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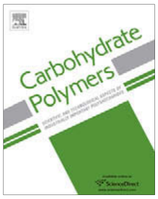

# Spruce galactoglucomannan films show promising barrier properties

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ABSTRACT

Films were prepared from sorbitol-plasticized spruce galactoglucomannans (GGM), which are a potential new product from forest biorefineries. GGM were also mixed with konjac glucomannan (KGM), poly(vinyl alcohol) (PVOH), and cellulose nanowhiskers (CNW). Permeability properties of GGM-based films were compared to those of films from commercial mannans, namely KGM, guar gum galactomannan (GG), and locust bean gum galactomannan (LBG). GGM-based films had lower water vapor permeability than the films formed from any of the other mannans. The oxygen permeability of GGM films was of the same magnitude as that of commercial polyethylene/ethylene vinyl alcohol/polyethylene laminate film. The aroma permeability of GGM films was low. All films were transparent in the visible region, but GGM films blocked the light transmission in the ultraviolet region of the spectra.

## 1. Introduction

Biodegradable packaging prepared from renewable materials can contribute to managing the carbon cycle in a sustainable manner (Narayan, 2007). The food industry is a large consumer of packaging materials and would benefit from new, ecological plastics to be used as self-standing packages, edible films, or coatings. Such films could act as barriers to gases, oil, and water; as binding agents, and as glazes (Fishman, 1997; Nussinovitch, 2000).

The requirements for barrier materials depend on the application and include gas permeability and light transmission. When the food is high in polyunsaturated fat, extreme resistance to oxygen transport is desired. However, when the edible film is applied to fresh fruits or vegetables to retard desiccation, some permeability to oxygen and carbon dioxide is necessary to avoid anaerobic respiration (Kester & Fennema, 1986). According to Bell and Labuza (2000), film permeability data can be used in product shelf life predictions and in tailoring the permeability properties of films for specific food applications. Water vapor permeability (WVP) and oxygen permeability (OP) are considered crucial with respect to many food destabilization processes. The light transmittance of a package affects the rate of oxidation of lipids, and thereby food quality. Haze, "scattering of light by a specimen responsible for the reduction in contrast of objects viewed through it" (ASTM, 2007), has an effect on the consumer appeal of the product. To preserve the sensory properties of food, such as taste and odour, aroma barrier properties of the package are needed.

Mannans are polysaccharides that can be used to form films. Guar gum galactomannan (GG) from *Cyamopsis tetragonolobus*, and locust bean gum galactomannan (LBG) from *Ceretonia siliqua*, both have a β-1,4-D-mannopyranosyl backbone and single D-galactopyranosyl side groups α-linked to mannose C-6 sites (Dea & Morrison, 1975). Mannose:galactose ratios of GG and LBG are approximately 1.5:1 and 3.5:1, respectively (Daas, Schols, & de Jongh, 2000). GG and LBG are widely used as thickeners and stabilizers in the food, cosmetics, and textile industries, and in the paper industry to improve paper strength (Maier, Anderson, Karl, Magnuson, & Whistler, 1993). Glucomannan from the tuber of *Amorphophallus konjac* consists of β-1,4-D-mannopyranosyl and β-1,4-D-glucopyranosyl units, some of which are acetylated at the C2 or C3 positions. The mannose:glucose ratio of konjac glucomannan (KGM) is 1.6:1 and the degree of acetylation is 5%. KGM is used for thickening, gelling, texturing, and water binding (Takigami, 2000). Norway spruce (*Picea abies*) galactoglucomannans (GGM) are a by-product of mechanical pulping of spruce. They can be recovered from the pulping process at a yield of 5 kg/ton pulp, but there are currently no industrial applications utilizing GGM. GGM have backbones similar to that of KGM, with some of the mannose units carrying galactose residues. The mannose:glucose:galactose ratio of GGM is 4:1:0.5. GGM have higher degree of acetylation than KGM, about 20–30% (Willför, Rehn, Sundberg, Sundberg, & Holmbom, 2003). The molar masses of galactomannans and KGM are approximately 1000 kDa (Dea &

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Morrison, 1975; Li, Xie, & Kennedy, 2006a) and those of water-extracted GGM vary from approximately 30–60 kDa (Willför, Sundberg, Tenkanen, & Holmbom, 2008).

