Research Article

Observation of CCNR-type electrical switching in $Zn_{0.3}Mn_{0.7+x}Si_xFe_{2-2x}O_4$ spinel ferrite series

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Abstract
A nonvolatile memory effect exhibited by electric field-induced resistance switching has been the topic of intense research not only due to its applications as resistive random access memory but also from the basic physics point of view. Among several binary and ternary mixed oxide compounds, the ones which possess magnetic ions have shown a great promise. Spinel ferrite system $Zn_{0.3}Mn_{0.7+x}Si_xFe_{2-2x}O_4$ with varying x is investigated for its novel electrical switching properties. Both temperature and applied voltage dependence of current-controlled negative resistance-type electrical switching showed better than 200% of resistive switching ratios. Bulk polycrystalline samples showed composition x dependence of resistive switching. The current–voltage characteristics are modeled for low and high applied field regime, and the presence of space-charge-limiting current is confirmed. Thin films of the ferrite system grown by pulsed laser deposition showed almost nonexistence of resistive switching, suggesting that the bulk composition of the compound has a major role to play against the film–electrode interface.

Keywords Spinel ferrite · Electric switching · Space-charge-limiting current · Thin film

1 Introduction

In search of novel memory devices in the modern semiconductor industry, the resistive random access memory (RRAM) has shown a great promise. Despite several complex systems exhibiting promising RRAM behavior, the governing mechanism of electrical switching observed in materials, either the bulk or films, is still under debate. An in-depth analysis of the current–voltage (I–V) characteristics of materials is key in discussing the mechanism of RRAM. Owing to the existence of charge carriers produced thermally, the I–V characteristics of most materials in a small applied electric field are Ohmic (linear) in nature. With the increasing electric field, I–V behavior begins to be non-Ohmic in the majority of nonmetallic substances. A rapid increase in I with sufficiently high V makes the characteristics nonlinear or rather an exponential dependence near to the electronic breakdown of the material. In certain compounds, the I increases in a linear manner up to a specific applied field and beyond that huge current flows with V abruptly decrease. The mechanism in which materials demonstrate a sudden changeover from high conduction state to low conduction state is referred to as resistive switching (RS). There are three types of RS, namely (a) negative resistance controlled by a voltage (VCNR) or N-type, (b) negative resistance controlled by current (CCNR) or S-type and (c) bi-stable or memory switching.

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Very recent (2019–2020) review articles describe all the aspects, starting from fundamentals of resistive switching (RS), mechanisms responsible for switching action, fabrication processes, materials properties, etc., of resistive switching devices for nonvolatile RRAM and computing applications [1–9]. Many pure oxide thin film heterostructures, perovskite oxides, metal halide perovskite, manganites, single-crystalline materials, and thin films of chalcogenide semiconductors, organic and hybrid materials including graphene oxide have shown to exhibit resistive switching [1–9]. Mixed metal oxide systems such as ferrites (spinels, garnets, orthoferrites, etc.,) exhibiting memory and switching characteristics are of prime significance in the field of digital electronics. In the last couple of years (2018–2020), a very few research reports are available on RS exhibited by spinel ferrites in nanocrystalline [10–12], thin films [13–20], and nanocomposite [21] forms. Interestingly and surprisingly, no work has been reported on RS action demonstrated by bulk polycrystalline ferrite materials. Of course, it is seldom observed phenomenon in such a class of materials. In this sense, the present work is important. On the other hand, quadruple perovskite, calcium-copper-titanate ($CaCu_3Ti_4O_{12}$), and their isomorphous systems, pristine and substituted with different cations in various forms are commonly exhibited room-temperature and high-temperature nonlinear current versus voltage characteristics suitable for varistor applications [22].

In the present investigation, the composition, $Zn_{0.3}Mn_{0.7}Fe_2O_4$, is selected as parent material and Si^{4+} is chosen for the substitution based on the following facts: (1) from the high-frequency applications' point of view, this composition possesses excellent properties, for instance high initial magnetic permeability, a large value of saturation magnetization, high electric resistivity and low power loss, (2) the substitution of a tetravalent cation such as Si^{4+} lowered eddy current losses and increased the temperature stability, (3) Si^{4+} ions have a tendency to segregate at the grain boundaries and create a low conductivity layer that strongly affects structural, microstructural, magnetic, electric and dielectric properties [23–28]. The recent advancements and emergent curiosity in the RS demonstrated by mixed oxides prompted us to re-examine the classic ferrite system to comprehend the high electric field instability in the multicationic spinel ferrite series, $Zn_{0.3}Mn_{0.7+x}Si_xFe_{2-2x}O_4$.

2 Experimental details

Comprehensive experimental technicalities relating to the synthesis of spinel ferrite series, $Zn_{0.3}Mn_{0.7+x}Si_xFe_{2-2x}O_4$ with $x = 0.0$, 0.1, 0.2 and 0.3, by usual two-step sintering ceramic route, crystalline phase identification as well as structural parameters determination by analyzing X-ray diffraction patterns are given in previous reports [23, 24].

The scanning electron microscope, model XL-30 ESEM with EDAX (make: Philips, Netherlands) operated at 30 kV, was employed to register energy-dispersive analysis of X-ray spectra. Current (*I*) against voltage (*V*) (ranging from 0 to 400 V) measurements were taken using Aplab made (model 7332) high-voltage dc regulated power supply at selected temperatures in the range of 300–673 K. The cylindrically pelletized samples having a diameter of 1.0 cm and thickness of the order of 0.3–0.4 cm were used for *I–V* characteristic measurements. The faces of the disc sample were polished by rubbing with zero-grade sandpaper and washed in mild hydrochloric acid (HCl) and propanone. Eventually, graphite was applied on both the plain faces of the pellets on which aluminum foil was also put up for perfect electrical contacts.

The high-quality ceramic target (having a 1.8-cm diameter) of $Zn_{0.3}Mn_{0.8}Si_{0.1}Fe_{1.8}O_4$ (ZMSFO) ($x = 0.1$) composition was intended for pulsed laser deposition (PLD) using Q-switched Nd: YAG laser (Ekspla Co., Model HT-303) having $\lambda = 355$ nm. The ferrite thin film was grown on $Pt/SiO_2/Si$ substrates with dimension of 15×15 mm^2. The laser pulse repetition frequency was kept at 10 Hz, and laser powers were fixed at 1.7 J for the PLD experiment [29]. During the film deposition process, temperature of the substrate was maintained at 973 K and oxygen partial pressure of 1mTorr was controlled. The ZMSFO film was deposited on the substrate with the aid of a metal shadow mask on an area of 10×15 mm^2, and film thickness was monitored to be ~ 260 nm. In order to create the top electrode (area 400×300 μm^2), highly pure Ag was evaporated thermally on the active layer of ferrite film through a metal shadow mask. The heterostructure $Ag/ZMSFO/Pt/SiO_2/Si$ was characterized at 300 K by means of grazing incidence X-ray diffraction (GIXRD, PANalytical), atomic force microscopy (AFM) (Nanosurf AG), stylus surface profiler (DekTac. 3.2, Veeco) and *I–V* characteristics (Keithley 4200 semiconductor characterization system).

3 Results and discussion

The elemental analyses of synthesized compounds of the series, $Zn_{0.3}Mn_{0.7+x}Si_xFe_{2-2x}O_4$ ($x = 0.0$–0.3), were conducted, and in Fig. 1 the representative EDAX pattern for the composition with $x = 0.2$ is displayed. The peaks are well assigned in accordance with the standard positions. The weight percentage (wt%) of various elements determined from the chemical formulae and that from EDAX analysis correspond well mutually. The results summarized in Table 1 confirm the expected stoichiometry without the loss of any ingredient. The peak-to-background (*P/B*) ratio was found to be large

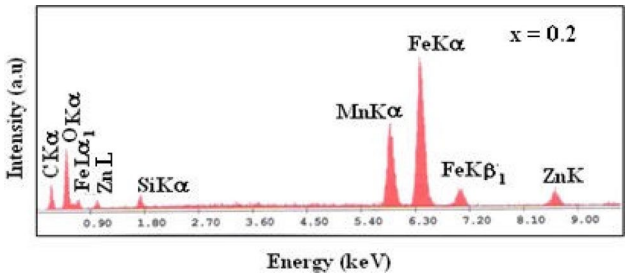

Fig. 1 Typical EDAX pattern for $x = 0.2$ composition of the system $Zn_{0.3}Mn_{0.7+x}Si_xFe_{2-2x}O_4$

Table 1 The results of the elemental analysis of $Zn_{0.3}Mn_{0.9}Si_{0.2}Fe_{1.6}O_4$ ($x = 0.2$) composition

Element	EDAX (wt%) ± 2%	Expected (wt%)	(*P*/*B*) Ratio
Fe	40.26	39.19	81.18
Mn	21.63	21.68	46.08
Zn	08.70	08.59	15.61
Si	02.45	02.46	05.66
O	26.96	28.07	54.37

for the different peaks, so background fitting was free from any inaccuracy.

Precise knowledge of the cation distribution over crystallographic sites in magnetic oxides is highly essential for understanding their physical properties. In order to determine the distribution of metallic cations among the crystallographic interstitial sites, tetrahedral (A-) and octahedral (B-) sites, X-ray diffraction line intensity calculations were performed using the powder – x software [30] and indigenous software [31] based on the formula suggested by Buerger [32]

$$I_{hkl} = \left|F_{hkl}\right|^2 \cdot P \cdot L_p \quad (1)$$

where I_{hkl} is the relative integrated intensity, F_{hkl} is the structure factor, P is the multiplicity factor and L_p is the Lorentz polarization factor = $[(1 + \cos^2 2\theta)/\sin^2\theta \cdot \cos\theta]$. According to Ohnishi and Teranishi [33], the intensity ratios of planes I(220)/I(440), I(400)/I(422), and I(220)/I(400) are considered to be sensitive to any change in cation distribution. The intensities of (220) and (422) planes are mostly sensitive to cations on the tetrahedral sites, while the intensity of (400) plane depends on cations on both the sites. There is a good contrast in the atomic scattering factor of Si^{4+} and Zn^{2+} to that of Fe^{3+} and Mn^{2+}, but the scattering factor of Mn^{2+} is close to that of Fe^{3+} [34]. We had estimated the amount of ferric (Fe^{3+}) ions on the A-site and B-site through low-temperature ($T = 80$ K) ^{57}Fe Mossbauer spectral intensity calculations by considering the integrated areas under the Lorentzians corresponding to the A- and B-sites, which were taken as proportional to the amount of Fe^{3+} ion on these sites. The details are given elsewhere [35, 36]. The values of the Seebeck coefficient and absolute ferric ion concentration on the B-sites are further used to calculate ferrous ion (Fe^{2+}) concentration as discussed in [35]. Any alteration in the distribution of cations causes a significant change in the theoretical values of the X-ray diffraction line intensity ratio. Therefore, in the process of arriving at the final cation distribution, the site occupancy of all the cations was varied for many combinations and those that agree well with the experimental intensity ratios, the fitting of the magnetization data at 80 K [26] and Mossbauer data analysis [36] were taken into consideration. The resultant cation distribution and comparison of intensity ratios of planes are shown in Table 2. The percentage accuracy in cationic occupancies is of the order of ± 5%.

Figure 2 depicts the current (*I*) against the electric field (*E*) plots for all compositions registered at various temperatures. It is found that for the pristine composition ($x = 0.0$) switching action was recorded at $T_s \geq 373$ K, while for the compositions, $x = 0.1$, 0.2, and 0.3, switching was noted, respectively, at $T_s \geq 323$ K, $T_s \geq 473$ K, $T_s \geq 523$ K. In

Table 2 Lattice constant (*a*), distribution of cations, oxygen deficiency (δ) and microstrain ($\Delta d/d$) for $Zn_{0.3}Mn_{0.7+x}Si_xFe_{2-2x}O_4$ system

Mn–Si content (*x*)	*a* (Å) ± 0.002 Å	Actual cation distribution	$\frac{I(400)}{I(422)}$		$\frac{I(220)}{I(400)}$		Oxygen deficiency (δ)	$(\Delta d/d) \times 10^{-3}$
			Obs	Cal	Obs	Cal		
0.0	8.465	$(Zn^{+2}_{0.25}Mn^{+2}_{0.40}Fe^{+3}_{0.35})$ $[Zn^{+2}_{0.05}Mn^{+2}_{0.30}Fe^{+3}_{1.02}Fe^{+2}_{0.63}]O_{3.68}$	1.924	2.103	1.122	1.264	0.32	–
0.1	8.488	$(Zn^{+2}_{0.25}Si^{+4}_{0.10}Mn^{+2}_{0.43}Fe^{+3}_{0.22})$ $[Zn^{+2}_{0.05}Mn^{+2}_{0.37}$ $Fe^{+3}_{1.49}Fe^{+2}_{0.09}]O_{3.95}$	2.107	2.257	0.992	1.052	0.05	1.3515
0.2	8.497	$(Zn^{+2}_{0.25}Si^{+4}_{0.15}Mn^{+2}_{0.45}Fe^{+3}_{0.15})$ $[Zn^{+2}_{0.05}Si^{+4}_{0.05}Mn^{+2}_{0.45}$ $Fe^{+3}_{1.36}Fe^{+2}_{0.09}]$ $O_{3.95}$	2.071	2.191	1.294	1.206	0.05	1.8805
0.3	8.505	$(Zn^{+2}_{0.25}Si^{+4}_{0.21}Mn^{+2}_{0.48}Fe^{+3}_{0.06})$ $[Zn^{+2}_{0.05}Si^{+4}_{0.09}Mn^{+2}_{0.52}$ $Fe^{+3}_{1.24}Fe^{+2}_{0.10}]$ $O_{3.95}$	1.800	1.951	1.066	1.189	0.05	2.3705

