On the Unprecedented Heat Burst Event and Subsequent Searing of Foliage over the Tropical Monsoon Region

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Abstract

A unique event of scorching wind that led to the wilting of plant leaves at some coastal regions of Southern India during the monsoon month of June 2015 is investigated. This strange phenomenon of hot wind during nighttime caused panic in the local residents. A plausible causative mechanism of this event is presented here combining the occurrence of heat burst - a rare atmospheric phenomenon in the tropics - and subsequent chemical processes involving oxidative stress mechanism in the leaves. Scanning Electron Microscope (SEM) and Energy Dispersive X-Ray Analyses (EDAX) of the wilted- and control- leaf samples revealed the signature of oxidative stress experienced by leaves during the heat burst. The analysis further suggests quick formation of antioxidants in the plant cells to safeguard against heat injury due to sudden rise of ambient temperature. Subsequent laboratory simulation mimicking abrupt wilting of leaves supports the abnormal and rapid oxidative stress within the leaf cells. The pronounced wilting effect of temperature rise compared to that due to sea-salt alone is also explored. The unprecedented heat burst event could be ringing the bell of a changing tropical monsoon climate, and calls for multi-disciplinary research initiatives to explore its impacts on the biota.

Keywords: Thunderstorm, Heat Burst, Scorching wind, Searing leaf, Oxidative stress, Plant response.

1. Introduction

This paper presents a brief description and an attempt to unravel the rarely reported scorching wind condition and subsequent searing of vegetation that occurred along parts of the coastal belt of the Arabian Sea adjacent to Kerala State in India. The phenomenon was observed by the local residents at the coastal locations during the nights of 17-26 June 2015. The scorching wind has been reported from individual coastal regions in the districts of Kasaragod, Kannur, Kozhikode, Thrissur, Ernakulam, Alappuzha and Kollam (Fig S1). Most of the places witnessed the event in the late night between 22:00 IST to 00:30 IST the next morning during the above mentioned period. It was observed that the event spanned for few minutes (around 5-10 minutes) only in the night at each site, but the vegetation dried up immediately in the overnight period. None of the places experienced the same event for a second time, and hence it was transient and all of them were independent events on different dates. Though, no serious burns of humans, animals or birds were reported, the local people felt great distress associated with hot wind condition during this midnight event. This phenomenon, occurred in the midst of the south-west monsoon, had triggered wild speculation among the common public. As a result, scientific teams including experts from various disciplines such as atmospheric science, hydrology, agriculture, fisheries, botany, and forest sciences had made field visit following news in local media. The field interactions indicated towards a sudden wilting of plants and most of them reported a high temperature during the night -
and early morning hours. The wilting was restricted to approximately 300 m from the coast line. This rare hot wind phenomenon remained perplexing for scientists due to lack of ample but accurate data sets.

2. Observation and Data

2.1 Location and Meteorology

Kerala is the southernmost State of India, and is the Gateway of south-west Indian summer monsoon (Fig S2, marked by black circle. URL: http://satellite.imd.gov.in/archive/KALPANA-1/ASIA-SECTOR/INFRARED/JUN_2015/). On the west side of Kerala is the Arabian Sea and to the eastern border is the Western Ghats. In Kerala the four major seasons observed are winter (December-February), pre-monsoon (March-May), monsoon (June-September) and post-monsoon (October-November; Nishanth et al., 2012). The most prominent meteorological feature at this location is the monsoon rainfall occurring in two spells in a year. The south-west monsoon is active during the months of June through September during which about 80% of the total rainfall is received in Kerala. The wind speed is usually high during the period from June to September and low from December to April. The region experiences easterly winds during winter months and westerly winds during summer months. The months, December through February with meager rain and relatively low humidity constitute the winter season, while from March to May...
is pre-monsoon marked by intense sun and high convective movement. The temperature is high in the months March to May and is low during June through August. The maximum humidity is measured during monsoon and the minimum is observed in the winter months. The maximum rainfall is recorded during monsoon, while the minimum is observed in the winter season.

