Geotechnical properties of siliceous sediments from the Central Indian Basin

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Indian Deep-sea Environment Experiment (INDEX) was carried out in a pre-selected area with low nodule abundance and uniform sediment type, for the purpose of environmental impact assessment of future deep-sea mining activities. Geotechnical testing of sediments was part of this multidisciplinary programme and was carried out on siliceous sediments from the Central Indian Basin. Sediments showed change in undrained shear strength and natural water content due to a simulated disturbance experiment conducted in the area. An increase in water content and significant decrease in the shear strength was observed in sediment layer of 0–5 cm from the disturbance area, but no significant changes were noted outside the area of disturbance. High values of porosity and water content were due to presence of 10–20% radiolarian tests and water-absorbing montmorillonite. The prominent loss of undrained shear strength of the sediments exposed to physical disturbance would affect the bearing capacity of the sediment and thus restrict the movement of the nodule collector. Other index properties such as wet bulk density, porosity and specific gravity inside and outside the disturbed zone remained unchanged, mainly due to similar grain size and dominant clay mineralogy.

POLYMETALLIC nodules from the world oceans have received considerable attention as potential mineral resource[1] as they contain valuable metals like copper, nickel and cobalt, in addition to manganese and iron. Though large reserves of nodules and metals have been proved to be present in the world oceans, their economic recovery remains a challenge, as no suitable mining techniques are available. At present the National Institute of Oceanography, Goa has been carrying out the survey and exploration work for nodules in the Indian Ocean since 1982, which culminated in the identification of potential nodule resources that have been reported earlier[2,3].

In spite of the strategic nature of cobalt and nickel, commercial mining of these voluminous nodule deposits is possible only through suitable nodule collector. Although no mining system is developed yet, efforts have been made by various groups to make a successful venture[4]. In this respect the sediment characteristics are important for development and operation of the mining system which can work at water depth of 5–6 km.

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The engineering properties of sediments associated with nodules are essential, to get an idea about the sediment–miner interaction on the seafloor[5]. Geotechnical properties of sediment provide an insight into their behaviour when the natural state of deposition is changed due to man-made or artificial conditions. Acoustic and gamma-ray attenuation methods permit their continuous recordings with core depth. Such studies invariably require large investment for good-quality data, sediment collection and ship time with extensive geotechnical instrumentation. Although, it is easy to collect *in situ* data from shallow-water sediments, their collection on undisturbed deep-sea sediments is difficult. Geotechnical properties also influence the distribution and abundance of benthic organisms and vertical distribution of meibenthos[6–8]. These properties are closely correlated[9], since their penetration depends upon physico-mechanical condition of the sediment. The sediment type, shear strength and the burrowing capacity of benthic organisms are mutually inter-related.

Nodule mining activity will create new environmental conditions on the seafloor, as nodules are found to occur along sediment–water interface. The sediment plume caused by deep-sea mining would increase turbidity of the water column. It is reported[10] that for every ton of nodules collected, about 2.5–5.5 tons of sediment would be resuspended. This would also create unsuitable conditions for benthic communities due to increase in sediment load in near-bottom waters, either by clogging of their filter feeding apparatus or burying them.

In order to study possible environmental impact due to nodule mining, a benthic disturbance experiment was carried out in a small area in water depth of 5200–5400 m in the Central Indian Basin (CIB). The disturbance was simulated using benthic disturber, viz. Deep-Sea Sediment Resuspension System (DSSRS) that fluidizes, lifts and discharges the sediment slurry 5 m above the seafloor. The same disturber has been used in other experiments, namely BIE[11], JET[12] and IOM-BIE[13] in the Pacific Ocean. In similar experiments by other research groups, the effect on geotechnical properties was not reported. This paper reports geotechnical properties of sediments and effect of the simulated disturbance on them. The study is part of the ongoing Environmental Impact Assessment programme for nodule mining in the CIB.

The Indian claimed area in the Indian Ocean is composed of siliceous ooze/clay with 10–20% biogenic component, mostly radiolarian tests[14]. It is marked by very slow sedimentation rates[15] of 2–2.5 mm ky^{-1} and water depth of about 5400 m. Bathymetric profiles showed that the area has a flat topography with four distinct sediment layers ranging in thickness from 40 to 90 m, and nodule abundance[16] of 2 kg m^{-2}. An area of 10 × 10 nautical miles with plain topography was chosen at 10°S latitude and 76°E longitude[17], for baseline data collection. A NW-SE trending strip of 3000 m length and

200 m width was selected for carrying out simulated disturbance studies in this area.

