Asian Journal of Chemistry; Vol. 35, No. 8 (2023), 1810-1818

ASIAN JOURNAL OF CHEMISTRY

https://doi.org/10.14233/ajchem.2023.27966

Corrosion Inhibition Potential of *Cymbopogon citratus* (Lemongrass) Leaves Extract on Mild Steel in 0.1 M Sulphuric Acid Medium at Different Temperatures

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Received: 4 May 2023; *Accepted*: 7 June 2023; *Published online*: 31 July 2023; AJC-21311

The role of the phytochemicals in *Cymbopogon citratus* (Lemongrass) plant is significant in preventing the corrosion. The current study investigated the effectiveness of lemongrass leaves extract (at concentrations ranging from 1-6%) in inhibiting the corrosion of mild steel (low carbon) in a corrosive medium of 0.1 M sulphuric acid. The extract was used as a green rust inhibitor at different temperatures (25, 35 and 45 ºC). Electrochemical impedance spectroscopy (EIS) and linear polarization studies were conducted to analyze the electrochemical behaviour and understand the corrosion inhibition mechanism. Additionally, weight loss studies were carried out. At 6% concentration and 25 ºC, lemongrass extract showed 92.01% corrosion inhibition efficiency. The surface analysis of mild steel samples was performed using both metallurgical research micrographs (MRM) and SEM techniques. Based on the results, the study concludes that the lemongrass leaves extract is an excellent green corrosion inhibitor.

Keywords: *Cymbopogon citratus* (Lemongrass), Corrosion, Mild steel, Sulphuric acid.

INTRODUCTION

Mild steel basically refers to a low carbon steel, which consist a composition of 0.15 wt.% of carbon [1]. Due to its strength, weldability and hardness, it is employed in a wide variety of industrial applications and production today. Although it has tendency to rust, still it is highly durable to building materials. Due to its low amount of carbon, it is highly resistance to breakage and so its mechanical propertiesare significantly considered.

The safeguarding of mild steel from corrosion damage has long been achieved through the application of corrosion inhibitors [2-4]. Researchers encouraged use of green corrosion inhibitors, since they are cost-effective and made from renewable resources as a result of the environmental damage caused by synthetic corrosion inhibitors [5]. Chemical substances with heteroatoms readily bind to metal surfaces and shield them from the corrosion damage [6-8]. Scientists have discovered that plant extracts from different plant parts can function as inhibitors of mild steel corrosion in acidic conditions [9,10].

Corrosion inhibitors from natural source are economic, efficient and safe for environment [11,12]. In recent times, the development of ecofriendly corrosion inhibitors has become a critical area of investigation. These inhibitors provide a convenient source of compounds that can be readily extracted and effectively adsorbed onto the metal surfaces [13-15]. The combination of phytochemicals in a plant extract that have different functional groups capable of adhering to a metal surface is often responsible for the plant extract's inhibitory effects [16,17].

Lemongrass (*Cymbopogon citratus*) is an easily growing herb comes under *Poaceae* family [18]. Due to its lemon-like flavour, it is used in both traditional and modern dishes. It is generally used in manufacturing of medicines due to its phytochemicals composition. Lemongrass contains mainly tannins, flavonoids and phenolics [19]. Researchers found antiseptic, antioxidant, anticorrosive, bactericide and fungicide properties in lemongrass plant [20-23].

EXPERIMENTAL

Preparation of mild steel samples: Mild steel sheet was purchased from the local market of Sirsa city of India. The size of mild steel samples was optimized to 1.5 cm × 3.0 cm as it was easy to handle in laboratory. In order to eliminate any impurities from the surface of mild steel samples, the specimens were polished with emery papers of varying grades (100, 220, 320 and 600). Subsequently, the prepared samples were carefully cleaned with acetone thoroughly.

Plant extract preparation: In order to remove any remaining foreign contaminants, *Cymbopogon citratus* plant's leaves, also known as lemongrass, were rinsed using flowing water and dried in a shaded area. A solution was prepared by soaking 5.0 g of powdered leaves in 500 mL of distilled water and shaked the mixture for 48 h at room temperature. The resulting aqueous solution was filtered, concentrated to 100 mL and tested for its ability to inhibit corrosion.

Weight loss study: In this experiment, mild steel samples were subjected to 0.1 M H_2SO_4 for 24 h at different temperatures of 25, 35 and 45 ºC, with and without varying concentrations of extract from lemongrass leaves. An analytical balance of Model AB 135-S/FACT was used to accurately measure the weight of the corroded samples, with a precision of 0.01 mg. Prepared samples were weighed before and after immersion in corrosive solution to calculate weight loss. Corrosion rate (CR) and percentage corrosion inhibition efficiency (PCIE) were calculated using the standard calculation method (ASTM G31) [3].

Electrochemical studies: Both linear polarization and EIS were measured experimentally with the help of a Metrohm Autolab PGSTAT128N. A mild steel sample was electrically connected to the potentiostat using 1 cm^2 from both sides of the top end, while only 1.0 cm × 1.0 cm from one side of the bottom end was used as the working surface, with the remaining area covered in lacquer. The electrochemical investigation was carried out in a glass cell with three electrodes; Ag/AgCl, mild steel sample and platinum wire serving as reference electrode, working electrode and counter electrode, respectively.