The rare phenomenon of heat burst occurred immediately after a light rain shower during the monsoon nights. The skies were partly cloudy, and frequent lightning flashes and thunder were observed, which implies that the rain originated from cumulus/cumulonimbus clouds. These thunderstorms over the coastal belt were identified from both the Kalpana Satellite Images (IR channel) and from Cloud Top Temperature data obtained from AVHRR onboard METOP-1 (see Fig 1 on 17th June 2015, marked by black circle) during those nights (http://www.incois.gov.in/WEBSITE_FILES/TERASCAN-IMG/CLOUDTOPTEMP/AVHRR/METOP-1/2015/20150625-170430Z-metop1-cloudtopbt4.jpg). This is relevant because taller clouds generally correspond to colder temperatures (Doraiswamy et al., 2013). On IR imagery, the cold cloud tops are easy to find because they generally correspond to the coldest colors on the color bar. The year 2015 was declared to be an El-Nino year, and the south-west monsoon seasonal rainfall in the State of Kerala was 32% short of its long term average (IMD, End of Season Report, 2015). In addition, the month of June itself witnessed a shortage of rain (-13%) for the State. It is during this time that the heat burst occurred over Kerala. The rain was confined to certain isolated pockets only, and the otherwise wide spread rainfall characteristics for the month of June was absent. In addition, it is worth noting that there was a depression formed around the Gujarat coast in India during this week, and the southern peninsula was almost free of monsoon clouds, and the skies were intermittently cloudy with cumulus/cumulonimbus population. Since this event occurred close to June 21, the Summer Solstice, the clear sky regions in Kerala were exposed to high intensity solar radiation. It is well known that convective activity plays a dominant role in the initiation and development of tropical weather systems (Kumar et al., 2016), and the occurrence of localized rain along the coast has been attributed to convectively unstable atmospheric condition. As a result of the localized rain, the alternating wet and dry regions caused a contrast in relative humidity (RH) conditions. Pockets of such RH regions could be one of the important factors that led to the occurrence of thunderstorms and subsequent heat burst (explained in Section 3.1). This entire process occurred as a result of the prevailing El-Nino condition during 2015. We believe the large-scale circulation pattern associated with El-Nino made the atmosphere conducive for the occurrence of strange phenomenon such as Heat Burst amidst the monsoon months.

Thunderstorms just prior to heat burst at Kerala coast are evident in Fig 1 (in which cloud top temperatures colder than -55°C are observed along the coastal area) and it substantiates the isolated events of hot winds by which leaves were charred. However, the eastern hillocks of Kerala state witnessed normal/above normal rainfall events during the same period due to local orographic dynamics. One favorable condition that leads to the formation of thunderstorms along the coastal belt is the presence of contrasting air mass (adjacent hot and cold air parcels). However, the heat burst event, which is characterized by the rapid rise in temperature and decline in humidity, alone is not sufficient to lead to wilting of plant leaves. Hence, we propose a plausible mechanism to explain all the aspects of this rare event by combining the plant response to such spontaneous environmental stress.

3. Theoretical Background and Experimental Methods

3.1 Heat Burst

A heat burst is a rare phenomenon, not reported earlier in tropics. However, it had been reported in many countries such as the United States, Australia, Canada etc., which lie outside the tropics (http://www.weather.gov/ilm/GeorgetownHeatBurst). Heat bursts are primarily characterized by a sudden and highly localized increase in air temperature, a simultaneous decrease in relative humidity, and strong gusty winds, typically associated with decaying thunderstorms (McPherson et al., 2011). It has been reported to occur mainly during night time. The small spatial extent and short duration of most heat bursts makes detailed study of these events difficult using the standard observation network (e.g. hourly observations) established in our country. Decaying nocturnal thunderstorms have been reported to produce hot, dry and gusty surface winds classified as “warm wakes, hot blasts, or heat bursts” by previous researchers (Williams, 1963; Froure and Simmonds, 1965; Johnson, 1983, Bernstein and Johnson, 1994; Petricic, 2000; Johnson, 2003; NOAA NWS, 2006; Gladich et al., 2008; Basara and Rowell, 2012). The event of heat burst occurs when the raindrops are evaporated by a dry air parcel situated high in the atmosphere but below the region of rain initiation. Subsequently, this dry air becomes cooler and much denser than the surrounding and suddenly descends at a higher speed due to loss -
Fig S2: Kalpana satellite image showing the location and weather pattern over Kerala at 23:15 hrs on June 17, 2015 (URL: http://satellite.imd.gov.in/archive/KALPANA-1/ASIA-SECTOR/INFRARED/JUN_2015/).