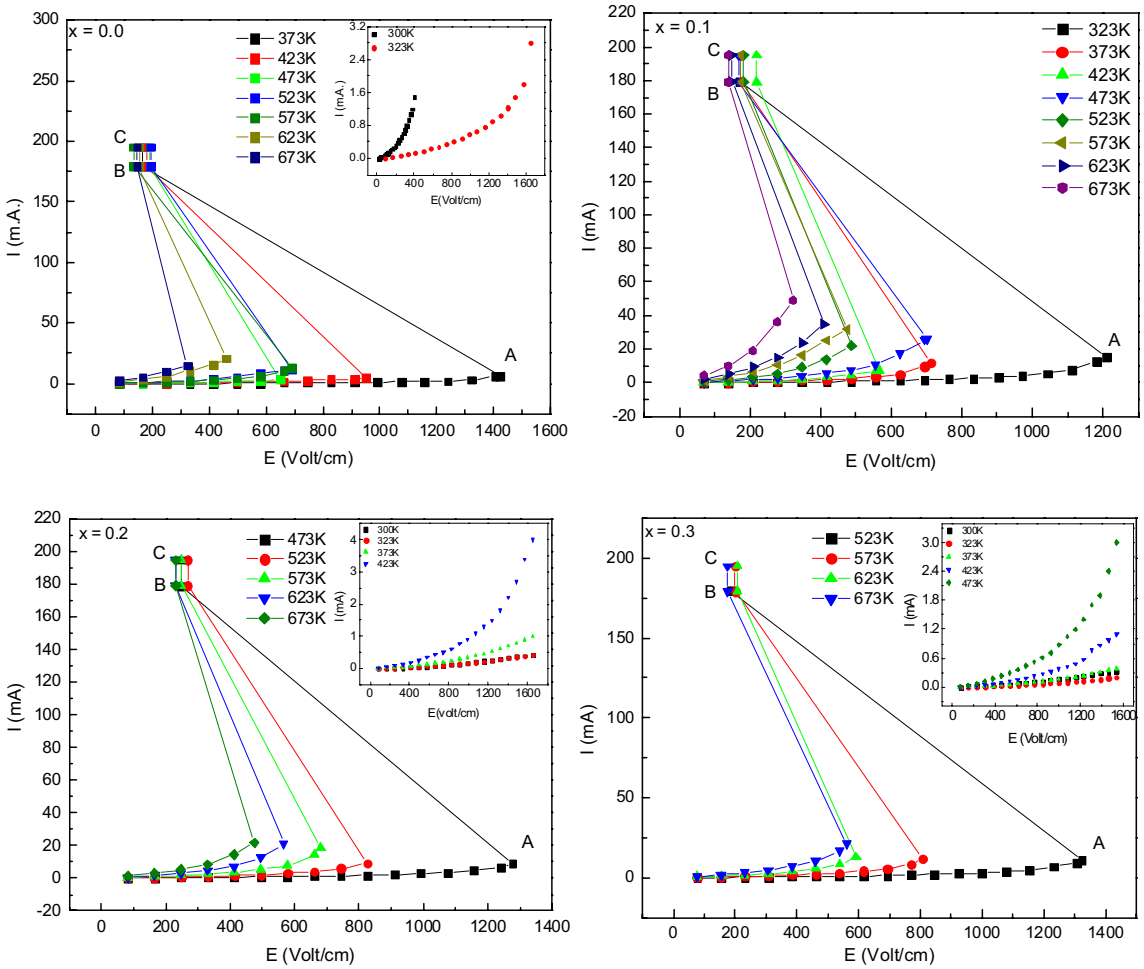

Fig. 2 Current (*I*) against electric field (*E*) characteristics for $x = 0.0$–0.3 compositions registered at selected temperatures

accordance with T_s, electric field strength (E_s) required for switching action to takes place is found to be 1416 V/cm for $x = 0.0$ composition, while for $x = 0.1$, 0.2 and 0.3 compositions E_s is found to be 1206 V/cm, 1276 V/cm and 1321 V/cm, respectively. In short, T_s and E_s increase with Mn–Si content (x) for $x \geq 0.1$. According to Vaingankar et al. [37], electrical switching is influenced by structural and microstructural parameters. The observed increase in the lattice parameter with x (Table 2) implies that charge carriers require more amount of energy to transfer from one cationic site to another. Thus, the observed increase in T_s and E_s may be correlated with a subsequent increase in the unit cell dimension. The compositional variation of lattice constant has clearly implied that in the system greater proportion of Si^{4+} ions residing at the grain boundaries, while a small quantity did indeed enter into the crystal lattice [24, 26]. Earlier, it has been shown in the case of W-type barium ferrite ($BaCo_{1.3}Zn_{0.7}Fe_{16}O_{27}$) that grain boundary occupancy of Si^{4+} ions is 5–10 times greater than Si^{4+} ions residing inside the grains [38]. Our results are consistent with these findings. The presence of silicon ions at the grain boundaries forms a low-conductivity layer as addressed above. Thus, on increasing the concentration (x) intragranular flow of charge carriers get restricted, which turns out in observed increase in E_s and T_s with content (x). Earlier, in the case of the $Cd_xCo_{1-x}Fe_{2-y}Cr_yO_4$ spinel ferrite system, it was reported that the switching field (E_s) decreases with a decrease in grain size (D) [14]. In the present case, an average grain size reduces from 12 µm ($x = 0.0$) to 6 µm ($x = 0.3$) [28], but at the same time E_s is found to increase with (x). This contradicts the previous results.

A careful examination of Fig. 2 revealed the nature of the switching performance. The deviation from the Ohm's law becomes more prominent with an increase in V across the sample when the E is just beyond the value designated by 'A.' During the first cycle, the breakdown abruptly takes place and the field drops to the value marked by B, specified as the first breakdown field; hereafter, the I increases monotonously, from B to C. The aggregate resistance

switching ratio (R_{high}/R_{low}) approximated for the different compositions is better than 200% at the respective T_s.

The aggregate ON-state current is noted to be ~ 179 mA at the distinct temperatures for all the compositions. It is interesting to note that the switching performance of the samples remains unchanged even when the cycle was performed again after 2 weeks indicating the absence of the 'aging effect.' On the other hand, when the ferrites were under the second switching cycle that was running later than the first cycle, it was observed that the lower value of the electric field is needed for breakdown to take place. This leads to the occurrence of Joule self-heating.

As discussed above, the large class of oxide systems exhibits this interesting phenomenon. Thus, it is difficult to pinpoint any precise reason as being responsible for electrical switching and it may be different for the different systems. Commonly, oxide series containing Jahn–Teller (JT) ions (Mn^{3+} and Cu^{2+}) are the most probable candidates expected to demonstrate switching actions [39].

The series $Zn^{+2}{}_{0.3}Mn^{+2}{}_{0.7+x}Si^{+4}{}_{x}Fe^{+3}{}_{2-2x}O^{-2}{}_{4}$ is fundamentally free from JT ions. Thus, the observed switching action cannot be ascribed to JT ions as suggested. The structural transformation observed [37] likewise cannot be admitted as the origin of this action, as neither of these ferrites demonstrated such transformation in structure as a function of temperature, which otherwise would have been observed in thermal variation of two-probe dc conductivity measurements [26]. The oxygen deficiency (δ), which is customary in aforesaid ferrites, should be allowed for the possibility, but this is most unlikely as verified by EDAX pattern analysis. Further, thermoelectric power measurements have shown that $\delta = 0.05$ remains constant for $x = 0.1$–0.3 compositions [35] (Table 2). Thus, oxygen deficiency cannot be responsible for observed switching action and corresponding changes in T_s and E_s values. Similar observations of the trivial role of oxygen vacancy on RS have been reported for NiO and perovskite manganite $La_{0.67}Sr_{0.33}MnO_3$ [40, 41]. The formation of JT Mn^{+3} ion is presumably in such systems, and concurrently, the formation of a comparable amount of JT ferrous ions (Fe^{+2}) from ferric ions (Fe^{+3}) is anticipated such that the charge neutrality retains. If switching in the system is accorded to the presence of Mn^{+3} ions in the series, then requisite E_s and T_s showed a decrease with Mn–Si content (x), but the findings show an opposite trend.

In addition, thermoelectric power measurements have also demonstrated that the ferrites under study are n-type semiconducting materials. Consequently, switching owing to the cooperative Jahn–Teller distortions does not appear to be tenable. On examining the cation distribution (Table 2), it is evident that on Mn–Si substitution (x), Fe^{3+} ion concentration decreases from the B-site as well as from the system itself. This restricts the exchange of electron among Fe^{3+}–Fe^{2+} ions, and as a consequence, the values of E_s and T_s required for switching action increase. When highly magnetic Fe^{3+} ions are replaced by non-magnetic Si^{4+} ions that do not take an active part in the conduction mechanism, that curtails the conduction via the B-site. Additionally, the space-charge-limiting current (SCLC) may also be responsible for observed switching action. As stated in the band theory of insulators, supplemental charge carriers are injected through a metallic electrode via an insulator–metal interface. In Fig. 3, it can be seen that for low-voltage region, up to 2.3 V, the current increases almost linearly, suggesting the slope value of log$I$ versus log$V$ curves to be approximately 1 for all the compositions. However, beyond 2.3 V, a sharp increase in the current deviates from the linearity and yields a slope of the curves between 1.8 and 2.8 (Fig. 3), which implies that in the high resistance state the conduction mechanism is static induction current (SIC) or SCLC-type. Similar findings and detailed mechanisms are reported in refs. [29] and [42] for binary and ternary oxide compounds, respectively. In SCLC over the insulating layers, increase in large current takes place when trapping sites in the insulating bulk are fully occupied at a threshold voltage (V_T). By and large, V_T is farther than 200 V in the primary action of RS. Beyond the V_T, I swiftly increases (Fig. 3). The drastic rise in I may be induced by trap charge—SCLC. Thus, when the thermally produced free charge carrier density within the system is higher as compared to the density of charge carrier injected, Ohmic ($I \alpha V$) characteristic is noticed. In the manner now being exemplified from the log$I$ against log$V$ plots (Fig. 3) which exhibit that at low voltage, I follows Ohm's law, and at breakdown voltage, the slope of the curve increases hinting the presence of SCL current which could be referring to as the possible cause of electric switching [43]. This is also an essential feature of CCNR type of electrical switching. Eventually, the I–E characteristics show gradual switching that can be thought of due to CCNR-type switching. On the other hand, fast switching action may be expected on account of VCNR-type switching. Further, I–E characteristics (Fig. 2) exhibited by all the compositions regardless of ferrimagnetic or paramagnetic in nature and are akin to the ON–OFF characteristics of a silicon-controlled rectifier. At long last, an effort has been made to correlate microstructural parameters [grain size (D) and density of defects (d_D)], similar to that of structural parameters (the lattice constant (a) and cation distribution), with electric parameters, E_s and nonlinearity coefficient (α). The values of α and E_s are deployed to characterize the functioning of a device. It is advisable to have a large value of α to protect the device against any electric surges. The α value determined from standard method [22], for example, increases from $\alpha = 2.0$ ($x = 0.0$) to $\alpha = 2.8$ ($x = 0.3$) at $T = 523$ K, consistent with the slope

