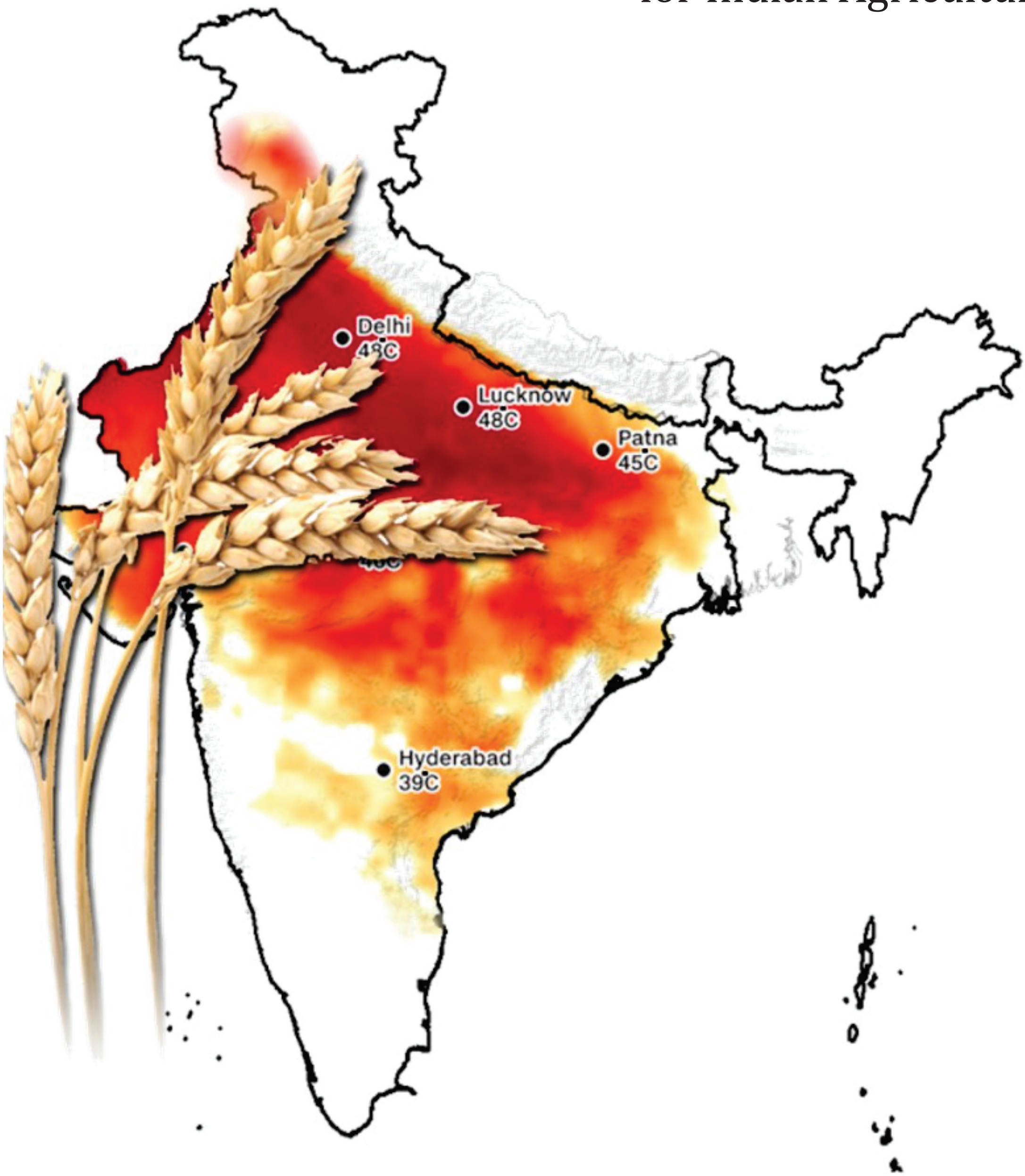
Heat Wave 2022

Causes, Impacts and way forward for Indian Agriculture



ICAR-Central Research Institute for Dryland Agriculture
Santoshnaagar, Hyderabad - 500 059, Telangana, India

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Causes, impacts and way forward for Indian Agriculture

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Message

Indian Agriculture continues to be vulnerable to weather vagaries despite self-sufficiency in food grain production. Climate change and increased extreme weather events in recent decades as well as uncertainty in prediction of those events further add to the woes of the farmers causing widespread losses of agricultural output. This year in 2022, extreme heat is gripping large parts of India, affecting hundreds of millions of people and agriculture in particular.

Thus, it is of paramount importance to predict our climate better and adopt climate-smart management practices for ensuring food security. Research initiatives on various aspects of management in field and horticultural crops, animals, fisheries and poultry in the event of unfavorable extreme weather events have necessitated the need for effective and foolproof measures. Amongst the weather hazards, heat waves cause physiological damage to crops, animals, poultry and fish; reduce water availability, increase demand of water and energy for use, reduce work efficiency etc.

This document is an attempt in this direction that includes information on the heatwave formation, heat wave vulnerable regions of India, the extent and spread of heat wave 2022 in northern and central India, possible impacts of heat stress on various aspects of agriculture and availability of technological interventions. Apart from crop, livestock, poultry and fishery specific management interventions, this bulletin also presents experiences from the technology demonstration component of NICRA.

I appreciate the initiative of ICAR-CRIDA, Hyderabad through the efforts of AICRP on Agrometeorology (AICRPAM) and National Innovations in Climate Resilient Agriculture (NICRA) for this timely document and hope this will be useful for researchers, farmers, extension specialists, policy makers and other stake holders for formulating strategies for minimizing the impacts of such vagaries in future.

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30.05.2022

Foreword

Intergovernmental Panel on Climate Change in its recent report projects an increase in the frequency of extreme weather events in future over the Indian sub-continent. In recent years, these extreme events posed a great challenge not only at the farm production level but also at the regional / landscape level. This year in 2022, anti-cyclones over western parts of India coupled with absence of western disturbances triggered the early and extreme heatwaves in the northern, north western and central parts of India for a quite longer period of time.

This analysis is an attempt to address the problem faced by Indian agriculture northern parts of the country due to heatwaves in the recent past. It covers the science behind occurrence of heatwaves, its impact on various sectors of agriculture and management strategies for overcoming the negative impacts. A critical analysis of the weather conditions that led to heatwave events in 2022 is analyzed by AICRP-AM and presented. As we expect such extreme weather events more frequently in future, I hope this document will serve as a reference material in the coming years and helpful to review the historical occurrences.

It has caused yield reductions in *rabi* crops especially under late sown conditions. This has called for a concerted scientific approach to study the natural disaster in detail. I am happy to share that National Innovations in Climate Resilient Agriculture (NICRA) is adopting a comprehensive approach for addressing such climatic extremes. Various commodity based ICAR institutes are actively involved in developing technologies that can minimize impact of climatic stresses. The promising technologies are taken to the farmers in a participatory approach which are being well accepted by the farming community. There is a need for mainstreaming the proven resilient technologies into the ongoing developmental programs / schemes.

I appreciate the efforts of the scientists of ICAR-CRIDA, AICRP-AM and NICRA in bringing out this timely document and believe that this publication will be of immense use in managing the episodes of heatwaves in the years to come.

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The severity and geographical spread of the heat wave 2022 and the extent of damage it caused to the Indian agriculture has compelled us to have an insight on the science aspect of this climatic extreme, its spatial distribution, impact on various sectors of agriculture and allied sectors, currently available adaptation strategies which may guide in prioritizing research efforts to minimize field level losses.

We would like to express sincere gratitude to Dr. Trilochan Mohapatra, Secretary, DARE & Director General-ICAR, for his valuable guidance and constant encouragement in bringing out this publication.

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We express heartfelt thanks to the directors of various ICAR institutes namely, ICAR-Indian Institute of Wheat & Barley Research, ICAR-Central Institute for Subtropical Horticulture, ICAR-Central Citrus Research Institute, ICAR-Directorate of Coldwater Fisheries Research, ICAR-National Research Centre on Litchi, ICAR-Indian Institute of Vegetable Research, ICAR-National Dairy Research Institute, ICAR-Directorate of Poultry Research for providing the necessary information about the impacts of heatwave on production systems and remedial measures.

We extremely thankful to all Directors and Nodal Officers of ATARIs for their support and guidance in providing the data on impacts and technological options for minimizing heat stress. We thank the Senior scientists and head and staff of KVK for providing information regarding the impact of the technologies in the NICRA villages. We are thankful to the Agrometeorologists of AICRPAM centres Ludhiana, Samastipur, Kanpur, Faizabad, Jabalpur, Raipur and Anand for providing information related to heatwave 2022.

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(Authors)

Executive Summary

The earth's average temperature has been rising. Heat waves are becoming extremely intense and frequent globally. In India, the months of March and April 2022, are the warmest on record, witnessed an unusual increase in maximum and minimum temperatures over most parts of the country. During this period, the extreme temperatures were found to be higher by +8 to +10.8°C and the rainfall lower by -60 to -99%, respectively compared to normal in 10 out of 36 meteorological subdivisions. In addition, 2022 will be remembered as a classic example of coupled impact of high temperature and subdued rainfall on agricultural production systems, specifically in northern and central India.

Agricultural production in India is vulnerable to climate variability and change. The abnormal increase in maximum and minimum temperatures during 2022, impacted crops, fruits, vegetables and animals in the states of Punjab, Haryana, Rajasthan. Jammu & Kashmir, Himachal Pradesh, Uttar Pradesh, Madhya Pradesh, Bihar and Maharashtra. The heat wave coincided with grain filling and development stage of wheat, yellowing and shriveling of grain, forced maturity, resulting in reduction of yields up to 15-25%. High temperatures resulted in moisture stress, sun burn, flower drop and less fruit setting in horticultural crops such as kinnow, pomegranate, mango and lemon. Similarly, in case of vegetables, significant impact was observed especially in tomato, cole crops and cucurbits. Loss of appetite and higher body temperature was observed in milch animals which led to reduction of milk yield up to 15%. The extreme temperatures resulted in drop in egg production and increased broiler mortality.