Okean box corer (50 cm × 50 cm × 50 cm) was used to collect sediment cores from different locations in the study area. Twelve cores of 30–40 cm length were collected before and after the disturbance experiment. In each box core, two acrylic tubes of 4 cm diameter and 50 cm length were inserted slowly, so that minimum disturbance was caused to the sediments. One tube was used for the shear strength determination on-board and the other for index properties in the laboratory.

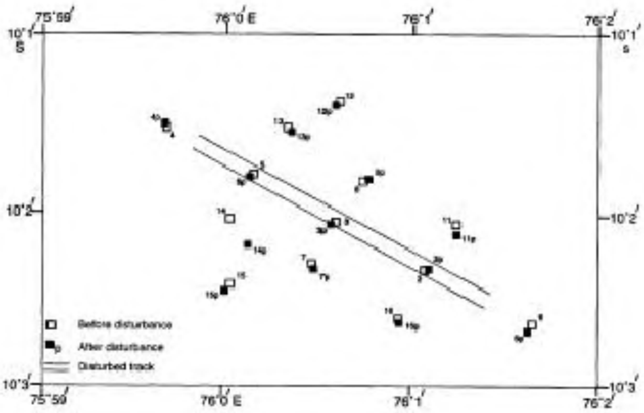

Figure 1. Core locations used for sediment collection from the study area.

The undrained shear strength of sediment was measured immediately using laboratory vane shear apparatus (AIMIL, India) with rotation rate of 90° min^{-1}. A vane of 2.54 cm height and 1.2 cm diameter was used for all measurements. The measurements were made at 4–5 depths within each core. The subsamples were preserved in polythene bags at 4°C, to avoid water loss. The samples for index properties were collected at 2-cm interval for the first 10 cm and at 5 cm interval thereafter. The water content was measured using weight loss after drying the sample for 24 h at 105°C. Water content was corrected for salinity[18] (0.035) and expressed in per cent on dry basis. Specific gravity was determined using specific gravity bottles[19]. Porosity, void ratio and wet bulk density were estimated[20] assuming complete saturation of sediments.

Cores from different locations do not indicate lithological change as the area is very small and homogenous. All cores, in general, have dark brown (5YR3/4) homogeneously distributed sediments in the upper 10 cm, followed by light yellowish-brown (10YR5/4) clays with grey, green and dark brown mottling, intercalation and features of bioturbation. The maximum length of the cores studied is 40 cm.

The values reported are from on-board analysis and do not necessarily represent *in situ* conditions, as they may undergo some alterations due to changes in pressure and temperature. Nevertheless, data give good idea about

