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Effect of lipid incorporation on functional properties of wheat gluten based edible films

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ABSTRACT

Wheat gluten is an inexpensive protein derived from mill industries with good film forming properties, which allows producing semipermeable membranes able to slow down water migration in foods.

The first objective of this study was to evaluate the effects of the incorporation of a lipid phase (25 wt%, dry basis) in wheat gluten on the functional properties of the film, such water sorption, surface hydrophilicity, water barrier properties, mechanical properties and thermal properties. The second one was to asses if such incorporation was able to reduce the water sensitivity of film mechanical properties.

Findings clearly showed that the incorporation of a lipid phase was able to decrease the water sorption, water affinity (hydrophilicity) and water transfer (≈2 times) of wheat gluten films. Moreover, mechanical properties are also affected by the lipid addition with a decrease in rigidity and, at high a_w, an increase in extensibility. However, the sensitivity of the mechanical properties to water was not modified. Lastly, DSC (Differential Scanning Calorimetry) analysis proved that changes in mechanical properties of films as a function of hydration state were the consequence of glass transition depletion, which allowed them to turn from a glassy-like behavior to a rubber-like behavior.

1. Introduction

Wheat crop ranked the first agricultural commodity in Europe in 2013, and the fourth in the world, with a world production of ≈716 million tons, after sugar cane, maize and rice (FAOSTAT, 2013). This large production covers the large amount of the wheat-based foods available and consumed by humans such as baked goods, pasta, snacks and breakfast products. One of the most significant reasons behind this success lies on the functional properties of the gluten-forming proteins (gliadins and glutenins) contained in wheat endosperm. Gliadins and glutenins are able to interact and to form a protein network (wheat gluten) as in dough making, which provides the essential viscoelastic properties for producing most of the wheat based foods consumed by humans (Lagrain et al., 2010). Depending on the quantity of wheat gluten bought, purity and supplier, the wheat gluten price varies from 0.5 to 2 dollars per kilogram. Wheat gluten is no more a co-product of the mill industry but it is now produced at large scale from wheat starch. It takes advantage of its functional properties, which are of industrial importance for food and not-food applications. Wheat gluten is largely used to fortify flours for improving their dough baking properties. It is also added in meat products to bind fat and water for improving taste and texture of sliced products such as hamburgers and hams. It is used by vegetarian industries to mimic the texture of meatballs, steaks or cheese. And, it is an important ingredient in pet foods and in cosmetics (Day et al., 2006; Lagrain et al., 2010).

An interesting approach to valorize this cheap protein is to use it as raw material for developing bio-packaging. It has been shown that wheat gluten has good film forming properties (Gontard et al., 1992), which can create semipermeable membranes to water vapor, oxygen and carbon dioxide molecules (Gontard et al., 1993, 1994, 1996). It can also be used as encapsulating agent of aromas compounds as D-limonene (Marcuzzo et al., 2012). Wheat gluten films could be thus applied as food coatings or edible films on naturally gluten containing foods (*e.g.* bakery products) in order to slow

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List of abbreviations

ASTM	American Society for Testing and Materials
a_w	water activity
BET model	Brunauer-Emmet-Teller model
C	surface heat constant of the GAB equation
DSC	differential scanning calorimetry
E.B.	elongation at break
EWG	emulsified wheat gluten-lipid films
EWG-air	surface of EWG films exposed to air during film drying
EWG-support	surface of EWG films in contact with the support during film drying
FAOSTAT	Food and Agriculture Organization of the United Nations Statistics Division
GAB equation	Guggenheim-Anderson-de Boer equation
k	multilayer factor of the GAB equation
k_{gt}	adjustable parameter of the Gordon-Taylor equation
LWTR	liquid water transfer rate
m_0	monolayer moisture content of the GAB equation
m	moisture content
PVC	polyvinyl chloride
R^2	coefficient of determination
T.S.	tensile strength
T_g	glass transition temperature
T_{gm}	glass transition temperature of the mixture
WG	wheat gluten film without lipids
WG-air	surface of WG films exposed to air during film drying
WG-support	surface of WG films in contact with the support during film drying
wt%	weight percent
WVTR	water vapor transfer rate
Y.M.	Young's modulus
% RH	relative humidity
Θ	water contact angle

down mass transfer phenomena such as water and oxygen, which are known to decrease the food quality. Water migration from different food domains or water sorption from the surrounding atmosphere could induce changes in the physical state of foods, increase the rates of chemical reactions and alterative phenomena such as microbial growth, therefore reducing the shelf-life (Labuza and Hyman, 1998). In a similar way, oxygen transfer could favor oxidation reactions of lipids or pigments contained in foods and generate off flavors and undesirable color change in the products.