Due to the efforts of the National Agricultural Research System, several technologies are currently available which can minimise the negative impacts of heat waves in various production systems. The proven technologies are being taken to farmers as part of Technology Demonstration Component of National Innovations in Climate Resilient Agriculture (NICRA). During this year, the technologies were found to be promising in minimising the impact of heat stress. For example, in Bathinda, Faridkot of Punjab, these technologies could produce wheat yields up to 91-97% of the normal year. Similarly, resilient technologies could help in achieving milk production to the extent of 95% of the normal year. There is a need to popularize and scale these technologies by way of integrating in to the ongoing development programs. In addition, strengthening the weather forecasts and agro-advisory services can help farmers taking informed decisions about the impending weather. Building capacities of farmers and large-scale awareness on climate resilient technologies is needed for enhancing their adoption. Such efforts will go a long way in enhance resilience of various sectors of Indian agriculture to climatic extremes, such as the heat wave witnessed during the year 2022.

1. Introduction

The earth's average temperature has been rising since the late 1970s. However, the year 2021 has broken the historical record of the global climate in many ways. The average global temperature across land and ocean surface areas in 2021 was 1.12°C higher than the twentieth-century average. Heat waves are becoming extremely intense and frequent in various parts of the world including India leading to losses in agricultural productivity and thousands of deaths. The Sixth Assessment Report of the IPCC has also reiterated that climate change is real and its impact is being felt throughout the globe. In many parts of India, warmer summer and droughts have significantly impacted agriculture. Global food production is steadily increasing, but the rate of increase especially for major cereal crops is declining.

Agricultural production in India is becoming increasingly vulnerable to climate variability and change characterized by temperature rise (Rao et al., 2015) and altered frequency, timing and magnitude of precipitation (Bal et al., 2022). In spite of the large-scale development of soil-water-and crop-based technologies to optimize and sustain agricultural productivity in recent years, the latter continues to be affected by a number of factors. Factors like temperature, rainfall, relative humidity, light, availability of water, mineral nutrients etc. determine plant growth and development. The effect of each atmospheric factor on crop performance depends on its intensity and duration. However, some of these factors become stressful, due to the recurring features of climate variability, e.g. heat/ cold waves, floods/ heavy rain, hail/ thunderstorms, cyclones/ tidal waves etc., and these critical environmental threats are often referred as extreme weather events (Bal and Minhas, 2017). As climate change has become a reality, the implications of global warming for changes in extreme weather and climate events are of major concern for farmers as well as the common public.

Sharma and Majumdar (2017) reported that in India, the percentage increase in the frequency of heat waves along with drought was most significant in parts of Maharashtra and southern Gujarat, Karnataka and Andhra Pradesh. They calculated the Heat wave Magnitude Index daily (HWMId) which combines the duration and magnitude of heatwaves, and the Standardized Precipitation Index (SPI), which defines meteorological drought from 1951 to 1981. Using this as the base, they compared it with the HWMId and SPI between the years 1981 and 2010. It was found that the area affected has increased from almost nothing in 1951, to nearly 4 percent by 2010. Nearly 18 percent of the country's area has been facing at least three days of temperatures above the 85^{th} percentile which is a cause of concern for agriculture and allied sectors. Chandran et al., (2017) characterized the Indian summer heat wave of 2015 using half hourly automatic weather station data for Andhra Pradesh, where maximum death was reported. The heat wave characterization using physiologically equivalent temperature (PET) revealed that extreme heat load conditions (PET >41) existed in all the four locations throughout May of 2015, with varying intensity. Higher relative humidity in coastal areas aggravated the situation.

In India, the months of March and April 2022 witnessed an unusual increase in maximum and minimum temperature with departure from mean exceeding by more than 5 ^{o}C at some places and appreciably above normal over most parts of the country. Northwest and central India experienced their hottest April in 122 years with average maximum temperatures reaching 35.9 and 37.8^{o}C, respectively. The increase in temperature coupled with lesser rain events due to weak activity of western disturbances has increased the overall irrigation water requirements. These heat wave conditions or large departure of maximum temperatures during this period is critical for winter (*rabi*) crops in general and wheat in particular. The reproduction and grain filling stages of most of the *rabi* crops occur during March. Therefore, an abnormal rise in temperature forces these crops to complete their life cycle early, thus affecting the grain yield. Similarly, horticultural crops, livestock, fisheries, and poultry sector got affected physiologically either directly or indirectly through increased demand for water during the heat wave/ heat stress periods.

The following sections elaborate on various aspects of heat wave characteristics, causes, damages and the way forward for Indian agriculture. Further, the technologies developed for minimising the impact of heat stress and the performance of these technologies during the heat waves of 2022 across various states is presented.

2. Heat wave

2.1. The science behind

A heat wave is a prolonged period of unusually high temperatures or hot weather, as felt by the general public and scientifically defined as the occurrence of temperatures greater than normal in a certain region. These are rare events that vary in character and impact even in the same location. A heat wave is defined by more than just a high daily maximum temperature. It also depends on how much it cools overnight. The maximum temperature will be achieved early the next day and will linger longer if the temperature remains high overnight. High levels of humidity and very light winds, if present, exacerbate thermal stress to people. Heat stress becomes a key element in health and infrastructure function when exceptionally high night and daytime temperatures continue. Hot nights make it more difficult to recuperate from the heat of the day during heat waves, putting extra stress on the living beings. Thus, although a heat wave is a meteorological event, it cannot be assessed without reference to human impacts.

Favorable conditions for heat wave in India

- Transportation / prevalence of hot dry air over a region (There should be a region of warm dry air and appropriate flow pattern for transporting hot air over the region). The synoptic situation favoring a heat wave is characterized by the presence of a powerful warm anticyclone covering the entire troposphere producing a blocking situation over a region. The pressure gradient is generally weak with associated light winds which tend to produce warm air advection.
- Absence of moisture in the upper atmosphere (As the presence of moisture restricts the temperature rise).
- The sky should be practically cloudless (To allow maximum insulation over the region).
- Large amplitude anti-cyclonic flow over the area. Heat waves generally develop over northwest India and spread gradually eastwards & southwards but not westwards (since the prevailing winds during the season are westerly to northwesterly). But on some occasions, heat wave may also develop over any region in situ under the favorable conditions.
- In addition, if the soil is very dry, all the solar radiation heat this, allowing the warming of the air in contact with the soil, promoting even higher temperatures.

What is the reason behind the current heat wave in India?

Anti-cyclones over western parts of Rajasthan in March and the absence of western disturbances had triggered the early and extreme heat waves. Anticyclones cause hot and dry weather by sinking winds around high-pressure systems in the atmosphere. The absence of periodic light rainfall and thundershowers, typical for this time of the year, is due to the lack of active western disturbances. Though north-west India saw at least four western disturbances in March and April, but were not strong enough to cause a significant change in the weather. The regions did not see any significant pre-monsoon activity from March 1 to April 20 in 2022 which compounded the severity of the successive heat wave events.

2.2. Heat wave declaration criteria

The World Meteorological Organization (WMO) has not adopted yet a standard and mathematically rigorous definition for heat waves. As per IMD, to declare heat-waves, the following criteria should be met at least in 2 stations in a meteorological sub-division for at least two consecutive days and it will be declared on the second day. Forecasts of heat-waves over a sub-division will be issued only if at least two stations in the sub-division are expected to experience such conditions.

Heat wave need not be considered till maximum temperature of a station reaches at least 40 ^{o}C for Plains and at least 30 ^{o}C for Hilly regions

- When normal maximum temperature of a station is less than or equal to 40 ^{o}C
  Heat wave: Departure from normal is 5 ^{o}C to 6 ^{o}C
  Severe heat wave: Departure from normal is 7 ^{o}C or more
- When normal maximum temperature of a station is more than 40 ^{o}C
  Heat wave: Departure from normal is 4 ^{o}C to 5 ^{o}C
  Severe heat wave: Departure from normal is 6 ^{o}C or more
- When actual maximum temperature remains 45 ^{o}C or more irrespective of normal maximum temperature, heat waves should be declared.

2.3. Heat wave characteristics

The main characteristics of heat waves are:

a) Frequency: the number of heat waves that occur every year

b) Intensity: increase in temperature along with wind speed, humidity

c) Duration: the length of individual heat wave in days

Types of heat wave

India Meteorological department has classified heat waves into two, *viz.,*

- Heat wave: either departure of daily maximum temperature is 4.5 to 6.4°C from the normal or when actual maximum temperature is in between 45 to 46.9°C
- Severe heat wave: either departure of daily maximum temperature is greater than 6.4°C or when actual maximum temperature is greater than or equal to 47°C Similarly, the Australian institute for disaster resilience has classified heat waves into three categories, *viz.,*
- Low intensity heat waves: more frequent during summer and are relatively easy to overcome
- Severe heat waves: less frequent and challenging for vulnerable sectors of the society
- Extreme heat waves: rare and may create problem for even healthy people. People who work outdoors have high risk of being affected by this.

2.4. Heat wave impacts on agriculture

2.4.1. Physical impacts

Water resources

Because of the close relationship between climate and water, heat wave intensifies the water crises in several regions, especially in arid and semi-arid areas. Excess water uses due to heat waves sometimes become detrimental in places suffering from water scarcity, especially in the context of climate change. Hatvani-Kovacs et al., in 2016 found that in Adelaide, almost one-fifth (19.18%) of peak water supply occurred only on heatwave days. As per National Institute of Disaster Management (NIDM), India, heat wave phenomena are silent killers as this increases the evaporation rate from the water resources. This increases demand for water both for general use and agricultural purposes. Indirectly, sustenance of crops and farm animals become difficult during this heat wave period (Guleria and Gupta, 2018).

Wild/Forest fires

Wildfires occurs in uncommon areas such as the Arctic (Watt, 2018). For instance, the U.S. West Coast, experienced the most dangerous and intense wildfires of the past decade (Dobuzinskis, 2018), while severe wildfires in Greece killed about 80 people (Smith, 2018). In addition, the extreme temperatures killed about 80 people in Japan, 70 people in Canada and 29 in North Korea (Haas, 2018). Heat waves account for more deaths than all other natural hazards combined in Australia (Coates et al., 2014). Forest Survey of India has estimated that 21.4 per cent (1,524,21 sq.km) area under forest is vulnerable to forest fires (www.indiaclimatedialogue.net).

