Coping with hailstorm in vulnerable Deccan Plateau region of India: technological interventions for crop recovery

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Vulnerability of agriculture to climate change is becoming increasingly apparent in recent years. During 2014 and 2015, India experienced trails of unusually widespread and untimely hailstorm events. The increased frequency of hailstorm events, especially in vulnerable ecosystem of Deccan Plateau region of India demanded appropriate measures to minimize adverse impact on agricultural crops. Therefore some of the post-hail measures including nutritional supplement, plant bio-regulators and canopy management were evaluated in field trials conducted at Maharashtra, India during 2014 and 2015. Amongst these, pruning of the hardy and indeterminate eggplant crop induced effective branches, which produced more flowers and fruits. Nitrogen supplemented with urea drenching and stress alleviating effects of salicylic acid promoted recovery in maize while drenching with humic acid along with spraying of potassium nitrate improved productivity of onion. These studies indicate the potential of technological interventions to cope with extreme events such as hailstorms.

Keywords: Bio-regulators, canopy management, crop recovery, hail-damaged crops, nutritional supplements.

AGRICULTURAL production continues to be vulnerable to unexpected and extreme weather events, the incidence and intensity of which increase with climate change[1]. Amongst the extreme weather events, hailstorm damages crops severely[2] within a short interval[3]. However, the extent of damage varies depending on crop species and crop growth stage when hail occurs[4]. Though there is much uncertainty about the effects of anthropogenic climate change on the frequency and severity of extreme weather events like hailstorms, and subsequent economic losses, few studies indicate that a strong positive relation exists between hailstorm activity and subsequent hailstorm damage which is likely to be aggravated by global warming. By 2050, the estimated annual hailstorm damage to unprotected farming could increase from 25% to 50% (ref. 5). Though hailstorm can occur in any part of the world, temperate zones are most vulnerable. Among the countries, hail related losses are most prevalent in USA[6]. However, in recent years, India experienced trails of unusually widespread hailstorm events during February–May 2014 and 2015 in northern, central and southern India due to more convective activities following rise in temperature as the season progressed from winter to spring[7]. These caused large scale destruction of crops in Indian states – including Uttar Pradesh, Madhya Pradesh, Maharashtra, Punjab, Gujarat, Uttarakhand, Haryana, Andhra Pradesh and Karnataka with central India and Deccan plateau region (Maharashtra, Madhya Pradesh and Karnataka) being the worst hit with varying levels of damage. Usually, the extent of damage by hail is determined by the size and density of hailstones that fall per unit area and wind force during the hail fall event[8].

In fact forewarning and preparedness for hailstorm is constrained mainly by the speed with which it occurs. Once damage occurs, specific management strategies are necessary in formulating the relief strategies for recovery, thus minimizing the hailstorm impacts. In addition to the type of crop, stage of growth, weather conditions and susceptibility to disease also determine the impact. Prolonged hot and wet conditions after the storm enhance losses by increase in incidences of diseases, particularly those caused by bacteria[9]. Though little information is available on measures for hastening recovery in hail damaged plants, application of additional nitrogen encourages new growth[8,10]. In plants with heavy foliage such as corn and sweet potatoes, additional feeding with plant bio-regulators (PBRs) even under other abiotic stress conditions[12] may be beneficial[11]. Under any tissue wound or damage or upon consequences of abiotic stress, (especially after hail, crop roots and stem get exposed to chilling stress injury) the free-Oxy, i.e. single oxygen molecule radicals get generated in cell/tissue, cause cell organelle damage and subsequently cause cell death. The PBR technology enhances redox-mediated singling mechanism by protecting the cell with enhanced anti-oxidative enzymes to develop resistance/tolerance to abiotic stress/osmatic stress of the cell in order to overcome the wounding caused along with chill injury[13]. However, scientific reports are limited on the PBR technology used for hail damage crop recovery in on-farm trials immediately after hail storm damage. Therefore, a series of experiments were conducted to explore nutritional supplement (NS), PBRs and canopy management (CM) as post-hail damage interventions for minimizing losses to the farmers.