One of the main issues related to the utilization of wheat gluten films is their inherent water sensitivity. The mechanical and the barrier properties are highly modified in wet conditions due to water sorption and subsequent plasticization (Gontard et al., 1993, 1996; Lens et al., 2003). One strategy largely considered for reducing water sorption and water transfer through edible films is to incorporate a hydrophobic phase constituted by edible lipids into the protein or polysaccharide matrix. Lipid incorporation is expected to increase the hydrophobicity of these films, to reduce the interactions with water and in contrast to other more invasive techniques (*e.g.* chemical hydrophobization) not to compromise the edibility of films. Several variables need to be considered to obtain satisfactory results. They include the nature and concentration of lipids, the crystal type, the size and distribution of lipids and the processing used (Callegarin et al., 1997; Debeaufort and Voilley, 2009; Morillon et al., 2002).

The first objective of this study was to evaluate the effects of the incorporation of an emulsified lipid phase in wheat gluten film properties. The second one was to determine if such incorporation was able to reduce the water sensitivity of film mechanical properties. To that aim, a comparative study between wheat gluten films with and without a lipid phase was conducted. Water sorption, surface hydrophilicity, barrier properties to water, mechanical properties and the thermal events of both types of films were assessed.

2. Material and methods

2.1. Film preparation

Two edible films based on wheat gluten were prepared using a solvent casting method adapted from Marcuzzo et al. (2010). Both films contained 25 wt% glycerol (wheat gluten basis) as plasticizer (99.5%, Sigma-Aldrich, St Louis, MO, USA). The two films differed by lipid incorporation and were referred to as WG (wheat gluten film without lipid phase) and EWG (emulsified wheat gluten film with lipid phase). Wheat gluten (protein purity of 83%) was purchased from Sigma-Aldrich. The lipid phase (25 wt%, total dry basis) was constituted by a commercial blend of acetic esters of mono and diglycerides and beeswax (Grindsted barrier system 2000, Danisco, Copenhagen, Denmark, melting point ≈ 57 °C) with glycerol monostereate (10 wt%, lipid basis) as emulsifier (99% purity, Prolabo, Fontenay-sous-Bois, France).

Briefly, 2.5 g of glycerol, 10 g of wheat gluten, 40 g of milli-Q deionized water, 50 g of absolute ethanol and hydrochloric acid were stirred for 30 min at room temperature to produce gluten acid film-forming dispersions at pH = 4 (adjusted with HCl). This low pH increases the solubility of wheat gluten and thus favors the formation of transparent films compared to high pH (>8) which induced brown and opaque films. The film-forming dispersions were submitted to ultrasound treatment (UPS200S ultrasonic processor Hielscher Gmbh, Teltow, Germany) for 12 min, and thermally treated for 15 min at 70 °C under magnetic stirring. The ultrasound device was equipped with sonotrode (2 mm of tip diameter), at an output power of 200 W, an ultrasonic intensity of 600 W/cm^2 and a frequency of 24 kHz. In the case of WG films, the gluten film-forming dispersions were directly cast on PVC (polyvinyl chloride)-coated plates using a thin-layer chromatography spreader (Desaga Heidelerg, Germany) and dried at ≈ 25 °C for 20 h. In the case of EWG films, the lipid phase and the emulsifier were melted at 70 °C and incorporated in the gluten film-forming dispersions using a homogenizer (Polytron PT3000, Kinematica AG., Littau, Switzerland). The prepared dispersions were then cast at 65 °C on PVC-coated plates as for WG films. Because of the lower solvent evaporation rate, two consecutive drying steps of EWG films were conducted, first at 25 °C for ≈24 h and then at 40 °C for 1.5 h using an oven (mod. HME061X, Lainox Ali S.P.A, Treviso, Italy). WG and EWG films were then equilibrated at 53% Relative Humidity (RH) using microclimate chambers at 25 °C containing magnesium nitrate saturated salt solution ($Mg(NO_3)_2$, Carlo Erba, Rodano, Italia) previously to all experiments (Greenspan, 1977).

2.2. Water vapor sorption isotherm

The water vapor sorption isotherm of WG and EWG films were determined at 25 °C using the microclimate method as described by Bell and Labuza (2000) with some modifications. Films were