Energy consumption

The energy sector is one of the key vulnerable industries in the wake of the projected rise in surface air temperature. Power outages are triggered by the disproportionally high electricity demand due to air-conditioning during heat waves. Nagar (2002) and Singh (2009) reported that the use of air conditioners in government and public sector offices in northern India is prohibited to avoid power shortages, especially during extremely hot days. Urban residents of India are exposed to health-related risks owing to the Urban Heat Island phenomenon which is instigated by more heat-absorbing surfaces, trapping of hot air between buildings and poor vegetation cover. Hence, this leads to an increased usage of air conditioners during heat wave conditions (Guleria and Gupta, 2018). According to Akpinar-Ferrand and Singh (2010), the usage of air conditioners in India would increase as an adaptation measure to heat wave conditions. Increase of air temperature under different population scenarios of India, the energy demand is projected to rise by 13,50,000 GWh in 2100 from 7,50,000 GWh in 2000.

2.4.2. Physiological impacts

Crops

High temperatures beyond certain optimum level reduce plant growth by affecting the shoot net assimilation rates, and thus the total dry weight of the plant is collectively termed as heat stress, which is one of the most important factors limiting crop production (Bita and Gerats, 2013). In higher plants, heat stress significantly alters cell division and cell elongation rates which affect both leaf size and leaf weight (Prasad et al., 2008). Heat stress induces changes in rate of respiration and photosynthesis and leads to a shortened life cycle and reduced plant productivity (Barnabas et al., 2008). As heat stress becomes more severe, a series of processes occur in plants which affect rates of important metabolic processes, including photosynthetic CO_2 assimilation, dark respiration and photorespiration (Sicher, 2015). As stress increases, closure of stomata slows down or stops CO_2 diffusion, consequent increase in photorespiration and ultimately inhibits growth processes of the plant. High heat-associated water uptake issue aggravates heat stress problem. There is a major slowdown in transpiration leading to reduced plant cooling and internal temperature increase. It also leads to inhibition of photosynthesis due to stomal closure (Lafta and Lorenzen, 1995). At the cellular level, as stress becomes more severe, there is loss of membrane integrity, cell membrane leakage and protein breakdown, and finally, if stress is severe enough, there can be plant starvation and death of the plant (Bita and Gerats, 2013). The heat stress also varies with the duration of exposure to high temperature, degree of heat and crop genotypes (Kim and Lee, 2011). The most affected stage is the reproductive growth, and the affected process is pollen grain development (Bita and Gerats, 2013). Sexual reproduction and flowering have been extremely sensitive to heat stress, which often results in reduced crop plant productivity (Thakur et al., 2010). In general, higher temperatures are associated with longer and intense radiation and higher water use. C3 plants generally have a greater ability for temperature acclimation of photosynthesis across a broad temperature range, CAM plants acclimate day and night photosynthetic process differentially to temperature, and C4 plants are adapted to warm environments (Yamori et al., 2014). CAM plants can also strengthen the CO_2 fertilization effect and the CO_2 anti-transpiring effect of C3 and C4 plants to a considerable extent. However, higher night temperature may increase dark respiration of plants and diminishing net biomass production. The reduction in crop yield in response to high temperature is due to disturbance of relationship of source and sink for assimilation of photosynthates (Johkan et al., 2011). The negative impact on yield of wheat and paddy in most part of India is due to increase in temperature, water stress and reduction in number of rainy days. For every 1°C increase in temperature, yield of wheat, soybean, mustard, groundnut and potato are expected to decline by 3-7% (Agarwal, 2009). In the year March 2004, temperatures were higher in the Indo-Gangetic plains by 3-6 °C, and as a result, the wheat crop matured earlier by 10-20 days. Presently, the Indian lowlands are the source of approximately 15% of global wheat production, but it is anticipated that climate changes will transform these into a heat-stressed, short-season production environment (Bita and Gerats, 2013). Many legumes and cereals show a high sensitivity to heat stress during flowering and severe reductions in fruit set, most probably as result of reduced water and nutrient assimilate transport during reproductive development (Young et al., 2004). In horticultural crops, temperature is the most important factor. In onion and tomato, bulb initiation and formation, its bulb and fruit size and qualities are affected by sudden rise in temperature. In most fruit crops, generally higher temperature decreased the day interval required for flowering and cooler temperature though required more days for flowering, but the number of flowers produced increased proportionally at this temperature (Srinivasarao et al., 2016). Optimum temperature range in citrus is 22–27 °C, and temperatures greater than 30 °C increased fruit drop. During fruit development when the temperatures exceed the optimum range of 13–27 °C with temperatures over 33 °C, there is a reduction in sugar content, acid content and fruit size in citrus (Hutton and Landsberg, 2000). These effects can lead to change in choice of orchid crop and geographical shift in cultivation of particular crop.

Livestock

Under heat stress, a number of physiological and behavioural responses of livestock vary in intensity and duration in relation to the animal genetic makeup and environmental factors (Freeman, 1987). In north Indian condition, livestock begins to suffer from mild heat stress when thermal heat index (THI) reaches higher than 72, moderate heat stress occurs at 80 and severe stress is observed after it reaches 90 (Upadhyay et al., 2009). Thermal stress lowers feed intake and reduces animal productivity in terms of milk yield, body weight and reproductive performance. Heat stress reduces libido, fertility and embryonic survival in animals. Enhanced heat dissipation during heat stress may also lead to electrolyte losses (Coppock et al., 1982). The poor reproductive performance in buffaloes especially during summer months is due to inefficiency in maintaining the thermoregulation under high environmental temperature and relative humidity (RH) as those have dark skin and sparse coat of body hair which absorb more heat along with poor heat dissipation mechanism due to less number of sweat glands (Marai and Haeeb, 2010). Genotype differences exist in HSP genes of indigenous breed and cross-bred dairy cattle indicating the relative heat stress tolerance phenotype of native indigenous cattle (Sajjanar et al., 2015). Weak symptoms of oestrous are exhibited in buffaloes during summer (Parmar and Mehta, 1994) which results in reduction of luteinizing hormone secretion and oestradiol production in anoestrus buffaloes (Palta et al., 1997) leading to ovarian inactivity, and also the survival of embryo in the uterus is impaired due to the deficiency of progesterone in the hot season (Bahga and Gangwar, 1988). This endocrine pattern may be partially responsible for the low sexual activities and low fertility in summer season in the buffaloes. The poor nutrition and high environmental temperature are the two major factors responsible for long anoestrous and poor reproductive performance in Murrah buffaloes (Kaur and Arora, 1984). Similarly heat stress in lactating dairy cows causes significant loss of serum Na^+ and K^+ and also reduces birth weights of Holstein calves (Collier et al., 1982). Heat stress in lactating animals results in dramatic reduction in roughage intake, gut motility and rumination which alters dietary protein utilization and body protein metabolism (Ames et al., 1980). High ambient temperature can adversely affect the structure and physiology of cells as well as functional and metabolic alterations in cells and tissues including cells of immune system (Iwagami, 1996). Temperature extremes can influence disease resistance in dairy calves (Olsen et al., 1980).

Poultry

Heat stress interferes with the broilers comfort and suppresses productive efficiency, growth rate, feed conversion and live weight gain (Yalcin et al., 1997) due to changes in behavioural, physiological and immunological responses. With rise in ambient temperature, the poultry bird has to maintain a balance between heat production and heat loss. This forces the bird to reduce its feed consumption by 5% to reduce heat from metabolism to a tune for every 1°C rise in temperature between 32–38°C (Sohail et al., 2012). In addition, heat stress leads to reduced dietary digestibility and decreased plasma protein and calcium levels (Zhou et al., 1998). Heat stress limits the productivity of laying hens, as reflected by egg production and egg quality, as the bird diverts feed metabolic energy to maintain its body temperature and also lower egg production and egg quality (Tinoco, 2001). The resulting hyperventilation decreases CO_2 blood levels, which may decrease eggshell thickness (Campos, 2000). Plasma triiodothyronine and thyroxine, which are important growth promoters in animals, adversely affect heat-stressed broiler chickens (Sahin et al., 2001). There are direct effects on organ and muscle metabolism during heat exposure which can persist after slaughter (Gregory, 2010); however, chronic heat exposure negatively affects fat deposition and meat quality in broilers (Imik et al., 2012). In addition, heat stress is associated with depression of meat chemical composition and quality in broilers (Dai et al., 2012). Chronic heat stress decreased the proportion of breast muscle, while increasing the proportion of thigh muscle in broilers (Lara and Rostagno, 2013) and protein content lower and fat deposition higher in birds subjected to hot climate (Zhang et al., 2012). Heat stress causes decrease in production performance, as well as reduced eggshell thickness and increased egg breakage (Lin et al., 2004). Additionally, heat stress has been shown to cause a significant reduction of egg weight, eggshell weight, eggshell per cent (Lara and Rostagno, 2013) and all phases of semen production in breeder cocks (Banks et al., 2005). In hotter climate, immune-suppressing effect of heat stress is more on broilers and laying hens (Ghazi et al., 2012) and will alter global disease distribution (Guis et al., 2012) through changes in climate.