KGM forms strong and transparent films and the film formation of KGM has been studied more extensively than that of galactomannans (Aydinli, Tutaş, & Bozdemir, 2004; Cheng, Karim, & Seow, 2007, 2008; Li, Kennedy, Jiang, & Xie, 2006b; Mikkonen et al., 2007; Xiao, Lu, Liu, & Zhang, 2001). Spruce GGM were recently reported to form, in a presence of a suitable plasticizer, cohesive films with low oxygen permeability (Hartman, Albertsson, Söderqvist Lindblad, & Sjöberg, 2006). Polysaccharide-based films are generally good barriers against grease and oxygen, but poor against water vapor (Gröndahl, Eriksson, & Gatenholm, 2004; Mikkonen et al., 2009; Péroval, Debeaufort, Despré, & Voilley, 2002; Talja, Helén, Roos, & Jouppila, 2007). We have previously studied the improvement of mechanical properties of glycerol-plasticized GGM films. The tensile strength and elongation at break of films increased by blending GGM with KGM or poly(vinyl alcohol) (PVOH). GGM–KGM blends were homogenous whereas GGM and PVOH were found to be immiscible (Mikkonen et al., 2008). Addition of cellulose nanowhiskers (CNW) as potential reinforcement of GGM films did not change the mechanical properties of films, although their morphology changed clearly (Mikkonen et al., unpublished results). The aim of the present study was to compare the permeability and light transmittance properties of films from GGM, and their mixtures with other polymers or CNW, to those of films prepared from other mannans. All films were plasticized with an equal amount of sorbitol, which was recently shown in xylan films to result in more stable plasticization (less migration of plasticizer) than glycerol and also to result in lower WVP and OP than glycerol (Mikkonen et al., 2009).

## 2. Experimental

### 2.1. Materials

Guar gum (GG, G-4129) and poly(vinyl alcohol) (PVOH, 98–99% hydrolyzed, $M_w$ 146,000–186,000 as reported by the supplier) were purchased from Sigma (St. Louis, MO) and locust bean gum (LBG, 62631) was from Fluka (Buchs, Switzerland). Spruce galactoglucomannans (GGM) were obtained from process water of a Finnish pulp mill in an industrial-scale isolation trial after ethanol precipitation (Willför et al., 2003; Xu, Willför, Sundberg, Petterson, & Holmbom, 2007). GGM was dissolved in water at 10 g/l, passed through a glass fiber filter to remove the small amount of non-dispersible material, concentrated using a rotary evaporator, and lyophilized. Konjac glucomannan (KGM) (Luxara 208-1, purity 80–85 wt%) was kindly provided by Arthur Branwell & Co. Ltd. (Epping, Essex, UK). Cellulose nanowhiskers (CNW) were the same as used previously (Mikkonen et al., unpublished results) and were prepared from microcrystalline cellulose (Vivapur 105, JRS Pharma GmbH & Co. KG, Rosemberg, Germany) by sulphuric acid hydrolysis according to Bondenson, Mathew, and Oksman (2006). Sorbitol (Sorbidex S58/16603) was from Cerestar (Krefeld, Germany). The $MgCl_2$, $Mg(NO_3)_2$, KCl, and anhydrous $CaCl_2$ with a granular size of 1–2 mm were from Merck (Whitehouse Station, NJ). Commercial film containing ethylene vinyl alcohol (EVOH) and layers of polyethylene (PE) on both sides was kindly provided by Wipak Oy (Nastola, Finland). The thickness of the PE/EVOH/PE laminate film was 40 μm and the thickness of the EVOH layer was 3 μm.

### 2.2. Preparation of films

Films were prepared from mannans, PVOH, blends of GGM:PVOH and GGM:KGM at the ratios of 1:3 and 3:1, and as GGM:CNW and KGM:CNW composites at the ratio of 95:5. Mannans and PVOH were dissolved in water under magnetic stirring at 95 °C for 10 min with CNW added at 5 min when used. Sorbitol was then added at 40 wt% of the weight of polymers. This plasticizer content was used because it is optimal for GGM and to have comparable results, the same plasticizer at the same content was selected for all films. The suspension was degassed by ultrasonication under vacuum, cast into Teflon plates or Petri dishes, and dried at 60 °C. The thickness of the films was approximately 40 μm. All films were conditioned in a climate room at 50% RH and 23 °C for at least 7 days before analysis. Migration and crystallization of sorbitol was not visible during that time.