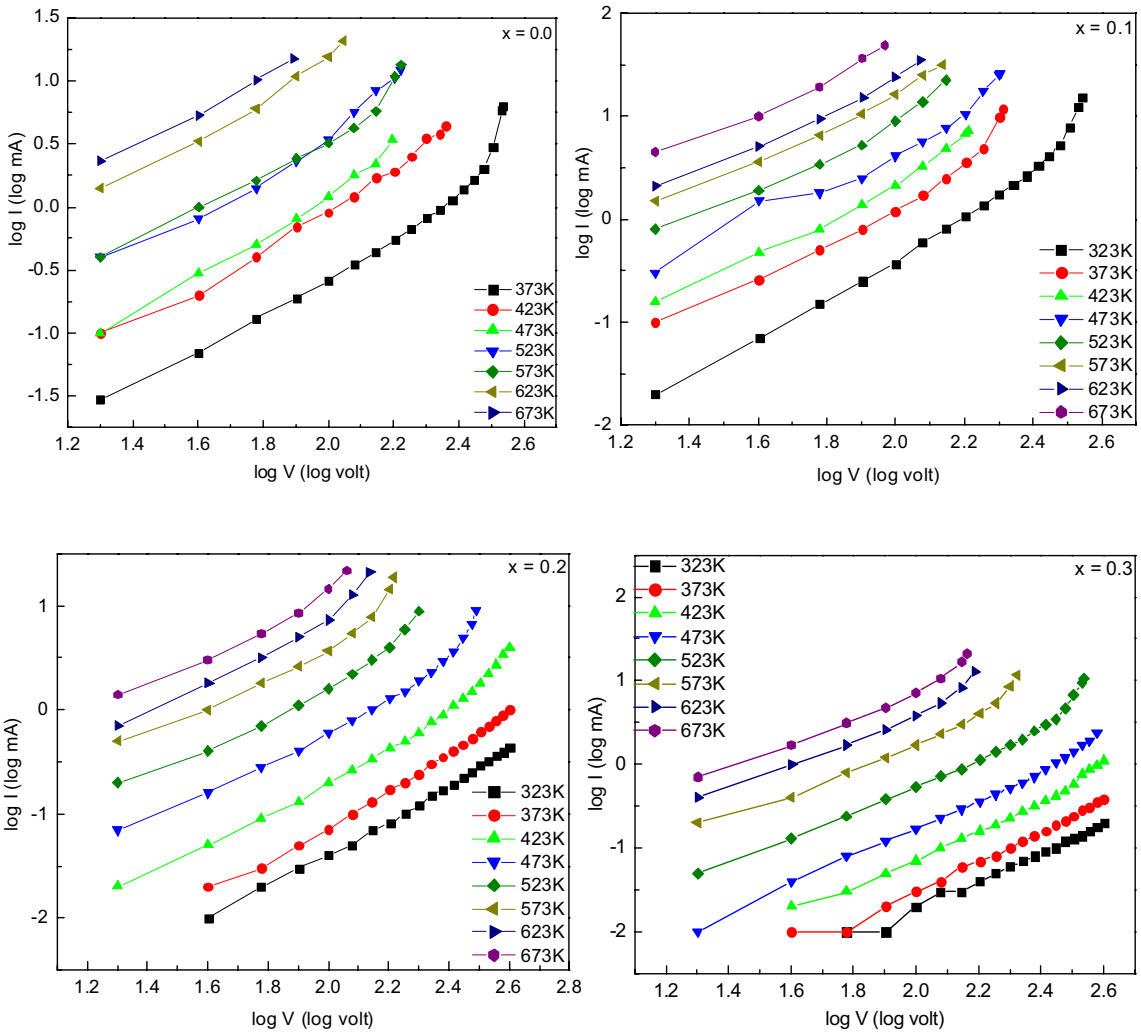

Fig. 3 Temperature dependence of log*I* versus log*V* plots for the $Zn_{0.3}Mn_{0.7+x}Si_xFe_{2-2x}O_4$ spinel ferrite series

values determined from log *I* versus log *V* plots (Fig. 3), as expected. It has been reported that $d_D \propto 1/D^2 \propto E_s^2$ [22]. On decrease in *D* with content (*x*), d_D is found to increase from $6.94\times10^9/m^2$ for $x=0.0$ composition to $27.8\times10^9/m^2$ for $x=0.3$ composition, suggesting an increase in microstrain due to the enhancement in tensile force acting on the planes. The variation in lattice microstrain, corresponding to a fractional change in plane spacing, $\Delta d/d$, has been computed for the substituted compositions by taking into account '*d*' spacing value of the most intense (311) peak and is presented in Table 2. This value of $\Delta d/d$, however, comprises both tensile strain and compressive strain and must be divided by a factor of two to get the maximum tensile strain alone, if these two strains are presumed to be the same in strength. Table 1 reveals that strain gradually increases with increasing Mn–Si content (*x*) for $x=0.1$–0.3 compositions. A single–peak analysis method [strain determination by the value of $\Delta d/d$ from only (311) reflection] is based on the assumption that strain broadening is Gaussian, while size broadening is Lorentzian. Other methods analyze the full diffraction pattern, trying to extract the information about the crystallite size and strain based on the different angular dependence of their respective broadening effects. A relatively simple and thus still widely used method is the Williamson–Hall (W–H) plot. This method actually considers the broadening (β) of peaks as a function of a diffraction angle (2θ), which is assumed to be the combined effect of size-induced broadening and strain-induced broadening. In this method, both size and strain broadening are assumed to be Lorentzian, and the integral breadth of both components is additive.

From the W–H plots (Fig. 4), the linear slope gives the value of the lattice strain. It is found that the system $Mn_{0.7+x}Zn_{0.3}Si_xFe_{2-2x}O_4$ ($x=0.0$–0.3) comprises positive and negative values of strain. The positive slope for $x=0.0$ composition suggests the presence of tensile strain

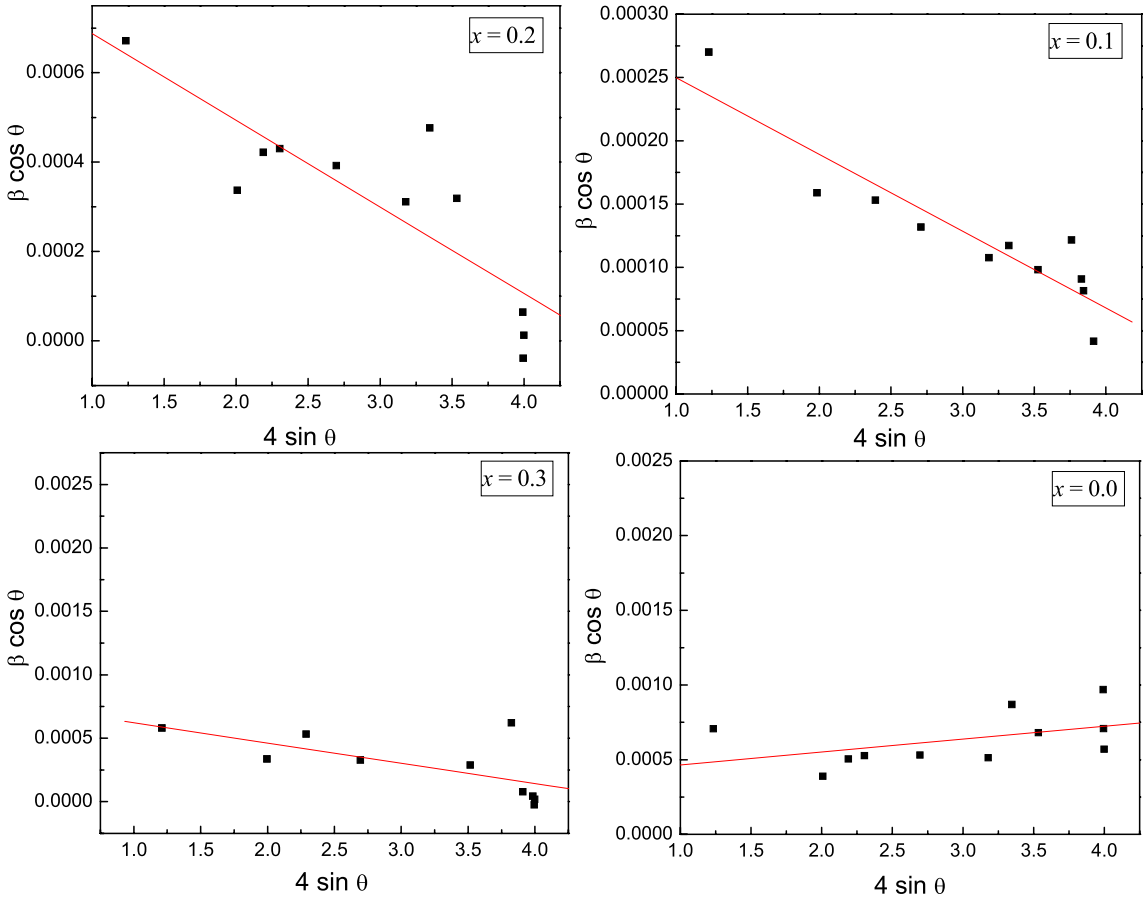

Fig. 4 Williamson and Hall plots for strain determination for all the compositions of the spinel ferrite series $Zn_{0.3}Mn_{0.7+x}Si_xFe_{2-2x}O_4$

(strain = + 0.865 × 10^{-4}), whereas the negative slope for $x = 0.1$, 0.2 and 0.3 compositions exhibits compressive strain [44] (strain = −0.606 × 10^{-4}, −1.59 × 10^{-4} and −1.93 × 10^{-4}, respectively). All the plots exhibit a scatter point known as a 'deviation pattern,' which is typical of strained cubic materials [45]. The co-substitution of Mn–Si causes significant changes in the structural properties and eventually affects other physical properties. The compressive strain also indicates that microstrains cannot be a dominant source of broadening [46]. On the other hand, in coarse-grained materials, crystallite/grain size has a negligible effect on X-ray diffraction line broadening. The compressive strain increases with increasing content (x) in the system. The variation of strain with x is similar to that of strain determined from single (311) reflection for $x > 0.0$ compositions.

The tensile strain increases owing to the increasing defect density (d_D) as discussed above. Earlier, a detailed role of defects in governing the RS has been reviewed for several oxide thin film systems [47]. Thus, one can expect better nonlinear behavior (higher value of α), as observed. At the same time, as a result, an increase in E_s with Mn–Si concentration (x) is anticipated as noticed for $x = 0.1$–0.3 compositions. These experimental outcomes are of great significance as they bring out the advancement of electric field-induced RS devices.

Figure 5 displays the GIXRD pattern and AFM image of the ZMSFO thin film. The diffraction line analogous to the single face-centered cubic (*fcc*) phase is clearly seen. The lattice parameter anticipated based on the GIXRD analysis was 8.43 Å, which is smaller as compared to the bulk counterpart ($a = 8.488$ Å) (Table 2). One or more of the following factors causes the smaller value of unit cell parameter for nanostructured thin film: (1) low degree of crystallinity in nanostructured thin film, (2) the alteration in the site occupancy of cations and (3) the existence of lattice defects that affect the surface of the nanoparticles. Surface energy and tension of the nanoparticles are significant that lead to shrinkage in the lattice, which elicits a reduction in lattice constant [48]. AFM image shows a homogeneous distribution of grains, and the aggregate particle size approximated is varying between 50 and 65 nm. The AFM analysis has shown RMS

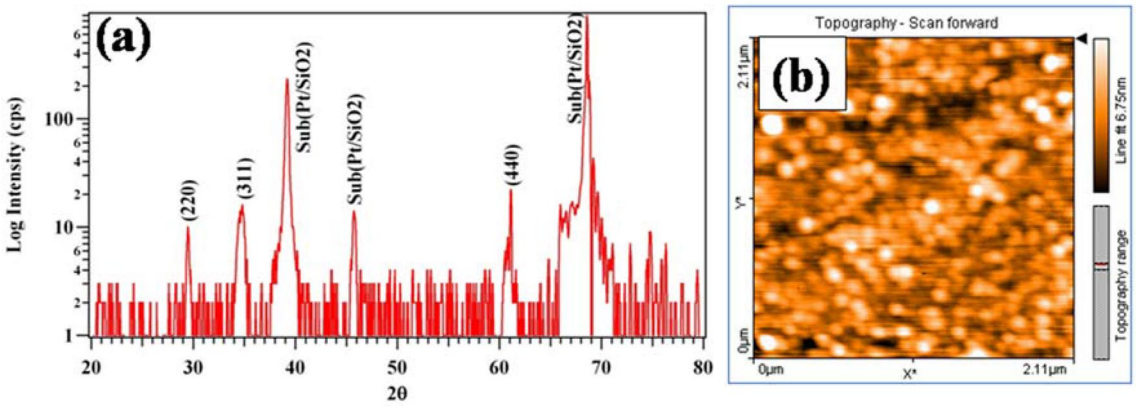

Fig. 5 GIXRD pattern of ZMSFO film grown on $Pt/SiO_2/Si$ substrate. A single cubic phase can be seen (**b**). Bi-dimensional AFM surface topography of $ZMSFO/Pt/SiO_2/Si$ heterostructure

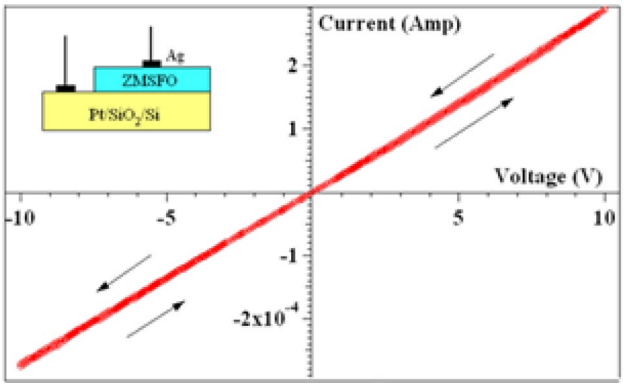

Fig. 6 *I-V* characteristics of $Ag/ZMSFO/Pt/SiO_2/Si$ heterostructure. The inset shows the schematic of measurement geometry and arrows indicate typical voltage sweeping cycles

roughness of the order of ~ 6.8 nm that is equitably modest alluding to even-textured grain morphology.

Figure 6 illustrates *I–V* characteristics of $Ag/ZMSFO/Pt/SiO_2/Si$ heterostructure examine by employing the bi-terminal method. The inlay shows a schematic of a cross section of the $Ag/ZMSFO/Pt/SiO_2/Si$ sandwich configuration intended for the *I–V* measurements. Figure 6 shows linear *I–V* behavior for every cycle of voltage sweeping implying the absence of RS characteristics. These outcomes point out that the electrical transport associated with the interface is most unlikely for the RS phenomenon in the ferrite thin film.