Fisheries

Climate change will affect fisheries and aquaculture via acidification, changes in sea surface temperatures and circulation patterns, frequency and severity of extreme events and sea level rise and associated ecological changes (Nicholls et al., 2007). With global warming, tropical and subtropical areas will experience more reduction in ecosystem productivity than temperate and polar ecosystems (Shelton, 2014). However, inland aquaculture will be affected by changing temperatures, water scarcity and salinization of coastal waters (Shelton, 2014). Increased temperature may affect the distribution pattern of some fish species where some of them may be migrate to the higher latitude for cooler place (Barange and Perry, 2009). Changes in temperature will have direct effects on swimming ability (Van-der-Kraak and Pankhurst, 1997). Sea level rise due to glacier melting will destroy the mangrove forest as well as destroy the marine fish nursery ground. With rising temperature, the physiological activity of the fishes also increases with increase in oxygen demand, whereas the solubility of the oxygen in water is inversely related to temperature and salinity (Chowdhury et al., 2010). Marine fisheries sector is already overexploited due to overfishing (Hilborn et al., 2003) and inland fisheries already affected due to pollution, habitat alteration and introduction of alien species/culture fish (Allan et al., 2005). The effects of increasing temperature on freshwater and marine ecosystems where temperature change has been rapid are becoming evident, with rapid poleward shifts in distributions of fish and plankton (Brander, 2007). High temperature can cause stratification leading to algae blooms and reduced levels of dissolved oxygen. Tilapia can tolerate dissolved oxygen concentration as low as 0.1–0.5 mg L^{-1} but only for a limited period (Bell et al., 2011).

2.5. Historical heat wave events in the world and India

Table 1: Major heat waves across the world and India since 1990

World				India		
Year	Country	Duration/ Season		Year	Month	Temperature
1995	Chicago, USA	12-16 July		1995	June	45.5 °C
1999	USA	Summer		1998	May–June	49.5 °C
2003	Europe	Summer		2002	April–May	49.0 °C
2009	Australia	Jan-Feb		2015	May–June	49.4 °C
2013	Australia, China	NA		2016	April–May	51.0 °C
2018	Japan	Mid-July		2019	May-June	50.8 °C

2.6. Heat wave prone districts of India

Higher daily peak temperatures and longer, more intense heat waves are becoming more frequent globally due to climate change. India too is feeling the impact of climate change in terms of increased instances of heat waves which are more intense in nature with each passing year, and have a devastating impact on human, agriculture, livestock and fisheries. Bal and Minhas (2017) have reported several parts of the country experiencing heat waves across the regions (Table 2).

Table 2: Most vulnerable areas of India affected by heat waves

March to July with peak temperatures in April, May, 2nd fortnight of October	South India: Khammam and Ramagundam (Telangana), Kalburgi and Bangalore (Karnataka)
	Eastern India: Bankura and Kolkata (West Bengal) and Bhubaneswar, Titlagarh and Jharsuguda (Odisha)
	North India: Punjab, Allahabad and Lucknow (UP), Gaya (Bihar), Delhi
	West India: Vidarbha and Marathwada (Maharashtra), Churu (Rajasthan), Ahmadabad (Gujarat)
	Central India: Jashpur (Chhattisgarh), Harda (Madhya Pradesh)

Source: Bal and Minhas, 2017

However, to re-assess the vulnerable regions (on district scale) of the country to heat wave, IMD gridded data (1991-2019 and 2011-2019) was analysed by following the IMD heat wave guideline. Districts vulnerable to heat waves were identified separately for plain region and hilly region (Tables 3 & 4). It was found that, number of districts with more than 4 days/year in plain region and more than 5 days in hill region varied during 1991-2019 and 2011-2019 period.

Table 3: Heat wave experienced for more than 4 days per year in districts (plain region) of India

State	District	Average days of heat wave per year	
		1991-2019	2011-2019
Rajasthan	Churu	4.79	5.33
Rajasthan	Karauli	4.14	4.78
Rajasthan	Dholpur	4.38	4.67
Madhya Pradesh	Morena	4.41	4.56
Madhya Pradesh	Gwalior	4.31	4.44
Rajasthan	Bikaner	4.07	4.44
Haryana	Fatehabad	4.48	4.33
Rajasthan	Dausa	4.00	4.33
Rajasthan	Bharatpur	4.28	4.22
Rajasthan	Sikar	4.48	4.22
Haryana	Sirsa	4.45	4.11
Punjab	Barnala	4.66	4.11
Punjab	Muktsar	4.79	4.11
Rajasthan	Ganganagar	4.24	4.11
Rajasthan	Hanumangarh	4.45	4.11
Uttar Pradesh	Jhansi	4.07	4.11
Madhya Pradesh	Datia	4.34	4.00
Punjab	Jalandhar	4.21	4.00
Punjab	Kapurthala	4.38	4.00
Punjab	Mansa	4.55	4.00
Punjab	Moga	4.52	4.00
Punjab	Taran Taran	4.38	4.00

Source: *AICRP on Agrometeorology*

Table 4: Heat wave experienced for more than 5 days per year in districts (hill region) of India

State	District	Average days of heat wave per year	
		1991-2019	2011-2019
Jammu & Kashmir	Kupwara	17.21	17.33
	Bandipora	16.69	17.11
	Baramula	16.69	17.11
	Ganderbal	16.69	17.11
	Srinagar	16.69	17.11
	Northern Areas	15.07	15.67
	Badgam	14.97	15.56
	Pulwama	14.97	15.56
	Kishtwar	13.72	14.11
	Anantnag	13.14	13.78
	Kargil	11.69	11.56
Himachal Pradesh	Una	8.28	7.44
	Bilaspur	7.07	6.22
	Hamirpur	7.07	6.22
	Kangra	7.14	6.11
	Solan	6.07	6.00
	Sirmaur	5.59	5.67
	Mandi	6.03	5.44
	Shimla	5.52	5.44

Source: *AICRP on Agrometeorology*

3. Trails of heat wave 2022 in India

3.1. Causes of heat wave 2022

Heat waves are not uncommon to Indian sub-continent during March to May. However, what made heat wave of 2022 deadliest is that it started very early and extended for a longer period. Weather experts have attributed the high temperature across the country to the absence of periodic light rainfall and thundershowers, typical for this time of the year, due to the lack of active western disturbances. In addition, anti-cyclones over western parts of Rajasthan in March and the absence of western disturbances had triggered the early and extreme heat waves. Anticyclones caused hot and dry weather by sinking winds around high-pressure systems in the atmosphere.

Northwest India recorded more than four western disturbances in March and April, but were not strong enough to cause a significant change in the weather. The region also did not receive any significant pre-monsoon rainfall from March 1 to April 20, which compounded the severity of the successive heat wave spells. The effect gradually progressed downwards to central India.

3.2. Location specific heat wave conditions observed at 6 locations across north and central India during February-March 2022

In general, higher maximum and minimum temperatures during February and March leads to yield loss in winter season crops especially wheat, as it affects the anthesis and grain filling. Higher temperatures in April and May also affect few agricultural and horticultural crops. This year the heat wave conditions impacted several parts of the country. Before going for detail characterization of temperature and rainfall scenario across the country, temperature and rainfall data recorded at six AICRP on Agrometeorology (AICRPAM) locations (Ludhiana, Samastipur, Raipur, Faizabad, Kanpur and Jabalpur) representing north and central India were analysed (Fig. 1a and 1b) to look at the departure of temperature and rainfall from the normal (1991-2020).

At Ludhiana, the weekly mean maximum (Tmax) and minimum temperatures (Tmin) was consistently higher than the normal during the entire March month, which coincides with the grain filling/development stage of wheat. The deviation of weekly mean Tmax and Tmin ranged +2.2 to +5.6 °C and +2.4 to +5.8 °C, respectively. At the same time, there was a marked reduction in rainfall during Feb-Mar (a reduction of 48.5 mm compared to the normal). Both of these changes may cause considerable yield reduction in wheat. The deviation of maximum day time temperature ranged +5.5 to +6.4 °C during 11-15 standard meteorological weeks (SMW), while the minimum night time temperature varied +2.3 to

+5.8 °C. No rainfall was recorded at Ludhiana during 10-20 SMWs, which might have aggravated the heat wave conditions there. During this time, a rainfall deficit of 55 mm was recorded.

The situation was more or less similar in Uttar Pradesh (Kanpur and Faizabad) but, with lesser magnitude. It was observed that the deviation of weekly mean Tmax was more than 3 °C for three consecutive weeks (12-31 March) at Kanpur; and two consecutive weeks at Faizabad (19-31 Mar). Again, the deviation of Tmax ranged +2.3 to +2.6 °C during 15-16 SMWs at Faizabad. At Kanpur, the Tmin was higher by 2.7 °C than normal during 11-12 SMWs. Higher than normal values of Tmin (> 2.5 °C) was recorded at Faizabad during 11-12 and 19-20 SMWs. Kanpur and Faizabad did not receive any rain during 6-20 SMWs, except during 18th SMW at Faizabad, during which it received 19.2 mm rainfall. Kanpur recorded a rainfall deficit of 37 during this period.

At Samastipur, the deviation of weekly mean Tmax was higher than normal by 2.4 °C during 19-25 Mar only. Mean weekly Tmin at Samastipur deviated +2.5 to +4.2 °C during 12-15 SMW. During 10-17 SMWs, Samastipur received 18 mm lesser rainfall compared to the normal, which might have aggravated the heat stress. However, during 18-20 SMWs, Samastipur received 67 mm higher rainfall compared to the normal, which resulted in below normal thermal regime.

Jabalpur recorded a higher maximum temperature more than normal by +2.5 to +3.7 °C during 11-15 SMWs. At the same time, it received below normal rainfall (46 mm deficit) during a longer stretch (6-20 SMWs).

At Raipur, maximum and minimum temperatures were higher than normal by 2.0 – 3.0 °C during 13-15 SMWs. There was no rainfall during 7-15 SMWs, which is quite an extended period. The combined effect of higher temperature without any rainy event might have negatively impacted the agriculture and allied sectors.

This analysis with data from six AICRPAM locations clearly indicate that the year 2022 experienced abnormally dry weather with higher maximum and minimum temperatures during February to May. These preliminary findings encouraged us to look at the temperature and rainfall status of the north and central part of the country, the region significantly receives rain due to western disturbance especially during December to April.