### 2.3. Water vapor permeability

The water vapor permeability (WVP) was determined according to the ASTM E 96/E 96M – 05 standard (ASTM, 2005). In addition to the RH gradient recommended in the standard (0/54%), RH gradient of 33/86% was studied. Films were sealed on aluminum cups containing 43 g $CaCl_2$ as a desiccant or 25 g saturated $MgCl_2$ solution to give an atmosphere of 33% RH (Labuza, Kaanane, & Chen, 1985). There was an air gap of 6 mm between the salt or salt solution and the underside of the film. The cups were placed in a desiccator cabinet equipped with a fan to circulate the air above the samples at a speed of 0.15 m/s. The cabinet was kept at 22 °C and its RH was maintained at 54% using saturated $Mg(NO_3)_2$ solution when the desiccant was used inside the cups, and at 86% using saturated KCl solution when the inner atmosphere was controlled with $MgCl_2$.

The cups were weighed 5–8 times at intervals of 45 min – 3 d. The temperature and RH of the cabinet was measured using a Rotronic HygroPalm RH meter prior to each weighing (Bassersdorf, Switzerland). The water vapor transmission rate (WVTR) was calculated from the linear regression of the slope of weight gain vs. time by dividing the slope by the test cell mouth area. The water vapor partial pressure at the underside of the film was calculated using the correction method described by Gennadios, Weller, and Gooding (1994). The water vapor permeability (WVP) was obtained by multiplying the WVTR by the thickness of the film and dividing it by the water vapor partial pressure difference between the two sides of the film. Three replicates of each film type were tested and their thickness was measured prior to testing at 10 points at 1 μm precision.

### 2.4. Oxygen permeability

The oxygen gas transmission rate (OTR) of the films was measured using an oxygen permeability (OP) tester with a coulometric sensor (Ox-Tran Twin; Modern Controls Inc., Minneapolis, MN). The specimens were placed in the instrument for approximately 20 h prior to testing to condition them to the RH inside the test cells, which is reported in the instrument manual to be 50–75%. The film was exposed to 100% oxygen on one side and to a mixture of 98% nitrogen and 2% hydrogen on the other side. The OP was calculated by multiplying the OTR by the thickness of the film and dividing it by the oxygen gas partial pressure difference between the two sides of the film. The measurements were carried out at 22 °C and normal atmospheric pressure. The specimen area was 5 $cm^2$ and the thickness of the film was measured after analysis at five points with a micrometer at 1 μm precision. The OP was determined on four replicates of each film. However, in some cases, some of the replicates leaked and fewer than four successful measurements could be done.

### 2.5. Aroma permeability

The aroma permeability of GGM and KGM films was studied with a quasi-isostatic method using gas chromatography as described by Vähä-Nissi et al. (2008). The test cell oven temperature was 40 °C. The test solution contained D-limonene, *cis*-3-hexenol, isoamyl acetate, and R-carvone in mineral oil (all from Sigma). Aroma concentrations were measured as a function of time for 10 days, while the compounds diffused as vapor from the source cell containing the model aroma solution through the tested material to the receiving cell.

### *2.6. Light transmittance*

The light transmittances of the films were scanned from 190 to 800 nm wavelength using a Shimadzu UV-2501 PC spectrophotometer (Kyoto, Japan) equipped with an integrating sphere detector. The measurement was done in triplicate and the average of the three spectra was calculated. In addition, the haze of the films was determined in triplicate at 550 nm wavelength as described in the ASTM Standard Test Method for Haze and Light Transmittance of Transparent Plastics (2007).

## 3. Results and discussion

### *3.1. Water vapor permeability*

The WVP test conditions were selected so that the RH gradient was approximately 50%. Use of desiccant inside the test cups is recommended by the ASTM Standard Test Methods for Water Vapor Transmittance of Materials (2005) and it gives reliable and comparable results with small standard deviation. However, the water activity of food is rarely even close to zero, so we used also the gradient of 33/86% RH to have conditions closer to those of a real food system. In that case, the WVP of films was high, leading to short testing time and some difficulties in estimating the height of the air gap inside the WVP cups. The WVP results are shown both uncorrected and corrected according to Gennadios et al. (1994) in Table 1. At high RH, the correction is more important than at low RH, but it also gives more error because of the above-mentioned reasons.