Fig 1: Cloud Top Temperature (CTT in °C) obtained from AVHRR onboard METOP-1 satellite showing the presence of thunderstorms (marked in circle) along the coastal belt of Kerala on June 17, 2015.
of buoyancy. During the descent, the parcel starts warming rapidly due to adiabatic compression, and reaches the surface similar to a downburst. The sudden large temperature rise and loss of humidity associated with nocturnal thunderstorms defines the heat burst (Johnson, 1983; Basara and Rowell, 2012). In addition to temperature rise and humidity fall, the heat burst is characterized by cloud erosion and gusty winds. The temperature may even rise by 10-13°C depending on the height of cloud base. At the time of dissipation of thunderstorm, the cloud layer starts to rise due to loss of weight, and a rain-cooled layer remains. This layer overshoots a burst of unsaturated air down towards the ground and thus causes a reduction in up-draft strength. Consequently, the raindrops begin to evaporate into dry air which amplifies the effect of heat burst. The downward motion develops in areas with a nearly dry adiabatic temperature lapse rate from the surface well into the mid-troposphere. In the history of meteorological events in the USA, it was observed that there were occasions characterized by decline of humidity or dew point after the passage of storms. An incident of sharp humidity fall during heavy rain had been reported earlier (Byers and Braham, 1949). An unusual temperature rise of as much as 6°C was reported (Johnson, 1983) in the late evening and early morning hours of 29-30 May 1976 in the central Oklahoma in USA. Such an event during the dissipation of thunderstorm at the Midland Texas was also reported (Wood, 1966). There is, even, evidence of suppression of deep convection due to static stabilization from an unsaturated mesoscale downdraft just below trailing anvil clouds (Koch and McCarthy, 1982).

### 3.2 Subsidence-induced Warming

Generally, thunderstorms formed over the coastal regions of Kerala have their bases (Convective Condensation Level - CCL) at height levels of 1-3 km above the ground (Vishnu et al., 2013). If a sudden downdraft occurs due to evaporative cooling of cloud-reminiscent layer, it warms at a rate by the Dry Adiabatic Lapse Rate (DALR, \( \Gamma_{\text{d}} \approx 9.8^\circ \text{C per kilometer} \)). Simultaneously, the surrounding air becomes warmer by the Environmental Lapse Rate (ELR, \( \Gamma_{\text{e}} \approx 6.5^\circ \text{C per kilometer} \)). Thus, as a first approximation, there is an additional difference in heating (i.e., \( \Gamma_{\text{e}} \Gamma_{\text{d}} \)) of the subsiding air parcel by around 3 - 3.5°C per kilometer. Based on near real time (23:30 IST) meteorological data from ERA interim re-analysis at different pressure levels, the cloud base was estimated to be around 3 km above the ground. Had the cloud base formed around 3 km, obviously the air might have warmed further by around 9- 10.5°C. This is believed to be the cause of the rapid increase in temperature experienced on the shore during the event. However, we doubt if such a temperature increase alone could be the sole reason behind the drying up of vegetation. If it is so, the leaves could not have been burned to the extent as they were. It was initially thought that sea-salt spray or acid rain event could be the cause of wilting. Upon detailed field examination and laboratory testing (not detailed herein), however, these factors were mostly ruled out. Further, they could not explain the midnight rise in ambient temperature felt by the local residents.

