Characterization of Alginate from *Sargassum duplicatum* and the Antioxidant Effect of Alginate–Okra Fruit Extracts Combination for Wound Healing on Diabetic Mice

Zulfa Nailul Ilmi 1, Pugar Arga Cristina Wulandari 1, Saikhu Akhmad Husen 2, Dwi Winarni 2, Mochammad Amin Alamsjah 3, Khalijah Awang 4, Marco Vastano 5, Alessandro Pellis 5,6,7,8, Duncan Macquarrie 5 and Pratiwi Pudjiastuti 1,*

1 Department of Chemistry, Faculty of Science and Technology, Airlangga University, Surabaya 60115, Indonesia; zulfanailulilmi@gmail.com (Z.N.I.); cristinapugar@gmail.com (P.A.C.W.)
2 Department of Biology, Faculty of Science and Technology, Airlangga University, Surabaya 60115, Indonesia; saikhu-a-h@fst.unair.ac.id (S.A.H.); dwi-w@fst.unair.ac.id (D.W.)
3 Department of Marine, Faculty of Fisheries and Marine, Airlangga University, Surabaya 60115, Indonesia; alamsjah@fpk.unair.ac.id
4 Department of Chemistry, Faculty of Science, University of Malaya, Kuala Lumpur 50603, Malaysia; khalijah@um.edu.my
5 Department of Chemistry, University of York, Heslington, York YO10 5DD, UK; marco.vastano@york.ac.uk (M.V.); alessandro.pellis@boku.ac.at (A.P.); duncan.macquarrie@york.ac.uk (D.M.)
6 Department for Agrobiotechnology, IFA-Tulln, Institute for Environmental Biotechnology, University of Natural Resources and Life Sciences, Vienna, Konrad Lorenz Strasse 20, A-3430 Tulln an der Donau, Austria
* Correspondence: pratiwi-p@fst.unair.ac.id; Tel.: +62-856-3390-952

Featured Application: In this study, we evaluated antioxidant effect of alginate–okra extracts combination as topical application (ointment) for wound healing on diabetic mice. Characterization of alginate was used to determine structural characteristics and Okra fruit extract was determined total flavonoids content that have effect of the antioxidant properties. The antioxidant properties of extracts combination reduce blood-glucose levels to non-diabetic conditions (normal) significantly by topical application of diabetic open wound. These conditions can accelerate the activities of wound-healing processes on diabetic mice. The activities of wound-healing processes were performing periodically by histopathology test on skin tissue to evaluated wound healing parameters (wound area, neutrophils, macrophages, fibrocytes, fibroblasts and collagen densities).

Abstract: Diabetes mellitus is a group of metabolic disorders characterized by high blood-glucose levels over a prolonged period that causes complications when an open wound is present. Alginate is an antioxidant and a good absorbent of exudates. Okra fruit contains flavonoids that can act as antioxidants. The antioxidant properties of extracts combination reduce blood-glucose levels significantly to accelerate the activities of wound-healing processes on diabetic mice. Alginate was characterized by Size Exclusion Chromatography-Multiple Angle Laser Light Scattering (SEC-MALLS), thermal stability and Proton Nuclear Magnetic Resonance (1H-NMR). The evaluation of wound healing on 36 male mice were divided into 12 groups including normal control (NC), diabetics control (DC), alginate (DA) and alginate–okra (DAO) groups in three different times by histopathology test on skin tissue. The results of SEC-MALLS analysis showed that alginate as single and homogeneous polysaccharide. The 1H-NMR spectrum showed that the manuronate/guluronate ratio of the used alginate was 0.91. Alginate, okra fruit extract and their combination were classified as moderate and strong antioxidants. The numbers of fibrocytes, fibroblasts, collagen densities had