earthquake region about 0.3 Ma and was reactivated on 24 August 2021. The sediments deposited in the adjoining parts of the mound structure were thicker by more than 1 km compared to those lying over the mound. This led to a notable differential sediment loading and vertical stresses on fault planes lying on the mound structure and in the adjoining oceanic basement. Therefore, it is considered that differential loading of sediments on the mound structure may possibly have triggered this moderate earthquake in BoB.

The earthquake that struck in the western BoB on 24 August 2021 is an unusual one compared to the previous event that occurred on 21 May 2014 in the eastern BoB with reference to both depth of origin and mechanism. The 2014 earthquake nucleated at 50–60 km depth within the upper mantle, while the present one has occurred at a shallow depth of 10 km immediately below the basement. The processes that led to the triggering of both earthquakes seem to be different. The 2014 earthquake originated at a greater depth within the oceanic mantle, where brittle failure may not have been a possible mechanism for its occurrence. Therefore, several non-brittle failure mechanisms were proposed for the generation of the 2014 earthquake in the eastern BoB[3–5]. Interpretation of seismic section reveals that weak fault zones exist within the upper oceanic crust in the vicinity of the 2021 earthquake location that got reactivated at 0.3 Ma (Figure 2). Earlier, Krishna *et al.*[1] had analysed the behaviour of a 300 km-long palaeo-fault system that exists on the central eastern margin of India. They inferred that rift-related normal fault was reactivated during the Early Miocene (~16 Ma) and continued its activity until 0.3 Ma before cessation. The plausible mechanism suggested for this episodic activity is due to the vertical loading of the sedimentary column exerted on underlying weak zones within the crust. Thus, we conclude that the differential sediment loading on both sides of the structural mound may be responsible for developing a vertical stress field and triggering the brittle failure of pre-existing weak zone/fault planes within the oceanic crust. In our view, large parts of the western BoB are mostly free from tectonic influence, but are experiencing differential stresses caused by variable sediment loading. This note presents some initial observations, and the focal mechanism is not constrained yet. Therefore, we cannot completely rule out other possibilities for the occurrence of this 2021 intraplate earthquake in the western BoB.

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M. Ismaiel and **K. S. Krishna*,** Centre for Earth, Ocean and Atmospheric Sciences, University of Hyderabad, Prof. C.R. Rao Road, Gachibowli, Hyderabad 500 046, India.
*e-mail: krishna@uohyd.ac.in

Accomplishments in edible seaweed domain in India and the way forward

Seaweeds have been commonly utilized as a component of oriental diet, especially in Japan, China and Korea since ancient times owing to the presence of beneficial nutrients. Although there is little tradition of using seaweed in Western cuisine, at present there is renewed interest in India to use seaweeds as sea vegetables. They possess not only nutritional value, but also pharmaceutical properties like anticoagulant, anti-mutagenic, antioxidant, anti-cancerous and antibacterial activity. Thus, seaweeds have enormous commercial importance for human food, nutraceuticals and pharmaceuticals production. The commercial seaweeds market was estimated to account for USD 13.3 billion in 2018. It is projected to reach USD 21.11 billion by 2023, at a compound annual growth rate of 8.4% in terms of value, 85% of which will be comprised of food products for human consumption[1].

Further, Global Hunger Index (GHI) 2020 puts India much lower in ranking (94) than some of the neighbouring countries[2]. It may be noted that India has a more calorie-deficient or undernourished population. Besides, the prevalence of underweight children and associated mortality is alarming. Based on the available statistics, an overwhelming 31% of the country's population follows strict vegetarian diet. This provides a perfect opportunity for introducing seaweed-based diet into the Indian culinary sector, especially in popular programmes like the 'Midday Meal Scheme' to enhance nutritional quality. This note highlights the major accomplishments carried out in the edible seaweed sector during the last few decades, and the way forward.