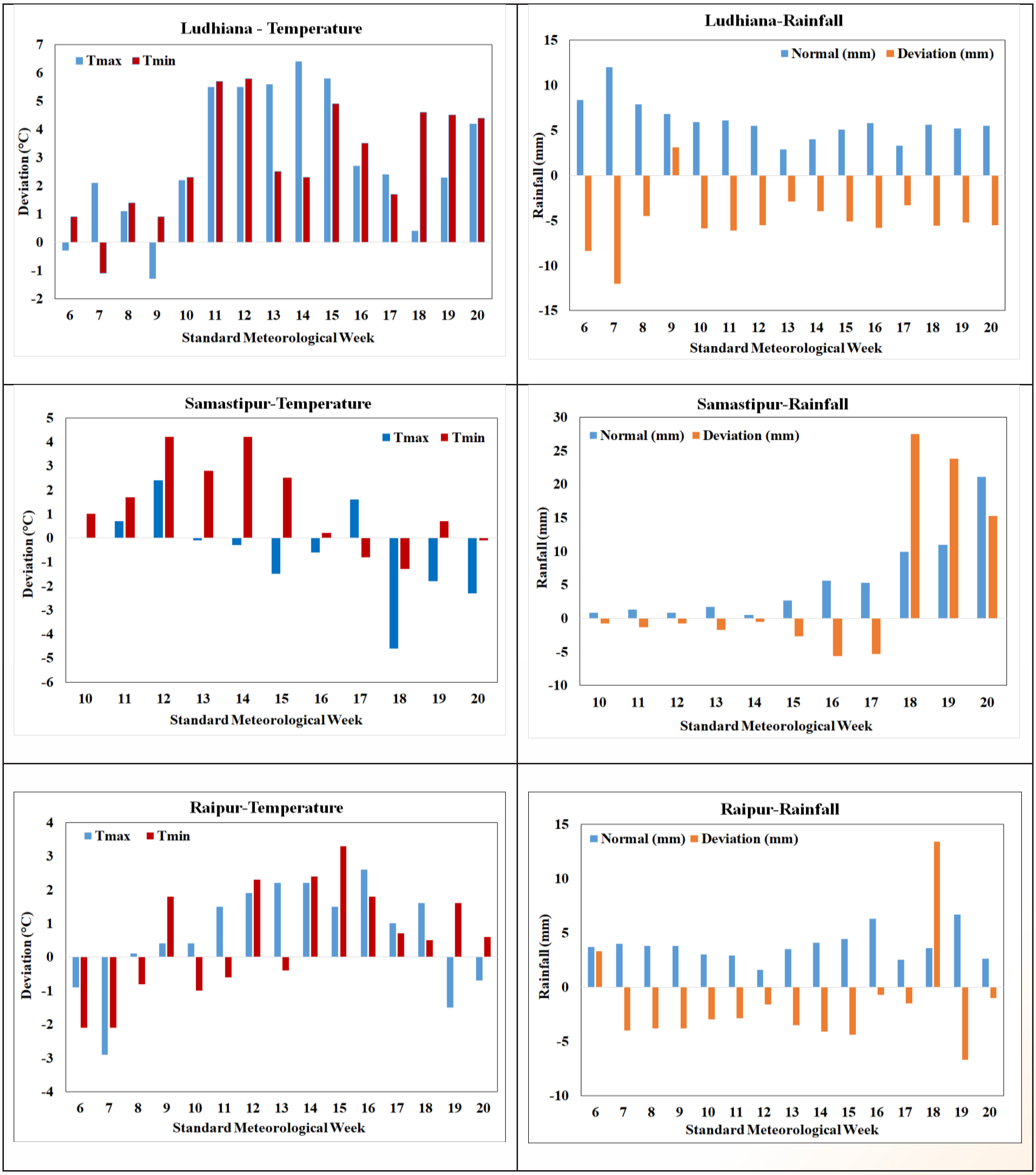


Fig.1a. Departure of temperature and rainfall at Ludhiana, Samastipur and Raipur during Feb-May 2022

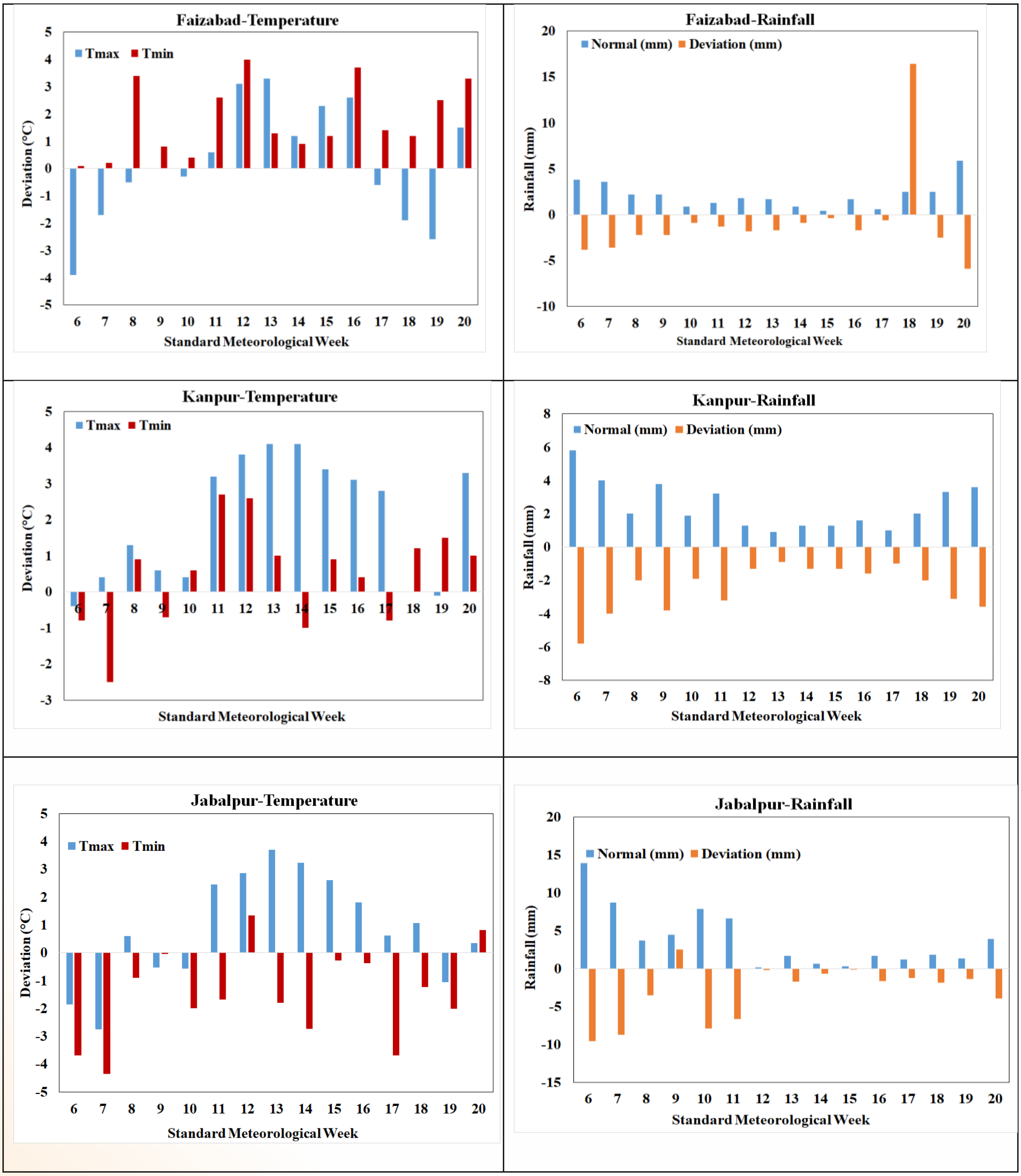


Fig.1b. Departure of temperature and rainfall at Faizabad, Kanpur and Jabalpur during Feb-May 2022

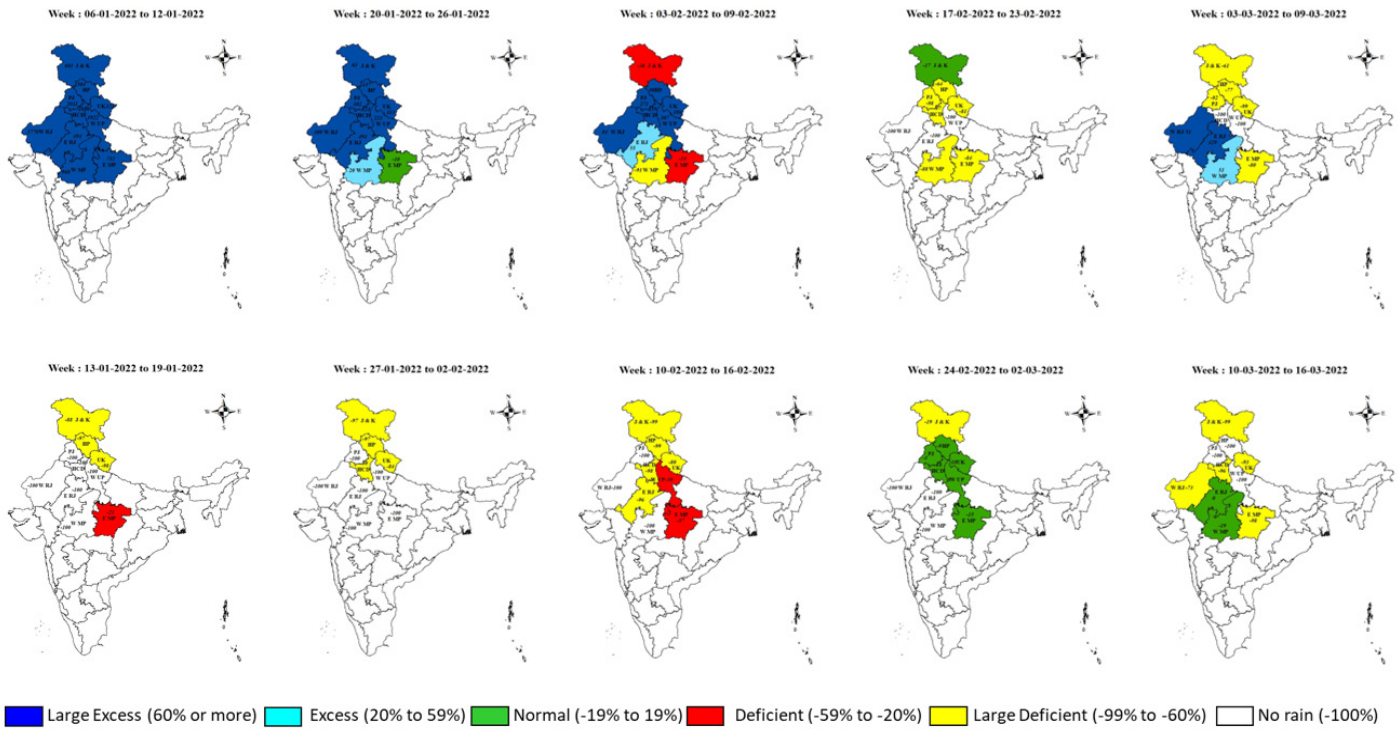
3.3. Impact of subdued western disturbances on aggravating heat wave conditions over northern India

A combination of low rainfall and high temperature has a more serious impact on agriculture than when these occur separately. The yield of wheat crops decreases substantially when high temperature and low rainfall occur together (Sharma and Majumdar, 2017).