The linear polarization studies were conducted potentiostatically at a scanning rate of 0.5 mV/s and a value below 200 mV and above +500 mV from the OCP value was taken as potential range. The electrochemical studies were conducted at 25, 35 and 45 ºC with and without the addition of lemongrass leaves extract (1-6%). Resistance, capacitance and current density variations were observed as a function of frequency and time. The signal used was an AC sinusoidal signal with a 10 mV amplitude and a 100-10,000 Hz frequency range. Nyquist graphs were generated in a potentiostatic way. An equivalent circuit (Randles circuit) was utilized consequent to this electrochemical analysis as illustrated in Fig. 1.

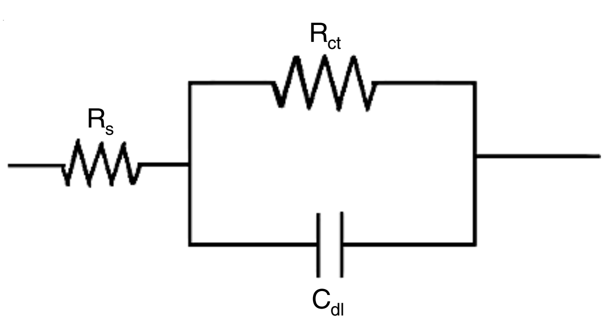

Fig. 1. Equivalent circuit (Randles circuit) consequent to electrochemical analysis

Surface studies: The surfaces of mild steel samples after exposure to corrosive medium of 0.1 M H_2SO_4 without and with corrosion inhibitor at 25, 35 and 45 ºC was investigated using Metallurgical Research Microscope (Kyova-Getner, Japan) and Scanning Electron Microscope (JEOLJSM7610F Plus).

RESULTS AND DISCUSSION

FTIR studies: The major peaks in FTIR spectrum of lemongrass extract are shown in Fig. 2. These peaks confirmed the presence of various functional groups (-OH, -NCS, C=O) in lemongrass extract. The presence of the hydroxyl group (-OH) was confirmed by a broad and prominent peak at 3438.24 cm^{-1} [24]. Adsorption band at 1636.71 cm^{-1} determine the presence of C=O group [25]. Another peak at 2062.18 cm^{-1} suggested the presence of an isothiocyanate (-NCS) functional group [26]. These groups facilitate the adsorption of compounds onto metal surfaces and block corrosive sites [27].

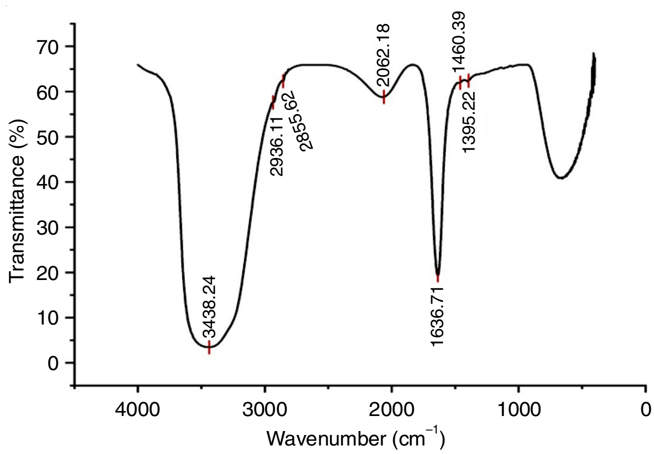

Fig. 2. FTIR spectrum of aqueous extract of lemongrass leaves

Weight loss technique: Corrosion rate (CR) and percentage corrosion inhibition efficiency (PCIE) were determined at 25, 35 and 45 ºC in the presence and absence of various concentrations (ranging from 1 to 6%) of lemongrass leaf extract. The weight loss experiments indicated that the lemongrass extract was an effective inhibitor of corrosion with PCIE values of 92.01%, 84.84% and 72.08% at 25, 35 and 45 ºC, respectively. The weight loss data clearly illustrates that the PCIE values increase with increasing concentration of the extract (Table-1). Linear fitted Langmuir adsorption isotherm was plotted to show the surface coverage by lemongrass leaves extract as illustrated in Fig. 3a. Additionally, the data shows that the PCIE decreases as the temperature increases, since it was higher at 25 ºC than at 35 ºC and 45 ºC as illustrated in Fig. 3b.

It is observed that as increase in the concentration of lemongrass extract, the corrosion rate decreases (Table-1). The maximum inhibition efficiency of lemongrass extract was found 91.69% at 25 ºC, 90.79% at 35 ºC and 85.85% at 45 ºC. The optimized concentration of corrosion inhibitor (lemongrass extract) was found 6% at 25 and 35 ºC and 7% at 45 ºC.

