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Machine-coated starch-based dispersion coatings prevent mineral oil migration from paperboard

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ABSTRACT

Mineral oil migration through paperboard presents a safety risk in modern food packaging. This study aimed to enhance the safety of fiber-based packaging by utilizing a bio-based composite barrier layer to protect against mineral oil. Starch-clay composite coatings on paperboard were created via dispersion coating. Thermal analysis of the coating components and field emission scanning electron microscopy imaging were performed to ascertain the physicochemical properties and morphology of the coatings. Coating functionality was evaluated using contact angles and transmission rate (water and oxygen) measurements. The packaging safety focus was implemented by measuring the gas phase migration of heptane and analyzing the migration of liquid mineral oil through the coated paperboards with FTIR. The functional properties of the coated paperboards were maintained or improved. The studied coatings were effective barriers against the migration of mineral oil and could hence improve the barrier properties and safety of fiber-based primary food packaging.

1. Introduction

The packaging of food involves a delicate balance between the need to provide sufficient protection to secure food quality and safety, and using the minimal amount of raw materials and natural resources to do so [1]. Packaging both fresh and prepared foods is also a way to reduce food waste, which would occur during transport and storage without the use of protective packaging. Indeed, the primary purpose of food packaging is to provide protection for the product. In addition, packaging assists in marketing the product, increasing consumer convenience during product use, and ensuring safety by providing traceability and tamper indications. Print on the surface of a package serves multiple functions. Principally, it identifies the brand and markets the product to consumers. In addition, the print plays an essential role as the carrier of information such as nutritional values, allergens and place of origin as required by legislation [2]. Further, voluntary labelling details, any proven nutrition and health claims as well as identifying organic production can be included. These roles of packaging are not to be taken lightly. Food packaging is the most important medium through which consumers obtain information regarding the contents of the product. This information is used to make purchase decisions and also helps consumers to protect their health (i.e., allergen information). Print will therefore remain an integral part of packaging.

The food industry is the largest user of packaging and packaging materials, both in terms of volume and monetary value. Currently, synthetic polymer materials, including polyolefins, polyethylene terephthalate and polyamides, are widely used as food packaging and barrier materials due to their good formability. Recently, increasing concern about environmental aspects, future raw material availability, and increased legislative restrictions have led to the need to improve the sustainability of packaging material production. This has caused researchers to look for alternative packaging and barrier material resources that promote circular economy and the use of recycled or bio-based materials and biopolymers [3–7]. The increased use of recycled fibers in packaging materials has been strongly encouraged [8]. However, the use of recycled materials may be limited in food packaging applications due to hygiene or migration concerns [6]. Printing inks, which are essential elements of packaging due to the information carrying and marketing roles, present a challenge to packaging safety due to the potential migra-

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Table 1
Sample codes[a], respective proportions of raw materials given as relative amounts of dry mass (pph, parts per hundred), and coating layer thickness. The uncoated and commercial reference materials are included in the table; however, detailed composition of the commercial references was unavailable and thus only the thickness of the dispersion coating layer is given.

Sample code[a]	Proportions of raw materials				Coating grammage (g/m^2)
	Starch (pph)	Latex (pph)	Kaolin (pph)	CMC (pph)	
St100	100	–	20	3.5	8
St85L15	85	15	20	3.5	7
St70L30	70	30	20	3.5	7
St55L45	55	45	20	3.5	13
Pfn210 (uncoated)	–	–	–	–	–
TL (commercial ref.)					10
TV (commercial ref.)					15

[a] St,L: Starch and Latex respectively in pph (parts per hundred).

tion of mineral oil. Recycled fiber materials often contain residue of adhesives or printing inks used in the packaging processes and so induce the risk that migration of these compounds to the food product may occur [9–14]. Therefore, fiber-based food packaging, especially primary packaging, is often restricted to virgin fibers or small amounts of recycled fibers. Plastic pouches may be used as inner packaging to counteract migration, although care should be taken when choosing the plastic material. For example, polyolefins are ineffective as barrier materials against mineral oil [11,15]. Currently, the most appropriate way to decrease migration is to use a barrier coating on top of the fiber material [11]. Ideally, this layer should be bio-based and/or biodegradable. However, this approach may result in some challenges, since the packaging materials and coatings have many, sometimes conflicting, requirements of their functional properties during both production and their intended end-use.