Rainfall during 01 March to 18 April 2022 was largely deficient (-99% to -60% of LPA i.e. 1971 to 2020) across the wheat growing areas of the country. This might have aggravated the negative impacts of higher maximum and minimum temperatures during the critical reproductive stage of wheat. North and North-western parts of the country normally get the winter rainfall during December to April months due to passing Western Disturbances from the extra tropics. These rains are most beneficial to the standing rabi crops like Wheat, Mustard, Potato and chickpea crops and other vegetables. These western disturbances also bring the cold weather and chilling temperatures between December end and January, which particularly helps wheat crop to have more tillering hence the enhanced yields.

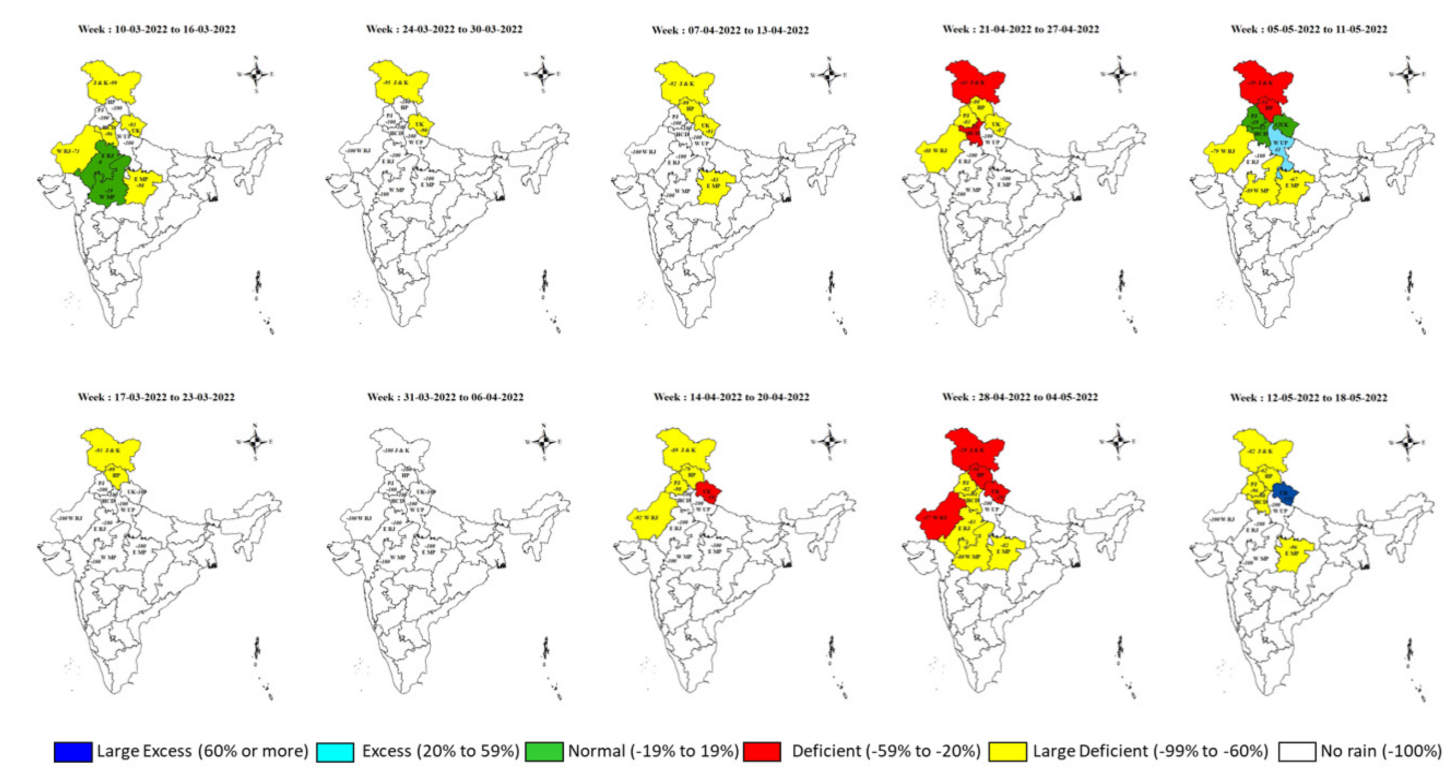
During 2022, from 4^{th} week of February to 3^{rd} week of May, it was observed that unusually the winter rains have missed in the Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Punjab, Haryana-Chandigarh & Delhi, Western Uttar Pradesh, West and Eastern Rajasthan, West & East Madhya Pradesh meteorological subdivisions (Fig. 2a and 2b). The rainfall deviations have almost reached -100% from March 17-23 onwards till 20-26 April 2022. Later, a slight increase in rainfall was observed but still deficient conditions of rainfall prevailed with rainfall deviation ranging from -62 to -100% was recorded during May 12 to 18 (Fig. 3). This triggered dryness in the environment and flow of hot desert winds caused the maximum temperatures to reach heat wave conditions.

Weekly temperature deviation maps of meteorological subdivisions Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Punjab, Haryana-Chandigarh-Delhi, West Uttar Pradesh, West Rajasthan, East Rajasthan, West Madhya Pradesh and East Madhya Pradesh were prepared from 3 March to 25 May 2022 (Fig. 4). Higher temperatures were observed in almost all the subdivisions from 3-9 March to 12-18 May. Maximum deviation in temperature was observed during the 7-13 April in Uttarakhand (10.8 ^{o}C), Himachal Pradesh (9.8 ^{o}C), Jammu Kashmir (9.1 ^{o}C), Haryana, Chandigarh & Delhi (9.0 ^{o}C) and Punjab (8.0 ^{o}C) (Fig. 5). This heatwave continued up to 12-18 May and subsided in the following week with the onset of a western disturbance over this region.



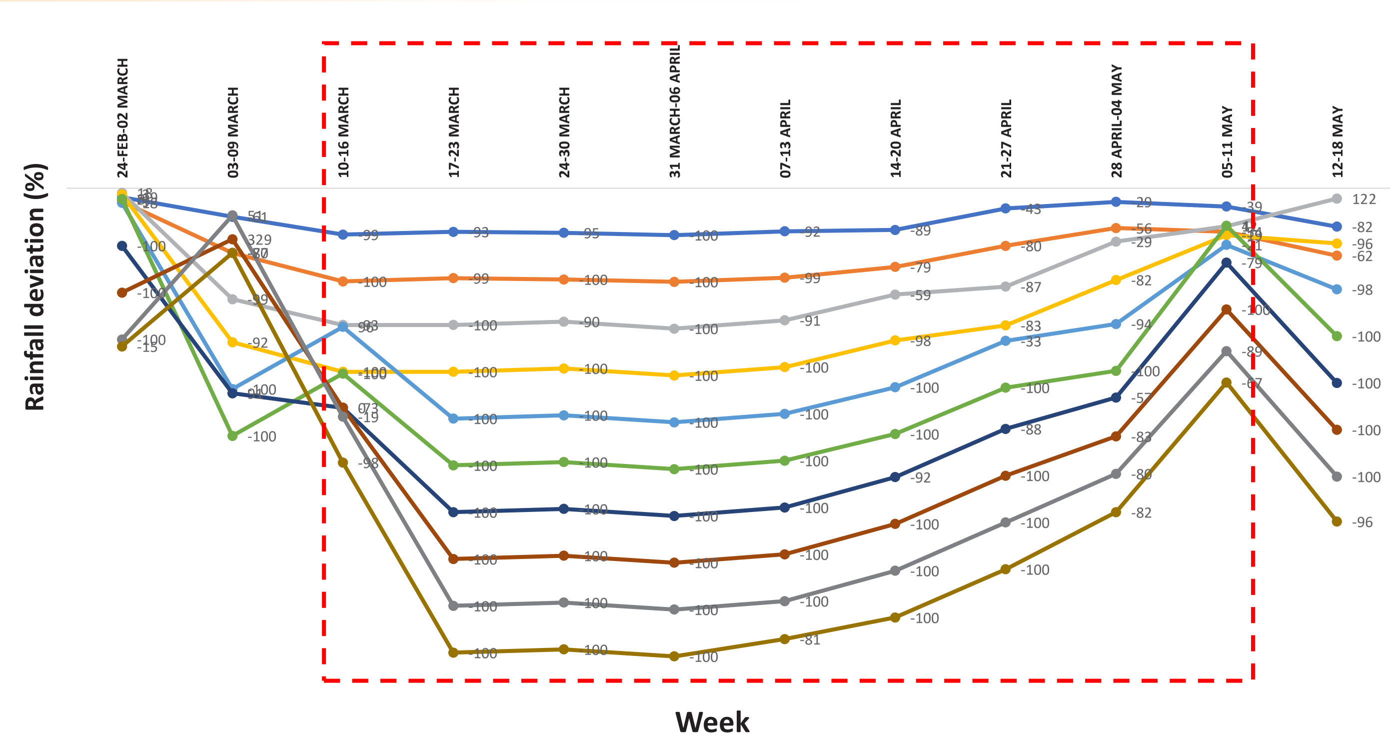
Source: *AICRP on Agrometeorology*

Fig. 2a: Weekly rainfall deviation in 10 meteorological subdivisions (northern and central India) during January-May 2022