The experiments for recovery of hail damaged maize and brinjal crops were conducted at the research farm of ICAR-National Institute of Abiotic Stress Management, Baramati, Pune, India (18°09′07.54″N; 74°30′03.17″E) and adjoining farmers' field near the institute (18°09′19.42″N; 74°30′33.72″E) respectively, where the hail damage occurred on 9 March 2014. The experiment

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Table 1. Weather parameters recorded at NIASM observatory before, on and after the hailstorm event (Hailstorm event: 9 March 2014 at 1505 h)

	Dates of March 2014						
Weather parameters	06	07	08	**09**	10	11	12
Maximum temperature (°C)	29.0	30.0	31.5	30.5	30.5	29.5	32.5
Minimum temperature (°C)	15.0	14.0	**18.5**	16.0	**14.5**	17.0	20.0
Soil temperature (°C) at 5 cm, morning	18.5	18.0	20.0	20.5	20.0	20.0	22.0
Soil temperature (°C) at 10 cm, morning	21.0	20.5	22.0	22.5	22.0	21.5	23.5
Soil temperature (°C) at 5 cm, evening	30.5	31.0	**32.5**	30.5	**30.5**	31.0	29.0
Soil temperature (°C) at 10 cm, evening	27.5	28.5	**29.0**	29.5	**28.0**	28.0	28.0
Relative humidity (%), morning	95	90	82	95	90	91	91
Relative humidity (%), evening	45	38	54	51	56	42	46
Rainfall (mm)	0.0	0.0	0.0	1.0	56.2	8.8	0.0

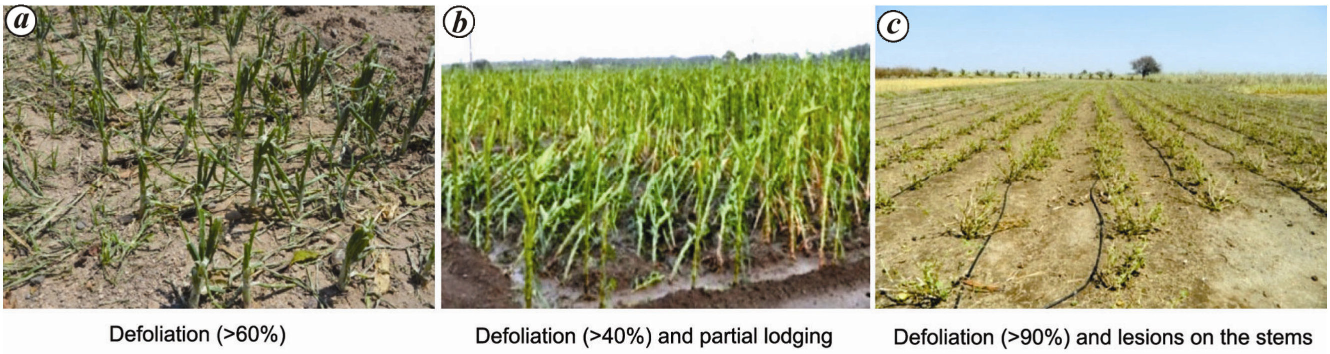

Figure 1. Severity of crop damaged due to hailstorm. ***a***, Onion; ***b***, maize; ***c***, brinjal.

for onion was conducted at Solashi village, Satara, Maharashtra, India (17°59′22.84″N and 74°01′55.16″E) where the hailstorm occurred on 2 April 2015. The pre- and post-hail weather parameters at the institute site are given in Table 1. The same could not be monitored at the farmer's field due to absence of a meteorological station nearby. Although there was no significant drop in maximum temperature after the hail event, the minimum temperature dropped by 4°C within two days (Table 1). The evening soil temperature at 5 and 10 cm depth dropped by 2°C and 1°C, respectively whereas there was no change in soil temperature recorded in the morning for the two different soil depths. There was severe damage to the crops selected for this experiment (Figure 1). Post-hail treatments imposed for recoveries were specific to each of the crops as described in the following section.

