Electrical and Electrochemical Characteristics of *Withania somnifera* Leaf Extract Incorporation Sodium Alginate Polymer Film for Energy Storage Applications

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**Abstract**

The current investigation addresses the alternating current electrical properties, electrochemical characteristics on biopolymer as *Withania somnifera* leaf extract incorporated sodium alginate [WLISA] polymer film prepared by solution casting method. Some crystallinity along with the amorphous nature of sodium alginate emerged due to the incorporation of *Withania somnifera* leaf extract [WSLE]. Two absorption maximum (λ<sub>max</sub>) were obtained for both WLISA and WSLE samples in the UV–Vis spectrum. The blue, green, and red emission of WSLE and weak blue emission of WLISA are studied by PL analysis. The more amount of strain that occurred in crystallization provides broaden peak in X-ray diffraction pattern. With aid of guluronic and mannuronic acids in sodium alginate making hydroxyl bond formation with leaf extract due to the cross-linking process can be analyzed from Fourier transform infrared spectroscopy. The EDAX analysis showed the chemical composition of WSLE. At room temperature, the prepared 5 ml leaf extract WLISA film has demonstrated the highest ionic conductivity in the typical value of 2.80 × 10<sup>−6</sup> S/Cm. The electrochemical window of the prepared polymer film is in the range of − 0.4 to 0.4 V suggesting that used as an electrolyte for supercapacitor applications.

**Keywords** AC electrical properties · *Withania somnifera* · Sodium alginate · Electrochemical window · Supercapacitor

1 **Introduction**

Polymers are long-chain monomers and it consisting of complex network form, which offers the understood of the unrealized macroscopic behaviour of molecules in an interdisciplinary system [1–3]. Naturally derived biopolymers from living organism such as plant, trees, algae are well suitable for biological and pharmaceutical industries because of that having biodegradable and biocompatible characteristics [4]. The huge amount of availability as natural resources and reproducibility of alginate may consider as a promising material in biodegradable and edible films. Alginate is a class of natural biopolymer, which has hydrophilicity, non-toxic, soluble in water, anionic, and low cost in nature. This flexibility of alginate is making as a base material in various technological applications such as food, drug delivery, and cosmetics areas [5–7]. Generally, alginites are a form of polysaccharides that are derived from brown seaweed algae, they chemically consisted of linear, unbranched polysaccharide monomers of 1–4 linked α-L-guluronic, and β-D-mannuronic acid residues are blocking...
on alternatively. It will form as homopolymeric (MM- or GG blocks) or heteropolymeric (MG- or GM block) sequences. Even structures are produced by M blocks, the egg-box type structures formed by G-block and more flexible structures are developed by MG block [4]. The crosslinking network of alginate film is easily thinkable because it possesses a large number of hydroxyl groups, and extra oxygen as well as making bond formation with any other cations [6]. *Withania somnifera* is an important reverted herb in Indian Ayurveda medicines their various aerial parts are used in various biological activities. Murad Ali Khan et.al have reported *Withania somnifera* having various metals like chromium, lead, copper, cadmium, nickel, manganese, and Iron [8]. The conductive polymers are considered electrode materials nowadays due to their fast ion/electron transfer process and specific surface areas. The high ionic conductivity of polymer electrolytes offers various advantages like flexibility, processability, and enhanced resistance to variations in the charge/ discharge process. In addition, biopolymer electrolytes have good chemical, thermal, and mechanical properties compared to synthetic hence they will be used for replacing synthetic polymer in electrochemical devices. Jothi et al. has used corn starch in proton-conducting polymer investigations [9]. Generally, the energy storage devices such as supercapacitor, batteries, electrochemical solar cells, electrochromic cells, and fuel cells are characterizing by solid-state ionsics and electrochemical investigations [10]. Likewise, there are so many methods are available today for efficient extraction taken from plant materials such as microwave-assisted extraction (MAE) [11], ultrasound-assisted extraction (UAE) [12], soxhlet extraction, and the maceration extraction. The microwave-assisted techniques (MAE) need to concern preventing sample thermal degradation and limited for small molecule phenolic compounds. An ultrasound-assisted extraction technique is disturbing the chemical and physical nature of the sample. The soxhlet extraction method took on more time nearly 5–6 h [13] and maceration extraction method required a large amount of organic solvents and it generates organic waste [14]. In addition, these techniques are required some involved procedures and sophisticated instrumentation. However, minimizing the risk of applied methods is one of the mottos of research work. In this way, a conventional extraction technique is simple, cost-effective, medium time consuming, and easy carried out in any laboratory. Therefore, researchers are used conventional methods for the extraction process from plant material still now. Very recently, Qasim et al. used *Withania coagulans* extract prepared from simple conventional method for the synthesis of iron oxide nanorods [15]. Hence, the present work aims to investigate the ionic conductivity and electrochemical performance of the sodium alginate film using *Withania somnifera* leaf extract by solvent casting method. The incorporated *Withania somnifera* leaf extract on sodium alginate polymer film is improved their ionic conductivity from $1.24 \times 10^{-7}$ to $2.80 \times 10^{-6}$ S/cm. Generally, this kind of improved ionic conductivity is possible through blending of two polymers or adding of ionic compound salt (e.g. lithium, ammonium salt) or using of nano fillers or using of plasticizer [16]. Previous works of literature are shown a similar kind of ionic conductivity in the development of biopolymer-based membrane by adding inorganic or synthetic polymers for eg. Fuzlin et al. have shown $5.32 \times 10^{-5}$ S/cm sodium aligned doped with glycolic acid, and Sadrabadi et al. have shown $1.67 \times 10^{-6}$ S/cm for double layer chitosan and Sunder et al. have reported $1.59 \times 10^{-6}$ S/cm for lithium bromide PEO/PVP electrolyte [17–19]. However, the novelty of the work is an improvement of ionic conductivity through the incorporation of leaf extract when compared to above mentioned literature without blending any other polymers, adding any other salt and plasticizer, and studied their response of electrochemical characteristics.