At both RH gradients used, GGM films had the lowest WVP of all mannan-based films. However, when GGM was blended with PVOH, particularly at the ratio of GGM:PVOH 1:3, the WVP was lower than that of films from GGM alone. The WVP of pure PVOH-based films was similar to that of GGM:PVOH 1:3 blend films. It was previously shown that at the ratio of GGM:PVOH 1:3, PVOH formed the continuous phase and GGM was located as small spheres inside the film, whereas at the ratio of 3:1, GGM formed the continuous phase and the PVOH formed large particles (Mikkonen et al., 2008). Thus the WVP was low when PVOH formed the continuous phase.

Addition of GGM significantly decreased the WVP of KGM films at the gradient of 0/54% RH, but not at 33/86% RH. Addition of CNW did not affect the WVP of GGM films, but somewhat decreased the WVP of KGM films at 0/54% RH. GGM contains acetyl groups, which have a more hydrophobic character than the free hydroxyl groups in sugar units, so GGM has fewer sorption sites for water than the other studied mannans. KGM carries a small number of acetyl groups, but GG and LBG are not acetylated. The higher WVP of films from GG and LBG in comparison to GGM films could also be due to differences in the molecular mobility of mannans in the film matrix. GG and LBG are more highly substituted with galactose than GGM. As discussed in our earlier work (Mikkonen et al., 2007), the smaller number of galactose side groups may allow denser packing of mannan chains in the films. This could further lead to decreased molecular mobility and lower WVP when compared to films from GG and LBG. The films from GG, which is more highly substituted with galactose than LBG, had higher WVP at the gradient of 0/54 than the films from LBG. At the gradient of 33/86, however, the uncorrected WVP of those films was similar and the corrected WVP was higher for LBG film. Thus the RH seems to affect the mechanism of WVP in galactomannan films. At high RH, the swelling of films can affect the solubility and diffusivity of water in the films.

The WVP values obtained in the present study are higher than those reported earlier for polyethylene glycol-plasticized LBG films by Aydinli and Tutas (2000). They determined the WVP of 6.3–11.6 × $10^{-8}$ [g/(m h Pa)], corresponding to 1.5–2.8 [g mm/($m^2$ d kPa)], at a gradient of 0/84% RH for LBG films plasticized with varying amounts of different polyethylene glycols. The WVP of sorbitol-plasticized potato starch films at a gradient of 0/54% RH was also slightly lower than the WVP of mannan films in the present study (Talja et al., 2007). Péroval et al. (2002) studied the WVP of corn arabinoxylan films at the RH gradient of 22/84%. Their results were lower than those determined at the RH gradient of 33/86% in the present study. However, Aydinli and Tutas (2000), Talja et al. (2007), and Péroval et al. (2002) did not report the use of a fan inside the desiccator, which increases the air circulation and WVP results. The WVP of sorbitol-plasticized oat spelt arabinoxylan films at the gradient of 0/54% RH, studied using the same fan-equipped desiccator cabinet as in the present study, was similar to that of GGM films (Mikkonen et al., 2009).

### *3.2. Oxygen permeability*

The OP of KGM films was slightly higher than that of GGM films (Fig. 1). GGM and KGM seemed to have some synergism, as the OP of their blends was lower than that of films from either of the raw materials alone. The use of CNW did not significantly affect the OP of films. The GGM:PVOH 3:1 blend and the film from GG leaked and thus only one and two replicate OP measurements were successful, respectively. The OP of those films as well as of the film from LBG was much higher than that of all others. Interestingly,

**Table 1**
Water vapor permeability (WVP), and corrected WVP (Gennadios et al., 1994) of films at different RH gradients and 22 °C (mean value ± standard deviation from three measurements).