The onion crop was transplanted on 18 January 2015 with a spacing of 15 cm × 10 cm. A hailstorm occurred there at bulb initiation stage on 13 March 2015 (Figure 1 *a*). Before imposing treatments, excess water was drained out of the field. Subsequently, dead and drooped leaves were removed and this was followed by spray of fungicide (Carbendazim) @ 1 g per litre to avoid secondary infection. Bio-regulators, nutrients and their combinations were evaluated for accelerating recovery of damaged plants. These included, spray of thiourea (10 ppm), KNO_3 (1.5%), humic acid (2 ml/l) and KNO_3 (1.5%) + humic acid (2 ml/l) along with a control (sprayed water only) after two days of hail event. These treatments were repeated twice at an interval of 15 days. All other agronomic practices were followed as per recommendations of ICAR-Directorate of Onion and Garlic Research, Pune (India). Changes in plant height and Soil Plant Analysis Development (SPAD) chlorophyll values were recorded at a monthly interval. Yield and bulb size were recorded at harvest (3 May 2015).

The maize crop was planted on 13 December 2013 with a spacing of 15 cm × 70 cm. It was at the milking stage when hailstorm occurred on 9 March 2014 (Figure 1 *b*). Various bio-regulators and nutrient supplements were tested for its recovery. These included: urea spray (0.5%), urea drenching (30 kg N/ha), thiourea (10 mM), ortho silicic acid (320 ppm), vigore (extract from natural sources rich in Plant Growth Regulators (PGRs), vitamins and mineral (1000 ppm), KNO_3 (2%), salicylic acid (20 μM), etheral (100 ppm), in four replications. The control plot was sprayed only with water and subsequently yield data at maturity was recorded.

Two-month-old transplanted brinjal crop (90 cm × 120 cm spacing) was affected by hail on 9 March 2014 at the fruiting stage (Figure 1 *c*). Fruits had already been picked twice before the said event. Keeping in view its indeterminate growth pattern and hardy stems, both pruning and nutritional options were evaluated. Twelve combinations of management options, i.e. (1) pruning of stems from a fixed height, viz. 20 and 30 cm and (2) foliar application of nitrogenous fertilizers, viz. urea (2% solution), KNO_3 (2% solution) and thiourea (10 mM) along with control were evaluated. The stems were cut after one week of hail damage and thereafter urea, KNO_3 and thiourea were sprayed after 4 days. A uniform dose of 100% water soluble fertilizers (18 : 18 : 18 NPK and sulphur 6.1% by wt.) @10 kg/ha was also applied with drip irrigation after cutting the stems for boosting the crop growth.

In all the three crops, post-hail treatments comprising spray of various agrochemicals and pruning were imposed in randomized complete block design with four replications. Data from the experiments were analysed statistically using SAS software (Ver. 9.3) in order to study the effect of these treatments on crop recovery. Duncan test and least significant difference (LSD) test were also performed for comparison. The critical difference at $P = 0.05$ was used to test the difference between means of individual treatments.

In general the damage caused by the hail storm was severe in all crops and the impact of damage due to dip in minimum temperature was assumed negligible as it prevailed only for two days. Though there were some common treatments to accelerate the recovery of crops from hail damage, we observed crop specific responses to the treatments imposed in these experiments.

All the chemicals used for foliar spray improved the bulb yield of the onion when compared to water spray. The maximum benefit of about 40% higher yield was observed in case of drenching with humic acid (HA; 2 ml/l) and spray of KNO_3 (1.5%) where the bulb yields were 23.4 mg/ha against 16.3 mg/ha when the crop was raised as such (Figure 2). It also increased the size of tubers as indicated by their number in super grade. It is well established that HA benefits crop production both directly by impacting enzymatic activities and membrane permeability and indirectly by changing the soil structure[14]. Thus humic acid led to invigoration of roots and helped the plants recover from cold shock whereas the KNO_3 spray further helped in recovery of foliage, improving nutrient acquisition, increasing the greenness, shortening the crop cycle and increasing the onion recovery rate and overall production (Figure 3). Abdel *et al.*[15] stated that humic acid increases plant growth through chelating different nutrients to overcome the lack of nutrients, and has useful effects on growth increase, production, and quality improvement of agricultural products due to hormonal compounds. Thereby, the application of humic acid improved growth parameters. Potassium might also have played a role in photosynthesis, osmotic adjustment, cell growth, stomatal regulation, water system of plant, downloading hydrocarbons made in the leaves into phloem, transporting them within the plant, anion–cation balance, and as accompanying cation in nitrogen transfer[16].