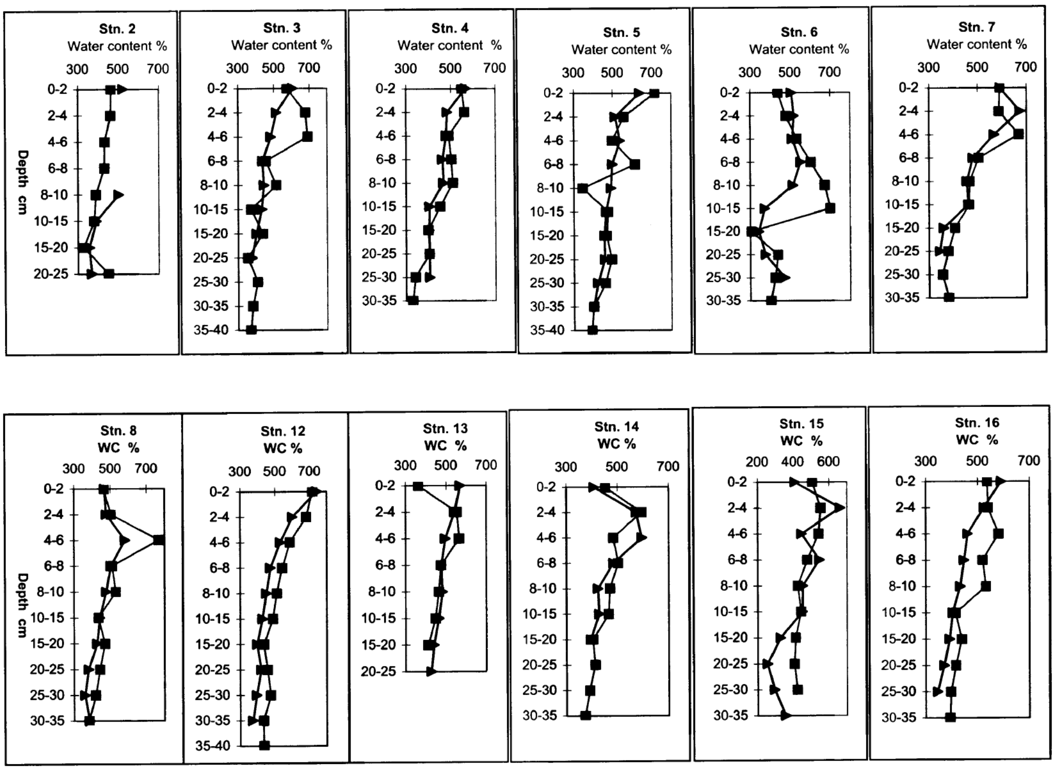

Figure 2. Profiles of water content of sediments before (▶) and after (●) the disturbance experiment.

sediment behaviour. The effects of simulated disturbance experiment on various oceanographic parameters have been reported earlier[17,21]. Deep tow photography showed that the disturbance is confined to the seabed and resedimentation due to plume migration is restricted to the adjacent area of the tow zone[21].

Box core locations sampled in the area before and after the disturbance experiment are shown in Figure 1. Downcore profiles of natural water content are shown in Figure 2 and those of undrained shear strength in Figure 3, before and after use of the disturber. Since the disturber could resuspend the top 10–15 cm of the sediment, its effect could be observed in the surface sediment only. Table 1 gives the range and average of index properties such as wet bulk density, specific gravity, void ratio and porosity. Since porosity value includes biogenic components, it is an apparent porosity. The changes in water content and shear strength in cores lying within the area of disturbance, i.e. the towing zone of the disturber, are shown in Table 2. Table 3 gives the property changes in cores lying outside the towing zone of the disturber. Figure 4 shows correlation coefficients for two properties before and after the disturbance. Detailed results of different parameters are given in the following paragraphs.

Index properties, which are useful for the sediment classification prior to tests for compressibility and other engineering characteristics, include liquid and plastic limits, grain size distribution, specific gravity, porosity and wet density. These properties can be recorded continuously on long cores to relate them to geological processes, as done in the Ocean Drilling Programme using gamma-ray attenuation technique[22]. Overall specific gravity, porosity and wet density of the sediments from the CIB measured before and after the experiment showed no significant changes in their values (Table 1). For example, average specific gravity changes from 2.31 to 2.38, average porosity from 91.1% to 91.7%, whereas