It is envisaged that an accompanying chemical reaction(s) involving oxidation could enhance the temperature which in turn could damage the chlorophyll content, and produce a burning effect to the leaves. We propose the formation of a strong oxidizing agent like Peroxy Radicals within the leaves to protect against the sudden heat stress due to the abrupt change in the ambient temperature. These oxidative compounds produced in the leaves are highly vigorous and they in turn initiated an oxidative stress in the leaf cells by which their metabolic activities were disrupted extensively. This abnormal metabolic activity induced by a rapid oxidative stress in turn added a pace to the destruction of chlorophyll. One of the unique observations is that the intensity of searing of leaves was much higher for those leaves which faced the wind direction and this could be explained by the exposure to rapid oxidation. However, we do not rule out completely the role of sea-salt spray which is quite abundant during this period. Thus, the weak monsoon condition which prevailed over Kerala coast and paved a platform to produce heat burst is the prime suspect behind the scorching wind and associated searing of foliage. It is further supported by the weak monsoon Low Level Jet (LLJ) observed during the period of heat burst (Fig 2). During active monsoon season, the speed of LLJ, which exists at around 1.5 km above ground, exceeds approximately 20 ms\(^{-1}\) (Joseph and Raman, 1966; Manoj et al., 2011). However, it was very weak (<3 ms\(^{-1}\)) during the mentioned period, as observed in the wind profiles obtained from a co-located Stratosphere-Troposphere Radar at the Advanced Centre for Atmospheric Radar Research (ACARR) at Cochin University of Science and Technology, Kerala, India. Fig 2 shows representative vertical profiles of zonal velocity for the period 23-25 June 2015 over Cochin. These are the instantaneous profiles at 17:30 IST on each day. In addition, we made the daily average profiles of horizontal wind, and they are essentially similar to the profiles given here. It was also observed that the westerly wind was quite weak for almost all the days in June 2015.
3.3 Evidence of Increase in Temperature and Winds

During a heat burst, one could expect a sudden increase in temperature and wind speed preceded by the occurrence of light rain. Since the very coastal region of Kerala is not having any Automated Weather Stations (AWS), it becomes difficult for the accurate estimation of heat burst-induced temperature increase. However, there is an AWS station at Edathiruthy village (10.38 N, 76.13 E), which is near to coast (approximately 4 km away from coast) in Thrissur District of Kerala, and it recorded around 4.5°C increase in the night of June 17, 2015, between 22:00 and 23:00 hrs IST (IST=GMT+05:30 hrs), immediately after a light rain. It is to be noted that the average temperature prior to the event was approximately 22°C. This AWS has been programmed to store the weather data at every one hour interval only. By considering the fact that heat burst is a short-term phenomenon (of the order of a few minutes), and the station is approximately 4 km away from the coast, it is difficult to observe a high peak in temperature for a few minutes in the 1-hour averaged data. Even after the weather data is averaged for an hour, the temperature increase of 4.5°C seems to be significant in the context of short term event like heat burst. The hourly averaged wind speed during the event of heat burst (22:00-23:00 IST on 17th June 2015) was 5.6 m s⁻¹, whereas the wind values just prior to (21:00 IST) and after (00:00 IST next day) the event were 0.8 m s⁻¹ and 1.2 m s⁻¹, respectively. The wind speed thus increased about five times during this event, even after time averaging. Concurrently, the humidity sensor showed a corresponding decrease of RH by about 21%. As the effects were mainly seen along the coastal lines, we expect that the effect originated at the coastal region, and considering the distance from the coastal line, the temperature at the source of origin should have been greater than 10°C. A sudden high temperature rise and lowering of moisture content in air wipes out cell water leading to oxidative stress and wilting. This is illustrated in Fig 3.

Since there is no solar radiation during night, and lightning and thunder were present associated with rain, and there was subsequent hot blast, the possibility of occurrence of heat-burst is justified. This being a rare event over this coastal location, the wilting of leaves was initially believed to be due to the effect produced by the excess sea salt spray on the plants by the gusty wind from the sea. The accumulation of sea salt can make injury to leaves only gradually, however, the immediate wilting of leaves in a short span of time motivated us to investigate the plant chemistry behind this effect. Thus wilted leaves were subjected to microscopic (Scanning Electron Microscope- SEM) analysis to retrieve the intensity of damage due to this phenomenon (explained in next section). This analysis provided a hint to a chemical reaction which actually resulted in searing of leaf. In order to characterize the chemical composition of deposited sediments in plant leaves, subsequently, an Energy Dispersive X-Ray Analysis (EDAX) was performed (See the following section for details). The EDAX results strongly support our hypothesis of deposition of anti-oxidant in leaves as a result of an oxidative stress mechanism.