## 2 Experimental

### 2.1 Materials

The homogeneous *Withania somnifera* leaves are collected from hills station of Kodaikanal, Tamilnadu, India. The sodium alginate is purchased from SRL chemicals, Mumbai, India used without further purifications for the preparation of sodium alginate polymer film.

### 2.2 Preparation of Sodium Alginate Polymer Film Incorporated by *Withania somnifera* Leaf Extract

The *Withania somnifera* leaf extract incorporated sodium alginate [WLISA] polymer film is synthesized via the ordinary casting method. 10 g of fresh *Withania somnifera* leaves cutting on uniformly then soaked in 100 ml of double distilled water in 250 ml conical flask and stirred with 70 °C for 1 h. The obtained solution was cool to room temperature and filtered by Whatman No.1 filter paper. The pure filtered extract was used to further process. The 0.5 g of sodium alginate is dissolved in 50 ml of water and this mixture is stirred constantly for 1 h at 70 °C. The complete yellow colour solution formed after the complete dissolution of sodium alginate. Now, various wt% like 2.5, 5, and 10 ml of *Withania somnifera* leaf extract [WLSE] is added to the yellow colour sodium alginate solution. These solutions are stirred continuously for up to 24 h, to get a consistent viscous solution. The same procedure was used for the preparation of pure sodium alginate film. The gathered viscous solution was poured into a polypropylene petri dish and dried for five days at room temperature. Free-standing
films with an average thickness range of 0.06 cm have been obtained. These films are subject to studies of various characterizations such as UV–Vis spectroscopy, Photoluminescence spectroscopy, Fourier transform infrared spectroscopy (FTIR), X-ray diffraction analysis (XRD), impedance analysis, and cyclic voltammetry (CV).