Application of salicylic acid (SA), KNO_3 and urea drenching led to considerable improvement in grain weight of major cobs especially when damage to cob was <20%. Recovery was not significant in case crop damage was more than 20% (Figures 4–6). Grain weight per cob was improved with application of PBRs compared to control plot in the range of 7% to 26.5% and 2.2% to 14.7% when damage of cob was <20% and >20 (20–80)% respectively, and among all treatments urea drenching and SA performed better (Table 2). The yield improvement ranged between 14% and 26% with urea drenching being most effective. Nitrogen fertilizer (N) is one of the most important nutritious factors for plant growth, plant productivity and crop grain quality[17]. Application of nitrogen had a significant effect on grain weight[18]. However, spray of urea did not have much effect on yield as that of urea drenching. This was mainly due to substantial reduction in leaf area due to hail damage which might have substantially reduced absorption of applied nitrogen. The same was also reported in sweet corn when leaf damage occurred in vegetative stages or at silking. Leaf loss near harvest had minimal effects[19]. SA and other derivatives are known to safeguard various physiological and biochemical activities of plants and have been reported to play a major role in regulating their growth and productivity, delaying senescence and increasing cell metabolic rate. Hence, such compounds can enhance dry mass production and carbohydrate content in corn[20–22]. SA also controls nutrient and water uptake by roots[22] and dry matter partitioning.

Close observation on regeneration pattern of plant growth in hailstorm damaged brinjal crop revealed that

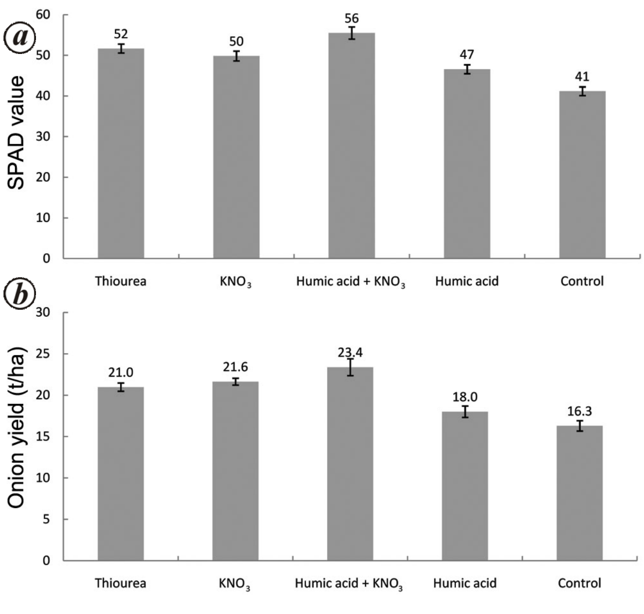

Figure 2. Leaf chlorophyll status as indicated by SPAD (***a***) and onion yield (***b***) in response to thiourea, KNO_3, humic acid-KNO_3 and humic acid applied after hail damage.

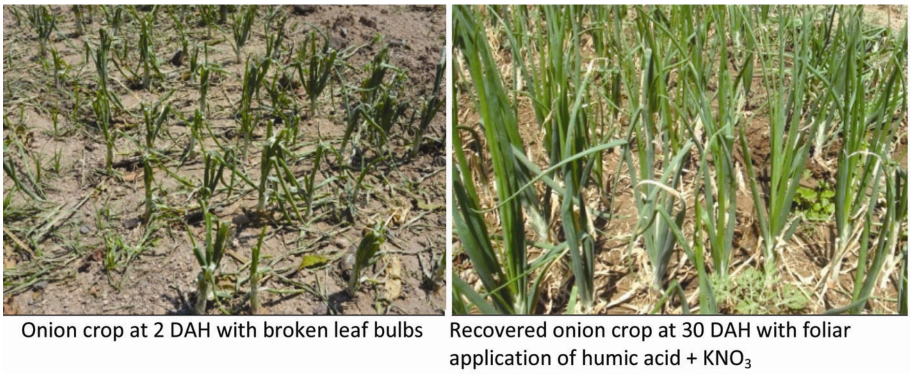

Figure 3. Crop recovery at 30 days after hailstorm.

Figure 4. General view of maize after hail damage (***a***) extent of damage in the cob (< 20%) and (***b***) in the cob (>20%).