Electrochemical polarization: In order to inspect the kinetics of electrochemical reaction on the surface of mild steel

TABLE-1
CORROSION RATE (CR) AND PCIE WITHOUT AND WITH THE ADDITION OF LEMONGRASS LEAVES EXTRACT OF DIFFERENT CONCENTRATIONS AT 25, 35 AND 45 °C

Inhibitor concentration (%)	25 °C		35 °C		45 °C	
	Corrosion rate (mpy)	PCIE (%)	Corrosion rate (mpy)	PCIE (%)	Corrosion rate (mpy)	PCIE (%)
0	635.01	–	1057.66	–	1423.78	–
1	233.31	63.25	432.13	59.14	1142.21	19.77
2	194.76	69.32	373.30	64.70	994.11	30.17
3	144.04	77.31	302.29	71.41	841.95	40.86
4	115.64	81.78	227.22	78.51	683.70	51.97
5	71.00	88.81	172.44	83.69	535.60	62.38
6	50.72	92.01	160.27	84.84	428.07	69.93
7	–	–	–	–	393.58	72.35

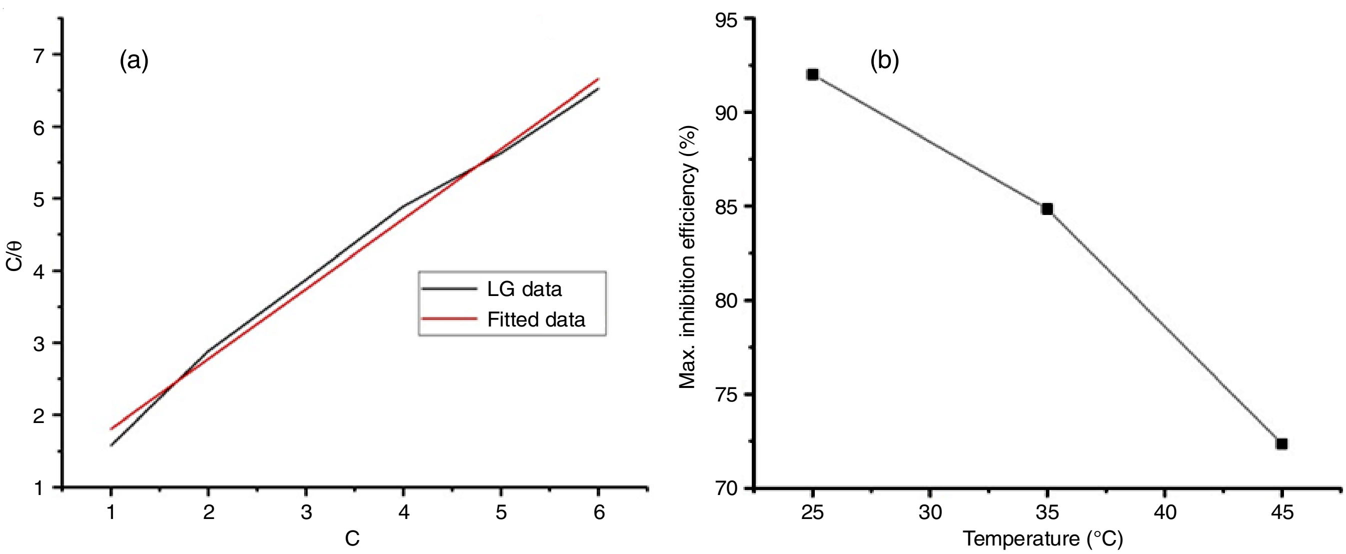

Fig. 3. (a) Linear fitted Langmuir adsorption isotherm for lemongrass leaves extract on mild steel at 25 °C (b) Effect of temperature on corrosion inhibition efficiency

and the inhibition mechanism of lemongrass extract, an electrochemical polarization experiment was conducted. Tafel plots were generated for mild steel in a corrosive medium of 0.1 M sulphuric acid, both without and with the addition of lemongrass extract (Fig. 4a-c). Table-2 presents different electrochemical polarization properties for the working electrode (mild steel sample) in 0.1 M H_2SO_4 at different concentrations of lemongrass extract. Tafel plots revealed that the lemongrass extract gives both cathodic and anodic curves thereby behave as a mixed-type corrosion inhibitor. A decrease in I_{corr} values accompanied by a rise in inhibitor concentration suggests that lemongrass has excellent corrosion inhibition properties in acidic medium for mild steel. The trends observed in the PCIE from both weight loss studies and electrochemical polarization experiments were quite similar.

Electrochemical impedance spectroscopy (EIS): EIS measurements were conducted to understand the nature of barrier film formed by lemongrass extract through the adsor-

