with E_{HB}, SD distribution and DI. The estimated values of IPs, BDEs, and PDEs shows that one step HAT is the mechanism that best explains the antioxidant potency of depsides in gas phase rather than SET–PT or SPLET while in water-phase two-step SPLET is the mechanism that best describes the antioxidant potency. The outcome of this work indicates that the O_2-H_3, O_9-H_{26} and O_4-H_{45} respectively are the most favored site of AT, EV and DF for homolytic as well as heterolytic −OH bond breaking in the gaseous phase and water phase.

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