| Film | WVP (RH 0/54%) ± sd (g mm/($m^2$ d kPa)) | Corrected WVP (RH 0/54%) ± sd (g mm/($m^2$ d kPa)) | WVP (RH 32/86%) ± sd (g mm/($m^2$ d kPa)) | Corrected WVP (RH 32/86%) ± sd (g mm/($m^2$ d kPa)) |
|---|---|---|---|---|
| GGM | 1.6 ± 0.05 | 1.7 ± 0.05 | 19 ± 1 | 33 ± 2 |
| GGM:PVOH 3:1 | 1.0 ± 0.1 | 1.0 ± 0.1 | 22 ± 3 | 37 ± 7 |
| GGM:PVOH 1:3 | 0.4 ± 0.06 | 0.4 ± 0.06 | 15 ± 2 | 22 ± 2 |
| PVOH | 0.5 ± 0.03 | 0.5 ± 0.03 | 15 ± 2 | 24 ± 3 |
| GGM:KGM 3:1 | 1.7 ± 0.2 | 1.7 ± 0.2 | 26 ± 3 | 43 ± 4 |
| GGM:KGM 1:3 | 1.9 ± 0.3 | 1.9 ± 0.3 | 29 ± 1 | 45 ± 2 |
| KGM | 3.6 ± 0.3 | 3.7 ± 0.3 | 24 ± 1 | 40 ± 2 |
| GGM:CNW 95:5 | 1.9 ± 0.3 | 2.0 ± 0.3 | 22 ± 3 | 37 ± 6 |
| KGM:CNW 95:5 | 2.6 ± 0.4 | 2.6 ± 0.4 | 24 ± 2 | 40 ± 3 |
| GG | 3.4 ± 0.5 | 3.5 ± 0.5 | 38 ± 1 | 47 ± 10 |
| LBG | 2.6 ± 0.1 | 2.6 ± 0.1 | 37 ± 1 | 61 ± 2 |

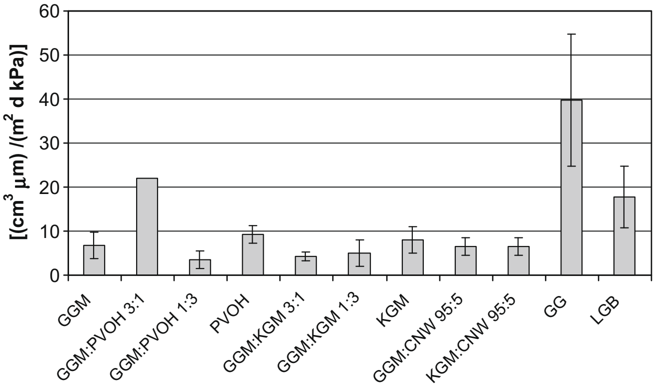

**Fig. 1.** Oxygen permeability of films at 50–75% RH and 22 °C. The averages are based on 3–4 successful measurements, except GGM:PVOH 3:1 and GG are from one and two successful measurements, respectively. The error bars indicate standard deviations.

at the ratio of GGM:PVOH 1:3, PVOH was able to decrease the OP of GGM films, which may be attributable to the phase separation of GGM:PVOH blends, as discussed earlier. At the ratio of GGM:PVOH 3:1, when large PVOH particles were located in the continuous GGM matrix, either holes, or zones where the continuous phase was thin, may have been formed and caused the high OP. As the OP of GG and LBG films was high, the galactose side groups may have loosened the film structure so it was more permeable to oxygen. In addition, the surfaces of GG- and LBG-based films were rough and uneven, which could cause the formation of pinholes allowing oxygen permeation. The surfaces of GGM- and KGM-based films were, in contrast, relatively smooth, when observed visually.

The OP of a commercial PE/EVOH/PE film was tested as comparison, because EVOH is widely used as an oxygen barrier material. Due to its high cost and sensitivity to water, it is usually laminated with some cheaper and more hydrophobic material such as PE. The OP of the PE/EVOH/PE laminate used was 4.4 $cm^3\ \mu m/(m^2\ d\ kPa)$, which is not significantly different from that of GGM films as such, with CNW, with KGM, or with PVOH at the ratio of GGM:PVOH 1:3.