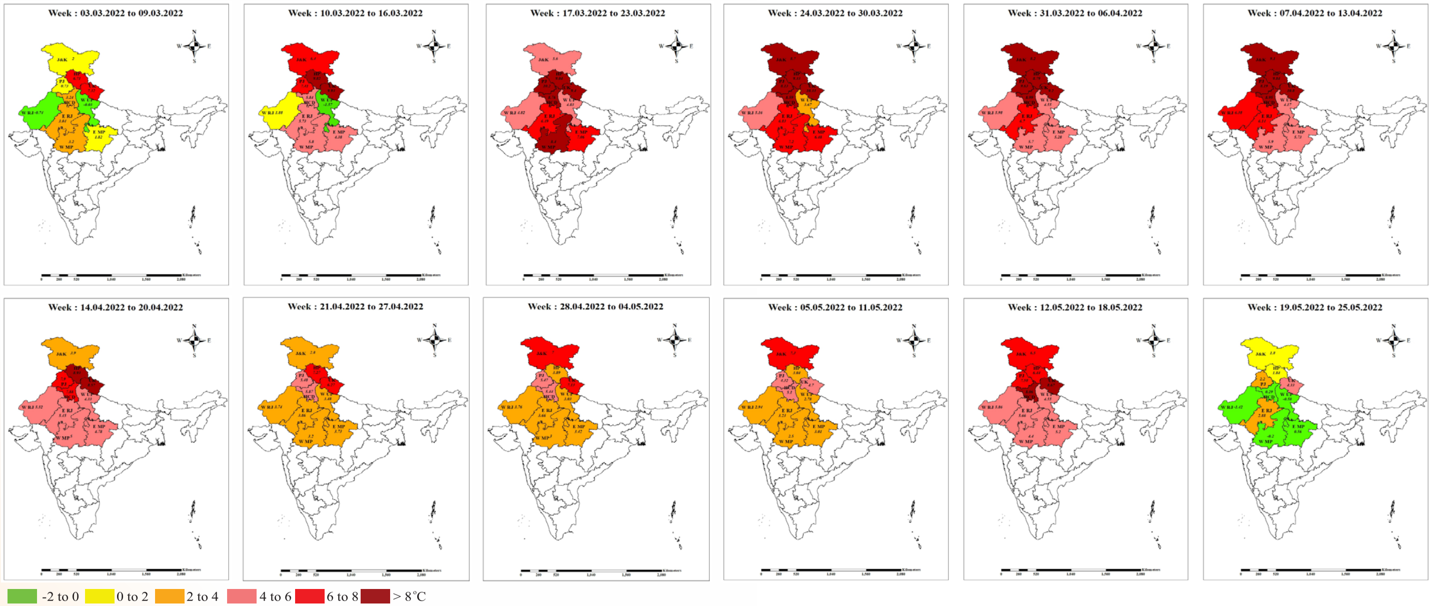
Source: *AICRP on Agrometeorology*

Fig. 2b: Weekly rainfall deviation in 10 meteorological subdivisions (northern and central India) during January-May 2022



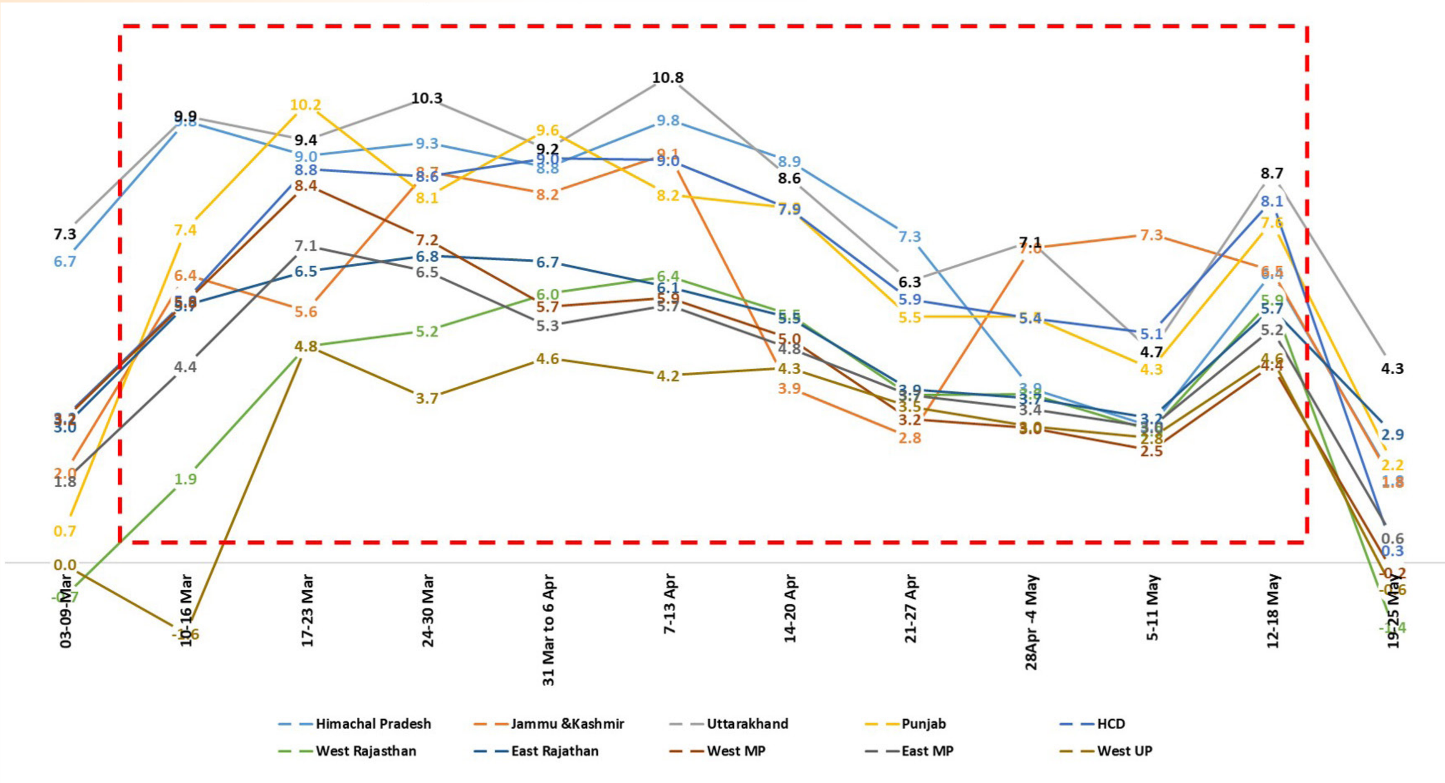
Source: *AICRP on Agrometeorology*

Fig 3: Weekly rainfall departure during February-May 2022



Source: *AICRP on Agrometeorology*

Fig 4: Weekly mean maximum temparature departure in 10 meteorological subdivisions (northern and central India) during January-May 2022



Source: *AICRP on Agrometeorology*

Fig 5: Weekly mean maximum temperature departure in different meteorological subdivisions during March-May 2022

4. Heat wave impacts on agriculture during 2022

During the months of March and April 2022, several states have recorded higher minimum and maximum temperatures. These extreme temperatures have considerable impact on crop growth and yield and caused substantial economic damage. The observed heat wave effects on crops, horticulture, livestock, poultry, fisheries and groundwater are elaborated in this section.

4.1 Crops

Increase of minimum and maximum temperatures during March and April 2022, resulted in dry winds, high evapotranspiration and moisture stress. Several districts of Punjab were affected with heat wave events due to increase in temperature which has resulted in yellowing and shriveling of wheat grain, forced maturity, resulting in reduction in yields up to 25%. Increased whitefly infestation, poor vegetative growth and poor pod setting was observed in green gram causing reduction in yields up to 20%. Retarded growth and fall army worm attack was observed in maize, led to reduction of yields up to 18% in maize in Faridkot, Bathinda and Gurdaspur districts of Punjab. Increase in maximum temperature up to 5°C over normal was observed in Kullu district of Himachal Pradesh, effected the *rabi* crops. Heat wave caused poor vegetative growth and poor pod setting in chickpea, wilting and forced maturity in wheat, resulting in yield reduction in these crops. Several districts in Haryana were also affected with heat wave, which resulted in wilting and shriveling of grains in wheat and chickpea. Heat wave led to reduction of wheat yield up to 10 to 15% particularly in the late sown wheat and up to 19% in chickpea. Extreme temperature in Datia, Morena and Tikamgarh districts of Madhya Pradesh resulted in early maturity and lower grain weight of wheat and chickpea.

Impact of heat wave on wheat and chickpea in the states of Punjab and Madhya Pradesh

Wheat and late sown mustard were also got affected in several districts of Uttar Pradesh. Heat waves resulted in reduction of wheat yield by 11 to 21% in Baghpat and Kushinagar, 9 to 21% in Gorakhpur, 15 to 20% in Gonda and 32 to 34% in Jhansi. In Gorakhpur and Kushinagar districts of Uttar Pradesh, mustard and cow pea yield were reduced by 14 to 18% and 9 to 11%, respectively. Similarly, several NICRA villages in Rajasthan experienced heat wave and recorded yield losses up to 4 to 5 q/ha in wheat and 2 to 3 q/ha in mustard compared to normal.

4.2 Horticulture

4.2.1. Fruits

In Himachal Pradesh, viral infection and petal fall in both royal and spur type apples were observed. Similarly, low fruit set in plum; malformation, flower and fruit drop in mango was observed in Chamba, Kullu and Bilaspur districts of Himachal Pradesh.

Impact of heat wave on apple in Chamba and Kullu districts and mango in Bilaspur district of Himachal Pradesh

Increase in temperature led to high incidence of insect pests, sun burn, less fruit set in lemon, scorching and fruit dropping of Kinnow in Faridkot and Bathinda districts of Punjab. Heat waves resulted in reduction of Kinnow yield up to 23% in Bathinda and Faridkot districts.