2.3 Characterization Techniques

The prepared WLISA film and pure sodium alginate film [PSA] structural behaviour were analyzed through the X-ray diffractometer [Brucker Eco D8 Advance with Cu-Kα radiation (λ = 1.5406 Å) with an SSD160 1D detector] with a scanning rate of 5°/minute in the range of 10–60°. The optical properties of WLISA, PSA, and WSLE are studied through UV–Vis spectra carried out in “Shimadzu UV-2400 pc series spectrophotometer” with spectrum range of 200–900 nm in single absorption mode (medium scan rate, slit width-2 nm, sample interval:1). Photoluminescence spectra were carried out in luminescence spectrometer, (model LS 45, Perkin Elmer) using Xenon laser as light source at 380 nm excitation wavelength. Functional groups on polymer matrix are identified through ATR—FTIR spectrum carried out using (IRTracer-100, accuracy ± 4 cm−1) Shimadzu with spectrum range from 4000 to 600 cm−1 at room temperature. ZEISS EVO-18 equipped (BRUCKER–X Flash–6130) scanning electron microscope attached with energy dispersive X-ray spectrometer (EDAX) used to analyze of the elemental composition of WSLE. The electrochemical impedance spectroscopy (EIS) of the prepared polymer film was performed on HIOKI 3532-50 LCR HI-TESTER with a frequency of 1 kHz. The electrochemical analysis of prepared alginate film was carried out in an electrochemical workstation (model-CHI 60008E, CH instrument, USA) with a conventional two electrode system.

3 Results and Discussion

3.1 UV–Vis Analysis

The UV–Vis spectroscopic analysis was carried out for WLISA, PSA, and WSLE samples. The recorded spectra are shown in Fig. 1a, b, c. The UV–Vis spectrum of WSLE in Fig. 1a shows two absorption maximum (λmax) at 348 and 377 nm and similar UV–Vis spectra reported for Withania coagulans leaf extract reported by Atarod et al. [20]. These absorption peaks are indicate attribution of n-Π*, Π-Π* transition of tyrosine, tryptophan, and phenylalanine residues presented as a protein in WSLE [21]. The UV–Vis spectra of PSA in Fig. 1b shows main absorption peaks at 276 nm and small absorption peak at 226 nm respectively and assigned for Π-Π* interband transition of sodium alginate. UV–Vis spectra of WLISA film are shown in Fig. 1c. The broad characteristic absorption band obtained in the wavelength range from 330 to 350 nm along with three small absorption peaks at 226, 352, and 380 nm. The broadband observed in the range of 330–350 nm can be attributed to the formation of double bond in sodium alginate after the main chain scission and hydrogen abstraction followed by ring opening in the radiation induced degradation process [22]. The absorption peaks were obtained at 352 and 380 nm along with broadband related to of n-Π*, Π-Π* transition of benzoyl system in WSLE [20]. The absorption peak at 352 and 380 nm of WLISA is blue shifted when compared to absorption peaks found at 348 and 377 nm of WSLE. This indicates interaction between the trace elements such as C, O, Mg, Al, Si, P, Mo, S, Cl, K, and Ca are present in the leaf extract of sodium alginate affect the native structure of sodium alginate and it provides some microenvironment for maintaining the originality of trace element even on the after incorporation [23] and which can be easily visualized from absorption variation between PSA and WLISA on the inserted image in Fig. 1a, b, c.