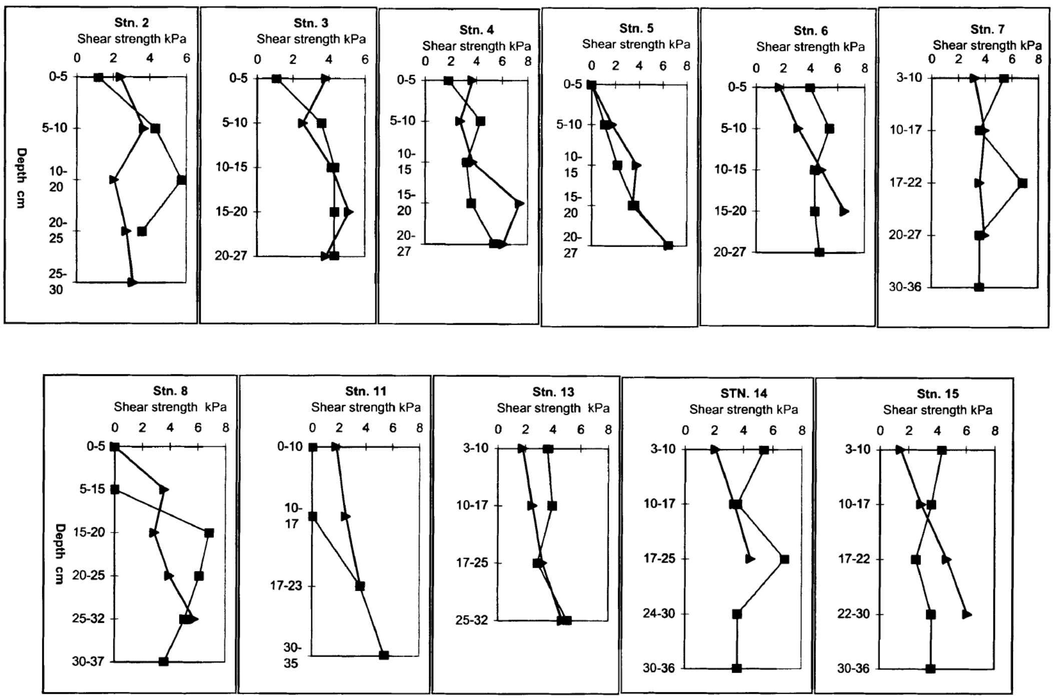

Figure 3. Profiles of shear strength of sediments before (▶) and after (●) the disturbance experiment.

Table 1. Summary of index properties observed before and after the disturbance experiment

	Pre-disturbance				Post-disturbance			
	Maximum	Minimum	Average	SD	Maximum	Minimum	Average	SD
Specific gravity	2.46	1.91	2.30	0.07	2.59	2.15	2.38	0.08
Porosity (%)	94.4	84.8	91.1	1.5	95.0	87.9	91.7	1.40
Wet bulk density (g cm^{-3})	1.21	1.10	1.15	0.02	1.20	1.10	1.15	0.02
Void ratio	16.9	5.6	10.6	2.0	18.9	7.3	11.3	2.24

SD, standard deviation; No. of observations = 103.

average wet bulk density remains unchanged at 1.15 g cm^{-3} after the disturbance. These are due to soil properties like grain size, clay mineralogy and voids present. High porosity is attributed to radiolarian tests present in the siliceous sediments of this area. It could also be due to bioturbation observed in all the cores, which increases the porosity and makes the sediments highly compressible with deposition. Void ratio, a ratio of volume of voids to volume of solids, increased from 10.6 to 11.3 due to loosening of particles after disturbance. Significant relationship of water content with porosity ($r = 0.940$) and wet bulk density ($r = -0.954$), and that of porosity with wet bulk density ($r = -0.902$) was encountered. Similar relationships among the index properties of deep-sea sediments have been reported elsewhere[23]. Measurements of liquid and plastic limits during baseline data collection showed sediments of medium to high plasticity. The plasticity index (difference between liquid and plastic limits) varied between 103 and 127% for the sediments in this area[24]. Water content is well in excess of Atterberg limits, indicating sediments possess low shear strength. The index properties in the pre-disturbance condition are comparable to those reported for nodule mining areas in the Central Pacific Ocean[25].

Sediment characteristics are governed by grain size distribution, density of packing, grain fabric and presence of water and air in the voids[26]. The sediments are silty-clays composed of clay minerals, viz. illite, smectite, chlorite and kaolinite in decreasing order of abundance[27], and have medium to high plasticity[24]. The water-absorbing capacity of smectite is the highest due to its higher specific area (800 m^2 g^{-1}) compared to 80 m^2 g^{-1} of illite and 15 m^2 g^{-1} of kaolinite[26]. Within the towing zone of the disturber, maximum sediment load in a fluidized state was absorbed through the pump and discharged in the water at a height of 5 m above the seafloor. Due to its fine-grained nature, sediment redeposition would have taken place slowly. In order to know the intensity of the effect, stations within and outside the tow zone were dealt with separately. Although the effect of benthic disturbance on physical parameters was not noteworthy, changes in natural moisture content and undrained shear strength were prominent, as described in the following section.