4 Conclusions

In conclusion, spinel ferrite system $Zn_{0.3}Mn_{0.7+x}Fe_{2-2x}O_4$ ($x = 0.0–0.3$) in its bulk and thin film forms have been studied for its current-controlled negative resistance-type electrical switching properties. Elevated temperatures and high electric fields are essential parameters along with the Mn–Si concentration (x) for the observed enhancement in the electrical switching in the ferrite oxide system. Moreover, the expansion in lattice parameter, abatement of octahedral site occupancy of Fe^{3+} ion in spinel lattice, and partial grain boundaries occupancy of Si^{4+} ions may have an important role for the switching characteristics. The modeling of the *I–V* data confirmed the presence of space-charge-limiting current, which could be a responsible source of observed switching. The PLD grown ferrite thin film shows linear behavior in current against voltage characteristic without any signature of resistive switching, suggesting that the bulk composition of the compound has a major role to play against the film–electrode interface.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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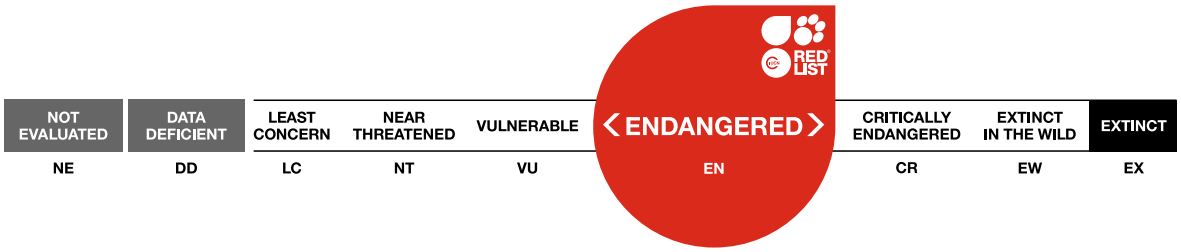
Scope(s): Global
Language: English

Commiphora stocksiana, Mitha Guggul

Assessment by: Patel, R. & Rana, K.



View on www.iucnredlist.org

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Taxonomy

Kingdom	Phylum	Class	Order	Family
Plantae	Tracheophyta	Magnoliopsida	Sapindales	Burseraceae

Scientific Name: *Commiphora stocksiana* (Engl.) Engl.

Synonym(s):

- *Balsamea stocksiana* Engl.
- *Balsamodendrum pubescens* Stocks

Common Name(s):

- Gujarati: Mitha Guggul
- Baluchi: Bayisa gugal

Taxonomic Source(s):

The International Plant Names Index. 2012. IPNI. Available at: http://www.ipni.org/. (Accessed: 17 June).

Taxonomic Notes:

The species was first reported from Sind province of Baluchistan, Pakistan by J. Ellerton Stocks in 1847 and described as *Balsamodendron pubscens* Stocks. In later years the species was also reported by Hooker (1849). Boissier (1872) reported its distribution in presidency of Bombay. The genus *Balsamodendron* was revised and renamed as *Commiphora* and the species *pubscens* revised and renamed as *stocksiana* Engler (Hooker, 1875). Woodrow (1897) reported this species in its earlier locality as reported by Stocks. In India, the genus *Commiphora* has four species which are *C. mukul* Hook. Ex Stock*, C. agollocha* Engl*. C. berryi* (Aen.) Engl. and *C. stocksiana* (Atal *et al*., 1975).

Identification Information:

Small trees; bark exfoliating. Leaflets 2-3 pairs with a terminal odd leaflet. Flowers sessile; bracts 2, opposite; sepals 4, connate into an urceolate 4-lobed tube, lobes valvate; petals 4 free, spreading; stamens 8, equal; ovary bilocaular; stigma bilobed. Fruit 0.5-1.5 cm long, red when ripe, marked with four white lines, the alternate ones not reaching the top. Gum resin is reddish - brown in colour and is neutral in taste. Leaflets entire, 3-5 foliolate, pubescent; petals not reflexed; stamens equal; fruit with 4 white longitudinal lines. The length of Corolla and calyx are equal.

Assessment Information

Red List Category & Criteria: Endangered B2ab(iv,v) ver 3.1

Year Published: 2020

Date Assessed: October 14, 2017

Justification:

This species is restricted to a single location in India and few locations in Pakistan. Overall, it is considered to have four locations according to the main threat to this species: exploitation due to the

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medicinal properties of oleo-gum resin, which is even more superior in quality than its allied species, *Commiphora wightii*. In addition, its estimated area of occupancy is 16 km^2. A continuing decline in mature individuals is projected, as the overall population is suspected to be decreasing, and the number of subpopulations is undergoing a continuing decline. Therefore, it is assessed as Endangered.

Geographic Range

Range Description:

This species was first collected from Sind province of Baluchistan, Pakistan by J. Ellerton Stocks in 1847 and described as *Balsamodendron pubscens* stocks. It was subsequently also reported by Hooker (1849). Boissier (1872) commented on its distribution in "The Bombay Presidency". The species was validly published in Monographiæ phanerogamarum by Candolle, Alphonse de, (1883) under the name *Commiphora stocksiana* (Engl.) Engl. Later, Woodrow (1897) rediscovered this species in the localities reported by Stocks. Rao *et al.* (1984) reported the species as an addition to the Indian flora, confined to a single locality in Kachchh district of Gujarat state.

Country Occurrence:

Native, Extant (resident): India; India (Gujarat); Pakistan

Distribution Map

Legend

EXTANT (RESIDENT)

Compiled by:

IUCN (International Union for Conservation of Nature) 2019

The boundaries and names shown and the designations used on this map do not imply any official endorsement, acceptance or opinion by IUCN.

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Population

Rao *et al.* (1984) observed around 15-20 individuals at Kachchh in India. After almost three decades, Patel *et al.* (2013) surveyed and rediscovered the plant from the same locality with only 3 individuals. However, the present scenario is that the wild population is less than 13 individuals while around 8 individuals are conserved *in-situ* at the agriculture hedges. There is no update regarding the population size other than in India.

Current Population Trend: Decreasing

Habitat and Ecology (see Appendix for additional information)

Commiphora stocksiana is a balsamiferous small tree or shrub in hilly and moderately undulating terrain. The tree prefers to grow in substratum of rocks or boulders and in sandy soil (Enright *et al.* 2005, Patel *et al.* 2013). The species is generally found in the tropical thorn forest especially in the area of mixed thorn forests. It is generally distributed in calcareous rocks and dry river beds of coastal regions. The tree species including *Acacia senegal*, *Euphorbia caducifolia*, *Grewia spp*. and *Salvadora spp*. are the associated species for *C. stocksiana.*

Systems: Terrestrial

Use and Trade

The Mitha Guggul gum was sold at the rate of 150 INR per kg (Mandvi market: April, 1981). Traders claim that Mitha Guggul gum, *C. stocksiana*, is superior in quality to the gum resin obtained from the species *C. wightii*. Further, experiments on chemical and pharmacological aspects of Mitha Guggul gum should be carried out to verify this claim. The results obtained from these studies will also be useful in determining identity and characteristics of good quality Guggul of the Indian market. This will be useful to workers in Ayurvedic formulations (Rao *et al*. 1984). The oleo-gum-resin of *C. stocksiana* is used by the villagers for curing inflammations, rheumatism, indolent ulcers, gum problems, tonsillitis, laryngitis, bronchitis, pneumonia, whooping cough, chronic dyspepsia, diarrhea, chronic endometritis, leucorrhea and piles (Sharma and Kumar 2012).

Threats (see Appendix for additional information)

A major threat faced by this species is over-exploitation for the medicinal use of its oleo-gum resin.

Conservation Actions (see Appendix for additional information)

Few mature individuals have been conserved at agricultural hedges of Haji Ismail in Lakhapar taluka of Lakhpat village and also Anjar taluka, Kachchh district. Anand Agricultural University has raised propagated plant saplings through cuttings as well as seeds. Further, Gujarat Biodiversity Board funded a project on *ex-situ* conservation of this species to Rohit Patel, where he developed and standardized the seed based nursery techniques and more than 2000 saplings were prepared and reintroduced at suitable habitats in Kachchh.

Credits

Assessor(s): Patel, R. & Rana, K.

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Reviewer(s): Puttick, A.

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Disclaimer

External Resources

For Supplementary Material, and for Images and External Links to Additional Information, please see the Red List website.

Appendix

Habitats
(http://www.iucnredlist.org/technical-documents/classification-schemes)

Habitat	Season	Suitability	Major Importance?
8. Desert -> 8.1. Desert - Hot	Resident	Suitable	Yes

Plant Growth Forms
(http://www.iucnredlist.org/technical-documents/classification-schemes)

Plant Growth Form
TS. Tree - small

Use and Trade
(http://www.iucnredlist.org/technical-documents/classification-schemes)

End Use	Local	National	International
Medicine - human & veterinary	Yes	No	Yes

Threats
(http://www.iucnredlist.org/technical-documents/classification-schemes)

Threat	Timing	Scope	Severity	Impact Score
5. Biological resource use -> 5.2. Gathering terrestrial plants -> 5.2.1. Intentional use (species is the target)	Ongoing	Whole (>90%)	Very rapid declines	High impact: 9
	Stresses:	2. Species Stresses -> 2.1. Species mortality		

Conservation Actions in Place
(http://www.iucnredlist.org/technical-documents/classification-schemes)

Conservation Action in Place
In-place research and monitoring
Action Recovery Plan: Yes
Systematic monitoring scheme: Yes
In-place land/water protection
Conservation sites identified: Yes, over part of range
Percentage of population protected by PAs: 0

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Conservation Action in Place
Occurs in at least one protected area: No
Invasive species control or prevention: Unknown
In-place species management
Harvest management plan: No
Successfully reintroduced or introduced benignly: No
Subject to ex-situ conservation: Yes
In-place education
Subject to recent education and awareness programmes: No
Included in international legislation: No
Subject to any international management / trade controls: No

Conservation Actions Needed

(http://www.iucnredlist.org/technical-documents/classification-schemes)

Conservation Action Needed
1. Land/water protection -> 1.1. Site/area protection
1. Land/water protection -> 1.2. Resource & habitat protection
3. Species management -> 3.2. Species recovery
3. Species management -> 3.3. Species re-introduction -> 3.3.1. Reintroduction
4. Education & awareness -> 4.3. Awareness & communications
5. Law & policy -> 5.4. Compliance and enforcement -> 5.4.1. International level
6. Livelihood, economic & other incentives -> 6.4. Conservation payments
6. Livelihood, economic & other incentives -> 6.5. Non-monetary values

Research Needed

(http://www.iucnredlist.org/technical-documents/classification-schemes)

Research Needed
1. Research -> 1.2. Population size, distribution & trends
1. Research -> 1.4. Harvest, use & livelihoods
1. Research -> 1.5. Threats
2. Conservation Planning -> 2.1. Species Action/Recovery Plan
2. Conservation Planning -> 2.2. Area-based Management Plan

Research Needed
2. Conservation Planning -> 2.3. Harvest & Trade Management Plan
3. Monitoring -> 3.1. Population trends
3. Monitoring -> 3.3. Trade trends

Additional Data Fields

Distribution
Estimated area of occupancy (AOO) (km²): 16
Continuing decline in area of occupancy (AOO): Unknown
Extreme fluctuations in area of occupancy (AOO): No
Estimated extent of occurrence (EOO) (km²): 53562
Continuing decline in extent of occurrence (EOO): Unknown
Extreme fluctuations in extent of occurrence (EOO): No
Number of Locations: 4
Continuing decline in number of locations: No
Extreme fluctuations in the number of locations: No
Lower elevation limit (m): 73
Upper elevation limit (m): 140
Population
Continuing decline of mature individuals: Yes
Population severely fragmented: No
No. of subpopulations: 2
Continuing decline in subpopulations: Yes
Extreme fluctuations in subpopulations: No
All individuals in one subpopulation: No
No. of individuals in largest subpopulation: 13
Habitats and Ecology
Continuing decline in area, extent and/or quality of habitat: Unknown
Generation Length (years): 10
Movement patterns: Not a Migrant

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The IUCN Red List Partnership

The IUCN Red List of Threatened Species™ is produced and managed by the IUCN Global Species Programme, the IUCN Species Survival Commission (SSC) and The IUCN Red List Partnership.

The IUCN Red List Partners are: Arizona State University; BirdLife International; Botanic Gardens Conservation International; Conservation International; NatureServe; Royal Botanic Gardens, Kew; Sapienza University of Rome; Texas A&M University; and Zoological Society of London.