3.4 Scanning Electron Microscopic (SEM) and EDAX Analyses of Wilted Leaves

A Scanning Electron Microscope (SEM) analysis has been performed to distinguish the burnt leaf structure from that of control leaf. SEM is an electron microscope which can produce images of a sample by scanning it with a focused beam of energetic electrons. Subsequently, the electrons interact with atoms in the sample, producing various signals that can be detected and that contain information about the sample's surface topography and composition. This has the facility to magnify the sample at the desired levels. In order to investigate the structure and degree of burn of affected leaves, a SEM analysis was performed and the photographs (Fig 4a and 4b) were examined. Two sample leaves of the same plant were chosen, one affected (Fig 4a) with burn and the other without burn (Fig 4b). Care has been taken to analyze the same portions (leading tips) of the two leaves in order to avoid any ambiguity. It was observed that the affected leaf had higher concentration of contaminants stuck to it than to the unaffected one. Also, the depth of burn effect is more pronounced in the affected sample. This leads to the conclusion that there occurred a chemical reaction which actually led to this severe burning.

In order to identify the chemical compounds deposited in plant leaves, an Energy Dispersive X-Ray Analysis (EDAX) was performed. This offers a promising tool for the chemical characterization of a sample. The EDAX analysis of the above two samples (one sample affected by heat burst and the other one unaffected) revealed the presence of carbon(C), oxygen (O), nitrogen(N), calcium (Ca), potassium (K), sodium (Na), sulphur (S), magnesium (Mg), silicon (Si) and chlorine (Cl). It is further observed that the amount of oxygen present in the burnt sample was higher (~9%) than that observed in unaffected sample. This is evident from Fig 5, which shows the normalized concentration of different elements.

4. Discussion

4.1 Chemistry of Chlorophyll Destruction
A close examination of the photographs of the wilted leaves reveals a maximum searing occurred along the leaf border, which could be due to its tenderness and a thin cuticle layer at the edges. Those leaves with fairly large surface area were only affected at their edges while those with smaller area were completely burnt. It was also observed that leaves with high water content were least affected. Likewise, the tip of lengthy leaves such as coconut leaves' tip were also severely affected. It was also observed that shrub-like plants were among the mostly affected species, and the bottom parts of the plants were vulnerable to intense burning. Salt-induced dehydration of leaf cells is one among many other chemical reactions possible in such a relatively high temperature environment.

Plants exposed to rapid temperature variations were often subjected to an abrupt metabolic mechanism within the plant cells to protect against the cell damages due to the thermal stress induced (Hasanuzzaman et al., 2013). Subsequently, the cellular changes produced by high temperature (HT) leads to the excess production and accumulation of Reactive Oxygen Species (ROS) in the cells. This abrupt build-up of ROS results in an oxidative stress in the cells (Mittler, 2002; Yin et al., 2006). The ROS in plant leaves initiates oxidation of membrane lipids when it reacts with unsaturated fatty acids leading to leakage of cellular contents, rapid desiccation and hence cell death. During the heat burst that occurred in night-time which was accompanied –
by a sudden increase in temperature followed by spontaneous reduction in the relative humidity, the production of antioxidant within the leaves was initiated. Several evidences suggest that, from among the generated ROS, Hydrogen Peroxide (H$_2$O$_2$) plays a pivotal role in these plant defense responses (Mehdy et al., 1996). Furthermore, in response to HT, the reaction catalyzed by ribulose-1,5-bisphosphate carboxylase oxygenase (RuBisCO) can lead to the production of H$_2$O$_2$ as a consequence of increases in its oxygenase reactions (Kim and Portis, 2004). This H$_2$O$_2$ decomposes into water and oxygen within the cells of the leaves when they are subjected to thermal stress. This excess oxygen is revealed in the EDAX analysis performed to identify the intrusion and formation of chemicals within the affected leaves. Fig 5 shows the excess oxygen (~9%) that was accumulated in the affected leaves compared to the control leaves in the analysis. Since, the heat burst was so rapid, the presence of oxygen enhanced the intensity of wilting. The diminished amount of carbon found in the burnt sample could be due to the reduced rate of fixing of carbon dioxide when the leaf is subjected to oxidative stress (Ahmad et al., 2008). Likewise, the absence of nitrogen in the wilted sample is due to the loss of protein content during the process of wilting. Generally, leaves produce antioxidants as a protective species within the leaves to safeguard against any stress experienced by the leaves. When plants are subjected to environmental stress conditions involving abrupt enhancement in ambient temperature and subsequent reduction in relative humidity, the rapid enhancement -
Fig S3: The calibration graph between temperature and relative humidity in the incubator chamber.