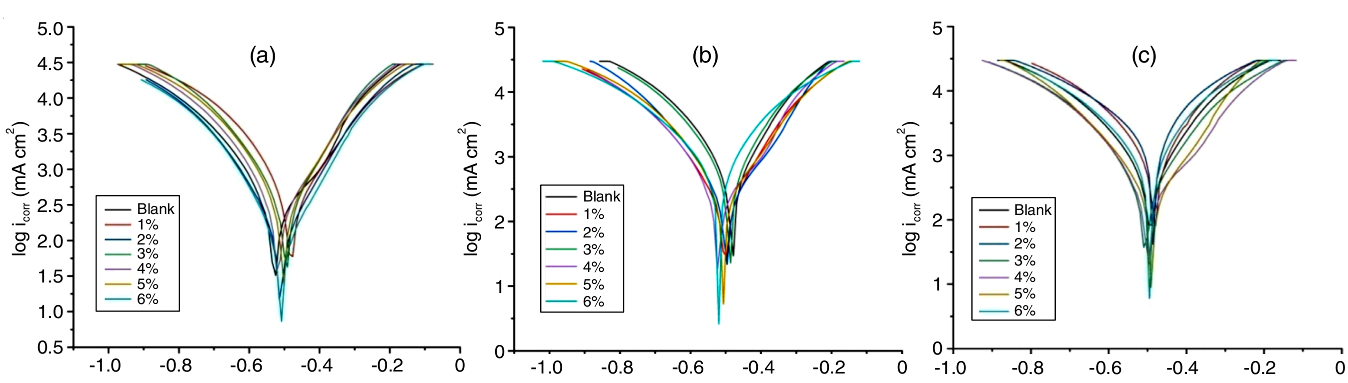

Fig. 4. Different anodic and cathodic polarization Tafel plots for mild steel samples after immersion in 0.1 M H_2SO_4 without and with the addition of different concentration of lemongrass leaves extract at 25 °C (a), 35 °C (b) and 45 °C (c)

TABLE-2
VARIOUS ELECTROCHEMICAL POLARIZATION PARAMETERS FOR MILD STEEL SAMPLES IN 0.1 M H_2SO_4 FROM 0-6% CONCENTRATION OF LEMONGRASS EXTRACT AT 25, 35 AND 45 °C

Conc. (%)	β_a (mV d^{-1})			$-\beta_c$ (mV d^{-1})			–OCP (mV *vs.* SCE)			I_{corr} (?A cm^{-2})			PCIE (%)		
	25 °C	35 °C	45 °C	25 °C	35 °C	45 °C	25 °C	35 °C	45 °C	25 °C	35 °C	45 °C	25 °C	35 °C	45 °C
0	352	308	295	420	757	410	525	486	486	2560	3626	4116	–	–	–
1	251	223	305	295	285	387	522	479	495	1303	1857	3142	49.10	48.78	23.66
2	228	229	252	280	303	329	501	491	479	1015	1496	2839	60.35	58.74	31.02
3	241	232	285	275	297	336	508	498	497	708	1023	2431	72.34	71.78	40.93
4	207	193	250	238	241	344	508	496	493	523	802	1942	79.57	77.88	52.81
5	187	215	279	244	246	308	501	512	510	431	613	1590	83.16	83.09	61.37
6	187	199	275	218	252	323	517	500	497	283	556	1477	88.94	84.66	64.11

ption at the surface of mild steel sample. Understanding the function of charge transfer resistance is critical for appreciating the character of barrier film, since it is directly tied to the amount of resistance that barrier film generates. Double layer capacitance (C_{dl}) and CR are both inversely proportional to the charge transfer resistance (R_{ct}) [28]. Fig. 5 shows the Nyquist graphs (EIS) in which mild steel in 0.1 M sulphuric acid medium without and with the addition of lemongrass leaves extract of different concentrations at 25 ºC (a), 35 ºC (b) and 45 ºC (c). With an increase in lemongrass leaves extract content, an increase in charge transfer resistance was observed.

It is clearly shown from Table-3, with the rise in concentration of lemongrass leaves extract an increase in charge transfer resistance (R_{ct}) was also observed and fall in double layer capacitance (C_{dl}) so that corrosion rate was also decreases.

Metallurgical research microscopic (MRM) studies: To investigate the effects of a corrosive medium (0.1 M H_2SO_4) on mild steel samples, the metallurgical research microscopy (MRM) technique was utilized at 25, 35 and 45 ºC, with and without different concentrations of extract from lemongrass leaves. Fig. 6 demonstrates that the absence of the corrosion inhibitor (lemongrass leaves extract) caused a significant amount of large pores formed on the surface of mild steel sample. However, a reduction in both the quantity and size of these pores was led by the increased concentration lemongrass leaves extract. Hence, the MRM images (Fig. 6) confirmed the outcomes obtained from electrochemical analysis and weight loss studies.

SEM studies: With and without the addition of lemongrass leaf extract, the SEM technique was employed to analyze the morphology of mild steel samples subjected to corrosive medium (0.1 M H_2SO_4) at 25, 35 and 45 ºC. Large size cracks and holes were made on the surface of mild steel samples in absence of lemongrass extract, however the size of holes and cracks was reduced in presence of lemongrass leaves extract as shown in Figs. 7-9, respectively. As the concentration of lemongrass leaves extract increases, the size of holes and cracks