Rotala mexicana, an addition to the flora of Gujarat, India

***Rotala mexicana* Cham. and Schlecht.: a—habitat | b—habit. © S.K. Patel & P.R. Desai.**

The genus *Rotala* L. with more than 55 species is distributed in tropical and subtropical regions of the world (Cook 1979) of which 29 species are reported so far from India (Narayanan et al. 2014). Lemiya & Pradeep (2015) recently described one more species *Rotala anamika* Lemiya from Kerala. The authors during their intensive botanical explorations in various parts of northern Gujarat came across an interesting specimen of *Rotala* at the plain terrain in Vijaynagar near Zer-Bhankhara forest of Sabarkantha District on soil following rain. It is restricted to a limited area with 6–8 individuals per square meter. The population distribution of the species is clumped. Specimens were collected and properly processed for preparing herbarium by using the standard methods recommended by Santapau (1955) and Jain & Rao (1977). After critical examination of all morphological features and perusal of relevant literature available (Cook 1979; Joseph & Shivrajan 1989; Lemiya & Pradeep 2015), the specimens were identified as *Rotala mexicana* Cham & Schlecht. Prior to this finding, there were four species of *Rotala* reported from Gujarat. *Rotala mexicana* was not recorded in any work pertaining to Gujarat. Hence, it forms a new addition to the flora of Gujarat State. A voucher specimen has been deposited at the Department of Botany, The M.S. University of

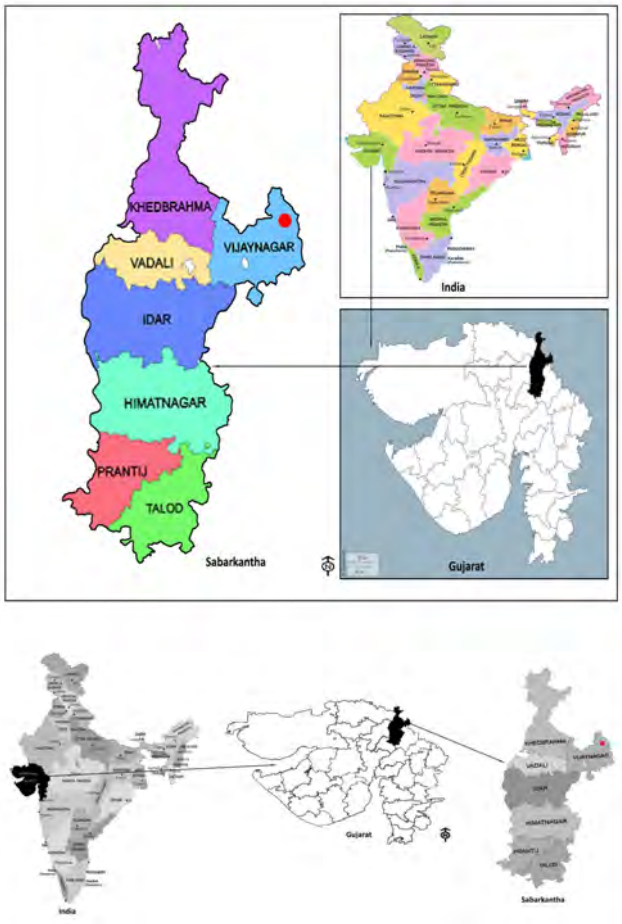
Baroda, BARO Herbaria, Vadodara (Gujarat). A brief description along with notes on habitat, distribution, phenological data, and photographs is provided here to facilitate easy identification of the species in the wild. In addition, a key to the species of *Rotala* found in Gujarat has also been provided.

Key to the species of *Rotala* found in Gujarat

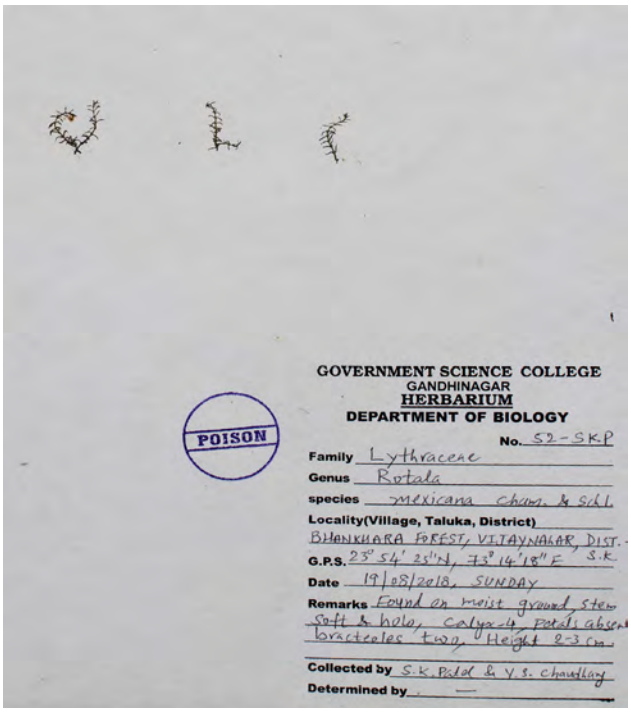
1. Leaves opposite decussate, flowers petaliferous 2
1. Leaves opposite decussate or in whorls of 3, flowers apetalous 4
2. Calyx appendages present ..... *R. densiflora*
2. Calyx appendages absent 3
3. Calyx tube constricted above; petals longer than calyx lobes ..... *R. serpyllifolia*
3. Calyx tube not constricted; petals half as long as calyx lobes ..... *R. indica*
4. Bracteoles leaf-like, partly or completely enclosing the flower ..... *R. occultiflora*
4. Bracteoles scarious, not enclosing the flower ..... *R. mexicana*

Rotala mexicana Cham & Schlecht., Linnaea 5: 567, t. 830; Koehne, Bot. Jahrb. 1: 150. 1880 & in Engl., Pflanzenr. 17 (4, 216): 29. 1903; Blatt & Hallb., J. Bombay Nat. Hist. Soc. 25: 702. 1918; Van Leeuwen, Blumea 19: 54. 1979; Cook, Boissiera 29: 33. 1979; Philcox, Kew Bull. 41: 43. 1986.

Prostrate herbs, 2–3 cm long, stem soft, hollow, branched, slender, 4-angled, creeping or ascending, rooting at nodes. Leaves in whorls (3 on each node) or opposite decussate in upper portion, linear-oblong. Bracts leaf-like. Bracteoles two, linear, scarious, not enclosing the flower, usually as long as calyx tube. Flowers monomorphic, apetalous, solitary, axillary, sessile, less than 1mm long. Calyx tube 0.6mm long, pink, lobes 4, triangular, without appendages. Petals absent. Stamens usually 2, inserted near the base of calyx tube, not exerted. Ovary globose; style short; stigma capitate. Capsule globose, ca. 0.8mm across, 2–3-valved, slightly exceeding the calyx lobes. Seeds 10–18, 0.3mm long, smooth, black, semi-obovate.



Map showing location of *Rotala mexicana* Cham. and Schlecht.



Herbarium sheet of *Rotala mexicana* [#SKP - 052].

Specimen examined: SKP-52, 19.viii.2018, Gujarat, Sabarkantha District, Vijaynagar, Zer-Bhankhara forest, 23.906^{0}N & 73.238^{0}E, 293m, coll. Suresh K. Patel (BARO Herbarium).

Field notes: It is found on wet mud following rain with limited distribution in the area. Several species seem to be associated with the plants including *Funaria* sp. *Ophioglossum* sp., *Eriocaulon* sp., *Lindernia ciliata*, *Lindernia indica*, *Cyperus triceps*, and grasses. It is very short lived and completes its life cycle within 30–35 days.

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Probiotics and Antimicrobial Proteins
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Evaluation of Probiotic Properties and Prebiotic Utilization Potential of *Weissella parameseteroides* Isolated From Fruits

Kinjal Pabari[1,2] · Sheetal Pithva[3] · Charmy Kothari[1] · Ravi Kiran Purama[4] · Kanthi Kiran Kondepudi[5] · Bharatkumar Rajiv Manuel Vyas[2] · Ramesh Kothari[2] · Padma Ambalam[1]

Abstract

Weissella parameseteroides has gained a considerable attention as bacteriocin and exopolysaccharide producers. However, potential of *W. parameseteroides* to utilize different prebiotics is unexplored area of research. Fruits being vectors of various probiotics, five *W. parameseteroides* strains, namely, FX1, FX2, FX5, FX9, and FX12, were isolated from different fruits. They were screened and selected based on their ability to survive at pH 2.5 and in 1.0% sodium taurocholate, high cell surface hydrophobicity, mucin adhesion, bile-induced biofilm formation, antimicrobial activity (AMA) against selected enteropathogens, and prebiotic utilization ability, implicating the functional properties of these strains. In vitro safety evaluation showed that strains were susceptible to antibiotics except vancomycin and did not harbor any virulent traits such as biogenic amine production, hemolysis, and DNase production. Based on their functionality, two strains FX5 and FX9 were selected for prebiotic utilization studies by thin layer chromatography (TLC) and short-chain fatty acids (SCFAs) production by high performance liquid chromatography. TLC profile evinced the ability of these two strains to utilize low molecular weight galactooligosaccharides (GOS) and fructooligosaccharides (FOS), as only the upper low molecular weight fractions were disappeared from cell-free-supernatants (CFS). Enhanced β-galactosidase activity correlated with galactose accumulation in residual CFS of GOS displayed GOS utilization ability. Both the strains exhibited AMA against *E. coli* and *Staph. aureus* and high SCFAs production in the presence of prebiotic, suggesting their synbiotic potential. Thus, *W. parameseteroides* strains FX5 and FX9 exhibit potential probiotic properties with prebiotic utilization and can be taken forward to evaluate synergistic synbiotic potential in detail.

Keywords *Weissella parameseteroides* · Probiotics · Prebiotics · Antimicrobial activity · Short-chain fatty acids

Introduction

Lactic acid bacteria (LAB) are predominantly present in various fruits, vegetables, and fermented foods, and in addition, they are present as normal flora of gastrointestinal tract (GIT) and vagina of humans and animals [1]. LAB produce lactic acid as a major end product of carbohydrate metabolism along with other end products such as acetic acid and CO_2 during heterolactic fermentation. Many LAB are characterized as potential probiotics, which are living microorganisms that when administered in adequate amounts confer health benefits to the hosts [2]. They may play a crucial role in modulating the physiological functions of the gut by improving digestion and by inhibiting the growth of pathogens, thereby preventing gastrointestinal infections [1, 3]. Strains of lactobacilli such as *Lactobacillus plantarum*, *Lact. fermentum*, and *Lact. rhamnosus* [4, 5] and certain other LAB such as

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s12602-019-09630-w) contains supplementary material, which is available to authorized users.

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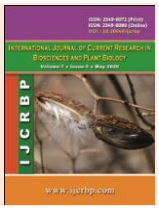

Short Communication **doi:** https://doi.org/10.20546/ijcrbp.2020.705.005

New distributional record of *Zeuxine strateumatica* (L.) Schltr. (Orchidaceae) to the State Flora of Gujarat from Sabarkantha district, India

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ABSTRACT

The present study found new distributional record of *Zeuxine strateumatica* (L.) Schltr., a terrestrial orchid *belonging to* family Orchidaceae to the Gujarat state flora from Sabarkantha district of North Gujarat Region. In addition to this the relevant citation, description, flowering and fruiting period, field notes and photographs are provided here for easy identification.

Introduction

The district Sabarkantha is situated in the North-Eastern part of Gujarat State between 23.05000000-24.50000000 N and 72.71666667-73.65000000 E. During our intensive botanical explorations in different areas in Sabarkantha district, an interesting plant species from Lebhor pond, Talod was collected, growing among grasses and sedges. Specimens were collected and properly processed for herbarium by using the standard herbarium methods (Jain and Rao, 1977). After critical examination with dissected floral parts and other morphological features and perusal of relevant literature available, the specimens were identified as *Zeuxine strateumatica* (L.) Schltr. (Shah, 1978; Abraham and Vatsala, 1981). *Zeuxine* Lindl. is a very widespread genus distributed from Tropical Africa to Central Asia and West Pacific represented by 170 species distributed around the world (Govaerts et al., 2011) of which 18 species are found in India (Misra, 2007). Prior to this survey, however, the Orchidaceous genus *Zeuxine* Lindl. was represented by a single species, i.e., *Zeuxine strateumatica* (L.) Schltr. in Gujarat state as reported by different localities (Thaker, 1910; Shah,1978; Raghavan et al., 1981; Bole and Pathak,1988; Pilo et al., 1996; Bhatt, 2018). Sabarkantha district is recorded to be with rich in floristic diversity and it is well explored by various plant taxonomists (Saxton and Sedgwick, 1918; Saxton, 1922; Bhatt and Bedi, 1969; Yogi, 1970;

Bhatt and Sabnis, 1987; Punjani, 1997; Patel, 2003; Pandey, 2011; Parmar, 2012).The species has not been reported from North Gujarat Region. So, it is a new distributional record from Sabarkantha district for Gujarat State. The distribution and current localities recorded of *Zeuxine strateumatica* (L.) Schltr. in Gujarat state is depicted in Fig. 1. A voucher specimen (SKP-081 and SKP-089) has been deposited at the Gujarat Arts and Science College, Ellisbridge, Ahmedabad, Gujarat. In addition to this the relevant citation, a brief description, phenological data, field notes and photographs are provided for easy identification of the species in the wild.

