CHAPTER VI:
DEGRADABILITY OF BIOCOMPOSITES PREPARED FROM STARCH AND LAYERED SILICATES
6.1. Introduction

In order to develop an environmental friendly material, many efforts have been made as the solution of plastic waste generated in the environment, particularly by one time use disposable commodity materials [1-4]. Polyolefins, the most recognized family of synthetic polymers for packaging materials, contribute significantly in the generation of waste whereas, these polymers can be bio-assimilated after generation of functional groups by different pretreatments [5-7]. Most of the research attention is focused on the replacement of petro-based commodity plastics by biodegradable material in a cost effective manner with competitive mechanical properties. The mixing of biopolymers in the matrix of these thermoplastics [2,3, 8-11] has been recognized as a relevant way to get rid of plastic waste but this blending leads to a phase separation and reduction in mechanical properties due to the lack of compatibility between hydrophilic biopolymer and generally hydrophobic thermoplastic. Therefore, in the resulting product, consumption of natural biomaterial by microbes takes place, leaving behind fragmented thermoplastic matrix. In the family of the polymers of renewable resources, starch has been considered as the most promising material for this purpose as it exists abundantly and may form a cost effective end product [12-14]. Compatibility of starch can be improved by the modification of hydroxyl group and may be used at fairly high amount in the composites to obtain the tailored material [15-17].

The blends of starch with anhydride-containing copolymers (upto 70 wt% starch in the whole composition) [18-19] have been reported. MaterBi® from Novamont is claimed a commercially available and compostable product made of compatibilized aliphatic PCL/starch blends and is being used for preparation of films and sheets [20]. By destroying the crystalline structure of starch under pressure and heat with plasticizers (e.g., water, glycerol and other polyols), it is possible to convert it into thermoplastic starch (TPS, where starch content is as high as 95%), which could be processed alone or with a particular synthetic polymer [16,21-23] but the moisture sensitivity limits its applications for many purposes. Although water resistance can be improved by adding poly(ethylene-co-vinyl alcohols) [24] or by cross linking [25-26], still it has not come to real practical use as traditional plastics. An increased biodegradability of starch-PCL blends was found with the compatibilization and it was displayed that the compatibilization not only increased mechanical properties but also the accessibility of comparatively less active matrix against microbes [27]. In all starch based systems, the mobility of polymer chains determine the generation of chain to chain interactions and entanglement, processing
parameters, and composition is believed to influence the mechanical properties but the
direct relation in the structure and properties of the resulting products are very complex
and is little known. Moreover, the total goal in the area of starch thermoplastic composites
is to enhance processibility, compatibility and water resistance in a very cost effective
manner as these factors decide the fate of starch based product in the form of a substitute
for petro based materials. Recently a new class of hybrid material of polymers and layered
silicates has been emerged and is well known for reinforcing the several material
properties due to the high aspect ratio and easy phase to phase energy transfer, even at
very low filler concentration, if uniformly and completely dispersed in the host matrix [28-
30]. A tremendous improvement in mechanical and barrier properties was observed when
starch matrix was filled with layered silicates and well ordered nanocomposites were
obtained by melt intercalation method [31,32] with plasticized starch. During synthesis of
nanocomposites, polymer chains from bulk, try to penetrate inside silicate layers and
depending on penetration extent, intercalated or exfoliated structure is formed. If polymer
chains are not able to penetrate effectively, microcomposites formation takes place. There
are a number of parameters which decide this degree of diffusion viz. modification of clay,
polar-polar interactions, molecular weight of polymer, packing density inside the gallery
and concentration of filler [33]. The preparation of nanocomposites is still a trial and error
effort, ranging broadly from a lower filler concentration to higher by varying the different
parameters like those mentioned above and optimization of parameters is usually done by
examination of several formulations. In the present study, it was found out that except all
these deciding parameters of composite structure, the sequence of mixing can also affect
the nature of the resulting product, whether it will be a nano level distribution or micro
level, at least in starch clay nanocomposites prepared by solution method. Since both
components (starch & plasticizer ) of composite (starch/ clay /plasticizer ) must show the
tendency towards accommodation inside the gallery space of filler, due to the presence of
polar –polar interactions with clay, the study of interactions may insure the preparation of
tailored nanocomposites of starch. In the present investigation, the behavior of starch /
plasticizer (glycerol) with clays was studied to determine the cause of intercalation and
hence to understand the process taking place. Mechanical properties, thermogravimetric
analysis, moisture sensitivity of the composites were studied. XRD results were used to
evaluate the interaction extent between filler and starch /glycerol and different structural
presentations were made on the basis of these results.
6.2. Experimental

6.2.1. Material
Native corn starch, with 15% moisture content and glycerol was obtained from S.D. Fine-Chem. Pvt. Ltd. (India). Clay, sodium montmorillonite (Closite Na+) was from Southern Clay Products, Inc. USA, having Cation Exchange Capacity (CEC) 90 meq/100 gm.