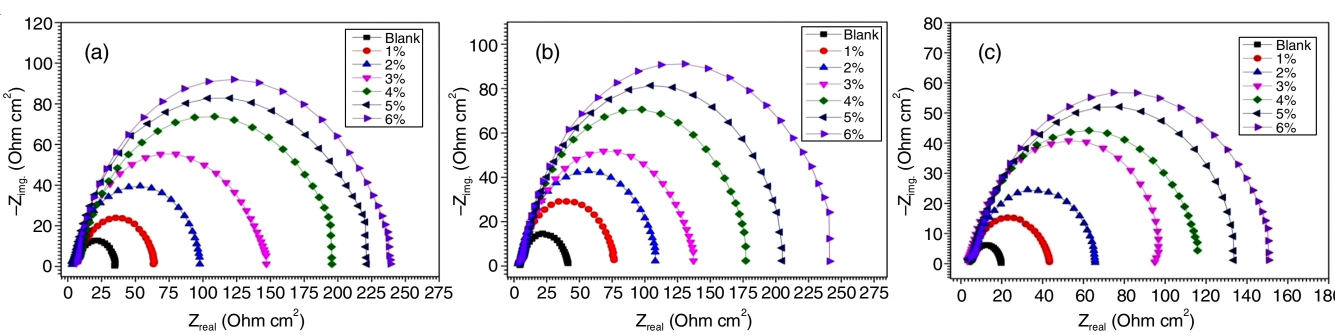

Fig. 5. Nyquist graphs (EIS) of mild steel exposed to 0.1 M H_2SO_4 at 25 °C (a), 35 °C (b) and 45 °C (c) without and with the addition of various concentrations of lemongrass leaves extract. Acquired at OCP in potentiostatic manner with an AC perturbation amplitude of 10.0 mV/s and 10 points/decade at frequencies between 1 and 100 kHz

TABLE-3
ELECTROCHEMICAL PROPERTIES OF MILD STEEL WERE EVALUATED UNDER VARIOUS TEMPERATURES, BOTH WITH AND WITHOUT THE APPLICATION OF LEMON GRASS LEAVES EXTRACT AT VARYING CONCENTRATIONS

Inhibitor concentration (%)	25 °C		35 °C		45 °C	
	R_{ct} (ohm cm^2)	C_{dl} (F cm^2)	R_{ct} (ohm cm^2)	C_{dl} (F cm^2)	R_{ct} (ohm cm^2)	C_{dl} (F cm^2)
0	41.44	2.6×10^{-4}	34.62	5.0×10^{-4}	19.79	1.3×10^{-3}
1	76.47	7.1×10^{-5}	63.36	1.0×10^{-4}	43.34	2.4×10^{-4}
2	107.93	3.4×10^{-5}	97.51	4.1×10^{-5}	65.73	9.8×10^{-5}
3	137.03	2.2×10^{-5}	146.78	1.9×10^{-5}	94.94	4.1×10^{-5}
4	177.01	1.2×10^{-5}	195.55	1.1×10^{-5}	115.72	3.1×10^{-5}
5	204.93	0.9×10^{-5}	221.35	0.8×10^{-5}	133.22	2.2×10^{-5}
6	240.69	0.7×10^{-5}	238.46	0.7×10^{-5}	150.12	1.8×10^{-5}

