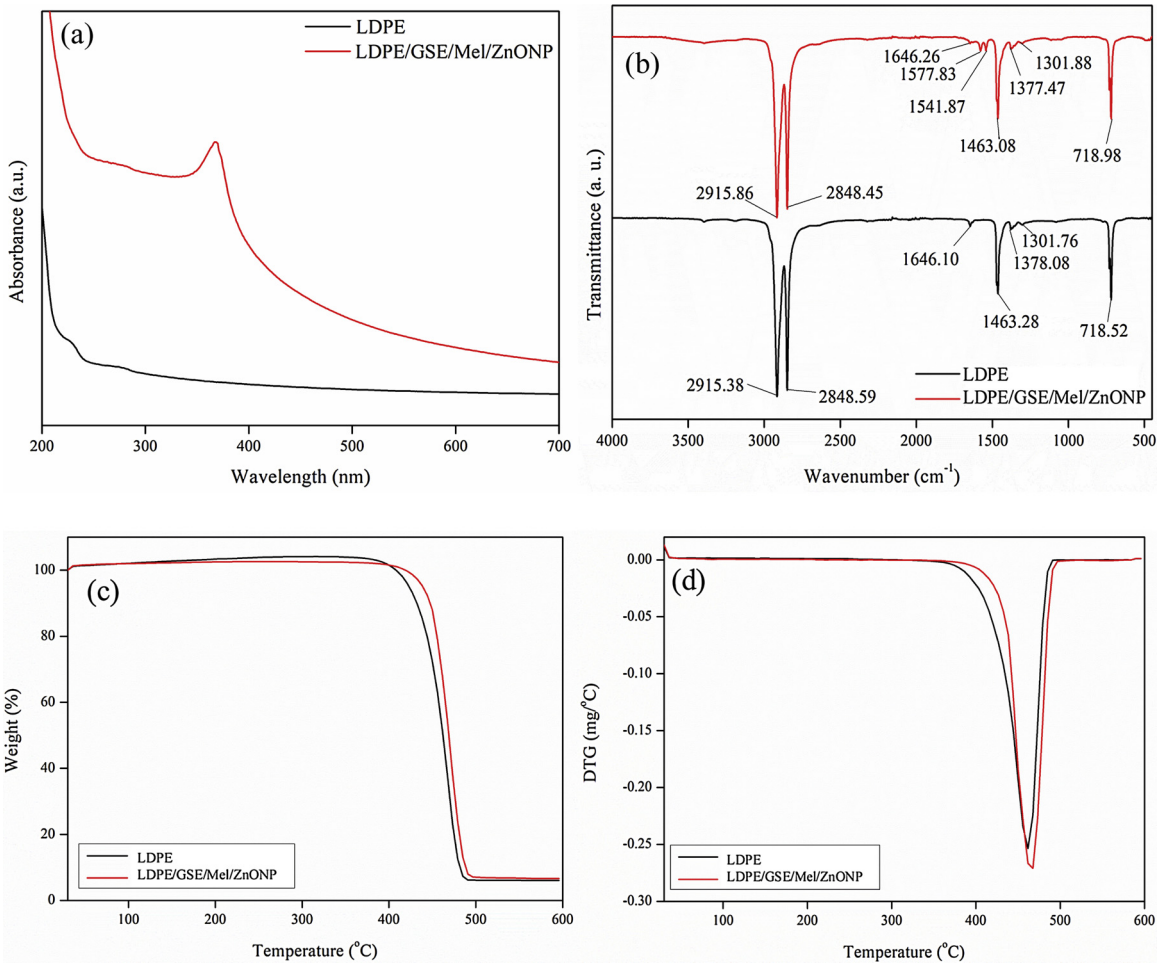

Fig. 2. (a) UV-visible, (b) FTIR, (c) TGA, and (d) DTG results of the LDPE and LDPE/GSE/Mel/ZnO composite films.

bacteria, whereas ZnONP has a stronger antibacterial activity against *E. coli* than *L. monocytogenes* (Shankar & Rhim, 2018c; Shankar, Wang et al., 2018). Using both GSE and ZnONP in this study probably increased the antimicrobial activity against both test organisms (*E. coli* and *L. monocytogenes*).

3.2. Characterization of coated paper

3.2.1. Morphology of coated paper

All papers coated with the LDPE and LDPE/GSE/Mel/ZnONP had a smooth surface with increased gloss. The LDPE layer adhered firmly to the base wrapping paper without delamination or cracks on the surface. Increased surface smoothness resulted from filling the gap between the cellulose fibers of the paper with the LDPE polymer. The increase in surface smoothness of the paper-based packaging materials was also observed in various types of biopolymer coated paper (Gällstedt, Brottman, & Hedenqvist, 2005; Khwaldia et al., 2010; Shankar & Rhim, 2018c). The performance of polymer-coated paper is affected by the coating method as well as compatibility between the coating material and paper (Aloui & Khwaldia, 2017; Shankar & Rhim, 2018c). The tightly adhered coating of LDPE and LDPE/GSE/Mel/ZnONP films indicated that both film layers were well compatible with the base paper.

The morphology of LDPE coating on the wrapping paper was also observed through FE-SEM images. The SEM images of the surface of the uncoated and coated papers are shown in Fig. 4. The surface of the uncoated paper showed a coarse and porous structure with gaps between cellulose fibers. However, the porous fibrous structure of the paper was covered and filled with the LDPE coating to form a smooth surface. Similar results of the smooth surface were obtained when a Kraft paper was coated with PBAT and PLA (Rhim et al., 2007; Shankar & Rhim, 2018c).

Table 2
Thickness, mechanical properties and water contact angle of LDPE-based composite films.

Films	Thickness (μm)	TS (MPa)	EB (%)	EM (MPa)	WCA (°)
LDPE (M)	60.0 ± 1.0^{a}	21.7 ± 1.1^{b}	806.2 ± 23.2^{c}	104.4 ± 3.6^{a}	84.2 ± 2.8^{b}
LDPE/GSE/Mel/ZnONP (M)	69.6 ± 0.3^{d}	17.0 ± 2.2^{a}	528.0 ± 21.8^{b}	102.9 ± 0.8^{a}	79.4 ± 2.6^{a}
LDPE (CM)	62.9 ± 0.3^{b}	22.6 ± 1.1^{b}	546.5 ± 14.5^{b}	104.5 ± 3.0^{a}	ND
LDPE/GSE/Mel/ZnONP (CM)	68.6 ± 0.2^{c}	15.1 ± 0.8^{a}	397.6 ± 30.3^{a}	113.2 ± 4.5^{c}	ND

The values are presented as a mean ± standard deviation. Any two means in the same column followed by the same letter are not significantly ($p > 0.05$) different from Duncan's multiple range tests. M: Machine direction, CM: Cross-machine direction.