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A review on nanocellulosic fibres as new material for sustainable packaging: Process and applications

H.P.S. Abdul Khalil [a,b,*], Y. Davoudpour [a], Chaturbhuj K. Saurabh [a], Md. S. Hossain [a], A. S Adnan [c], R. Dungani [d], M.T. Paridah [b,e], Md. Z. Islam Sarker [f], M.R Nurul Fazita [a], M.I Syakir [a], M.K.M. Haafiz [a]

[a] School of Industrial Technology, Universiti Sains Malaysia, 11800 Pulau Pinang, Malaysia
[b] Institute of Tropical Forestry and Forest Product, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
[c] School of Medical Sciences, Universiti Sains Malaysia, 16150 Kota Bharu, Kelantan, Malaysia
[d] School of Life Sciences and Technology, Institut Teknologi Bandung, Gedung Labtex XI, Jalan Ganesha 10, Bandung 40132, West Java, Indonesia
[e] Department of Forest Production, Faculty of Forestry, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
[f] Department of Pharmaceutical Technology, Faculty of Pharmacy, International Islamic University Malaysia, Kuantan Campus, Bandar Indera Mahkota, Kuantan 25200, Pahang, Malaysia

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ABSTRACT

The demand for exploring advanced and eco-friendly sustainable packaging materials with superior physical, mechanical and barrier properties is increasing. The materials that are currently used in packaging for food, beverage, medical and pharmaceutical products, as well as in industrial applications, are non-degradable, and thus, these materials are raising environmental pollution concerns. Numerous studies have been conducted on the utilization of bio-based materials in the pursuit of developing sustainable packaging materials. Although significant improvements have been achieved, a balance among environmental concerns, economic considerations and product packaging performance is still lacking. This is likely due to bio-based materials being used in product packaging applications without a proper design. The present review article intends to summarize the information regarding the potential applications of cellulosic nanofiber for the packaging. The importance of the design process, its principles and the challenges of design process for sustainable packaging are also summarized in this review. Overall it can be concluded that scientists, designers and engineers all are necessarily required to contribute towards research in order to commercially exploit cellulose nanofiber for sustainable packaging.

Contents

* Corresponding author at: School of Industrial Technology, Universiti Sains Malaysia, 11800 Pulau Pinang, Malaysia.
E-mail address: akhalilhps@gmail.com (H.P.S. Abdul Khalil).

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1. Introduction

The use of non-biodegradable and non-renewable materials (i.e., plastics, glass, and metals) in packaging applications has raised concerns about environmental pollution and thus there is demand for the safe management of such waste. Large amounts of packaging materials are produced every year with the intention of use and throw. Traditional methods for handling post consumer plastic wastes include incineration and land filling [1]. However there are some apprehensions related to these methods like during incineration of non-biodegradable packaging materials greenhouse gases generated which pose a threat to our health and environment [1,2]. Extensive research has been conducted to develop alternative packaging materials, with the emphasis on reducing the environmental impact of petroleum based packaging materials. Studies have reported that the use of bio-polymer based materials may minimize the generation of packaging waste and thus consecutively solve the waste disposal problem to some extent owing to its biodegradability [2–4]. One added advantage of synthetic plastics is that they are recyclable, however, thermosetting plastics are not recyclable, contaminated plastics are not easy to recycle, recycling deteriorate the properties of plastics and recycling opportunities in many countries are not fully utilized. Thus due to concern over recycling procedure bioplastics has an added advantage over recyclable plastics. Nevertheless, one of the major limitation for wide spread commercial application of bioplastic is cost. However, recently cost of bioplastics per pound has dropped significantly for example PLA which cost $3/lb in 1990s has dropped to 90cents/lb in 2010. Furthermore, the rise in oil price has made bio based plastics price comparable to the price of petroleum based thermoplastics. In terms of energy, production of biopolymer based plastics required less energy than conventional counter parts such as 1 kg of PLA need only 27.2 MJ of fossil fuel based energy. In contrast, polypropylene and high density polyethylene require 85.9 and 73.7 MJ/kg, respectively. Thus it can be concluded that bioplastics successfully address concerns regarding cost, energy consumption, sustainability and recycling procedure when compared to synthetic counter parts. However, poor mechanical and barrier properties of bio-polymer based packaging materials compared to those of non-biodegradable materials have limited their widespread application. For successful practical use of bio-polymer based film various methods have been proposed for improvement in properties like addition of plasticizer, chemical modification of polymer, gamma irradiation etc. One of the most frequently used method is the addition of nanomaterials especially cellulose nanofibers. Due to its nano scale size it interacts with matter at the atomic, molecular, or macromolecular level thus affects functional behavior of biopolymer films.

Cellulose nanofibres from natural resources are recognized as the most abundant and renewable polymeric material as well as a key source of sustainable materials at the industrial scale. Because of their attractive properties, such as biocompatibility, biodegradability and chemical stability, cellulosic materials have been utilized for more than 150 years as raw materials in the production of paper, pharmaceutical compounds, and textiles [5,6]. In recent years, nanocellulosic materials have attracted the interest of scientists for maximizing the mechanical and barrier properties of packaging materials. Use of cellulosic nanofibres in packaging will minimize the costs of packed products due to their wide availability and low cost. It will also preserve the environment owing to its recyclability and reusability [7,8]. Cellulose nanofibres primarily consist of cellulose fibrils embedded in a learning matrix, and thus, these nanofibres may provide superior rigidity, tensile and flexural properties [9]. Therefore, an innovative approach with cellulose nanofibres can be a useful tool for the development of sustainable packaging with improved characteristics and for qualitative environmental management of packaging materials. An effective design of cellulose nanofibres for sustainable packaging may consist of qualitative and quantitative functioning of the product throughout its entire life cycle. Moreover, designing nanocellulosic materials will create a better experience for the end user and also allow for efficient manufacturing systems.

Functional products are produced by an engineering design process which is a methodical process. In general, the engineering design process is a key factor in developing effective manufacturing processes and technology for innovative products [10]. The utilization of the design process for the isolation of cellulose nanofiber will ensure product quality and the requirements of product packaging, such as level of safety, ergonomics, size, height, thickness and stress levels prior to being marketed, as well as its quantitative life cycle assessment and cost [10]. The primary role of a design process is to define the possibilities, limitations and suitability of cellulose nanofibres in the development of sustainable packaging [11]. In this paper, a systematic review is conducted on cellulose nanofibre, including its isolation, characterization, properties, simulation and its applicability towards sustainable packaging. The need of designing technologies for the production and processing of cellulose nanofibre as well as principles, importance and challenges in designing sustainable packaging are also discussed in this paper.

2. Production of nanocellulosic fibres

Nanotechnology is a multidisciplinary science that includes mathematics, physics, and chemistry for producing materials that have at least one dimension in nanoscale (10^{-9} m) [12]. Extensive studies have been conducted on the isolation of cellulosic nanomaterials from various sources and their applications in the development of value-added products [5,12,13].

Cellulose nanofibres can be extracted from a wide range of cellulose rich sources, such as cotton, kenaf, banana, oil palm, bamboo, wheat, rice, and bagasse [5,9,14]. Selection of source is