6.2.2. Preparation of nanocomposites
The clay was dispersed in water at 35 ± 5°C for 48 hrs. till the formation of colloid like hazy suspension. Weight of clay and starch was taken after drying at 110°C. Plasticizer concentration was 20% (w/w) of dry starch and clay concentration was constant at 5% (w/w) in all the compositions. The starch/clay/glycerol (75/5/20) were mixed by the following ways: i) Starch was gelatinized with water followed by plasticization and then clay slurry was added. This mixture was heated for 30 minute at boiling point and obtained composite samples were designated as STN1, ii) The clay slurry was mixed with starch in water and heated at boiling point for 30 minutes with constant high stirring, followed by the addition of plasticizer. These samples were named as STN2, iii) starch, clay slurry and glycerol were mixed together and heated for 30 minute at boiling point, these specimens were known as STN3 and iv) glycerol was mixed with clay slurry and stirred for 5 hrs. at room temperature followed by addition of starch. This mixture was heated with water at boiling temperature for 30 minutes and samples were designated as STN4. The glycerol-clay (ST-GLC) mixture was also prepared under the same condition to study the migration efficiency of plasticizer into clay layers. Commonly, after completion of all procedures, solution was poured in petridishes and dried in vacuum oven at 50-60°C. The films of ~150-200 μm thickness were obtained and samples were equilibrated at 25±2°C for two weeks at 43% relative humidity (RH) according to the ASTM E 104.

6.2.3. Characterization and measurements

6.2.3.1. WAXD
The WAXD pattern of samples was obtained by a Rigaku (Japan) diffractometer with Cu-Kα radiation at 50 kV between the scan range of 20 from 2-10 degree by the scan rate of 1°/minute. The d-spacing was calculated by Bragg’s equation where the λ was 0.154 nm.

6.2.3.2. Thermogravimetric analysis (TGA)
TGA was performed under nitrogen flow at heating rate of 10°C/min in the temperature range of 25-500°C by the Perkin Elmer TGA-7 instrument after maintaining the samples for 2 weeks at 25±2°C.
6.2.3.3. Mechanical properties

These all samples were molded at 150 ± 5°C for 40 seconds in between Teflon sheets at 5000 pound pressure followed by quench cooling for 2 minutes. Mechanical properties of five samples for each composition, were determined using an Instron universal machine at 27 °C with cross head speed of 1.5 mm/min, after conditioning for 3 weeks at 67 % RH. The data for the samples those failed close to the grip was excluded.

6.2.3.4. Water uptake (WU)

The specimens were cut in the shape of rectangular strips with dimension of 10 mm X 10 mm X 1 mm. It was supposed that films were thin enough so that molecular diffusion was considered to be one dimensional. The samples were dried till the constant weight under an vacuum oven to remove the moisture before water absorption testing by gravimetric methods and this weight was taken as initial weight (Wi). The samples were conditioned at 98 % RH for 50 hrs. and increase in weight was taken as final weight (Wf). The water content or water uptake percentage was measured by using following formula \[
\frac{Wf-Wi}{Wi} \times 100
\]. This type of water sensitivity measurements are better than classical technique of immersion in water as starch is very sensitive to water which may partially be dissolved after exposure. Conditioned samples were removed gently and weighed using a four-digit balance. The samples were dried till the constant weight under an oven to remove the moisture.

6.2.3.5. FT-IR and biodegradability in compost.

FT-IR (Fourier Transform infrared 16 PC Spectrometer) was used to characterize the composite samples, interest was focused mainly on the changes in CH$_2$ stretching and bending bands. SEM was done after complete drying of the samples after composting as was given in Chapter 3 and 4. The samples were exposed to compost for different time intervals. The nature of compost was same as has been described in the Chapter 1. Additional feeding was done by mixing 100gm bread in the composting bin. Variation in sample weight was used to determine the biodegradation. In fact, all samples showed a weight increase in the starch-based systems due to water absorption after immersing in the compost. The weight loss is defined as the difference between the water absorption in pure water and in compost at the same exposure time. In the second case percentage of water absorption is always lower than in pure water.