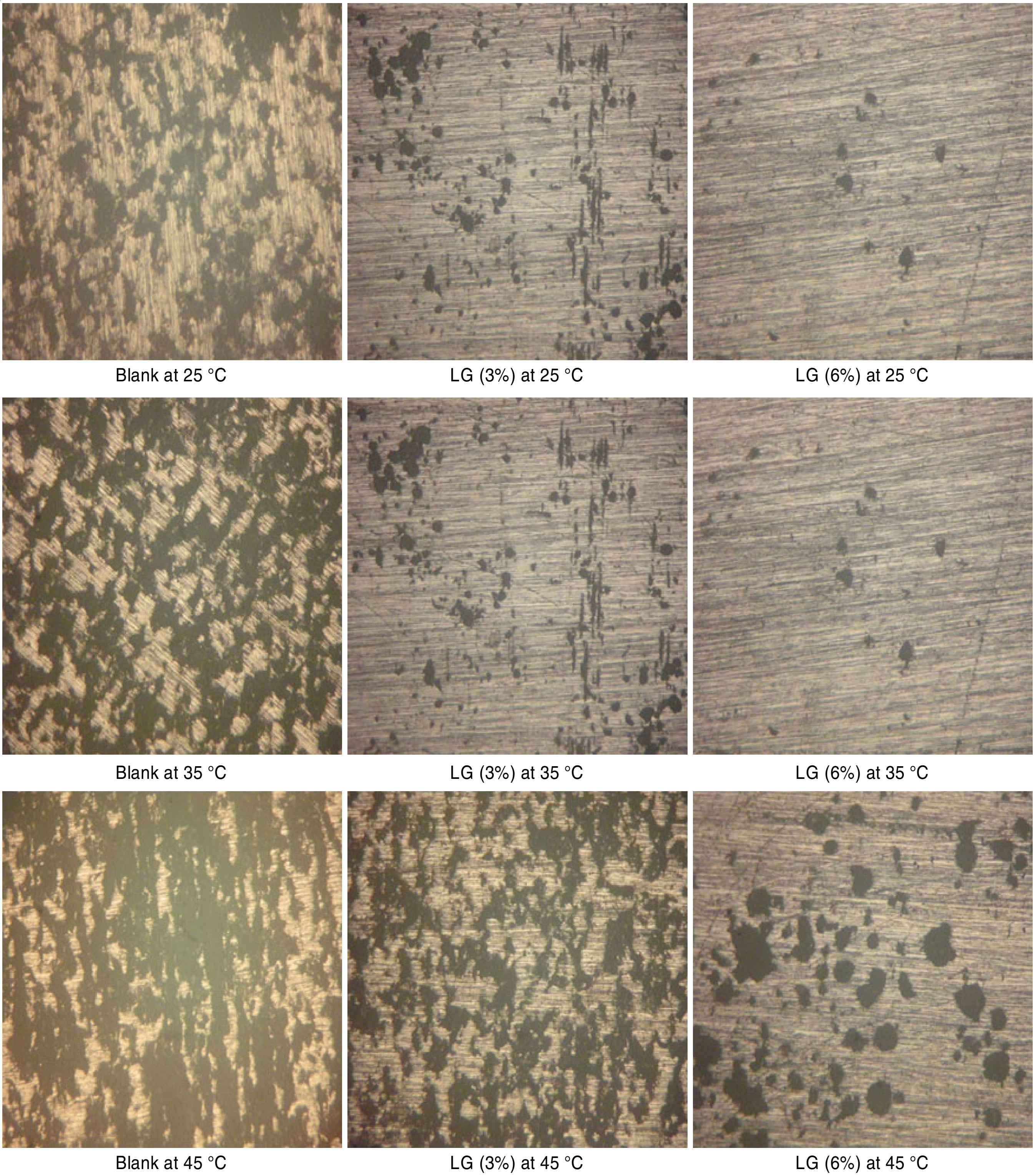

Fig. 6. Metallurgical research microscopic images of mild steel samples of different concentrations at different temperatures

was more reduced. The maximum reduction in size of holes and cracks was shown at 6% concentration of inhibitor. The effect of temperature was also noticed during the SEM analysis. At 25 ºC, the size of holes and cracks was almost reduced in presence of lemongrass leaves extract. However, the anticorrosive effect of lemongrass leaves extract was reduced to some extent at 45 ºC.

Conclusion

As mild steel is widely utilized in the industrial sector due to its strength, weldability, and durability, this study set out to examine its corrosion characteristics. To inhibit corrosion, natural lemongrass leaves extract was utilized in 0.1 M H_2SO_4 corrosive medium. The FTIR studies of the extract revealed