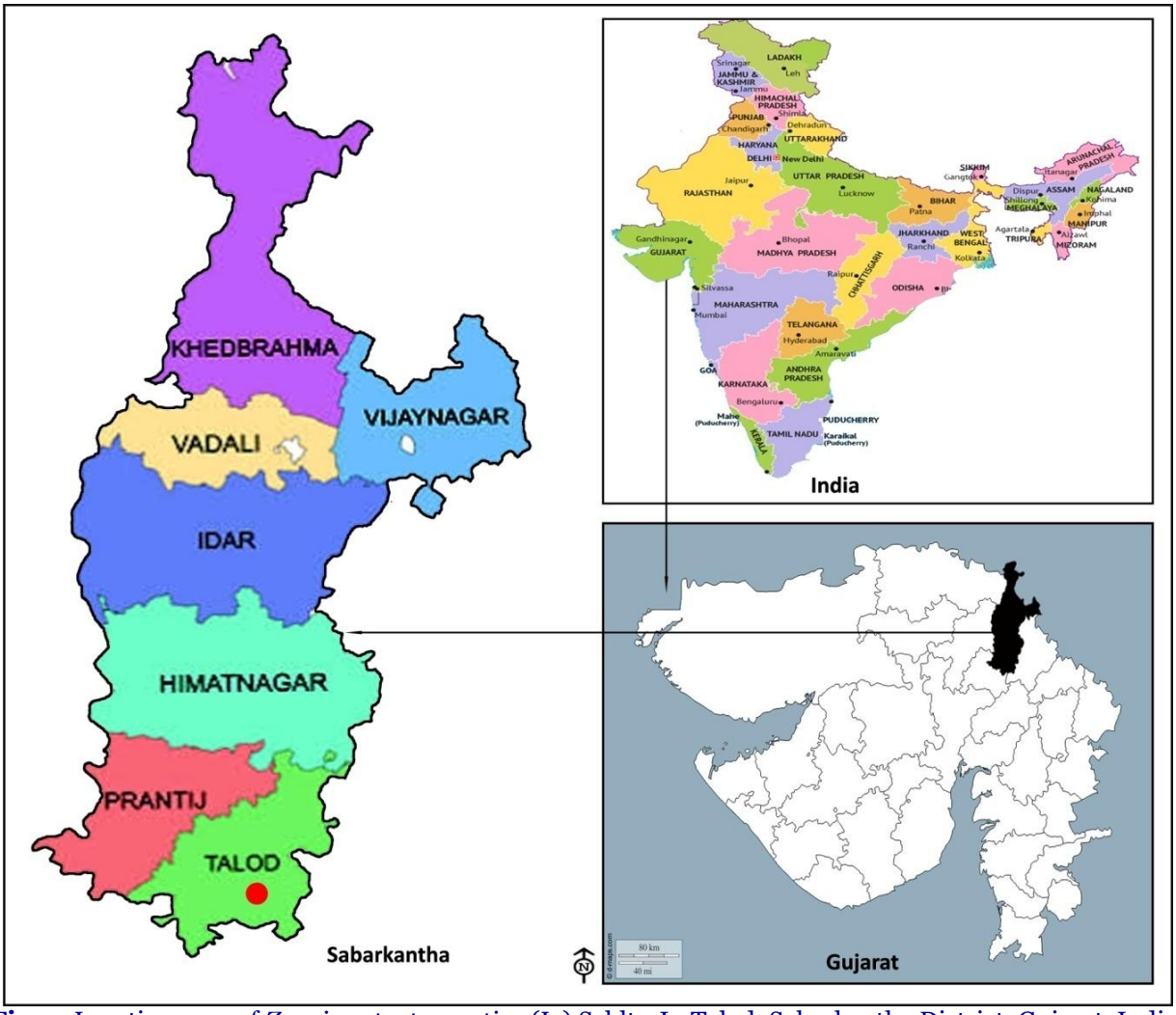

Fig. 1: Location map of *Zeuxine strateumatica* (L.) Schltr. In Talod, Sabarkantha District, Gujarat, India.

Taxonomic description

Zeuxine strateumatica(L.) Schltr. in Bot. Jahrb. Syst. 45: 394. 1911; Santapau and Kapadia, Orchids Bombay 167. t. 38. 1966; Shah, Fl. Gujarat 2: 663. 1978; Raghavan et al. in Bull. Bot. Surv. India 84, 1981; Pandey in Shetty and Singh, Fl. Rajasthan 2: 825. 1991; T. Cooke, Fl. Pres. Bombay 3: 213. 1958. (Fig. 2 a, b)

Terrestrial, erect, grass-like herbs, it is 8-30cm high, growing from upper node of an ascending stem like rhizome. The Leaves are grass like, 2–8, clasping, erect, alternate, sessile, linear-lanceolate, acuminate and passing upward into foliar sheaths. Inflorescence terminal, erect, spike with 3–19 flowered, dense. Flowers sessile, not opening well, perianth oblique on ovary, white. Sepals unequal, obtuse; dorsal ovate, base saccate; laterals

obliquely oblong-ovate, cymbiform. Petals falcately oblong lanceolate, subacute, cohering with dorsal sepal to form a hood over the column. Lip tongue shaped, with upturned sides, yellow; basal part saccate, bearing inside two obliquely oblong, blunt pillar glands; middle part contracted to a short claw; terminal lobe short, hunch backed, ovate in outline, mucronate, hammer headed, two-lobed, the lobes upturned, sub-quadrate; epichile 2-lobed, sometimes appearing 1-lobed, sub-reniform, yellow or greenish-yellow or brownish-white, margin entire.

Fig. 2: *Zeuxine strateumatica* (L.) Schltr; **a.** Whole plant **b**. close up view of flowers.

Flowering and fruiting: February – March

Specimen examined: Lebhor Pond, Talod, Sabarkantha District, Gujarat (GPS coordinate: 23.334785 N & 72.952330 E), SKP-081, Dt. 23.III.2019; SKP-089, Dt. 20.II.2020

Field notes: The field investigation revealed that this species is found on the margin of the pond, closely associated with grasses and sedges(Several species of *Cyperus*, *Eleocharis*, *Fimbristylis* and *Scirpus* genera were frequently encountered and they exhibited very wide range of distribution in the area) and herb species like *Ammania* sp., *Ludwigia* sp., *Polygonum* sp., *Bacopa monnieri* (L.) Pennell, *Limnophila heterophylla* (Roxb.) Benth., they are surrounding associated species, while *Ipomoea fistulosa* Mart. ex Choisy, *Typha angustifolia* L. growing on the margin of the pond. The population of this orchid is confined to only one locality with eighty (80) individuals from Lebhor pond in Talod taluka of Sabarkantha district. This pond was previously a natural pond but the government dug up it and made it a bigger water reservoir for the surrounding farmers for the irrigation to their fields. Many threats in this area were found to be solid waste dumping, water pollution, manmade construction, habitat fragmentation, grazing and other anthropogenic pressure, these all factors could deplete the number of the species in its natural habitat in the future. If we want to conserve this species, a ban to these all harmful activities are urgently needed, otherwise species will be disappearing from the natural habitat.

Many importance species found in this pond like, *Blyxa octandra* (Roxb.) Planchon ex Thwaites, *Dopatrium junceum* (Roxb.) Buch.- Garten., *Limnophyton obtusifolium* (L.) Miq., *Potamogeton perfoliatus* L., *Sagittaria sagittifolia* L., *Utricularia reticulata* Sm., and Some pteridophytes viz. *Azolla pinnata* R. Br., *Isoetes coromandeliana* L. f., *Marsilea minuta* L. were also reported in the same wetland. In future, we have to give main priority to sustainable development, so that mankind gets enriched by combination of modern technology and beauty of the nature. Studies on wetland plants pertaining to their distribution pattern, status, major threats and other ecological aspects are also highly recommended.

Conflict of interest statement

Authors declare that they have no conflict of interest.

Acknowledgement

The authors are thankful to Dr. B. L. Punjani, Principal, Smt. S. M. Panchal Science College, Talod Sabarkantha district for his constant support during the field work and encouragement. We would also like to extend our sincere gratitude to our colleagues for their support.

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Lindernia tamilnadensis M.G. Prasad & Sunojk. (Linderniaceae): A new record to the flora of Gujarat state, India

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Abstract
Lindernia tamilnadensis M.G. Prasad & Sunojk. (Linderniaceae) is reported as a new record to the flora of Gujarat state and new distributional record for India from Vijaynagar forest area in Sabarkantha District. A brief description, field notes, field photographs and distribution of the species are provided to facilitate for easy identification.

Keywords: *Lindernia tamilnadensis*, Linderniaceae, New record, Gujarat state

Introduction

The genus *Lindernia* comprises of about 100 species [1] distributed almost throughout the tropical and temperate regions of both the old and new world [2]. The centers of diversity of *Lindernia* are situated in Africa [3] and South East Asia. They fall in 3 main geographical groups, the largest in Asia followed by Africa and the Americas [4]. This genus was originally placed in the Scrophulariaceae; however, based on molecular studies; [5] segregated *Lindernia* along with 12 other genera from the rest of Scrophulariaceae to a new family Linderniaceae. According to him, the new family forms a monophyletic group characterized by a unique abaxial staminal filament with a club shaped appendage. A preliminary study on the genus *Lindernia* shows that there are 31 taxa reported from India, among them 25 are known from South India [6, 7, 8, 9, 10, 11, 12]
The district Sabarkantha is one of the tribal districts and it is situated in the North-Eastern part of Gujarat State between 23.05000000-24.50000000 N & 72.71666667-73.65000000 E. This district is known for rich in floristic diversity and well explored by various plant taxonomists [13, 14, 15, 16, 17, 18, 19, 20, 21]. Present study was aimed to find out the occurrence of endemic and noteworthy threatened species of North Gujarat Region. During this study, we came across good population of an interesting semi aquatic species found growing on wet soils along with grasses and many herbs from Vijaynagar forest area in Sabarkantha district. Specimens were collected and properly processed for herbarium specimen preparation by using the standard herbarium methods [22]. After critical examination with dissected floral parts and other morphological features and perusal of relevant literature available, the specimens were confirmed as *Lindernia tamilnadensis* M.G. Prasad & Sunojk. It is one such an endemic species known to occur only in Tamilnadu [12] and Maharashtra [23] states of India. There are 11 species of *Lindernia* those have been reported from the Gujarat state while, *Lindernia tamilnadensis* M.G. Prasad & Sunojk. has not been reported from the Gujarat state [24, 25, 26, 27, 28, 29, 30, 31, 32, 33]. Thus, it constitutes as a new addition to the flora of Gujarat state as well as new distributional record to the flora of India. In addition to this the relevant citation, a brief description, phenological data, field notes and photographs are provided for easy identification of the species in the wild. The current localities of *Lindernia tamilnadensis* M.G. Prasad & Sunojk. in Gujarat is depicted in Fig. 1. A voucher specimen (SKP-99, Date-29/11/2020) has been deposited at the Gujarat Arts and Science College, Ellis Bridge, Ahmedabad, Gujarat.

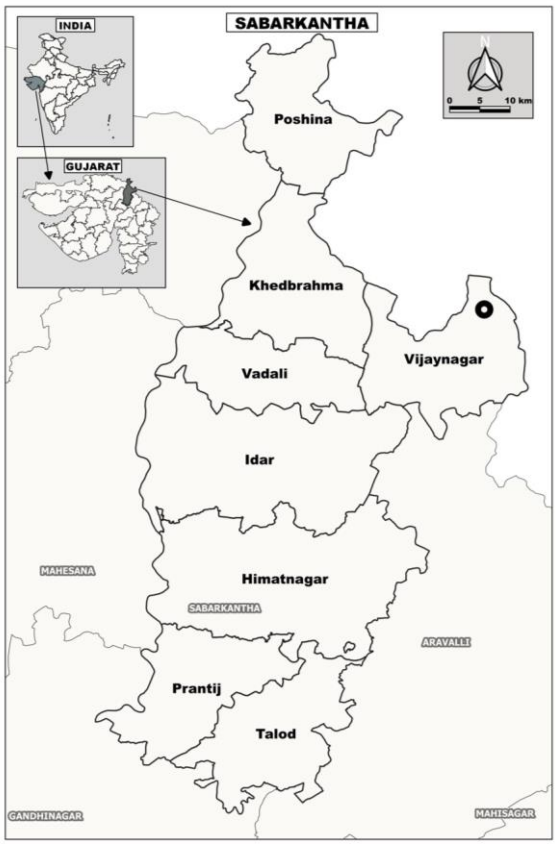

Fig 1: Location of *Lindernia tamilnadensis* M. Prasad & Sunojk. In Gujarat

Taxonomy

Lindernia tamilnadensis M.G. Prasad & Sunojk. Fig. 2; a-d

Type:-INDIA. Tamil Nadu: Tirunelveli district, Vijayanarayanam, 40 m, 18 March 2012, M.G. Prasad & P. Sunojkumar CU117880 (Holotype: CALI; Isotypes: CALI, MH).