6.3. Results and discussion
6.3.1. Structure of nanocomposites

The dispersion extent of silicate layers has typically been elucidated by XRD, which allow a direct evidence of polymer chain confinement into the silicate gallery. The XRD pattern of all samples is shown in Figure 6.1, which suggest the presence of ordered structure in all the composites as complete diminishing of characteristic peak of clay (Closite Na+, 2θ = 7.54, d-spacing = 1.17 nm) was not found. The presence of narrow peaks except STN2, is an evidence of the higher stacking order in clay layers and confirming the finite diffusion of polymer chains with repeat distance of few nanometers between chains and layers. The highest increase in d-spacing for STN2 specimens (2θ = 3.30°, d-spacing = 2.68 nm) and lowest for STN1 (2θ = 6.37°, d-spacing = 1.38 nm) was observed whereas, STN3 shows a significant shift of theta towards lower direction with an intermediate gallery height (2θ = 4.58°, d-spacing = 1.93 nm). From the observations, it was apparent that there must be some interactions, which decides the chain diffusion into gallery of clay, as all components had the same concentration in composites. After plasticization, starch chains could not be diffused inside clay gallery and this must be due to the electrostatic attraction between the functional groups of starch and glycerol resulting in the formation of a big mass by developing hydrogen bonding bridges, affecting the global mobility of polymer (Figure 6.2). Another cause is the decrease in polar-polar attraction between the hydrophilic clay and starch as in this case starch is also attracted by the plasticizer. In other words, a counter balance of driving forces (polar-polar attraction of clay is partially balanced by electrostatic hydrogen bonding between starch and plasticizer) takes place, which consequently decrease the attractive forces between clay and starch. This argument was more explanatory by obtaining the XRD pattern of clay and starch mixture where an increase in d-space was higher than STN1 (for ST-GLC, 2θ = 5.43°, d-spacing = 1.62 nm and for STN1, 2θ = 6.37°, d-spacing = 1.38 nm), and this fact gave the credit to conclude that plasticizer also face the difficulties in moving towards the gallery due to the electrostatic H-bonding with starch and could not intercalate as freely as in the absence of starch. Further, when the composites were prepared without earlier plasticization (STN2), the characteristic peak was highly diminished giving the indication of high extent of intercalation i.e. the extensive diffusion of polymer chains inside galleries of clay, which results in high dispersion of filler throughout the matrix. These results confirm the presence of attractive forces in all the systems, which are decisive factors for the effectiveness of dispersion in the overall polymer matrix. The gallery height was not increased in the case of STN2 after plasticization, suggesting that
plasticizer can be accommodated among starch chains which may not lead to any further increase in gallery height. In the case of STN3, increase in d-spacing was less than STN2 but significantly higher than for STN1 and little higher than glycerol-clay mixture which may be attributed to the diffusion of starch chains inside the filler. Here, if we suppose that, complete diffusion of plasticizer had taken place in this sample, and then also the increase in gallery height is more than in ST-GLC, which confirmed the migration of starch chains. Since complete diffusion of plasticizer is not possible due to the presence of interactions between plasticizer and starch, it was concluded that both the components have moved towards gallery faster than STN1 and slower than in STN2 in the STN3 samples. In a previous study [31,32], the non escaping of small molecules in thermoplastic starch–clay nanocomposites, prepared by melt intercalation method, inside gallery was argued by the absence of significant increase in gallery height. Thus, there is a clear effect of preparation method on the starch migration inside clay galleries, which increase when solution method is applied. In the present system, a clear migration of plasticizer inside unmodified clay layers was observed. Moreover, the possibility of better dispersion of clay in the starch matrix decreases if glycerol and starch will allow together for the diffusion inside the layers of silicates.