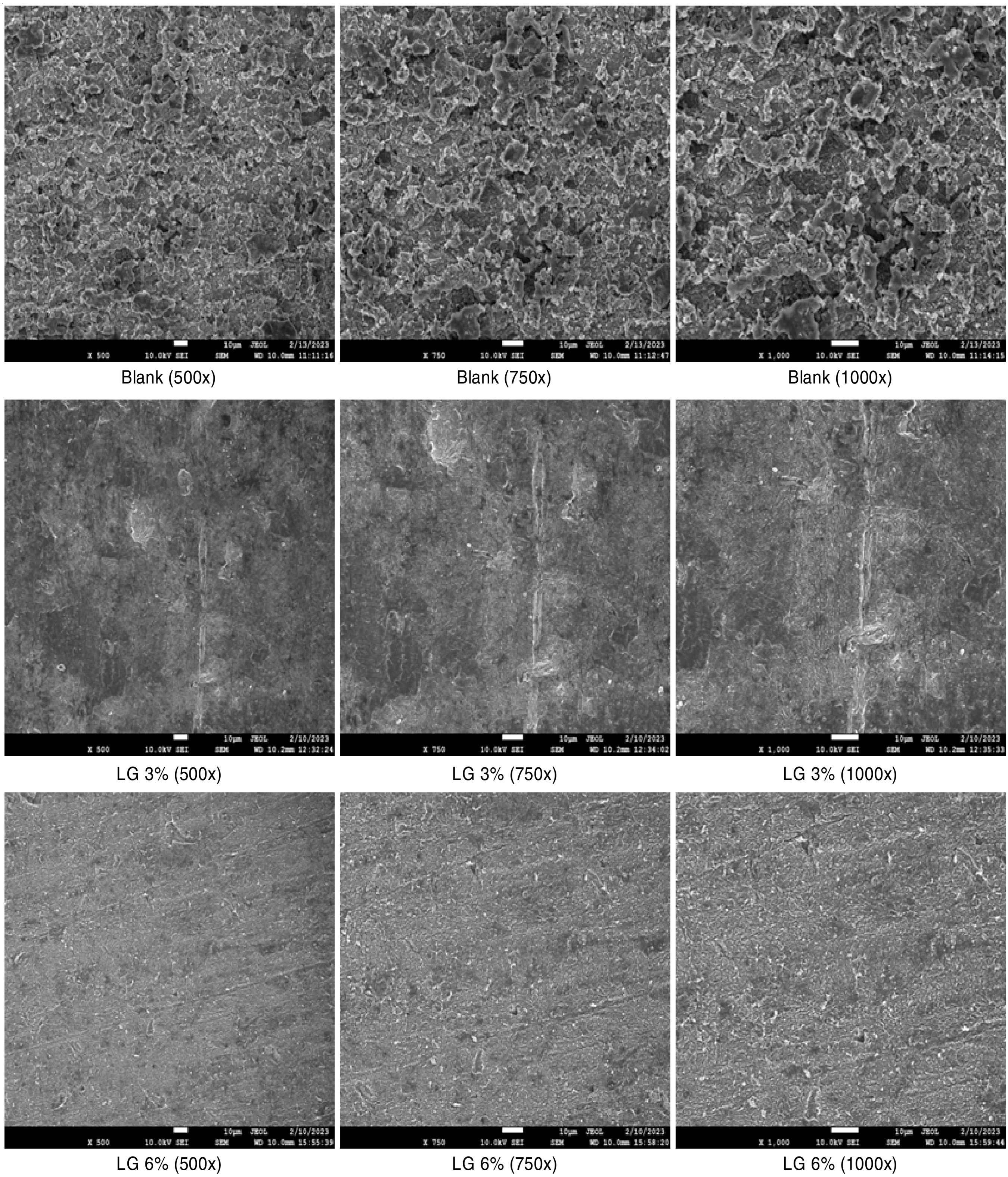

Fig. 7. SEM images of mild samples of different resolutions and different concentrations of lemongrass leaves extract at 25 °C

the presence of heteroatoms that could easily adsorb to the mild steel surface. The minimum inhibitory concentration of lemongrass leaves extract was determined to be 1% and concentrations ranging from 1-6% were used to coat the mild steel surface at 25, 35 and 45 ºC. Weight loss studies indicated that the maximum percentage corrosion inhibition efficiency (PCIE) was achieved at a concentration of 6% lemongrass leaves extract, reaching 92.01%. The highest charge transfer resistance (R_{ct}) of 240.69 Ω cm^2 was observed at 25 ºC and 6% concentration of lemongrass extract. Tafel plots demonstrated that an increase in extract concentration resulted in a reduction in I_{corr} values, with the greatest reduction observed at 6% concentration. The

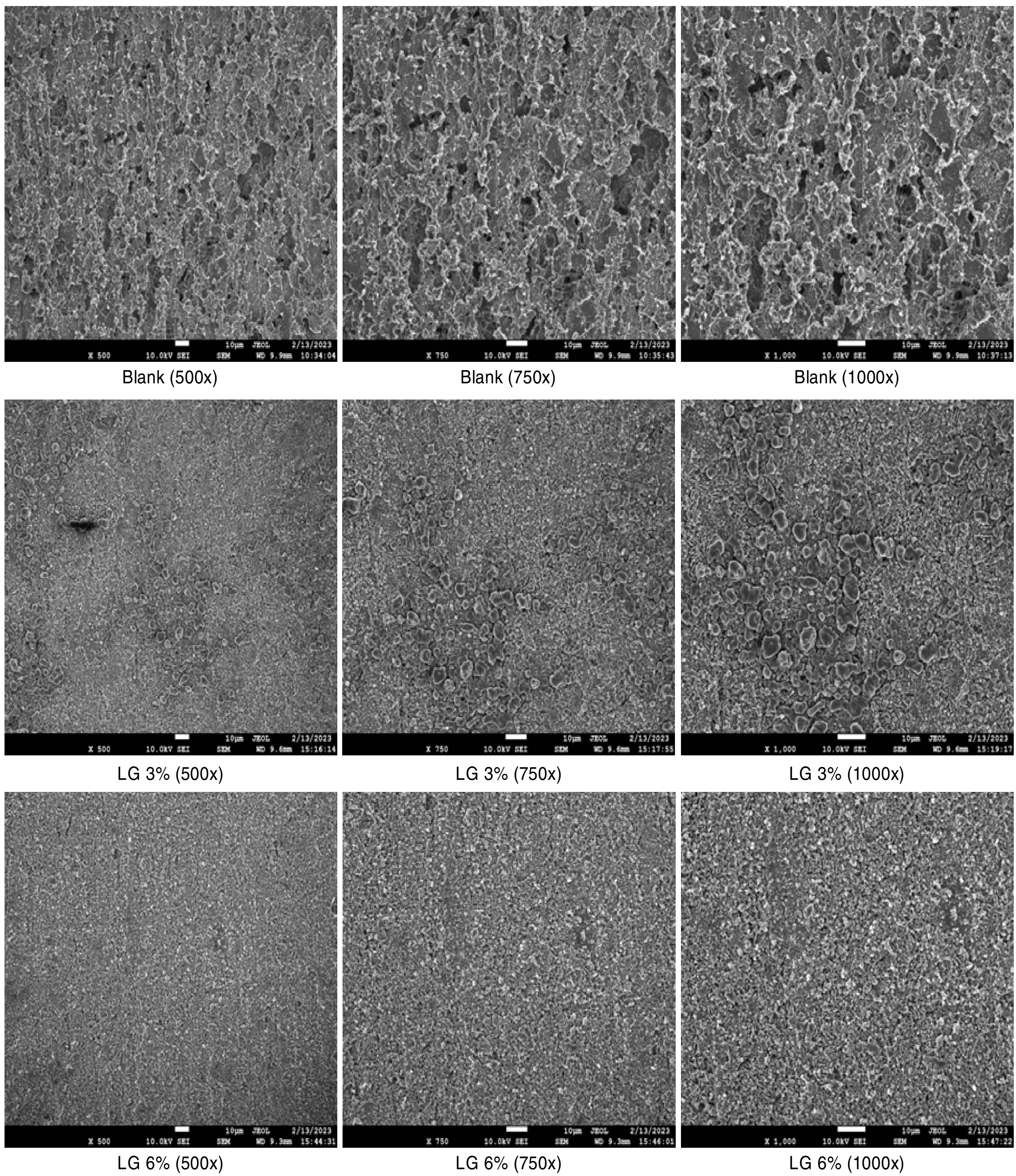

Fig. 8. SEM images of mild samples of different resolutions and different concentrations of lemongrass leaves extract at 35 °C