Erect or procumbent tufted herb, up to 15 cm high, rooting from the basal nodes. Stem slender, weak, 4-angled, glabrous, highly branched from the base; internodes about 2.5 cm long. Leaves sessile, 0.5–1.5×0.4–1.2 cm, ovate, base sub-cordate, apex acute or sometimes rounded, margins entire towards the older parts, 2–4 dentate towards the apex, glabrous, basally 3–5 nerved, veins distinct, lamina glandular punctate. Flowers pedicellate, axillary, solitary, alternately on leaf axils, one per node; pedicel slender, ca. 5-12 mm long, 4-angled, glandular hairy; fruiting pedicel glabrous, erect. Calyx 2–2.5 mm long, deeply 5-lobed, glandular hairy outside, glabrous within; lobes lanceolate, 1.5–2×0.3–0.5 mm, apex acute. Corolla 4–5 mm long, 2-lipped, white with pale blue blotches on lower lip; corolla tube cylindrical, 3–4 mm long, glabrous; upper lip 1×1 mm, slightly emarginated at apex, glabrous; lower lip distinctly 3-lobed, lobes 1×1 mm, rounded, glabrous. Perfect stamens 2, coherent below the upper lip, filaments ca. 1 mm long, glabrous, anthers 2-lobed, lobes ovate, acute. Staminodes 2, linear, ca. 1 mm long, glandular hairy throughout, dense yellow glandular hairs at the base of filaments and corolla tube below, bluish towards apex, hairs 2–3-celled, a distinct spur present just below the staminodal apex. Gynoecium 3–3.2 mm long; ovary 1.0×0.5 mm, bicarpellary, syncarpus ovary, ovate–acute, subglobose, glabrous; style 2 mm long, glabrous; stigma simple, bilobed. Capsule globose, 2.5×2 mm, glabrous, shiny, slightly exceeding the length of persistent calyx. Seeds numerous, minute, 0.3×0.15 mm, bended, golden yellowish, distinctly 5-ridged.

Fig 2: *Lindernia tamilnadensis* M. Prasad & Sunojk.; a. Habit; b. Flower; c. Flower closeup (Front view); d. Capsule

Flowering and fruiting

October–January.

Specimen examined

Gujarat: Sabarkantha Dist., Vijaynagar Polo forest, SKP-52, Dt.29.xi.2020 (24.23333333 N & 73.47416667 E, 351 m), collector S. K. Patel

Distribution

Endemic to India; Tamilnadu, Maharashtra, now in Gujarat.

Habitat

It is found in semi aquatic habitat in dry deciduous forests of Northern part of the Gujarat state. It is also found growing on wet soils around the ditches/pools soon after the rainy season.

Notes

L. tamilnadensis is closely related to *L. rotundifolia*, but differs mainly in comparatively smaller floral parts, in the absence of trichomes at the base of the anterior corolla lobes, the presence of staminodal appendages, undeflexed fruiting pedicels and globose capsules.

Acknowledgement

Authors are grateful to Dr. M. G. Prasad, CSIR-National Botanical Research Institute, Lucknow, India for the confirmation of the identity and his valuable support as well as encouragement. We are thankful to Dr. K. S. Rajput, M. S. University, Baroda, Gujarat and Dr. S. L. Meena, Botanical Survey of India, Howrah, Kolkata for his valuable inputs. We are also thankful to forest department, Sabarkantha district, Gujarat for permission to undertake field studies.

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OPHIOGLOSSUM JAYKRISHNAE (OPHIOGLOSSACEAE) : A SPECIES NOVO FROM GUJARAT STATE

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ABSTRACT

A new species of *Ophioglossum* (= *Ophioglossum jaykrishnae*) is collected from Jambughoda Wild life Sanctuary, Gujarat, India. The newly collected species is depicting the dark brown-pink colour, rhizomorphs tuberous, trophophylls lanceolate, erect, coriaceous, having pseudo-costa, forming 30^0–60^0 angle with fertile stalk, parallel venation and spore diameter 20–30 µm, exine tuberculate-varicose which hitherto an undescribed species. The detailed taxonomic description, distribution, ecology, conservation status and photographs are also given.

Key Words : *Ophioglossum*, dark brown trophophylls, semi-arid, India, data deficient.

INTRODUCTION

Ophioglossum L. is a diverse fern genus, belongs to the primitive family Ophioglossaceae and is one of the most important fern genera from an evolutionary point of view. About 52 species of the genus have been reported world wide, of which 23 species are documented from India (Patil *et al*., 2018; WCSP, 2020; Fraser-Jenkins, 2020). Most of them are ground growing forms except two species *viz*. *O. pendulum* L., and *O. palmatum* L., are epiphytic. The genus was studied for the first time from India by Beddome (1883). After his monumental contribution on the Indian ferns, the genus *Ophioglossum* received more attention by contemporary researchers like Hope (1903), Blatter and d'Almedia (1922), Mahable (1962), Panigrahi and Dixit (1969), Khandelwal (1987), Khullar (1994); Goswami (2007) Patil and Dongare (2014) and Kachhiyapatel, (2018). Recently, four new species of *Ophioglossum* were reported and described from Gujarat, India by Patil *et al*., (2018a), Patel and Reddy (2018a, 2019) and Patel *et al.,* (2018) respectively.

Since, last four years (i.e. 2017) authors are studying a unique population of *Ophioglossum* along with other species growing at Lafni and Dhanpuri (Jambughoda Wild life Sanctuary), Gujarat. On the basis of last four years field visits and critical examination of morpho-taxonomic characters of *Ophioglossum*, it is concluded that the population observed in Jambughoda Wildlife Sanctuary shares the features of hitherto undescribed species. Therefore, the main aim of the present study is to describe the new species of *Ophioglossum*.

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MATERIALS AND METHODS

Collection of plant specimens : Field survey were carried out from June 2017 to October 2020 from different regions of Gujarat state. Specimens were collected in sterile polyethylene bags and brought to the laboratory for further processing.

Literature survey and identification of taxon : A critical examination of the related literature has been used for the confirmation of the identity of the taxa under investigation. The detailed information of the *Ophioglossum* species were gathered from national as well as regional floras, books, journals, periodicals and research publications. Characteristics of each specimens were compared with the available literature (Burrows, 1990; Roux, 2001 & 2009; Fraser-Jenkins *et al.*, 2017, 2018; Patil *et al.*, 2014; Patil *et al.*, 2018).

Herbarium deposition : Voucher specimens were deposited in BARO herbarium of the Department of Botany, The Maharaja Sayajirao University of Baroda, Vadodara (Gujarat).

Conservation status : It was analysed by using the criteria given by IUCN Red list of Threatened Species (Version 2020-1).

SYSTEMATIC TREATMENT

Ophioglossum jaykrishnae S. M. Patil, S. K. Patel, Raole & K. S. Rajput *sp. nov.* Fig. 1 & 2.

Type : India, Gujarat, Lafni, Jambhughoda wildlife sanctuary, altitude <300 m asl, 20/07/2018, Patil & Rajput, 1082. (Holotype CAL!; Isotype BARO!; SUK!; BSJO!)

Etymology : The species is named after father of plant taxonomy of Gujarat, Mr. Jaykrishna Inderji Thaker (1849-1902). A distinguished botanist born in Kachchh in 1849, pioneer plant taxonomic researcher from Gujarat. He is a self-made creative scientist, who had best scientific temper without any entry in college and university and described as well as wrote the flora in regional language (Flora of Barda Mountain) and second book Plants of Cutch and their Utility. He emphasised ethno-therapeutical information, social forestry program and environmental awareness highlighted in these books. His contribution to plant science in general and medicinal plants in particular is acknowledged here.

Description : Plant terricolous, small-medium sized, dark brown-pink colour, 4–10 cm in height; *rhizomorph* 0.2–0.4 cm, subterranean, tuberose-subglobose, arises few fibrous roots (sometimes stoloniferous); *common stalk* 0.8–1.1 cm, subterranean-terranean, white; *trophophylls* 0.5–2 × 0.5 cm, 1-2 (rarely >3) per rhizomorph, brownish-pink, forming 30^0–60^0 angle to the fertile stalk; *lamina* lanceolate, apex acute, base almost truncate, margin entire, pseudo-costa present, brown coloured, sheathing leaf base absent; *venation* simple,parallel areoles, not visible; *fertile segment* 3–8.5 cm long, inserted at the base of the lamina, round, abaxially grooved, dark brownish (sometimes pinkish); *strobili* 0.5–2 cm long, thick, apex acute–acuminate, dark brown-pink; sporangia 4–8 pairs,

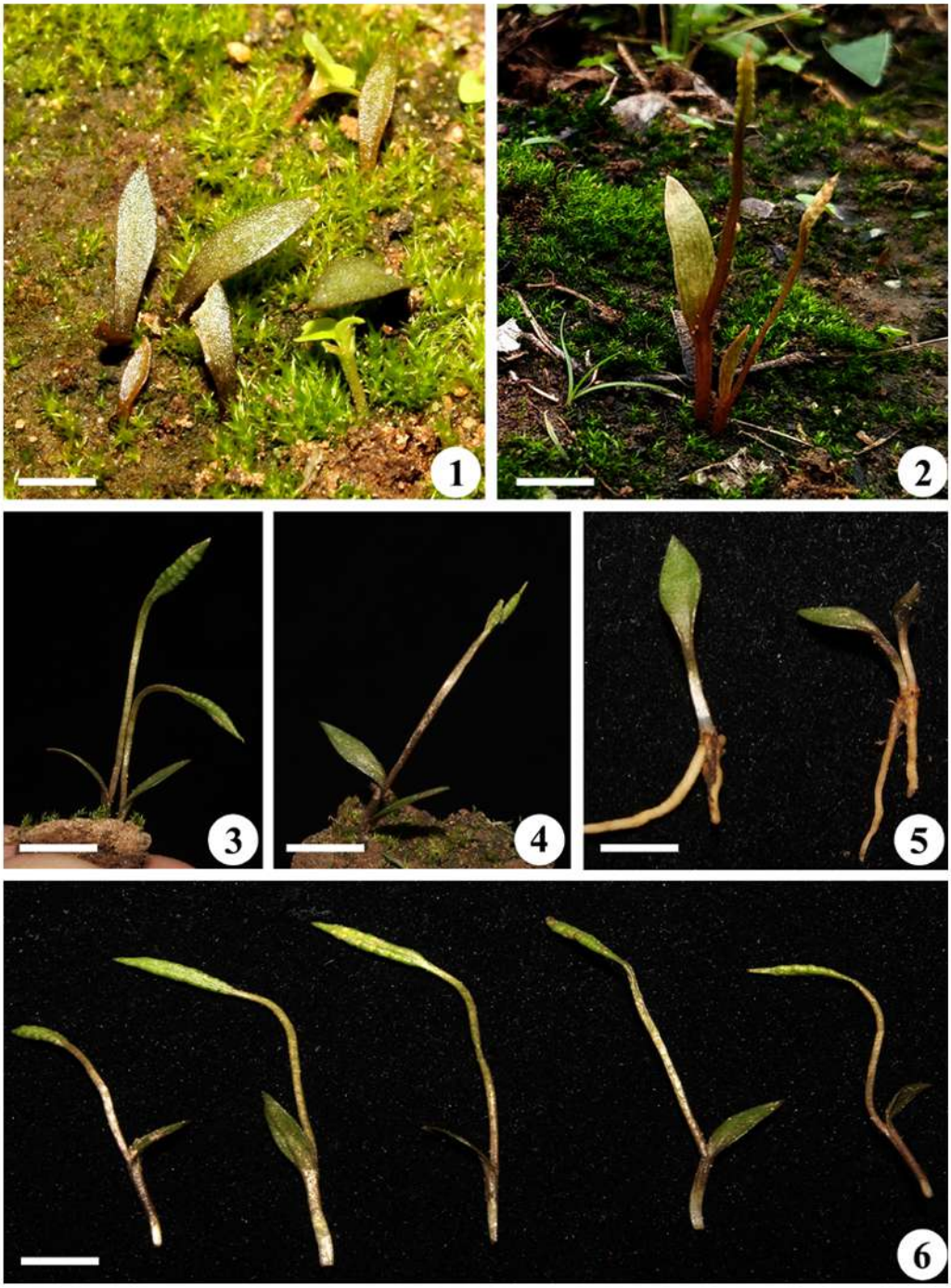

Figure 1 : *Ophioglossum jaykrishnae* : 1-3. Habit, **4.** Unusual form with bifurcate strobili, **5.** Individuals showing tuberous rhizomorph, **6.** Range of variations in trophophylls.