The average OP of GGM film, 6.8 $cm^3\ \mu m/(m^2\ d\ kPa)$, was somewhat higher than the value reported for GGM-sorbitol film by Hartman et al. (2006), 2.0 $cm^3\ \mu m/(m^2\ d\ kPa)$. Hartman et al. (2006) obtained an OP of 4.6 $cm^3\ \mu m/(m^2\ d\ kPa)$ for GGM/alginate/glycerol blend. The OP of the GGM films in the present study was lower than that of glycerol-plasticized amylose and amylopectin films (Rindlav-Westling, Stading, Hermansson, & Gatenholm, 1998), but not as low as that of sorbitol-plasticized aspen glucuronoxylan films (Gröndahl et al., 2004). The OP of oat spelt arabinoxylan films plasticized with 40% sorbitol was 4.7 $cm^3\ \mu m/(m^2\ d\ kPa)$, which is slightly lower than that of GGM films (Mikkonen et al., 2009).

### 3.3. Aroma permeability

Due to the length of the test, only two film types, GGM and KGM, were selected for aroma permeability measurement, and both had very low aroma permeability. The diffusion coefficients were lower for GGM films than for KGM films (Table 2), which were lower than those measured previously for low density polyethylene coated paper (Vähä-Nissi et al., 2008). The diffusion coefficients of GGM and KGM films for D-limonene were slightly higher than those of sodium ionomer, but lower than those of ultra-low-density polyethylene, polycaprolactone, and polyhydroxybutyrate with 12 mol% of valerate (Hernandez-Muñoz, Catalá, & Gavara, 1999; Sanchez-Garcia, Gimenez, & Lagaron, 2008). GGM and KGM films were especially good barriers against R-carvone, which did not pass the films during the measurement time (10 days). In comparison, carvone was reported to pass starch films (Ylmaz, Jongboom, Feil, van Dijk, & Hennik, 2004). The results indicate that GGM and KGM films have potential as aroma barrier materials.

**Table 2**
Diffusion coefficients ($\times 10^{-15}$ $m^2/s$) of aroma compounds in GGM and KGM films. The two replicate results are shown, except for *cis*-3-hexenol, for which only one measurement was done due to long testing time.

| Film | GGM | | KGM | |
|---|---|---|---|---|
| | A | B | A | B |
| Isoamyl acetate | 3.2 | 2.6 | 5.3 | 5.5 |
| D-Limonene | 2.3 | 2.9 | 5.7 | 5.6 |
| *cis*-3-Hexenol | 1.0 | nd | 2.6 | nd |

nd, not determined.

### 3.4. Light transmittance

All films were transparent in the visible region of the spectrum (Fig. 2). GGM-based films blocked the ultraviolet light transmission, which can be beneficial for product preservation in some food applications as the most pronounced deleterious effects of light on food are caused by ultraviolet light (Bekbölet, 1990). Addition of CNW did not affect the light transmittance. KGM films had the highest light transmittance throughout the scanned wavelength region. Use of PVOH at the GGM:PVOH ratio of 3:1 somewhat decreased the light transmittance. All mannan-containing films showed a small drop in the ultraviolet light transmission at approximately 290 nm, and the films from galactomannans GG and LBG had another drop near 350 nm. Opacity in the ultraviolet region of the spectra could be due to some aromatic impurity, such as lignin or protein.

The haze values were low for KGM films and for films with a high content of KGM (KGM:CNW 95:5, and GGM:KGM 1:3) (Table 3). The haze of GGM films was 23.5%, which was clearly higher than that of KGM films, 4.6%, but of the same order of magnitude as those of GG and LBG films. Addition of CNW slightly increased the haze of both KGM and GGM films. Blending of PVOH clearly increased the haze of GGM-containing films. The highest haze value was found in pure PVOH films. The haze of LBG films, plasticized with sorbitol in the present study, was 22.5%, which is of the same magnitude as measured by Aydinli et al. (2004) for LBG films plasticized with a low amount of polyethylene glycol. Haze values correlated well with the visual appearance (clear/cloudy) of the films. The results indicate that KGM films were very clear, but that the other studied films were translucent.

