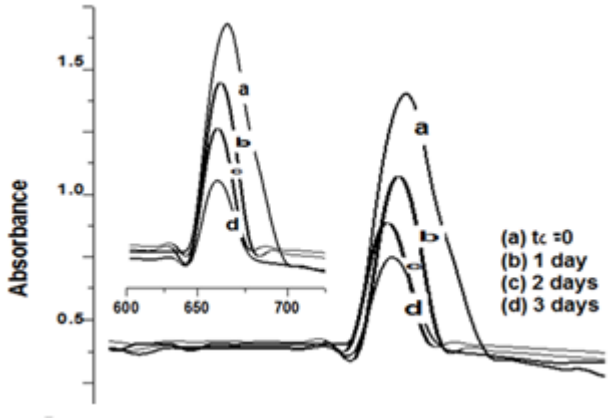

Figure 3: Visible absorption spectra of Fe/Mn- Chl complex compared with Fe–Chl complex (left small plot), for different time periods *(t_c)*.

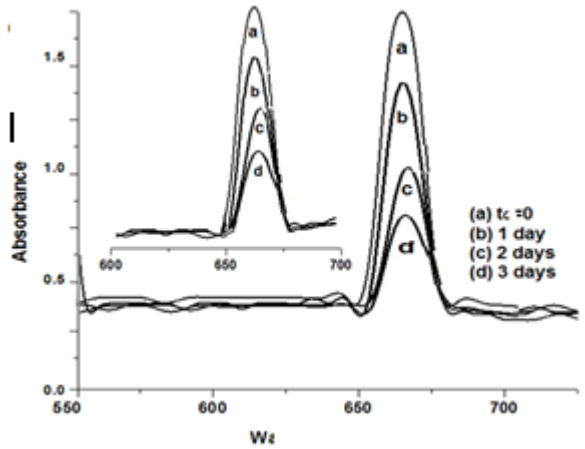

Figure 4: Visible absorption spectra of Mn/Pb-Chl (left small plot), for different time periods *(t_c)*. Chl complex (left small plot), for different time periods *(t_c)*.

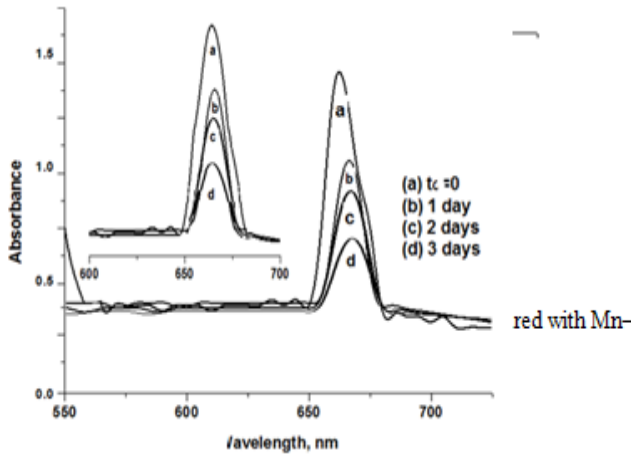

Figure 5: Visible absorption spectra of Fe/Mn/Pb- complex compared with Mn– Chl complex compared with Pb–Chl complex

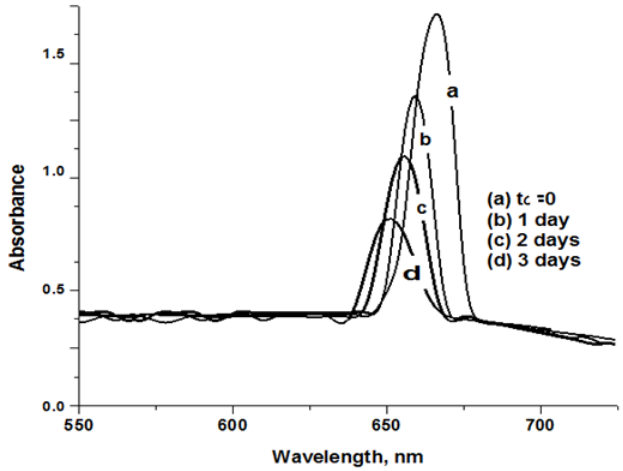

Figure 6: Visible absorption spectra of Cu/Fe/Mn/Pb-Chl, for different time periods *(t_c)*.