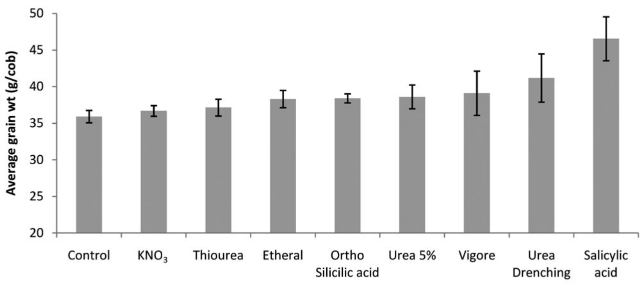

Figure 5. Grain weight of maize at harvest in response to bioregulators and nutrients applied after hail damage.

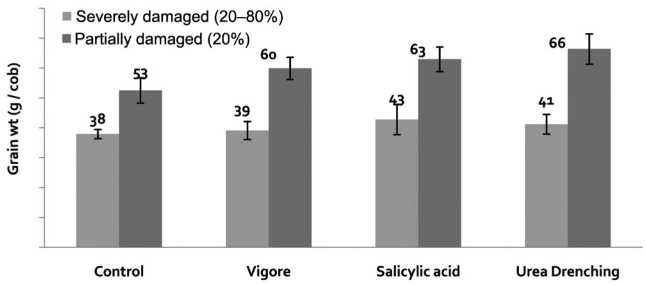

Figure 6. Grain weight per cob in fully and partially damaged maize after treatment of bioregulators at harvest.

Table 2. Seed weight of cobs in response to different treatments in maize

Treatments	Seed weight per cob (g) Damage (<20%)	Damage (>20%)
Urea drenching	66.4	41.2
Salicylic acid	63.0	40.8
KNO_3	60.8	36.7
Vigore	59.9	39.1
Ortho silicic acid	57.1	38.4
Thiourea	56.6	37.1
Urea 0.5%	56.5	38.6
Control	52.5	35.9

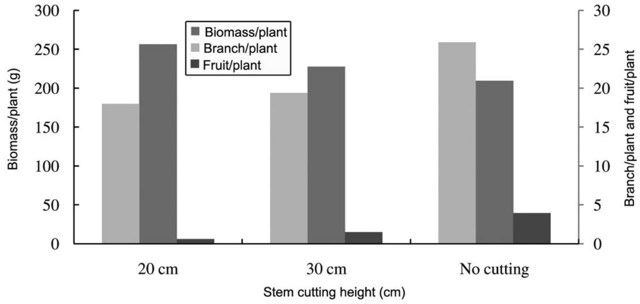

Figure 7. Recovery of growth and development of hail damaged brinjal plants in response to stem pruning.