3.2 Photoluminescence Analysis

The earlier researcher Zhu et al. reported the existence of several trace elements in plant leaves enhanced the photoluminescence properties [24]. The photoluminescence study was used to identify the structural changes of the local environment of WLISA, PSA, and WSLE and recorded PL spectra shown in Fig. 2a, b, c. Herein, investigate the photoluminescence properties of WLISA and compared with WSLE polymer film. Three emission peaks and one small emission peak are observed in WLISA and WSLE.
respectively. The PL spectra of WLSE in Fig. 2a shows excitation band at 387 nm has been observed, which is caused by a different functional groups in leaf extract are supplement the excitation-dependent phenomenon [25] due to various energy levels are cooperate with different surface states of trace elements in the Withania somnifera. The broad emission peak observed in 475 nm (blue emission) mixed with 510 nm (green emission) reveals that the presence of strong structural defects and single ionized oxygen vacancies in leaf extract [26] and availability of more oxygen position on their surface make a predominant characteristic emission peak at 666 nm (red emission). It may be assisted to high recombination process in-between valence band to the conduction band by the electron excitation. Meanwhile, the blue (475 nm), green (510 nm), red (666 nm) emissions are noticed in WSLE. This is well matched with an earlier report of maple leaf by Anastasia Kharcheva et al. [27] which might be arises from the majority of silvery white trace elements presents such as Ca, K, and Al in WSLE. The PL spectra of WLISA shown in Fig. 2b displays the characteristic intense peak observed at 387 nm noticed highly polarised chemical environment of the polymer matrix. This excitation wavelength indicates the uniform surface of carboxyl moieties in sodium alginate. The weak PL emission peak observed at 524 nm, it exhibits green emission of sodium alginate. This result suggested that the proximity of carboxylate and isolation of oxygen atoms in sodium alginate is not sufficient for electronic conjugation and similar result were discussed by Xueyu Dou et al. [28]. Hence, the sodium alginate has been low recombination process when compared to leaf extract. Although, PL spectra of PSA are shown as insert image in Fig. 2c because there are no distinctive changes in the shape of spectra upon the incorporation of WSLE when compare to WLISA. These results can be ascribed that inter and intra molecular hydrogen bond among in sodium alginate facilitate cross-linking with trace elements and maybe chance to form as “clustered chromophores” due to quenching effect [29] and it reflected as some crystallinity in XRD pattern in Fig. 4b. However, the mobility of the ions can be enhanced by the addition of leaf extract that disturbs the crystalline phase of sodium alginate which is subjected to the local free volume and viscosity of electrolyte medium. The PL spectra of WLISA polymer film show the minimum emission intensity compared to the WSLE which may be
attributed to the minimum local viscosity of the sample. This result is well supported with a higher degree of ionic conductivity.

3.3 FTIR Analysis

The FTIR spectra have been used to investigate the occurred chemical composition and their interactions in the prepared sample. Figure 3a, b displays FTIR spectra of pure and Withania somnifera leaf extract incorporated sodium alginate polymer film. Both spectra show a broad-band centered absorption at approximately 3300 cm\(^{-1}\) this may be arises from the stretching mode of the OH hydroxyl group of phenols and alcohols and the low-intensity peak at 2920 cm\(^{-1}\) indicates –CH\(_2\) group of alkyls. The peaks appeared at 1589 and 1413 cm\(^{-1}\) are attributed to symmetric and asymmetric mode of carboxylate (COO\(^{-}\)) salt group and peak at 1323 cm\(^{-1}\) shows plane deformation of the C–H group. The number absorption band assigned at 1105, 1060, and 1028 cm\(^{-1}\) reveal the existence of C–O–C glycoside bonds in polysaccharides [30]. The peaks are observed at 945, 896, 813, 715, and 615 cm\(^{-1}\) suggested the presence of guluronic acid and mannnuronic acids in sodium alginate [31]. The Withania somnifera leaf extract incorporated sodium alginate FTIR spectra in Fig. 3b shows the disappearance of peak at 945 cm\(^{-1}\) which confirms that guluronic acid from sodium alginate strongly binder with Withania somnifera leaf extract. In addition, the reduction of intensity of carboxylate salt group at 1589 cm\(^{-1}\) reveals the cross-linking of sodium alginate with leaf extract through the ionic bonding. This is assured by the formation of a new peak at 2204, 2152, and 2036 cm\(^{-1}\) which are belongs to ionic bonding of OH hydroxyl groups, hence to be obtained homogeneously dispersed solution during synthesis.