Dispersion coating is a means of creating a coating using mostly biodegradable ingredients. Dispersion coating has the technological advantage of being a fast and efficient production method [1] and can even be used to create barrier layers against organic solvents and acids or to decrease the water vapor transmission rate (WVTR) in paper [16] and board. Dispersion coating allows for the coated cardboard to remain repulpable and even compostable with the right kind of coating [17]. To maintain these environmental and repulping advantages, the research and development of biopolymer coating materials has become increasingly popular among scientists [5,18,19]. Biopolymers are increasingly used as the main ingredient in dispersion coating formulations. Other components are also included in the formulations. Blends of biopolymer, synthetic polymer and rheology modifiers can improve the coating rheology and convertibility, while mineral pigment fillers enhance optical and barrier properties. Small amounts of other chemicals, such as antifoaming agents, also have specific functions.

Starch is one of the most abundant natural materials available for dispersion coating. The challenge with biopolymer materials is their runnability on the coating unit, film formation properties, and film products' high affinity for water and water vapor. Therefore, studies of the physico-chemical and barrier properties of biopolymers, starch, and starch blends as coating materials are widely performed [3,20–25]. Thorough studies have been performed to identify the best formulations for coating processability [5] and an improved grease barrier [5,26,27]. The present study aimed to exploit all of the valuable properties of bio-based dispersion coatings – renewability, processability and grease barrier capacity – to further enhance the functionality and safety of fiber-based food packaging. To enable and promote the safe use of recycled fibers in food packaging, the emphasis was on characterizing the coating barrier function against mineral oil migration. In addition to recycled fibers, the approach is also widely applicable for other packaging containing a printed surface, including practically all fiber-based primary packaging. Furthermore, a variety of important coating properties were evaluated with respect to the end-use application requirements of food packaging materials. The present work clearly shows that sustainable, bio-based coatings can act as efficient barriers and inhibit mineral oil migration in paperboard packaging.

2. Experimental

2.1. Materials

The coated board samples were produced with a KCL Pilot Coater (KCL Oy, Finland) using the parameters and conditions described in [26]. The base board in the samples was a Performa Natura commercial paperboard with a grammage of 210 g/m^2 (Pfn210, Stora Enso; Imatra, Finland) pre-coated with pigment from the outside. Aqueous coating dispersions were applied to the other side, which would be the inside in a box construction.

The main component of the coatings was a commercial biopolymer, oxidized and hydroxypropylated low-viscosity potato starch (Solam Gmbh, Emlichheim, Germany) in cooked form. The variable component was the latex, a water-based dispersion (Basonal 2020.01, BASF SE, Ludwigshafen, Germany). The other coating components were barrier-grade kaolin pigment with a high aspect ratio (Barrisurf LX, Imerys Performance Minerals Ltd, Cornwall, Great Britain) and Na-salt of carboxymethyl cellulose (CMC) (Finnfix 30, CP Kelco, Äänekoski, Finland). The dispersion slurry was prepared using an industrial scale dispergator to a solids content of 64.2 %. Slurry pH was 5.9, temperature of 23 °C and Brookfield viscosity at 100 rpm was 395 cP. The sample codes and proportions of the raw materials are indicated in Table 1, wherein the nominal ratios between the components are given as relative amounts of dry mass (parts per hundred). The samples were stored at 23 °C and 50% relative humidity (RH). When dry samples were required, the raw materials were dried in a vacuum desiccator. The base paperboard was used as an uncoated reference, along with two commercial coated paperboards, Tecta Lite and Tecta Vapor (Premium Board Finland Oy, Juankoski, Finland). Additionally, 30 μm thick aluminum foil was used as a non-permeable barrier reference to validate the methods.

A set of the starch composite coated samples and the uncoated reference paperboard Pfn210 were further coated with a low density polyethylene layer to a target coat weight of 15 g/m^2 using a pilot extrusion coating line at the Tampere University of Technology.

The migration testing was performed using Heptane (Chromasolv for HPLC (34873); Sigma-Aldrich Finland Oy; Helsinki, Finland) as a model liquid for mineral oil and actual mineral oil (PKWF 4/7, Haltermann, Germany) commonly used in offset printing inks [28].