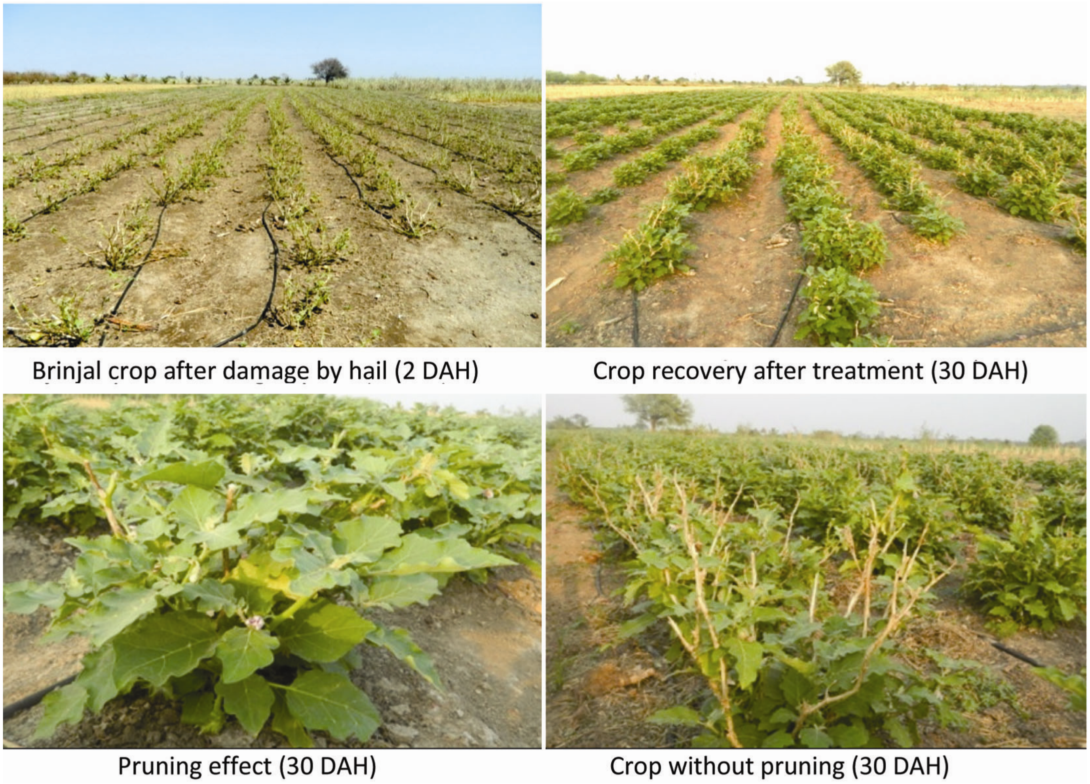

Figure 8. Effect of pruning management and foliar spray of nitrogenous fertilizers on recovery of hail damaged brinjal plants.

most of the effective and sturdy branches developed from the basal nodes of the plants. However, auxiliary branches also developed from upper nodes of the plant but a reduction in vigour of growth was observed with increasing height of the stem. The number and size of leaves to support the growth of fruits in the uppermost auxiliary branches were limited. Therefore, a branch that developed at the upper most nodes of the plant mostly had smaller fruits that affected the overall productivity of the crop despite high number of fruits/plant. However, plants that recovered after pruning stems at 20–30 cm height, looked like a normal transplanted crop within a month after start of treatment (Figures 7 and 8). These plants were found healthier compared to the plants that recovered without pruning. Wilting was almost negligible in these plants when compared to those which were not pruned. Thus pruning led to increase in number of effective branches, improvement in size of fruits and overall plant growth and development compared to control and other treatments. Ambroszczyk *et al.*[23] found that plants pruned more intensively produced more class-I fruits, as stem pruning increased fruit load to restore source sink balance in plants. This is achieved through a higher relative increase in generative sink strength compared to the relative increase in source strength from increased leaf area index (LAI)[24]. Less intensive pruning resulted in increase in the number of unmarketable fruits and affected fruit qualities. Pruning at 20 cm had greater advantage

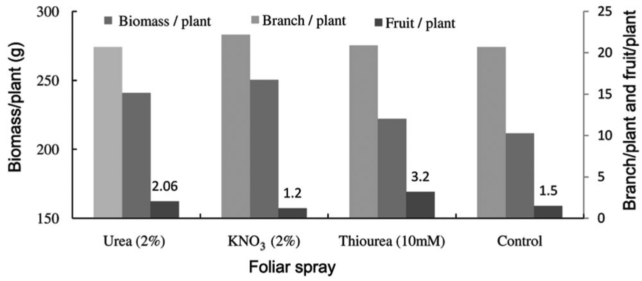

Figure 9. Effect of foliar spray of nutrient and bioregulators on biomass, branches and fruits per hail damaged brinjal plants.

than the same at 30 cm due to higher number of branches from basal nodes resulting in higher biomass/plant. It was noticed that deep pruning delayed flower bud formation only by 3–4 days in case of plants pruned at 20 cm height when compared to unpruned plants. Ambroszczyk *et al.*[23] also reported that earliness of production was not affected by the systems of pruning under green house. Normal flowering and fruiting was restored in all plants after 30–35 days of treatment. It was also observed that timely removal of damaged fruits and dried twigs or branches from plants helped in faster recovery of the crop and also facilitated picking of fruits and other operations.

Foliar spray of nitrogenous fertilizers such as urea (2%), KNO_3 (2%) and thiourea (10 mM) also resulted in improved plant growth and development that was monitored in terms of plant height, branch/plant and chlorophyll index (Figure 9). Overall vigour and biomass of the crop was found higher in response to KNO_3 followed by urea and thiourea respectively, when compared to untreated plants (control). Among the three sources of nitrogenous fertilizers, KNO_3 was found to be more promising in terms of accumulation of maximum plant biomass and plant vigour followed by urea and thiourea. Maximum number of fruits was observed in thiourea treatment which might have promoted reproductive growth followed by urea, when compared to KNO_3 and control treatment. Tongumpai *et al.*[25] also found improved terminal bud break in mango by use of thiourea. In general, spray of nitrogenous fertilizers resulted in accelerated growth and development of crop and also faster recovery from hail damage compared to control. Beneficial effect of different chemicals used in these experiments may be attributed to their role in improving the physiological processes including nitrate assimilation[27,28], stomatal mechanisms[13,23] and photosynthesis[29–31].