Taxonomy and utilization

The earlier taxonomic works have enlisted 8 species of *Ulva* and 13 species of *Enteromorpha* along the Indian coast[3,4]. Two species of *Monostroma*, namely *M. latissimum* and *M. oxyspermum* were reported from the west coast of India[5]. Seven species of *Porphyra* were reported from the country[6]. The interest in the edible aspects of seaweeds has been generated primarily due to their medicinal properties rather than nutrition benefits. Two projects were sponsored by the Department of Ocean Development, Government of India, to study antibacterial (especially anti-tuberculosis) activities from *Enteromorpha* and iodine content of seaweeds from India – with special reference to Gujarat. The initial work by Parekh and his team at CSIR-Central Salt and Marine Chemicals Research Institute (CSMCRI) (1983–85) covered biochemical analysis of several components of seaweeds, especially amino acids, minerals, proteins, pigments and lipids. Mention should also be made of the critical work on proteins, amino acids and peptides from seaweeds by Lewis at CSIR-CSMCRI (1962–80). The overall work can be divided into two domains, viz. biological (mostly cultivation) and chemical constituents of edible seaweeds.

Cultivation

G. edulis was cultivated only with the sole aim of making food-grade agar. The species along the Gulf of Mannar (GoM) was exploited from 1960s for catering to domestic demand, and subsequently to export to foreign nations. The experimental and pilot-scale trials of its farming were successfully conducted mostly in Krusadai Island, Tamil Nadu. An yield of 3.5–4 kg fr wt m^{-1} length rope has been reported[7,8]. The technology upgradation happened later and floating bamboo raft method was developed. Crop yield of 35 tonne dry wt ha^{-1} yr^{-1} biomass in six harvests was reported[9].

Subbaramaiah[10] and Oza *et al.*[11] studied the method for production of swarmers in the laboratory and field cultivation of *Ulva*/*enteromorpha*. The problem with these techniques is that material used for spore induction needs to be mature, preferably collected during spring tide taking advantage of natural dark : light photoperiod for maturation of seed material. Mantri *et al.*[12] developed a technique for artificial induction of zoo-spores in *U. fasciata* by manipulating salinity and temperature. The optimum salinity and temperature requirement were found to be 15 psu and 25°C respectively. The optimum regeneration (78.53 ± 10.05%) was recorded at 25°C under 30 psu salinity. The maximum daily growth rate (16.1 ± 0.28%) was recorded at 25°C under 30 psu salinity. Since green seaweed is propagated only through reproductive bodies (with gametes or zoospores), artificial seeding is essential for the success of commercial cultivation.

Mairh *et al.*[13] developed a technology for cultivating *U. flexuosa* through spores using synthetic nets (Nori nets–size 18 m × 1.65 m) obtained from Japan. The cultivation has been carried out during October to March with December and January being the favourable period. Biomass of 681.2 fr wt or 82.76 g dry wt m^{-2} within two harvests of six weeks was reported. The estimated yield of 1.9 tonnes (dry) ha yr^{-1} was reported. Biomass of 829.9 g dry wt m^{-2} in 11 weeks of the growth period in *U. fasciata* was cultivated using the same technique[14].

The feasibility of year-round culture of *Enteromorpha flexuosa* in outdoor tanks (capacity of 7 l and 7.07 m^2 surface area) was established[15]. Maximum growth was obtained when (i) nylon threads were seeded with 10 ml swarner suspension of 200 ppm, and turbidity (7 cm OD) diluted to 200 ml; (ii) plants were maintained floating near surface waters and up to depths of 10–15 cm; (iii) seawater enriched with $NaNO_3$ or NH_4NO_3 (7 mg $N.l^{-1}$) and $Na_2HPO_4 \cdot 2H_2O$ (1 mg P l^{-1}) and micronutrients, and (iv) temperature was maintained between 17°C and 32°C, and solar irradiance of 1100 $\mu m^{-2} S^{-1}$. Biomass of 996–1350 g (fr) wt or 132.8–95.5 g (dry) wt m^{-2} area; 283 to g (fr) wt or 35 to 26.7 g (dry) wt m^{-1} length of nylon thread and 4.42–5.15 g (fr) l^{-1} or 0.54–0.36 g (dry) l^{-1} of seawater.