Small variations are observed in shear strength and water content of sediments. If stations inside the tow zone are considered (Table 2), there is a marginal increase in average water content in 0–5 cm layer from 544 to 563%. On the contrary, in layers 5–10 cm and 10–20 cm, average water content shows marginal reduction after the disturbance. There is significant reduction in shear strength in 0–5 cm layer from 2.08 to 0.75 kPa. Whereas shear strength of the 5–10 cm layer in stations 2 and 3 is slightly higher in post-disturbance (Figure 3), indicating no effect of the disturbance below this depth. Increase in

Table 2. Water content and shear strength changes observed in the towing zone of the disturber (stations 2, 3, 5)

	Pre-disturbance				Post-disturbance			
Depth (cm)	0–5	5–10	10–20	> 20	0–5	5–10	10–20	> 20
Water content (%)								
Maximum	638	501	465	458	715	614	476	493
Minimum	482	436	356	367	432	345	328	353
Average	544	474	417	405	563	457	410	412
Shear strength (kPa)								
Maximum	3.84	3.68	5.12	6.52	1.18	4.31	5.74	6.46
Minimum	0.00	1.72	2.06	2.74	0.00	1.08	2.15	3.59
Average	2.08	2.65	3.71	4.05	0.75	2.99	4.02	4.79

Table 3. Water content and shear strength changes observed outside the towing zone of disturber (stations 4, 6–8, 12–16)

	Pre-disturbance				Post-disturbance			
Depth (cm)	0–5	5–10	10–20	> 20	0–5	5–10	10–20	> 20
Water content (%)								
Maximum	741	551	464	471	769	673	701	475
Minimum	408	423	328	255	363	425	302	340
Average	541	476	407	374	552	511	446	415
Shear strength (kPa)								
Maximum	3.68	3.95	7.36	6.10	5.39	5.39	6.82	6.10
Minimum	0.00	2.72	2.51	3.23	0.00	0.00	3.23	2.87
Average	1.80	3.36	4.07	4.66	2.38	3.30	4.07	4.40

water content is marginal (3.5% of the total), but decrease in shear strength is prominent (64%) at the surface.

The drastic change in strength cannot be ignored for the purpose of mining activity using crawler, as it controls the bearing capacity and settlement behaviour of the sediments. The high water content values are due to water-absorbing clays, smectite, high porosity (91%) and dominant clay-sized grains deposited very slowly on the seafloor. The shear strength of 0–3.84 kPa in the 0–5 cm layer shows that despite high water content, the grain fabric and density are such that sediments show some resistance to failure when dynamic load is applied through vane blades. This, in fact, could be a favourable condition for the movement of the nodule miner on the seafloor. But the loss of shear strength would play a major role during the movement of the miner on the seafloor, implying that the nodule collector cannot traverse on a track that has been mined earlier, due to the possibility of its sinking in the sediments.

If the stations from outside the tow zone are considered (Table 3, Figure 3), then average water content in all layers shows an increase, whereas shear strength remains either the same or shows little increase after disturbance experiment. This is the area where sediments resuspended during the experiment could get deposited adjacent to the tow zone. In the 0–5 cm layer, average water content goes up from 541 to 552% and average strength also goes up from 1.80 to 2.38 kPa. The 5–10 cm, 10–20 cm and > 20 cm layers show an increase in average water content, but no significant change in shear strength is observed in the disturbed sediments. The shift of 20 m in core positioning also could be responsible for higher strength, as the same location could not be exactly hit after the disturbance (Figure 1).

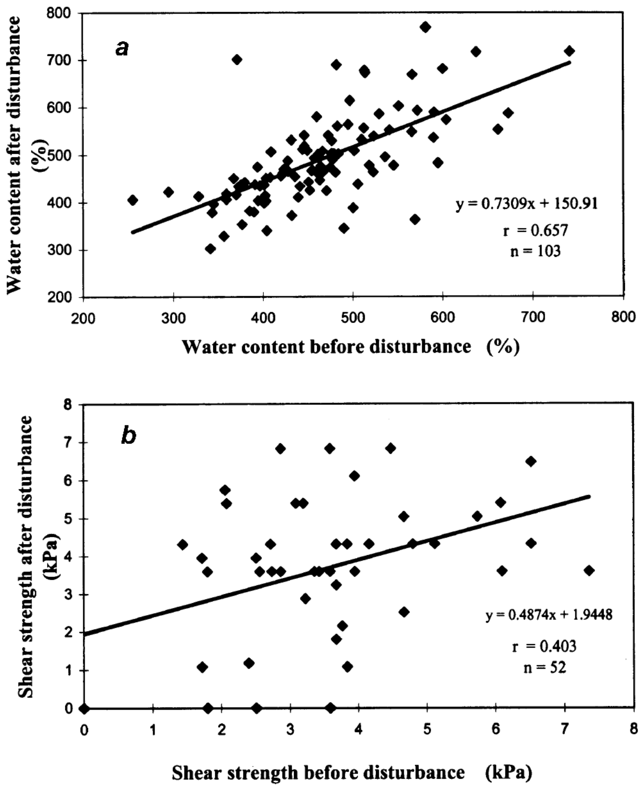

Figure 4. Relationship of water content (***a***) and shear strength (***b***) of sediments before and after the benthic disturbance.