Fig S4: Photographs taken at nearly different intervals of temperature for control leaf, salt-only sprayed leaf, H$_2$O$_2$-only sprayed leaf nearly at: (a) 32 °C, (b) 35 °C, (c) 40 °C, (d) 42 °C, (e) 45 °C, and (f) 46 °C.
in the production of reactive oxygen species (ROS) paved a platform for initiating an oxidative damage (Singh and Upadhyaya, 2014; Spychalla and Desborough, 1990).

Numerous studies also have shown that abiotic stress results in the formation of ROS in plants which creates oxidative stress that can damage cellular components (Apel and Hirt, 2004; Almeselmani et al., 2006; Babu and Devraj, 2008; Huang and Guo, 2005). Oxidative stress is classified as a common metabolic route of different stresses (Apel and Hirt, 2004), and the mechanism of oxidative stress is generally an indication of abiotic stress tolerance of plants as described in different studies (Ashraf, 2009; Hasanuzzaman et al., 2012a; 2012b; 2012c). Hence the elevated temperature often accelerates the generation of ROS including singlet oxygen (1O₂), superoxide radical (O₂⁻), hydrogen peroxide (H₂O₂) and hydroxyl radical (OH•), and the excess amount of these oxidative species can cause extensive oxidative stress in plants (Mittler, 2002; Potters and et al., 2007). As a result, the dramatic increase in ROS level can induce the damage to cell structure (Mittler et al., 2004). One of the core effects of ROS is the autocatalytic peroxidation of membrane lipids and pigments, modification of membrane permeability and functions (Hasanuzzaman et al., 2012a; Xu et al., 2006). Thus the abrupt increase in lipid peroxidation due to rapid oxidative stress induced by HT stress in plants can damage the cell which is followed by a sudden reduction in the rate of respiration (Hasanuzzaman et al., 2013). This abnormal metabolic activity initiated by the extensive generation of ROS within the plant cells in a hot and dry environment can straight away damage plant cells by which the leaves start wilting immediately. Thus, the wilting of leaves is primarily due to oxidative stress within the plant cells associated with thermal stress induced by rise of temperature. In order to simulate the drying up of leaves, the same plant leaf samples were subjected to the similar environmental conditions of temperature and relative humidity set up in a laboratory. For this purpose, a temperature controlled incubator attached with thermometer and hygrometer was effectively used for simulating the environment which lead to the wilting of leaves (see the following section).

4.2 Laboratory Simulation of Leaf Searing

For confirming the charring of leaves under high temperature and low humidity conditions, a temperature controlled incubator attached with thermometer and hygrometer was employed. Fig (S3) shows the calibration graph between temperature and relative humidity in the chamber of the incubator and it suggests a negative relationship between temperature and relative humidity which is significant. Freshly collected leaves from the heat burst affected sites were thoroughly washed with distilled water prepared in the laboratory and they were subjected to different temperatures. For this purpose, we prepared four different samples, the first being the control leaf, the second being sprayed with H₂O₂ alone, the third being sprayed with varying concentrations of salt alone (NaCl), and the fourth being sprayed with both H₂O₂ and different concentrations of salt. The salt solution was prepared in accordance with the concentration normally observed in sea water (30 gram/litre) in order to retrieve the impact of sea salt on the wilting of leaves. The third and fourth categories of samples themselves were further sub-divided into four samples based on different concentrations of salt solution (25, 30, 35, and 40 gram per litre of distilled water). H₂O₂ being a strong oxidising agent, a spray of H₂O₂ on the surface of leaves could induce an artificial oxidative stress to the leaf samples.