SEM and MRM techniques were employed to analyze the surfaces of mild steel samples. Large size cracks and holes were made on surface of mild steel samples in absence of lemongrass extract, while the size of pores decreased in the presence of lemongrass leaves extract, as revealed by SEM images. Therefore, it can be concluded that lemongrass leaves extract is an excellent corrosion inhibitor for mild steel, based on the results of this research.

ACKNOWLEDGEMENTS

This research work was fully supported by Chaudhary Devi Lal University, Sirsa, India. The authors also thank to

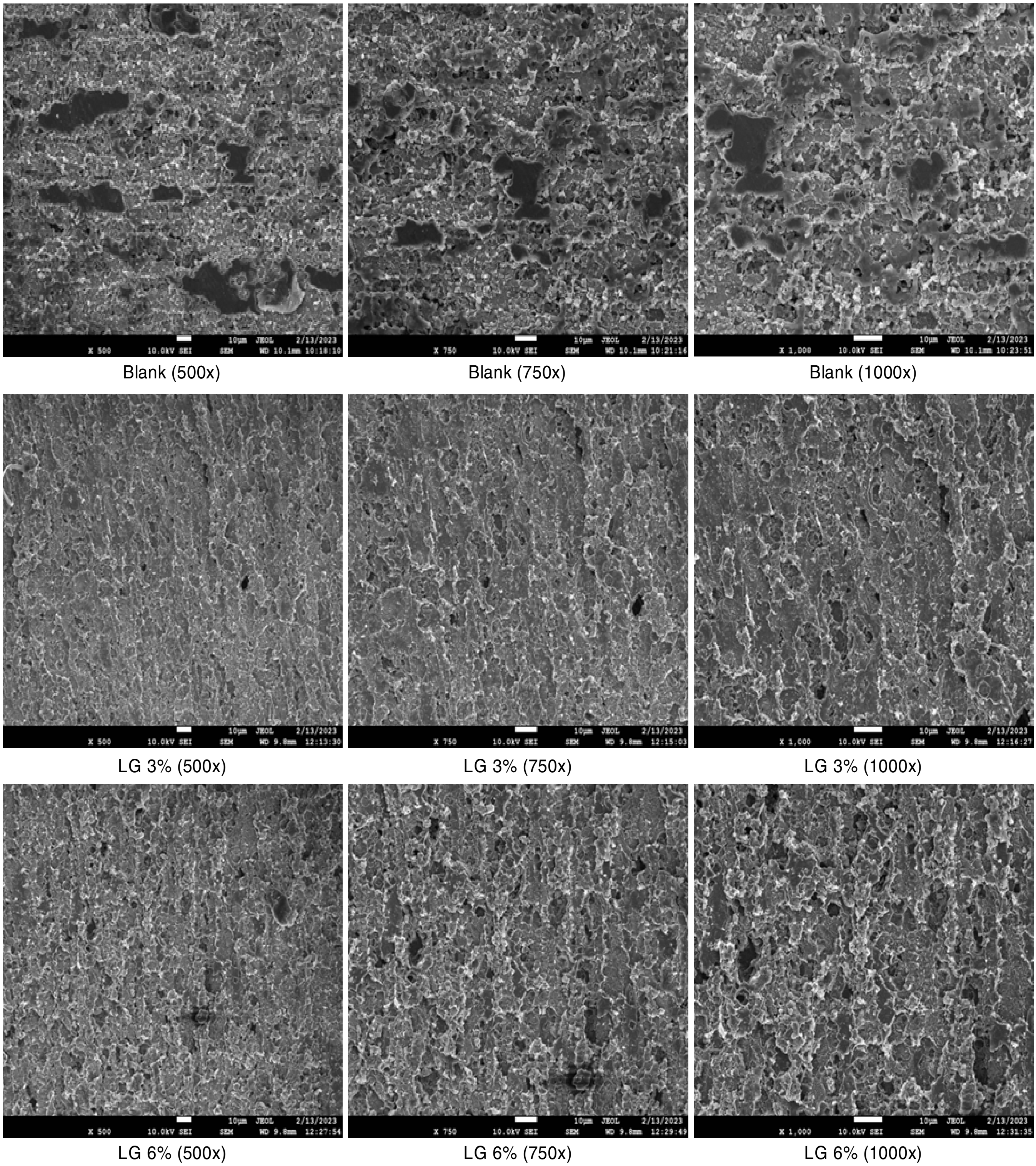

Fig. 9. SEM images of mild samples of different resolutions and different concentrations of lemongrass leaves extract at 45 °C

Central Instrumentation Laboratory (CIL), Guru Jambheshwar University of Science & Technology, Hisar, India for their significant contribution for this research work.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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