3.4 XRD Analysis

The crystallinity/amorphous nature of pure and leaf extract incorporated sodium alginate film are determined through XRD analysis and their diffraction pattern is shown in Fig. 4a, b. As shown in Fig. 4a, two characteristic broad humps can be seen from 10 to 30° are illustrating the semicrystalline nature of sodium alginate because of ions dislocations that occurred in the prepared sample, it is a good agreement with earlier reports [9]. The appearance of crystalline peaks at 31.41°, 32.64°, and 46.42° in Fig. 4b is due to the addition of leaf extract. The leaf extract contains a notable amount of trace elements such as carbon, oxygen, magnesium, aluminium, silicon, phosphorus, molybdenum, sulphur, chlorine, potassium, and calcium and it has introduced some crystallinity along with amorphous nature. The observed crystalline peaks are due to the intermolecular interaction between the hydroxyl groups and leaf extract, which are helpful to the formation of hydrogen bonds and facilitate the chain movement of sodium alginate [32]. The increasing crystallinity exhibits the saturation state of the host matrix and this may be due to the recombination of ions. Furthermore, it has been indicated incomplete dissociation of trace elements in sodium alginate through the recrystallization process while adding on leaf extract. These characters are may restrict the motion of ions in the electric field [33]. Thus from XRD data, we can understand sodium alginate well connected to Withania somnifera leaf extract via ionic bonding.

The crystallite size of recrystallized sodium alginate has been calculated from Debye-Scherer’s formula

\[
D = \frac{k\lambda}{\beta\cos\theta}
\]

where; \(D\) represents the crystalline size, \(k\) represents Scherer constant (\(k = 0.94\)), \(\lambda\) represents X-ray wavelength (\(\lambda = 1.54178 \text{ Å}\)) for Cu K\(_{\alpha}\) radiation, \(\beta\) represents full width half maximum (FWHM) and \(\theta\) represents diffraction angle. The calculated average peak crystallite size is found to be 22 nm. Furthermore, this crystallite size was again evaluated by stress–strain plot (Williamson–Hall) method displayed in Fig. 5. The graph is plotted between 4sin\(\theta\) versus \(\beta\cos\theta\) and fitted on linear fitting origin lab software. This figure represents recrystallized sodium alginate strain is assumed to be uniformly in all crystallographic directions, thus considered the isotropic nature of crystal. According to the W–H method slope of the plot is strain, hence the value of strain (\(\varepsilon\)) is = 0.20461 obtained and strain (\(\varepsilon\)) is dimensionless quantity because of the ratio between the two lengths. The value of y-axis—intercept “c” = 0.156 is used to calculate the crystallite size and calculated from the following equation

\[
D = \frac{k\lambda}{\beta\cos\theta}
\]
The calculated crystallite size is 8.8 nm by the stress–strain plot method. The crystallite size of Scherer’s method is two times more than the crystallite size of the stress–strain method. The strain is more non-uniform in formed sodium alginate film and this behaviour exhibit broadened peak in XRD analysis. A similar kind of result is discussed by earlier literature [34].

3.5 EDAX Analysis

The EDAX analysis was carried out for Withania somnifera leaf grinding powder after dried for 30 days under room temperature and this study was used to examine the elemental composition of Withania somnifera leaves. The recorded EDAX spectra are shown in Fig. 6. It confirms the presence of all chemical constituents of trace elements i.e. carbon, oxygen, magnesium, aluminium, silicon, phosphorous, molybdenum, sulphur, chlorine, potassium, and calcium in Withania somnifera leaves. The trace element chemical constituent’s representation is shown in Fig. 6 as an inserted image.