The above samples were subsequently subjected to different temperatures ranging from 31°C to 50°C and corresponding humidity varying from 72% to 36%. In general, it was observed that the leaves started wilting with increasing temperature (beyond 35°C), and increased salt concentration. However, it is quite interesting to note that the intensity of wilting was found to be different for samples sprayed with salt/H₂O₂ or both. The maximum wilting was observed for leaves sprayed with both H₂O₂ and salt, and the minimum injury occurred for control leaf. Intermediate wilting occurred for leaves sprayed with H₂O₂ alone and salt alone, but the injury due to H₂O₂ alone was found to be much higher compared to salt alone. The above observations are deduced from the photographs taken at nearly equal intervals of temperature (Fig S4 a-f). From this result, it was confirmed that H₂O₂ is a prominent agent that provided a pace to the wilting of leaves in accordance with the plant physiology discussed by several investigators (Mehdy et al., 1996; Ahmad et al., 2008; Singh and Upadhyaya, 2014).

5. Summary and Conclusion

Though various hypotheses were proposed for the unique event of scorching wind and associated searing of foliage, no single theory could explain all the observed phenomena in a conclusive manner. In this paper, a plausible mechanism is put forth that attempts to unravel this phenomenon by considering virtually all scientific aspects. We propose that the weak monsoon associated with the El-Nino condition in 2015 brought highly sporadic and spatially asymmetric rains over the Kerala coast. Though monsoon onset occurred on June 05 in 2015, it was not active and uniform over this region in the subsequent leg. Moreover, the rains were
characterized by both monsoon and pre-monsoon showers, with frequent lightning/thunder and gusty winds. In a climatological sense, lightning and thunder are not common during the south-west monsoon season. The state as a whole received rainfall by about 13% less than the normal accumulated rainfall in June. This in turn led to pockets of convectively unstable atmosphere producing intermittent rainfall. The overhead position of the Sun under cloud-free conditions could expedite the instability condition further.

Our hypothesis combines a thermodynamical approach followed by chemical reactions. A heat burst is the prime cause behind the scorching wind condition that occurred. The elevated temperature resulted from the heat burst could have damaged the plant cells due to the oxidative stress produced by the ROS generated in the plant cells, to protect against rise in ambient temperature resulted by the heat burst. The abundance of sea-salt is also thought to be a minor catalyst responsible for drying up of leaves, but the oxidative stress in plant leaves induced by the increase in ambient temperature during night time heat burst wilted the leaves within short span of time. The SEM analysis performed in wilted leaves confirms the extensive surface damage of leaves due to heat burst. The EDAX investigation further identified the traces of excess oxygen in the wilted samples, which clearly indicates the oxidative stress induced by the rise in temperature due to heat burst. The laboratory simulation carried out in the incubator finally confirmed that the abrupt wilting of leaves was primarily due to oxidative stress occurred within the leaves and this rules out salt stress alone being responsible for wilting. Thus, the wilting of leaves due to scorching wind was as a consequence of weak monsoon combined with afore-mentioned environmental conditions. However, this being a preliminary investigation to explore the wilting of leaves due to heat burst, further research is required to explore the chemistry of antioxidants in the plant leaves with the aid of biochemical analysis. This is the first observation of a rare episode of heat burst occurred in the tropics during the south-west monsoon period over the west-coast region of the Indian sub-continent. Thus, this unprecedented event could be ringing the bell of a changing tropical monsoon climate, which may repeat in the future in similar environmental conditions.

Acknowledgements
The first (MGM) and last (KMK) authors wish to express their gratitude to the Department of Science and Technology (DST), Government of India for awarding the grant to establish the ST-Radar Facility at CUSAT. The Authors are thankful to Dr. Jagannath Bhat of STIC, CUSAT for his support rendered in SEM analysis and relevant discussions. We also thank Mr. Titu Samson, Rakesh V, Rejoy Rebello, Ajiil Kottayil and Mrs. Sunitha Nair of ACARR, CUSAT for their help in collecting samples and analysis of the same.

Author Contributions
MGM, MKS and KMK observed and investigated the unusual event of scorching heat burst occurred at different locations in Kerala. MGM explored the science of heat burst. MKS, JJ, SS, KAS, KMS and MGM collected the data, conducted the laboratory simulations and explained the oxidative stress mechanism within the plant cells. MGM, MKS, SS and KAS were involved in preparing and compiling the manuscript.

References
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