Scale bar : 1-6 = 2 cm

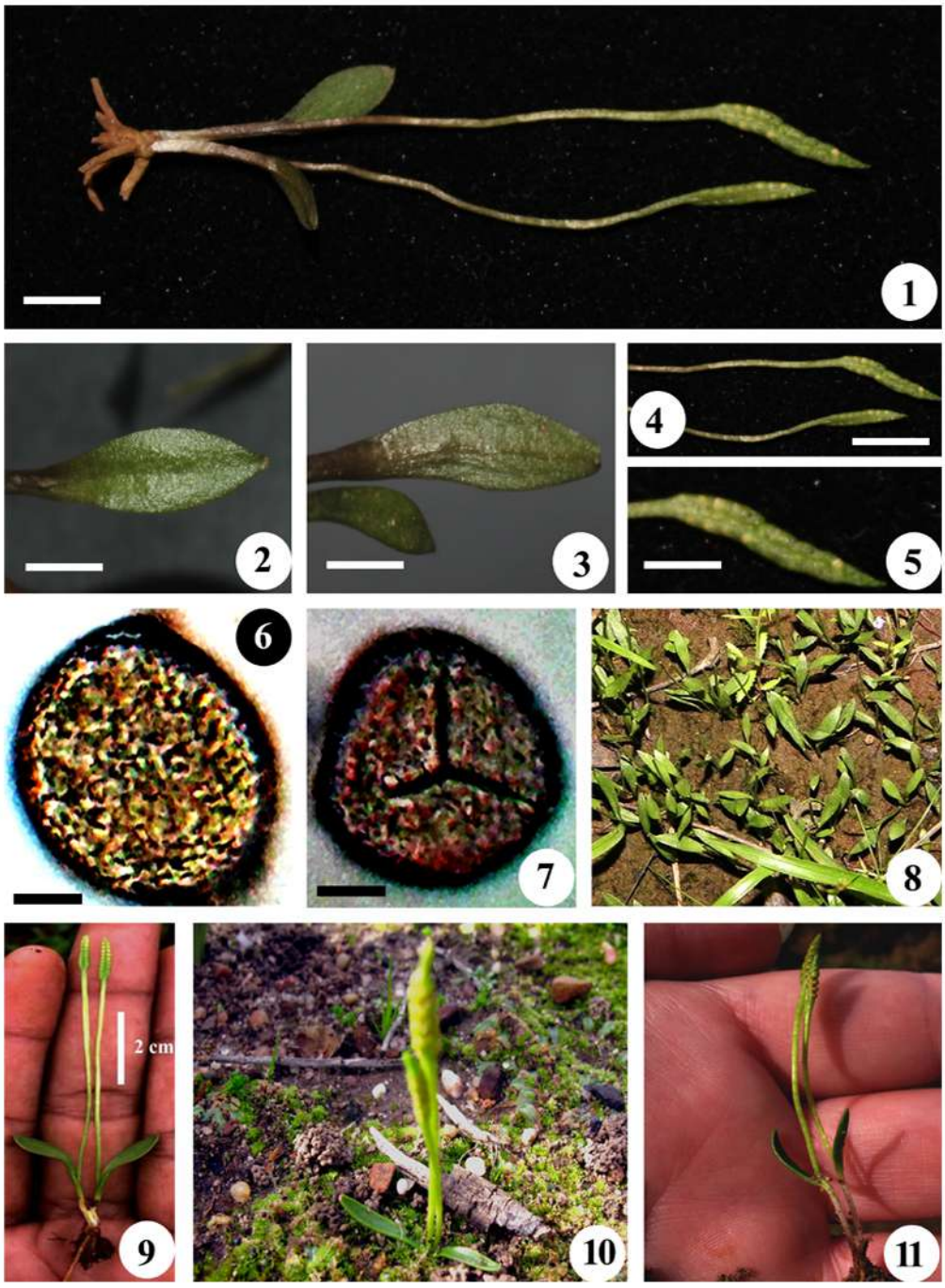

Figure 2 : *Ophioglossum jaykrishnae* : 1. enlarged habit; **2-3.** trophophylls showing pseudo-costa, **4-5.** fertile stalk & strobilus, **6-7.** Spores; **8-9.** *O. lusoafricanum,* **10-11.** *O. lusitanicum*; **Scale Bar : 1-5** = 1 cm, **7-8** = 5 µm.

*** Photo courtesy for Figure 10 & 11 (True *O. lusitanicum*) is provided by Mr. C.R. Fraser Jenkins.**

arranged in two alternate rows; *spores* 20–35 µm dia., trilete, exine tuberculate-varicose.

Distribution : Gujarat, India

Ecological note : Seasonal plant growing in open grass land or on the floor of deciduous forest at an altitude 200-300 m asl., associated with *O. costatum* and *O. gramineum.*

Conservation status : *Ophioglossum jaykrishnae* is collected from Semi-arid region of India. A population of about 100–200 individuals was found at each locality. The area of occupancy (AOO) is 50–60 km^2. However, other similar wildlife areas of the country are yet to be explored wholly and it presumes that the species might be spread in similar ecological conditions. Thus, more floristic surveys are required to determine and document the full range of distribution of *O. jaykrishnae.* Therefore, according to IUCN criteria, at present this species is considered as data deficient (DD).

Specimen examined : INDIA, Gujarat, Panchmahal dt., Jambughoda Wildlife Sanctuary, Dhanpuri, 200 m, 12/07/2019, SMP & KSR (1082) BARO; INDIA, Gujarat, Panchmahal dt., Jambughoda Wildlife Sanctuary, Lafni, 200 m, 12/07/2019, SMP & KSR (1083) BARO.

DISCUSSION

The true *O. lusitanicum* is very small, having linear trophophylls and misreported from India (Fraser-Jenkinset al., 2018). In India different populations are considered as *O. lusitanicum.* The population from Deccan Peninsula and Western Ghats is considered as *O. lusoafricanum* (Farase-Jenkins, *et al.*, 2020). Recently, Patil and Rajput (2020) studied the *Ophioglossum* from Goa state and reported six species, including the *Ophioglossum*

TABLE 1 : Comparative morphology of closely related species

Attributes/Species	*O. jaykrishnae*	*O. indicum*	*O. lusoafricanum*
Rhizomorph	Tuberous	Subglobose-tuberose	Subglobose-tuberous
Common stalk	Subterranean-terranean	Subterranean	Subterranean-terranean
Trophophylls	erect, form 30^0–60^0 angle with fertile stalk	erect, forming 10^0–30^0 angle with fertile stalk	erect, form 60^0–90^0 angle to the fertile stalk
Lamina	Lanceolate, brown-pink	Ovate-lanceolate, Pink-red	Elliptic-lanceolate, green
Apex	Acute-apiculate	Acute-apiculate	apiculate
Base	Cuneate	Truncate-cuneate	cuneate to attenuate
Pseudo-costa	Present	Absent	Absent
texture	Coriaceous	Herbaceous	Herbaceous
Venation	Parallel	Reticulate	Reticulate
Spores	20–35 µm dia., Trilete, tuberculate-varicose	16–28 µm dia., trilete, reticulate-varicose	42–61(–75) µm, alete or trilete, reticulate-varicose

lusitanicum (shown there as Fig. 4). However, recent discussion with Mr. Fraser-Jenkins, Prof. Khullar and Dr. B. S. Kholia, it was accepted that true *O. lusitanicum* is not present in India. The reported populations are either *O. luesoafricanum* or *O. gomezianum* or *O. jaykrishnae*. Therefore, authors here rectify that the *O. lusitanicum* reported from Goa state is mixture of two different populations i.e. *O. leusoafricanum* (shown there as Fig. 4 a-e, g, i & j) and *O. jaykrishnae* (shown there as Fig. 4 f & h). Furthermore, in semi-arid region two populations of Indian *O. lusitanicum* were observed, of which one is *O. lusoafricanum* having subglobose-tuberous rhizomorph, common stalk subterranean-terranean, trophophylls green, elliptic-lanceolate, herbaceous, apiculate apex, cuneate to attenuate base, pseudo-costa absent, veins reticulate, spores 48–61 µm in diameter, alete or trilete, reticulate-varicose exine whereas another population is dark brown-pink colour, rhizomorph tuberous, common stalk subterranean-terranean, dark brown-pink, lanceolate trophophylls with pseudo-costa, veins parallel with few areoles, spores 20–35 µm in diameter, trilete, tuberous-verrucose which hitherto as undescribed species (Fig. 1). The newly described species is compared with *O. indicum* which is having tuberous-subglobose rhizomorph, trophophylls pink coloured, ovate-lanceolate, herbaceous, acute-apiculate, cuneate-attenuate base, simple reticulate venation,spores 16–30 µm diameterwith reticulate-varicose exine (Table 1). After comparing the morphological characters, it is concluded that the population observed in Jambughoda Wildlife Sanctuary shares the features of hitherto undescribed and reported as new species *viz*., *Ophioglossum jaykrishnae*.

CONCLUSION

Biogeographically, Gujarat is considered as one of most varied state due to its unique position in Indian peninsula, as it falls under 3 major ecoclimatic zones i.e. arid, semi-arid and moist deciduous forest. This leads to Gujarat as a hotspot for the genus *Ophioglossum*, because amongst 24 species reported from India, 16 species (including 5 endemic species) are alone nestled in the state at a very small ecoregions in Vadodara and Panchmahal district.

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IMPACT FACTOR
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WEED DIVERSITY AND THEIR SEASONAL FLUCTUATIONS IN GANDHINAGAR DISTRICT, GUJARAT, INDIA

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ABSTRACT:

To find the diversity of weeds of Gandhinagar district the study was carried out for period of 2 years from March '2011 to February '2013. The present study was carried out on 20 selected sites of four talukas of Gandhinagar district. Weed collection was made with repeated field trips encompassing all the different seasons. During the field work and collection, special attention was given to record the characters of weeds. Weeds have been investigated by collection and identification. During summer season total 44 species, during monsoon season total 67 species and during winter season total 73 species were recorded in present study. Total 184 weed species were recorded.

KEYWORDS: *Weed diversity, Gandhinagar, Gujarat, India.*

INTRODUCTION:

"Weed" is applied to many plants that grow and reproduce aggressively and invasively. In general therefore, a weed is a plant that is considered by the user of the term to be a nuisance. They are usually the native plants which are best adapted to the environment where they grow, so can easily out-compete with our crop plants. It traditionally has been defined as "A herbaceous plant not valued for use or beauty, growing wild." According to Brenchely (1920) weed is a plant that

grows so luxuriantly that it chocks out of all other plants that possess more valuable nutritive properties. According to Gohil (2010) "A weed is a plant out of place".

MATERIALS AND METHODS:

The present study was undertaken during year 2011 to 2013. Extensive collection was made with repeated field trips encompassing all the different seasons. During the field work and collection, special attention was given to record the characters of weeds. Identification of the weed species was done by 'Flora of Gujarat State' (Shah, 1978). Quantitative analysis of weeds was done by types of weeds and season wise distribution of weeds.

RESULTS AND DISCUSSION:

The present study was carried out for period of 2 years from March '2011 to February '2013. Total 184 weed species were recorded in present study. This study was carried out most of the farmlands covered with weeds. Many of the 184 weed species identified occurred in all the three seasons and no single season contained all the 184 weed species.

Profile of types of weed species across season

Acrachne racemosa (Heyne ex R. & S.) Ohwi, *Aristida funiculata* Trin. & Rupr. Sp. Gram., *Avena sterilis* L., *Brachiaria setigera (Retz.) Hubb, Cenchrus pennisetiformis Hochst. & Steud., Chloris montana Roxb. Hort. Beng., Chloris virgata Sw. Fl. Ind. Occ., Cynodon dactylon (L.) Pers. Syn., Dactyloctenium aegyptium (L.) P. Beauv., Dichanthium annulatum (Forsk.) Stapf., Digitaria adscendens (H.B. & K.) Henrard, Digitaria ciliaris Prain, Dinebra retroflexa (Vahi) Panz., Echinochloa colonum (L.) Link. Hort. Chenopodium album L. Chenopodium murale L. Amaranthus spinosus* L. *Amaranthus viridis* L. were recorded dominant during winter season. Poaceae is the largest family among the monocotyledon recorded during winter season and Amaranthaceae, Asteracae, convolvulaceae and chenopodiaceae are main families of dicotyledon recorded during the same season. Poaceae family represented the highest number of species. In dicotyledone, Aateraceae family represented the highest number of genera and species. *Commelina benghalensis L., Commelina diffusa Burm. F. Fl. Ind., Cyperus compressus L., Cyperus esculentus L., Cyperus rotundus L., Tephrosia villosa* (L.) Pers. were recorded dominant during monsoon. Commelinaceae, Cyperaceae, Papilionaceae and Cesalpiniaceae family recorded during monsoon season. *Argemon maxicana* L., *Blepharis repens (Vahl) Roth, Cadaba fruticosa (L.) Druce, Capparis deciduas (Forsk.) Edgew., Mollugo nudicaulis* Lam. Encycl were recorded during summer season. Amaranthaceae, Asteracae, Papilionaceae and Poaceae family observed dominant in Gandhinagar district due to their high number of recorded species. Udoh *et al*. (2007) recorded total of 33 dominant weed species were identified of Poaceae, Asteraceae, Euphorbiaceae,

Febaceae, Cyperaceae, Commelinaceae, Nyctaginaeae and Sterculiacecae families. Gohil (2010) recorded total 203 weed angiosperm plant species in Valsad district, South Gujarat in his study. Jangid and Sharma (2011) recorded 204 weed species in Modasa taluka of Sabarkantha district. The present study shows that maximum numbers of weed species (73 species) were found in winter season. In monsoon it was recorded quite high (67 species) (Table – 01). In present study the % population was found highest (39.67 %) in winter because of the highest number of weed species was found in this season. In monsoon it was recorded quite high (36.41%). During summer season the % population of weeds was recorded quite low because the total no. of weed sp. was also recorded quite low (44 species). It was 23.91 % of weeds in summer season (Table – 01).

In Gandhinagar district, winter weeds are most dominant represented growth with 39.67% species. In summer the percentage of weeds were recorded 23.91%, in monsoon the percentage of weeds were recorded 36.41%. This is shown in Table – 01.

CONCLUSION:

Total 184 weed species were recorded in Gandhinagar district. Out of these 73 species (39.67%) were recorded during winter season. In summer the percentage of weeds were recorded 23.91%, in monsoon the percentage of weeds were recorded 36.41%. Different seasonal weeds show very little variation in their percentage representation over different season.

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