Frequent occurrences of hail events in the northern and central parts of India call for stronger relief measures to minimize crop losses. Pre-storm measures are, however, constrained by highly unpredictable and localized nature of hail storm events. Amongst the various post-hail management options, nutrient supplement, plant bio-regulator and canopy management were tried in onion, maize and brinjal. In brinjal, pruning of uppermost damaged parts helped in maintaining sufficient number of effective branches, flowers, and fruits and also improved the availability of current photosynthates for fruit development. Urea drenching along with salicylic acid induced significant recovery in maize crop both when cobs were moderately or severely damaged. In onion leaf, neck and bulb tissues were injured and hail damage reduced functional leaf area. In onion drenching with humic acid (2 ml/l) along with KNO_3 sprays was effective in recovery.

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IHHNV infection from the wild shrimps of Andaman and Nicobar Islands, India

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The present study was intended to screen the wild shrimps of Andaman and Nicobar Islands (ANI) against infectious diseases. A total of 175 shrimp samples (35 pools) consisting of *Fenneropenaeus indicus*, *Penaeus monodon*, *Penaeus merguiensis* and *Metapenaeus monoceros* were collected from different landing centres across ANI. Out of 35 pools of samples analysed by polymerase chain reaction (PCR), a total of 10 pools of *Penaeus monodon* collected from Betapur (1 pool), Lohabarrack (4 pools) and Campbell Bay (5 pools) were found positive for Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV). Nucleotide sequence of IHHNV isolated from ANI showed 100% identity to the sequences of IHHNV reported from Vietnam, Taiwan, Australia, China, Egypt, USA, Ecuador, 99% identity to IHHNV reported from Brazil, Venezuela, Korea, 96% identity to IHHNV reported from Thailand and 95% identity to IHHNV reported from India. Based on phylogenetic tree analysis, IHHNV of ANI is closely related to IHHNV of Vietnam. Histopathological analysis revealed typical eosinophilic intranuclear cowdry type A inclusion bodies in gill lamellae which further confirmed the IHHNV infection. The present study provides a definitive evidence for the first report of infectious IHHNV in wild *P. monodon* from ANI.

Keywords: Andaman and Nicobar Islands, disease surveillance, IHHNV, *Penaeus monodon*, wild shrimp.

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ANDAMAN AND NICOBAR group of Islands belonging to the union territory of India are situated between 6°–14°N and 92°–94°E in the Southeast of Bay of Bengal and consist of 572 islands coming under three districts namely, North and Middle Andaman, South Andaman and Nicobar. India ranks second in shrimp production next to China[1]. As India is one of the top ranked shrimp producers of the world, viral diseases pose a serious threat to Indian shrimp culture. Presently, the viral diseases detected in the mainland of India include White Spot Syndrome Virus (WSSV), Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV), Hepatopancreatic Parvo Virus (HPV), Monodon Baculo Virus (MBV) and Laem-Singh Virus (LSNV)[2–5]. At present, only freshwater carp farming is being practised in Andaman and Nicobar Islands (ANI), while brackishwater aquaculture, mainly shrimp farming and mariculture are the identified potential areas for development in aquaculture sector. When compared to mainland of India and neighbouring Southeast Asian countries, very few aquatic animal diseases, mainly shrimp diseases like vibriosis, LSNV and WSSV were reported from ANI[6–9]. ANI are believed to be free from many fish diseases as well as shrimp pathogens compared to the mainland of India and other neighbouring countries though it shares close proximity with Southeast Asian countries like Indonesia, Thailand and Malaysia where shrimp diseases like White Spot Disease (WSD), Infectious Hypodermal and Haematopoietic Necrosis (IHHN), Taura Syndrome (TS), Yellow Head Disease (YHD) and Monodon Baculo Virus Disease (MBVD) were reported[3,10–13]. The absence of many diseases in ANI may be due to geographical