3.2. Morphological Analysis

Figs. 7a-e exhibit the optical microscopic images of free Chl "Mg-Chl" and HMS-Chl products "Cu-Chl, Fe-Chl, Mn-Chl and Pb-Chl", respectively, at room temperature. Microscopic images obtained from free Chl do not manifest any fractal structures (Fig. 7a), whereas those formed from interaction of HMS with Mg-Chl manifest various fractals as shown in Figs 7b-e. In general, the fractals have several branched structures as observed in Mn-Chl and Pb-Chl images (Figs. 7d and 7e) at room temperature. Clear dense fractal structures of Fe-Chl (Fig. 7c) may related to the peripheral chelate formation, wherea in case of Cu-Chl (Fig. 7b) may due to central-complex and peripheral-chelate formation at the same time. The difference between the fractal structures of HMS-Chl images obtained at room temperatures may attributed to the complex formation process, the Chl concentration and the period required for drying. The major formation mechanism which detects the expansion of the fractal structures from chlorophyll based mainly on the concept of molecular diffusion [30, 31]. There are several techniques used to characterize the fractal dimensions of Chl structures as function of concentration such as box counting method [32].

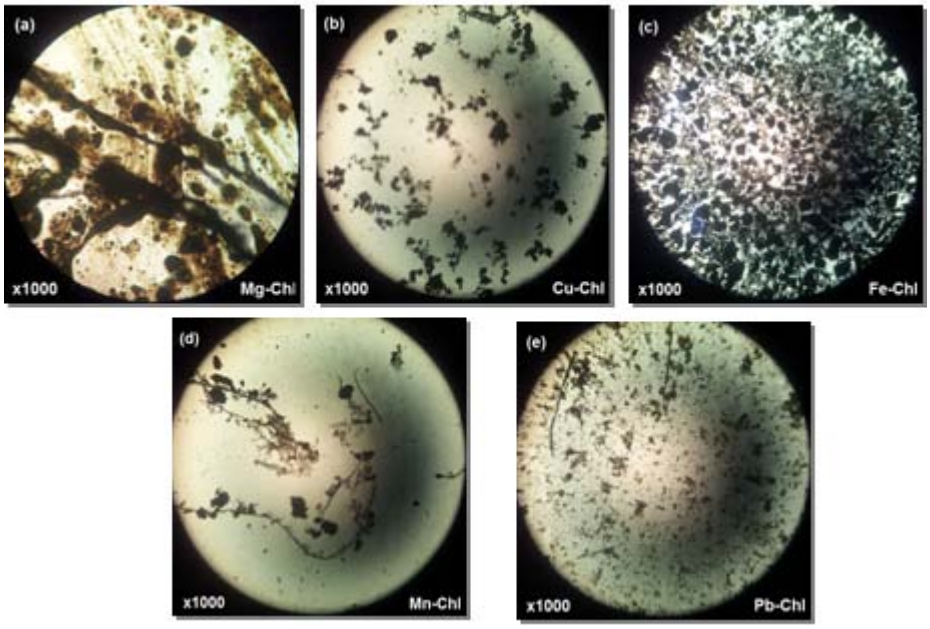

Figure 7: Optical microscopic images of free Chl and HMS-Chl complexes; (a) Mg-Chl; (b) Cu-Chl; (c) Fe-Chl; (d) Mn-Chl; (e) Pb-Chl, respectively, after 3 days of complex formation

4. Conclusions

This research presents the interactive effects of four heavy metals "Mn, Fe, Cu and Pb" with extract chlorophyll using morphological and visible spectrophotometric analysis. Predominantly, central Cu-Chl complexes formed by the replacement of the central Mg-atom of chlorophyll with Cu-atom, it was not clearly appeared in case of the other three metals. On the other hand, the microscopic morphology of all Chl-HMS products may contemplate the prospect for peripheral chelation. This case may leads to chlorophyll degradation and the formation of stringy products.

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