3.6 Impedance Analysis

The PSA and WLISA polymer film Cole–Cole plots at different temperatures are shown in Fig. 7. The different wt% of WLISA Cole–Cole plots is shown in Fig. 7a. In our study, all the graphs are shown the semi-circular portion in one spike. The semicircle on the Cole–Cole plot in high-frequency regions illustrates the parallel combination of bulk resistance and bulk capacitance present on polymer because of its found to be in bulk effect in the electrolyte. The spike on Cole–Cole plot in the low-frequency region shows that the blocking effect to be obtained on the electrode/electrode interface [35]. The ionic conductivity of the prepared polymer is calculated from the following formula

$$[\text{Y- Intercept } ] ce = K\lambda/D \text{ and } K\lambda/0.156 = D$$  \hspace{1cm} (2)

$$\text{[} \sigma = l/(R_bA) \text{]} \text{s/cm}$$  \hspace{1cm} (3)

where, l represents thickness (cm$^2$) of alginate film, A indicates the surface area (cm$^2$) of the alginate film and $R_b$ represents the bulk resistance (ohms) of alginate film. The bulk resistance ($R_b$) of polymer is intercepting on the real axis at the lower frequency of the end of the Cole–Cole plot, which has been calculated by Z view software. The pure sodium alginate Cole–Cole plots are showing the different bulk resistance values for different temperatures. While increasing the temperature from the ambient condition, the bulk resistance increases up to level of 358 K after this temperature alginate film has been started to exhibits decreased bulk resistance and it has lies between 328 and 348 K. The PSA film exhibits the highest ionic conductivity at $1.24 \times 10^{-7}$ S/cm. As the concentration of WSLE changes from 2.5 up to 10 ml also showing some degree of changes in Cole–Cole plot. While changing wt% of WSLE, 5 ml of leaf extract incorporated film only showing the lowest bulk resistance and improved ionic conductivity at room temperature when compared to others such as PSA, 2.5 ml, and 10 ml of WLISA film. Hence, we are used 5 ml of leaf extract only used to further studies of various impedance spectra at different temperatures and electrochemical analysis. The improved ionic conductivity of 5 ml of WLISA film is $1.24 \times 10^{-7}$ S/cm which is due to the number of free ions migration in the alginate polymer film is increased by the addition of leaf extract. The leaf extract’s other concentrations are making more crystallinity in polymer electrolytes.

3.7 Conductance Spectra Analysis

The conductivity of PSA and WLISA polymer film was determined from the following relation

$$[\sigma = ne\mu]$$  \hspace{1cm} (4)

where n and $\mu$ are the number of charge carriers, mobility of the polymer respectively. Figure 8 depicts the plot of

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**Fig. 6** EDAX analysis of Withania somnifera dried leaves powder
conductivity log (σac) versus log (f) for various temperatures of the optimized WLISA and PSA film. The plots exhibit all the three well-defined conductance spectra religions. The low-frequency dispersion region to be obtained with low conductivity value due to the space charge polarisation or interfacial impedance occurred in the blocking electrode which indicates the non-debye characteristics of studied polymer film [36]. The middle frequency-independent plateau
region shows the DC conductivity of bulk material, which is due to the migrations of ions to the neighbouring side. The DC conductivity value calculated from the conduction spectra by extrapolating the middle frequency-independent plateau region meets on log $\sigma$ in the y-axis. The maximum DC conductivity obtained for 358 K typically their value is $1.98 \times 10^{-5}$. This is a good agreement with the Cole–Cole plot. At higher frequency region, conductivity ($\sigma$) increases with increasing log ($f$). Moreover, the conductivity value of WLISA polymer film was found to be higher compared to PSA film which implies that leaf extract incorporation within the polymer may augment the mechanism of charge conduction moderately faster. Also, this augmentation may note out to increase in disorder degree that controls the mobility of charge carriers and reveals the creation of an interconnected percolating chain that is appropriate for the mechanism of charge transfer. The increasing conductivity of WLISA polymer represents leaf extract is suitable for the synthesis of sodium alginate polymer film for electrolyte applications.