When another set of the composites (STN4) were prepared by the mixing of starch in the mixture of clay and glycerol, which had already been stirred at room temperature for 5 hrs., followed by heating the whole solution at boiling point for 30 minutes, a XRD pattern showing greater gallery height than ST-GLC and STN1 but less than STN2 & STN3 was found (STN4, 2θ = 4.96°, d-spacing = 1.78nm). These results were surprising because glycerol was supposed to increase the gallery height and act as surfactant, which would have been facilitated the penetration of starch chains. Further, in this composition starch diffusion should be more as starch chains have two attractions one; with clay and other one with plasticizer, inside the clay. The explanation for this behavior may be as follows;

1. There was enough amount of plasticizer outside the clay stacks after a optimum migration inside the layers as only glycerol can not cause the individualization of silicates layers. The un-migrated plasticizer can form hydrogen bond bridges with the starch molecules resulting in slow diffusion as in STN1. Further, the un-plasticized starch chains may require an additional force to replace the plasticizer on the surface of filler. Thus, the number of contact decrease by starch on the clay surface.
2. The tetrahedral sites in the layers, containing Si\(^{4+}\) (a Lewis acid site), might be helping in intercalation of oxygen containing functional groups (O-H-) in starch. In the case of STN 2, these sites were engaged with OH of glycerol and unavailable during penetration of starch chains as the diffusion start after surrounding the filler particles. Again the concentration of glycerol inside the gallery may increase the packing density, which will disfavor the penetration of polymer chains.

3. Another the most probable explanation may be that, as soon as starch chains start interacting with glycerol present in the gallery, a close packing starts, which may generate a solid like structure after a definite penetration of starch chains. At this stage diffusion of other chains becomes difficult resulting a micro- composite.

The migration of plasticizer inside clay galleries was studied by FT-IR spectroscopy, which gives more realistic information about the different interactions at molecular level. IR bands between 2800-3000 cm\(^{-1}\) are related to the stretching of CH\(_2\) and bands around 2920 and 2850 cm\(^{-1}\) generates due to the asymmetric and symmetric stretching of methylene, respectively. Peaks at 1472-1466 cm\(^{-1}\) arises due to the scissoring vibrations of CH\(_2\). These scissoring bands shows variations with inter chain interactions, packing arrangement and ordering of methylene chains\(^{[34]}\).

Figure 6.3 showed FT-IR spectra of glycerol, obtained at room temperature, with different components. The shifting of band from 2925 to 2920 cm\(^{-1}\) after clay mixing suggest an increase in packing density, thus, the surface area per guest (starch) chains decreased. There was no change in this band for STN4 specimen, which was attributed to the close packing in the silicate layers. The increase in packing density or decrease in chain motion of glycerol after mixing with clay was further confirmed from the rising of CH\(_2\) bending at 1472 cm\(^{-1}\). Thus, the migration of glycerol into silicate layers increases in the absence of starch which increase the packing density increase, which inhibit the further penetration of starch chains resulting in conventional type of composites.

6.3.2. Effect of filler dispersion on the material properties

6.3.2.1. Mechanical properties

The results, obtained by measurement of mechanical properties of the composites are tabulated in Table 6.1. The modulus of composites increased significantly for all candidates as compared with unfilled matrix irrespective of the preparation fashion. The highest enhancement in STN2 and lowest in STN1 suggests that the stiffness increase with
Figure 6.1. The XRD pattern of all composites and neat Cloisite Na+ including glycerol–clay composition
Clay  

Plasticizer Starch  

Plasticizer-Starch electrostatic attraction may effect the global migration of the chains toward the clay gallery

Figure 6.2. Representation of interactions between plasticizer and starch during migration towards clay galleries

the gallery height of silicate layers in the matrix. Such kind of improvements are well known in intercalated /exfoliated nanocomposites for other polymers also and are attributed to the higher reinforcing effect of layered fillers [28,29]. A significant increase in STN2 as compared with other samples, indicates that the extent of plasticization is sufficient enough which allow the segmental mobility of starch chains. Thus, when glycerol was mixed after starch diffusion inside the clay gallery, it can migrate throughout the system owing to its smaller size and retaining the plasticizer efficiency. In the case of STN1, a significant reduction in strain is attributed to the presence of large stacks of filler inside the matrix consisting agglomerates of layered silicates those are surrounded by polymer chains. STN3 showed intermediate results but strain was less than unfilled starch.
Figure 6.3. FT-IR spectra of glycerol clay mixture (I), STN4 (II) and glycerol (III) which confirm the decrease in plasticization efficiency. The specimen of STN4 exhibited the results close to STN3 but are not significantly different which gives the information that most of the glycerol resides inside the gallery space and is not available for electrostatic bonding with starch leading a restricted motion of chains.