Laboratory experiments were performed to optimize the conditions for scaled-up culture of *Monostroma* sp.[5]. The effects of salinity (15–45 psu), photoperiod (8 : 16–16 : 8 L : D), light intensity (2–60 μmol photon m^{-2} s^{-1}) and temperature (15–35°C) were assessed. The maximum growth rate of 5.73–14.41% day^{-1} was recorded at 35 psu salinity, 25°C temperature, 14 : 10 (L : D) photoperiod, and 60 μmol photon m^{-2} s^{-1} irradiance. The effect of different culture media was also evaluated, namely PES (Provasoli's enriched seawater), MP1 and Strasberg's media. The MP1 medium was modified in two gradients as 1/2 and 1/4 strength. MP1 (full strength) medium showed higher growth rate (5.73 ± 1.07% day^{-1}) than Schreiber's (3.28 ± 0.36% day^{-1}) and PES (1.89 ± 0.16% day^{-1}) media. Further, 1/4 strength reported highest growth of 14.41 ± 0.47% day^{-1}. The initial experiments of scaled-up operations at 50 l outdoor tank recorded 14.38 ± 0.32% day^{-1} using 1/4 MP1 as the culture medium.

C. lentellifera, a potential food alga was reported from the Indian coast after a gap of half a century, from the Gulf of Kutch (originally reported from Krusadai Island, GoM)[16]. The cultivation of this species reported doubling time of 15 days under outdoor tank culture at Tuticorin[17].

Protoplast isolation and culture for seedling/nursery development: The technique for protoplast isolation and culture in *Ulva*, *Monostroma*, *Enteromorpha* and *Porphyra* was perfected. The technique for improved enzyme preparation for rapid mass production of protoplasts in green algal genera of *Ulva*, *Enteromorpha* and *Monostroma* with a single commercial enzyme, e.g. cellulase through exclusion of macerozyme was developed. Recently, an innovative model has been developed by integrating a prototype with protoplast culture, seedling production and propagation for the continuous production of seedlings from green seaweeds. Biomass of 0.25 kg fr wt (>200-fold of initial biomass) in 44 days culture period over 0.33 m^2 surface area was produced through protoplast of *Ulva*[18].

Siddhantha *et al.*[19] extracted and analysed water-soluble polysaccharides from *Ulva lactuca*, *Ulva fasciata*, *Ulva reticulata* and *Ulva rigida*. A higher yield was reported in *U. fasciata* (6.5% in cold-water extract and 16.5% in hot-water extract). They found more hexose sugar in cold-water extracts, and rhamnose, xylose and glucose in hot-water extracts. The average molecular weight of these polymers was in the range 1.14 to 2.0×10^6 Da.

The antioxidant activity of *U. compressa*, *U. linza* and *U. tubulosa* has been assessed[20]. The maximum total phenol content was observed in the extracts of acetone (11.63 ± 0.39%), methanol (3.45 ± 0.18%) and acetone (6.30 ± 0.06%) for *U. compressa*, *U. linza* and *U. tubulosa* respectively. The methanolic extract of *U. compressa* showed excellent DPPH radical scavenging (IC_{50} 1.89 mg/ml) property. The acetone extract of *U. tubulosa* showed greater reducing power compared to the extract of *U. compressa* and *U. linza* at 0.1 mg/ml. Methanol and propanol extracts of *U. compressa* showed good ferrous ion chelation activity. The extracts of these three seaweeds exhibited high antioxidant activity in linoleic acid system and ascertained their utility in pharmaceutical applications.

The method was developed to integrate the extraction of crude proteins for the recovery of minerals rich sap, lipids, ulvan and cellulose from fresh biomass of *Ulva lactuca* in sequential manner. The protein content extracted was 11 ± 2.12% on dry wt basis with recovery efficiency of 68.75 ± 4.01%. The amino acid composition of crude protein fraction showed isoleucine as the most abundant amino acid (16.51 ± 0.03%), followed by histidine, arginine, tyrosine, serine, aspartic acid, threonine, phenyl alanine, leucine, alanine, lysine, glycine and glutamic acid (0.22 ± 0.24%). The digestibility of the protein was as high as 85.86 ± 5.92%, indicating its suitability for use in food supplements[21].