To evaluate statistically the effect of disturbance on sediment properties, the correlation coefficients for data sets of water content and shear strength measured before and after the disturbance, were considered. In Figure 4, the cluster of data points for water content with significant positive correlation ($r = 0.657$) indicates that an increase in water content will be inevitable if sediments are subjected to artificial change. The increase in water content could be estimated by the following equation.

$$Y = 0.7309X + 151 \text{ (\% dry basis)},$$

where X and Y are water content before and after the disturbance, respectively. Although there is an increase in water content after the disturbance, the overall (average) values for the study area do not show very significant changes, except in the top layer that is disturbed and redeposited. In contrast, the shear strength data are widely scattered with a positive but non-significant correlation coefficient, $r = 0.403$. This implies that the change in shear strength is not uniform and predictable like the water content. Therefore based on the present data, this relationship is weak and has to be used cautiously.

Benthic disturbance experiment, although in a very small area, showed changes in sediment characteristics, especially in the area of disturbance. Natural water content showed an increase from 544 to 563% in surface sediments (0–5 cm). Below this it does not show much variation. Shear strength, the critical parameter as far the nodule miner is concerned, exhibits significant loss from 2.08 to 0.75 kPa in the surface 0–5 cm layer. The changes in sediment properties from stations outside the tow zone of the disturber are not prominent. The index properties, viz. wet bulk density, porosity and specific gravity do not show very significant changes due to disturbance. The shear strengths measured during this experiment are consistent and comparable to those reported for nodule mining areas of the Northeastern Pacific Ocean based on *in situ* measurements[28].

The aforesaid effects, though small, have to be considered, since the movement and settlement behaviour of the nodule miner would depend upon the undrained shear strength and bearing capacity of sediments associated with polymetallic nodules. Since such changes affect the distribution patterns of benthic communities, geotechnical properties are essential for environmental studies also. Although present data do reveal good information on sediment characteristics, *in situ* measurements in future would give more precise data and valuable insight into geotechnical behaviour, which is essential for the design of a suitable nodule mining system.

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Qualitative assessment of tissue culture parameters useful in transformation of indica rice

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***In vitro* response of several elite indica rice cultures was compared with that of the most responding japonica type, Taipei 309, for enumerating critical tissue culture parameters that subscribe to successful genetic transformation. Callus induced from mature seeds of indica rice genotypes was more compact and proliferated slowly. Formation of friable callus, rapid proliferation and sustenance of regeneration capacity for 9–10 weeks, are identified as the key features that favour success of transformation in a variety and recovery of transformant through subsequent selection and regeneration. Differences in regenerating and nonregenerating green regions were presented to differentiate them at the early stages.**

DEVELOPMENT of productive transgenic rice lines requires routine and efficient gene transfer method. The process of genetic transformation entails several steps, the most important being (i) DNA delivery method, (ii) efficient selection for transformants, (iii) regeneration of transformants. While an array of DNA delivery methods have been reported in rice transformation, key to recovery of transformants lies in post-transformation selection and regeneration. Sifting of transformants involves stringent selection for 2–3 cycles on selection medium and thus maintenance of regeneration capacity of transformed tissue assumes significance. Earlier reports on callus induction and regeneration indicate large differences in tissue culturability between japonica and indica varieties. The former were found to be more responsive[1,2]. Thus, many advances in tissue culture and genetic transformation methods were often demonstrated using japonicas and to a lesser extent with a few responsive indica varieties[3,4]. Study on the differences between the *in vitro* response of the two subspecies, japonica and indica, as well as the superiority of japonica types over indica types for parameters that have a direct bearing on transformation, is vital. The present study involves a comparative analysis of tissue culture response of several elite indica genotypes with a japonica genotype, Taipei 309. Critical tissue culture parameters that subscribe towards transformation and recovery of transgenics were identified as aid to genetic transformation of indica genotypes of choice.

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