Table 6.1. Mechanical properties of different composites

<table>
<thead>
<tr>
<th>Sample</th>
<th>Young's Modulus [MPa]</th>
<th>Maximum strain [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasticized starch</td>
<td>790</td>
<td>10</td>
</tr>
<tr>
<td>STN1</td>
<td>820</td>
<td>6</td>
</tr>
<tr>
<td>STN2</td>
<td>825</td>
<td>12</td>
</tr>
<tr>
<td>STN3</td>
<td>824</td>
<td>9</td>
</tr>
<tr>
<td>STN4</td>
<td>821</td>
<td>7</td>
</tr>
</tbody>
</table>
6.3.2.2. Moisture resistance

Moisture sensitivity of starch-based material is a key challenge towards the substitution of traditional plastics for commodity, most precisely, for packaging applications. The water uptake during the exposure at RH 98 % was evaluated for 50 hrs. (Figure 6.4). The increased permeability of starch films after plasticization has been reported against water, gas and solute [35]. The plasticized starch films showed the highest moisture sensitivity in comparison of other samples. Plasticization increased the hydrophilicity of the starch matrix as around 1.5 times, which is attributed to the increase in chain mobility at room temperature by breaking the attraction forces in the host matrix and consequently increase in concentration of exposed moisture prone hydroxyl groups, facilitating diffusion of water molecules throughout the polymer matrix. After mixing with clay, an overall decrease in hydrophilicity, regardless the clay concentration in the systems, must be attested to the presence of barriers in the form of torturous path of clay, which generate difficulties in diffusion through the matrix. The STN1 specimens absorbed less moisture than plasticized starch, which was due to the increased pathway generated by clay dispersion.

![Figure 6.4. Water absorption at 98% RH and 25 ± 2°C for 50 hrs.](image)

The concomitant increase in water resistance in case of STN2 must be attributed to the excellent dispersion of fillers resulting in a higher engagement of OH groups with layers, making them less available for moisture. Secondly, the number of barriers also increased in this composition. Since the plasticizer was added after clay dispersion in the
matrix therefore, the plasticizer also moved towards gallery i.e. there were two attraction forces working together to pull the plasticizer inside the gallery, clay –plasticizer and plasticizer- starch attractions. This conclusion was strongly supported by increase in elongation at break of this system. The resistance shown by STN3 against moisture was comparatively higher than STN2. Thus, water sensitivity can be altered more effectively by dispersion extent of clay than the presence of moisture sensitive groups, as the concentration of theses functional groups present in STN3 was higher than STN2. Water absorption by STN4 is higher and almost equal to STN1. Thus, for higher water resistance, clay must have an optimum ordered structure that could develop an effective and sufficiently enough diffusion paths.

6.3.2.3. Thermal properties

In general, thermal stability of polymers increases after filling with inorganic fillers [28]. The results of TGA are depicted in Figure 6.5. A three-step process was clearly observed in the composites. All specimens showed highest weight loss at 296 °C. The I, II and III steps were attributed to the water loss, starch plus glycerol decomposition and final decomposition of remaining starch during oxidation. The percentage mass loss was decreased in second step and increased in third for all composites suggesting that the decomposition temperature of glycerol and starch has shifted to higher temperature i.e thermal stability increased for starch and glycerol after clay filling and this must be because of protection of starch and glycerol by silicate layers. Furthermore, STN2 presented the highest thermal stability in comparison of all specimens, which is attributed to the higher dispersion of filler in the matrix. The concentration of exposed hydroxyl groups was least in the STN2, as has been discussed earlier, which may be another cause of thermal stability. Significant difference was not found in the thermal stability of STN1, STN3 & STN4 but it was better than unfilled plasticized-starch matrix. The decrease in plasticization extent after removal of water is expected, at least at those segments of polymer where glycerol could not reach effectively as it was not perfectly homogenized in these systems (STN1, STN3 & STN4), and since water content was more in STN 1, this effect (decrease in plasticization efficiency) was obviously more pronounced. As soon as water evaporates, the starch chains may tend to reorganize and low degree of ordering tend to convert into higher degree. The over all phenomenon may result in the re-association of starch chains after formation of entanglement or juncture points and again the chances of helical structure formation increases. This reorganizing may decrease the thermal decomposition temperature of the matrix. Thus, there may be three factors deciding the
fate of clay filled starch against thermal treatment, i) exposure of hydroxyl groups ii) clay dispersion extent in the host matrix and iii) reassociation of starch chains. The factors can be written in the following order of effectiveness of samples during thermal treatment:
Clay dispersion > Hydroxyl groups exposure > Reassociation of matrix chains.