The lipid and fatty acid (FA) composition for 100 marine macroalgae was determined and discussed in the context of chemotaxonomic and nutritional perspectives. In general, the lipid content in seaweeds was low (2.3–20 mg/g fr wt), but with substantially high amounts of nutritionally important polyunsaturated fatty acids (PUFAs) such as linolenic acid, a-linolenic acid, stearidonic acid, arachidonic acid, eicosapentaenoic acid and docosahexaenoic acid, it ranged from 10% to 70% of total fatty acids. More than 90% of the species showed nutritionally beneficial n6/n3 ratio (0.1 : 1–3.6 : 1)[22].

Eighteen abundant tropical seaweeds were chosen to estimate their phenolic, flavonoid and amino acid composition[23]. LC-MS analysis revealed the presence of polyphenols and flavonoids, including ascorbic acid, gallic acid, catechins, myricetin, proanthocyanin, kaempferol, quercetin, apigenin and lutein. The highest amount of ascorbic acid (26.3 mg g^{-1} dry weight (DW)) was detected in *U. fasciata*, followed by *U. lactuca* (20 mg g^{-1} DW) and *Grateloupia indica* (11.5 mg g^{-1} DW). Gallic acid was reported in all green and red species, with the highest (9 mg g^{-1} DW) in *Amphiroa anceps*, followed by *Caulerpa racemosa* var. *macrophysa* (8.5 mg g^{-1} DW) and *C. corynephora* (4 mg g^{-1} DW). The highest catechin content was found in *A. anceps* (14 mg g^{-1} DW), followed by *C. racemosa* var. *macrophysa* and *Spatoglossum asperum* (11 mg g^{-1} DW). The highest amounts of leucine (0.2 mg g^{-1} protein), lysine (0.5 mg g^{-1} protein), methionine (0.4 mg g^{-1} protein), phenylalanine (0.2 mg g^{-1} protein), valine (1.3 mg g^{-1} protein), proline (48 mg g^{-1} protein) and tyrosine (28 mg g^{-1} protein) were detected in *Caulerpa* spp. High contents of sulphur-rich methionine (1 mg g^{-1} protein) and cysteine (9 mg g^{-1} protein) were found in *Gracilaria corticata*.

Way forward

The food-processing domain in India is currently growing at 8.41% per annum, and is expected to reach USD 544 billion by 2020–21. The market is driven by innovative ideas and thus there is ample scope of incorporating seaweeds as flavouring or garnishing agents in over 1000 types of available snack foods. Further, under the ‘Pradhan Mantri Matsya Sampada Yojana’ commercial opportunities in this arena are high[24].

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Vaibhav A. Mantri, Division of Applied Phycology and Biotechnology, CSIR-Central Salt and Marine Chemicals Research Institute, Bhavnagar 364 002, India, and Academy of Scientific and Innovative Research, Ghaziabad 201 002, India.
e-mail: vaibhav@csmcri.res.in

MEETING REPORT

Water security in the Himalaya through spring-ecosystem assessment and management*

Natural springs are the main source of freshwater for millions of people across the Himalaya. About 60% of the local habitants of the Indian Himalayan Region (IHR) depend on the springs to meet their daily water requirements. According to a rough estimate, there are three million springs in the IHR alone and approximately 50% of them have dried up or become seasonal[1]. Drying up of springs or declining water discharges as well as quality degradation of spring water have manifold repercussion in the IHR; drying up of spring-fed rivers, water insecurity in mountain habitats, decrease in agricultural practices, travelling long distances to fetch water (especially by women), shifting of natural water supply scheme to borewell or pumped water supply system and disturbance in spring water-dependent flora and fauna are some of them. This not only leads to migration of people, but also disturbs the hill economy in a negative manner along with change in ecology in the spring ecosystem. It also sabotages the social, cultural and religious relevance in the IHR[2]. While addressing the pan-Himalayan solution to these problems, it has been noted that neither the interaction of dependent ecosystem services of springs is documented or studied, nor has there been a systematic effort or methodology for comprehensive spring ecosystem health assessment. Therefore, realizing the wide-ranging socio-ecological values of springs and threats for their well-being, an effort is being made to understand the spring

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