### 3.8 Dielectric Analysis

Figure 9 displays the variation of the real part of complex permittivity ($\varepsilon'$) for PSA and WLISA studied for different temperatures. The permittivity ($\varepsilon'$) of PSA and WLISA studied films are shown the frequency and temperature dependence. It has been exhibited decreasing permittivity with increasing temperature and becomes saturated at high-frequency levels. The high dielectric permittivity of both films are obtained at lower frequencies might be on grounds that indicates dipoles have enough time to make changes in the electric field [37]. The dielectric permittivity scaling down is due to the inability of dipoles to align rapidly in the electric fields at high frequencies. The increasing real dielectric permittivity may be due to the decrement of charge carrier in sodium alginate which can be attributed to the homogeneous distribution of leaf extract in sodium alginate film. The accumulation of charge carriers at internal interfaces of studied films is giving information about the micro-capacitor network which is demonstrated by Maxwell–Wagner–sillar effects [38]. At low frequencies, real dielectric permittivity increases with increasing of temperature may be due to the slight decreasing of sodium alginate viscosity and this behaviour making easy rotation of dipoles with AC electric field, which are causing the molecular orientation and rearrangement increment with temperature [39]. The interfacial and dipolar polarization is temperature-dependent that creates a significant effect on the dielectric constant of leaf extract incorporated alginate film. The combined effects of interfacial and dipolar polarization are resulting in a rapid increment of dielectric constant with the temperature at lower frequencies.

The imaginary part of complex permittivity ($\varepsilon''$) of PSA and WLISA polymer film at different temperatures are shown in Fig. 10a and b. It was displayed that temperature dependence at a lower frequency. The imaginary part of complex permittivity ($\varepsilon''$) increases while increasing the temperature from ambient to 358 K at lower frequencies. The influence of temperature not making any changes at high frequency, as predicted which could be interpreted by the suggested model of Maxwell–Wagner.
3.9 Modulus Spectra Analysis

Figures 11 and 12 depict the real and imaginary part of the dielectric modulus of PSA and WLISA polymer film. At lower frequencies, the values of $M'$ and $M''$ are close to zero for both films at different temperatures. The electrode and electrolyte interface effects of $M'$ and $M''$ contributions are negligible in this region. Hence, it was exhibited a long-tail appearance of a certain frequency and having a large capacitance related to the electrodes. However, it indicates that non-debye nature of prepared samples. While on high frequencies, the values of $M'$ increase for all temperatures and reach the optimum value. This may be caused by a lack of restoring forces to the carrier charges under the action of the motivated applied field. These kinds of behaviour have been obtained in many sodium alginate polymers [40]. The peaks of $M''$ are represented the relaxation conductivity of mobile ions and are related to the dynamics of transition ions. The values of $M''$ decrease with increasing temperature and peaks are moving towards the high frequencies assure that the relaxation mechanism having a polarity. The shift of the $M''$ relaxation peaks gives information about the incorporation of leaf extract that may reduce the interfacial strength of the polymeric matrix. Argand et al. plot real ($M'$) and imaginary ($M''$) to display the relaxation process nature of leaf extract incorporated polymer film in Fig. 13. It shows semi-circular formation, which depicts the Debye model relaxation process, single relaxation time in the studied film [41]. In this model, all the dipoles might be identical and this ideal dipole relaxation to the alternating electric field makes the Debye model.
3.10 Tangent Analysis

The variation of dielectric dissipation factor \( \tan \delta \) with a frequency of WLISA polymer film is shown in Fig. 14. The tangent analysis is used to analyzing the relaxation mechanism of the prepared samples. It denotes the ratio between the amount of energy loss and the amount stored in a polymer film. Generally, that has been calculated from the following equation.

\[
\tan \delta = \left( \varepsilon''/\varepsilon' \right)
\]  

(5)

The \( \tan \delta \) values are to increase with frequency at different temperatures attains maximum than decreases further increasing of frequencies. When increasing the temperature \( \tan \delta \) frequencies are shifted towards lower frequency, this behaviour ensures that studied polymer films have parallel RC elements. This frequency shifting is established by the increment of charge carrier density in this sample; hence, the addition of leaf extract makes faster segmental relaxation in this sample.