Figure 6.5. Mass loss (%) during thermogravimetric analysis of samples at the rate of 10°C/min. [I step corresponds to the weight loss of water, II step is the weight loss relative to total mass of samples and III step is the weight loss relative to mass of plasticizer and starch in the samples]
All three are present effectively in the STN2 whereas, poorly in STN1 and as intermediate in STN3 and STN4. Finally, all results of this study tend to demonstrate the effect of preparation methods and sequence of addition of components, on the composite nature. The possible ways of interaction by which the four types of composites were obtained are illustrated in Figure 6.6. Starch and glycerol migrate into clay galleries as both have polar-polar attraction with clay. Glycerol is preferred over starch in this competition owing to its smaller size. The rate of diffusion of both starch and glycerol inside the layers decrease when mixed together because of mutual attraction forces, which formed a mass like structure resulting in slow transport around the tectoides and
consequently delay in migration inside the silicate layers (Figure 6.2). If already plasticized starch is mixed with clay, a microcomposite formed and whatever the increase in gallery height observed is due to the migration of some glycerol inside the layers. The best nanocomposites were formed when first starch-clay was mixed followed by plasticization. In this case, starch chains involve only in one dominant polar-polar attraction with clay and confinement occurs without interference. At this moment, the plasticizer molecules have double attraction towards gallery space; first with clay and second due to electrostatic hydrogen bonding formation with starch chains. Since the plasticizer is small in size, it can be accommodated in gaps of starch chains between the silicate layeres. This process leads to an efficient plasticization of starch matrix retaining the elongation of resulting product. The significant increase in modulus was not observed in these composites, indicating the insufficient amount of filler as modulus can be increased by many fold in microcomposites of higher filler concentration [36]. The composites can not be immersed in water due to extreme moisture sensitivity. All the composites were water resistant at least till 50 hrs. and this fact (high water resistance) may be easily eliminated for prolonged exposure because clay will swell and gallery space will increase with time which may result in complete leaching of components.
Figure 6.6. Different structure of composites. Composite formed by the mixing of filler into plasticized starch (STN1), composite structure formed by the mixing of filler into starch followed by plasticization (STN2), composite structure formed by mixing of all components (clay/starch/plasticizer) together (STN3) and composite structure formed when starch was mixed into slurry of plasticizer and clay (STN4). The thick bold rods indicate the silicate layers whereas, light, small fragments and dark colored longer chains represents the plasticizer and starch respectively.

6.4. Degradability of composites

Biodegradability was measured in compost and percentage weight loss is shown in Figure 6.7. Samples could not be recovered after 3rd week of composting. The exfoliated composites showed slow degradability in the beginning of the experiments, which became almost equal to other samples after last limit of composting. It must be due to the high diffusion path generated by layered silicates and the diffusion of microbial chemicals.
which are responsible for the degradation slowed down. It has been found that layered structure of clay blocks the transmission of moisture through the starch matrix. This dramatic lowering in water vapor diffusion was attributed to the presence of dispersed clays which increase the path of diffusion [31]. As soon as time of composting increases, this factor may be excluded due to the swelling of clay, which further enhance the microbial action for biodegradation. Similar conclusion was drawn by Lee et al. [37] in case of unsaturated polyester, clay nanocomposites, prepared by melt intercalation, that the decrease in biodegradability under composting with intercalation must be due to high aspect ratio and better dispersion of clay in matrix which generate a more tortuous path for penetration of microorganism inside the bulk and hindered their diffusion.

Figure 6.7. Compostability of composites
6.5. Conclusions

An improvement in material properties of all the composites could be achieved by better dispersion of clay. Better dispersion can be achieved by first mixing of starch and filler followed by plasticization. Thus, the interplanar distance of clay strongly depends on the sequence of mixing. Although the enhancement of mechanical properties takes place in the clay filled composites, still the water resistance is too poor to use these composites in packaging applications at least for liquids. From moisture sensitivity point of view, well ordered intercalated structure are also helpful to increase the moisture sensitivity in comparison of the structure consisting of individual nanometer dispersion of layered silicate in starch matrix. Diffusion of plasticizer inside the clay is easier than starch. Starch chains must penetrate through clay galleries first, followed by plasticization in order to maintain the plasticization efficiency. The biodegradability was affected initially by dispersion of clay layers but reached equal after last limit of composting. The material properties of layered silicate–starch composites may not change very significantly by a small decrease or increase in gallery height of filler. The composites obtained, are very far from becoming a substitute for traditional commodity plastics like polyethylene and polypropylene mainly because of their extreme moisture sensitivity.
6.6. References:


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