## 4. Conclusion

Sorbitol-plasticized GGM films showed promising barrier properties. The WVP and OP of GGM films were lower than those of films from other mannans and the OP of GGM films was comparable to that of a commercial PE/EVOH/PE laminate film. The WVP was even lower with PVOH as the continuous phase of the film. The OP of GGM–PVOH blends depended on the blend ratio and at the ratio of GGM:PVOH 1:3, it was lower than that of films from either of the polymers alone. The WVP of GGM–KGM blends was lower than that of films from pure KGM at the RH gradient of 0/54%. GGM and KGM showed synergism as the OP of the blends was lower than that of either pure film. Unexpectedly, the presence of 5% of CNW did not significantly affect the WVP or OP of films, even though it changed their appearance. Aroma permeability of both GGM and KGM films was low. All films were transparent in the visible region of the spectra, but films containing GGM blocked

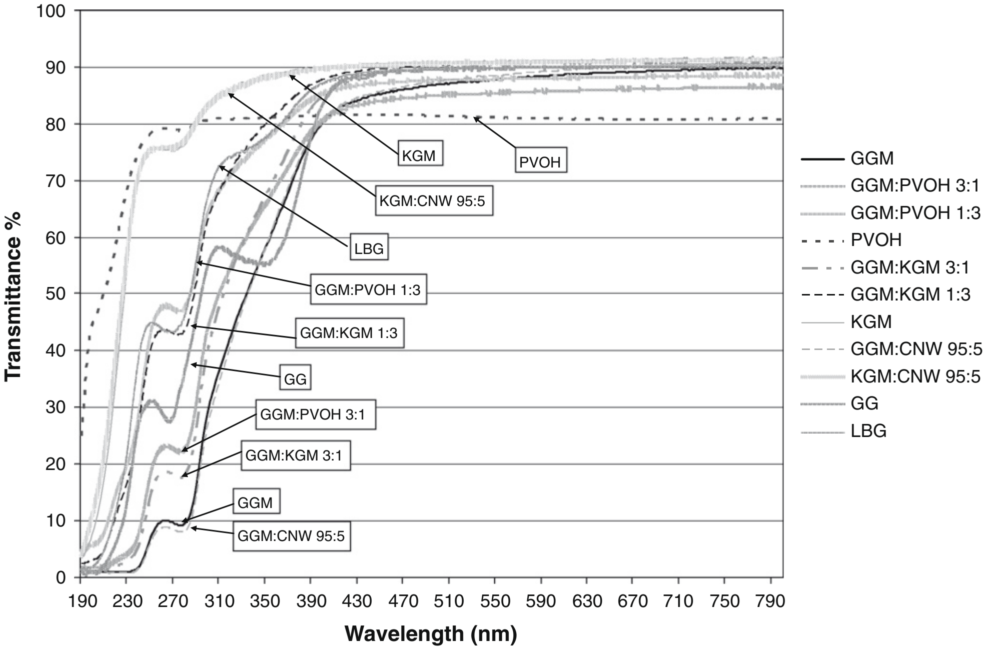

**Fig. 2.** Light transmittance of films.

**Table 3**
Light transmittance and haze of films at 550 nm ± standard deviation.

| Film | Transmittance % (550 nm) | Haze % (550 nm) |
|---|---|---|
| GGM | 87.9 ± 0.5 | 23.5 ± 0.1 |
| GGM:PVOH 3:1 | 85.4 ± 0.5 | 30.7 ± 2.2 |
| GGM:PVOH 1:3 | 87.9 ± 0.8 | 58.3 ± 0.5 |
| PVOH | 81.0 ± 3.8 | 70.4 ± 7.3 |
| GGM:KGM 3:1 | 89.1 ± 0.4 | 28.5 ± 1.1 |
| GGM:KGM 1:3 | 90.5 ± 0.4 | 7.7 ± 0.4 |
| KGM | 91.0 ± 0.3 | 4.6 ± 0.3 |
| GGM:CNW 95:5 | 88.4 ± 1.1 | 25.6 ± 0.8 |
| KGM:CNW 95:5 | 90.6 ± 0.1 | 7.7 ± 0.9 |
| GG | 89.8 ± 0.1 | 18.8 ± 1.0 |
| LBG | 89.7 ± 0.4 | 22.5 ± 1.3 |

transmission in the ultraviolet region. The haze of GGM films was higher than that of KGM films and the use of CNW further increased the haze. GGM films could be used as oxygen or aroma barriers at relatively low RH conditions or if coated with a more hydrophobic material, similarly as starch films. However, GGM have the advantage of being a by-product and not energy nutrient, which makes them an interesting raw material for packaging industry. The drawback with GGM is, however, that they need a relatively high amount of plasticizer, which can be a problem in food applications because of migration. The stability of plasticization is a subject of further studies.

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