3.11 Electrochemical Analysis

3.11.1 Cyclic Voltammetry

The electrochemical reversibility performance of the prepared polymer is analyzed by cyclic voltammetry. The measurement of CV analysis has been carried by silver|electrolyte|silver configuration. This plot has taken on potential window – 0.4 V to 0.4 V at ambient temperature.
with various scan rates such as 25, 20, 15, 10, and 5 mVs\(^{-1}\) are as shown in Fig. 15. It shows that well defined anodic and cathodic current peaks, which are pointed out the pseudo capacitor behaviour of the prepared sample. The fast ionic reactions at the nearby surface region of the electrode produce this pseudo capacitor behaviour due to oxidation and reduction reactions are occurred at faradic energy storage system [41]. The linearly increased titled spark in Cole–Cole plots at low-frequency regions are proved this capacitive nature, which is occurred by the ionic absorption at the electrode–electrolyte interface. The redox peaks are increasing while increasing on scan rate, which is caused by the increment of ions migration due to decreased resistance. Hence, improve the accumulation of charges at the electrode–electrolyte boundary. The simultaneous broadening area of the CV curve along with scan rate confirms the interfacial compatibility, polaron, and ionic conduction in the prepared WLISA polymer sample.

4 Conclusion

In summary of this report, we have prepared sodium alginate polymer electrolyte through the incorporation of different concentrations of *Withania somnifera* leaf extract by the solution casting method. This leaf extract incorporated sodium alginate (WLISA) electrolyte exhibits the improved maximum conductivity $2.80 \times 10^{-6}$ from $1.24 \times 10^{-7}$ S/cm at room temperature through the regulation of an appropriate amount of ionic liquid. This increasing conductivity represents *Withania somnifera* leaf extract is suitable for the synthesis of sodium alginate polymer film. While increasing the temperature of prepared polymer film giving the following results (i) bulk resistances are increases up to 358 K (ii) maximum DC conductivity $1.98 \times 10^{-5}$ obtained on 358 K (iii) Real dielectric permittivity increases with increasing of temperature that making easy rotation of dipoles with AC electric field. Hence, rapid increment of dielectric constant with temperature given by combined effect of interfacial and dipolar polarization. The XRD analysis reveals that incorporation of leaf extract introduces some crystalline nature along the amorphous of sodium alginate due to recrystallization process by itself found on dislocations in sodium alginate. Thus, results are facilitated chain movement through the formation of hydrogen bonding and show the well and good bind of leaf extract with sodium alginate. The UV–Vis spectra of WLISA show the existence of double bond in sodium alginate main chain scission and along with the originality of benzoyl system in WSLE. The PL spectra
illustrate weak green emission due to the close proximity of carboxylate and isolation of oxygen atoms in sodium alginate. The EDAX analysis confirms the correlation of trace elements in WSLE with other studies. Further, the results were supported and confirmed by the disappearance of glucuronic acid peaks in FTIR spectra by the ion formation via cross-linking of leaf extract to sodium alginate. The recrystallized sodium alginate crystal nature evaluated by Williamson–Hall method, it’s demonstrated their crystallographic directions is isotropic. The cyclic voltammetry analysis confirmed well-defined oxidation and reduction peaks at potential window ranges of −0.4 V to 0.4 V and their pseudo capacitive nature was proved in the Cole–Cole plot at low-frequency region by the linearly increased titled spark. Based on the results it suggests that Withania somnifera leaf extract mediated sodium alginate electrolyte is one of the promising candidate for supercapacitor application.

Author Contributions KC, TT, KG and MSR were involved in the preparation of sodium alginate polymer film incorporated by Withania somnifera leaf extract, and the preparation of the manuscript. KK, VK, HP and SC helped in the characterization techniques and drafting the manuscript. KG, KK, and VK revised the manuscript. KC analysed the data and revised the manuscript. KG drafted and revised the manuscript. All the authors read and approved the final manuscript.

Declarations

Conflict of interest Authors declare that there is no conflict of interest among the co-authors.

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