Scorching of leaves of lemon and fruit drop in Kinnow in Bathinda and Faridkot districts of Punjab

Mango orchards in several districts of Madhya Pradesh, Jharkhand and Bihar were affected. Severe flower and fruit drop, reduction of fruit size was observed in mango in Tikamgarh district of Madhya Pradesh, Godda district of Jharkhand and Darbhanga district of Bihar. The Kesar and Alphanso varieties of mango which are grown in Konkan and Marathwada regions, got impacted by Tauktae cyclone, very low temperature, isolated unseasonal rainfall and fog in December-January and high temperature in the month of March resulting in lower yields.

Drying of leaves and plants in guava, lemon and mango; flower and fruit drop in papaya was observed over Bhilwara and Sirohi districts. Flower and fruit drop in pomegranate and lemon was observed in Pali district of Rajasthan.

Impact of heat waves on lemon, mango and pomegranate in different districts of Rajasthan

4.2.2. Vegetables

Extreme temperatures resulted in poor vegetative and stunted growth in vegetables like cabbage and cauliflower in several districts of Himachal Pradesh. Reduction of vegetable yields up to 50% compared to normal was observed in Chamba district of HP. Similarly, heat waves in several districts of Jammu and Kashmir resulted in poor vegetative growth, reduction of plant canopy, severe flower and fruit drop in several vegetable crops, early drying of cucumber, bitter gourd, cracking and scalding in tomato, caused reduction of fruit size and weight loss by 40 to 50%. Heat waves also led to reduction of cucumber and bitter gourd yield by 30 to 50%, and more than 40% in tomato compared to normal situation in Kathua and Bandipora districts of Jammu and Kashmir.

Reduction in plant canopy, severe flower and fruit drop, forced ripening of fruits, fruit burning and sunscald in tomato, reduction of fruit size and weight by 40% was observed. Heat wave resulted in reduction of tomato yield by 40 to 50% in Bathinda and Sirsa districts of Punjab and Haryana, respectively.

Impact of increased temperature in vegetables in Bathinda district of Punjab and Sirsa district of Haryana

Increased maximum temperature led to stunted plant growth, early onset of reproductive phase, high infestation of white flies, wilting and scorching of okra, reduction of fruit size and weight by 40 to 50% due to forced ripening of fruits, cracking and sunscald symptoms in tomato, and reduction of bulb size of onion by 30% was observed in Uttar Pradesh. Due to heat wave, yields of okra, tomato and onion was reduced by 20 to 25% in Gorakhpur, 25 to 40% in Gonda and Jhansi and 25 to 30% in Kushinagar, respectively as compared to normal situation.

4.3 Livestock

Hot weather increased the body temperature of livestock and milch animals by 0.5 to 3.5°C. Increase in temperature led to increase of water intake and loss of appetite in milch animals resulting in reduction in milk yield in Kathua district of Jammu and Kashmir. In Bathinda and Faridkot districts of Punjab, dairy animals faced the problem of increased calf mortality and skin infection. Due to the high temperature, milk production got reduced in dairy animals in Tikamgarh district of Madhya Pradesh. In Godda district of Jharkhand, livestock lost appetite and recorded higher body temperature, which led to reduced milk yield up to 15%. In Gorkhpur and Jhansi districts of Uttar Pradesh, heat wave resulted in less availability of green fodder for milch animals and reduction in milk yield up to 11% was noticed.

4.4 Poultry

Heat wave reduced the egg production up to 10% in layers during the initial 2 days of heat wave and then the drop was maintained at about 4-7% during the subsequent days based on the ambient temperature. The body weight loss in broiler chicken was about 500-600 g/bird compared to the prescribed standard (about 2 kg at day 35). During the summer season, the reduction in performance was closely associated with significant reduction in feed intake (15-20% in broilers and up to 35g/bird/day in egg laying chicken). The reduced feed intake also associated with reduced egg weight by about 3-5g.

Heat wave increased the mortality of layers up to 3.5-4.0% per month against the regular mortality of 0.5% per month. Similarly, in broiler chicken heat wave increased mortality up to 8%. Immune suppression was attributed as the cause for disease outbreak and mortality during the acute heat stress.

Impact of heat wave on poultry in TDC-NICRA districts of J&K and Punjab

4.5 Fisheries

Warming of water impacts fish diversity, distribution, abundance and phenology. Most fish species have a narrow range of optimum temperatures related to their basic metabolism and availability of food organisms. Even a difference of 1°C in seawater affect their distribution and life processes. Heat wave affects the fish farming in plain areas due to water scarcity.

Rainbow trout farming is prominent in the coldwater regions of India. The total trout production is approximately 2500 tonnes in different hill states. The ideal water temperature for production of trout is one that does not rise too high beyond 18°C. The best possible water supply is one in which the temperature remains in the range of 13-18°C for longer period. The temperature of water supply should never exceed 18°C. Increasing water temperature directly affects fish as well as reduces the dissolved oxygen content in pond water.

4.6 Groundwater

The extreme temperatures or heat waves increased the transpiration and resulted in increase in the number of irrigation for crops. At several locations, heat wave enhanced consumption of water resulting in greater withdrawal of groundwater causing the depletion of the groundwater and greater use of electricity resulting in higher emissions.

4.7 Humans

Heat waves posed severe challenges to human health and have created public health emergencies. Prolonged heat exposure causes heat strokes and heat exhaustion and causes various respiratory and cardiovascular diseases. Livelihoods of poor and marginal farmers is negatively impacted due to the loss of working days. Apart from the impact on farmers, heat waves disproportionately impact the lives of agricultural laborers, small street vendors, brickmaking workers, construction workers, and rickshaw pullers. In India, it is estimated that heat wave results in loss of working hours by 9.04% of agriculture workers, 5.29% of industry workers, 9.04% of construction workers and 1.48% of other service workers by 2030 (International Labour Organization, 2019). Heat waves have an adverse impact on these workers' productivity and thereby affect the overall economy of India.

5. Technologies/strategies for heat wave management

5.1 Crops

Increase in temperatures in many parts of India has triggered the heat wave conditions during March-April 2022, impacting the yields of *rabi* crops particularly wheat. The prevailing maximum temperatures have increased by 4-5°C compared to the previous year at several locations. Wheat crop experienced heat stress during 3rd and 4th weeks of March where the crop is at milking stage and resulted in shriveled grains, affecting both quality and weight of output.

In India, wheat crop was sown in an area of about 31 million ha during 2021-22 crop season. Out of this approximately 75 per cent lies under timely sown (planted on or before November 15). Timely sown crop was in excellent condition under NWPZ (Haryana, Punjab, West UP) and NEPZ (east UP, Bihar and West Bengal) till second week of March but suddenly rise in temperature affected the crop. The late sown crop (in about 6-7 million ha area) got affected severely.

Table 5: Wheat varieties possessing heat tolerance traits (HSI<1.0) for different zones of India

Zone	Varieties
North Western Plains Zone (NWPZ)	DBW327, DBW332, DBW 303, DBW 187, WH 1270, DBW 222, HD 3226, PBW 723, HD 3086, JKW261, HD 3298, HI 1621, HD 3271, PBW-725, PBW 757, DBW 173, DBW 90, WH 1124, DBW 71, HPW 368, HD 3059, DBW296, HUW838, HI 1628, NIAW 3170, HD 3237, HI 1620
North Eastern Plains Zone (NEPZ)	DBW222, HD 3249, DBW 187, NW 5054, K 1006, DBW 39, Raj 4120, K 307, HD 2824, HI 1621, HD 3271, DBW 107, HD 3118, HD 3293, DBW 252, HI 1612, K 1317, HD 3171
Central Zone (CZ)	**Bread Wheat:** DBW187, GW513, HI1636, HI 1544, GW 366, GW 322, JW-3288, GW 273, HI 1634, CG 1029, MP 3336, MP 1203, HD 2932, MP 4010, DBW 110, MP 3288, MP 3173, HI 1531, HI 1500 **Durum Wheat:** HI8823(d), HI 8759(d), HI 8737(d), HI8498(d), DDW 47(d), UAS 466(d)
Peninsular Zone (PZ)	**Bread Wheat:** DBW 168, MACS 6478, UAS 304, MP1358, NIAW 3170, GW366, HI 1605 **Durum Wheat:** DDW48, MACS 3949(d), NIDW 1149 (d), MACS 4058(d), GW 1346(d), HI 8777(d), UAS 446 (d)

Various technologies are available to minimise the yield loss in wheat due to heat wave and some of them are transferred to farmers' fields. Several heat tolerant wheat varieties, PBW 803, DBW 187 and DBW 222 can tolerate high temperatures and can produce normal yields compared to local variety HD-3086 (Table 5). Technologies such as residue management of rice by various machines enable timely sowing of wheat. Direct seeding of rice can result in early maturity by 10 days which can enable timely sowing of wheat. Spray of KNO_3 @ 0.5% at boot leaf and anthesis stages can minimise the yield loss. Providing additional irrigation through effective methods during heat stress period can alleviate the stress with optimal water use.

Wheat variety HPW 368 in Kullu district

Wheat variety JW-3288 in Satna district

Wheat variety PBW-725 in Faridkot district

5.2 Horticulture

In Uttar Pradesh, about 5°C temperature increase in March from the normal, has resulted in mango flower drop and lots of *Jhumka* problem in mango due to poor pollination. Due to recent increase in temperature in Vidarbha region, citrus orchards witnessed fruit drop in several areas. In order to mitigate these problems, ICAR-Central Citrus Research Institute (CCRI) and ICAR-Central Institute for Sub Tropical Horticulture (CISH) have issued advisories for orchard growers to be followed during the months of April-May.

- If the orchard is more than 6 years age, 150-240 litres water/day/tree is required. Drip irrigation with organic mulch should be preferred. In conventional method of irrigation, time of irrigation is to be prolonged.
- Mulching helps in maintaining the soil moisture for long period. Mulch the soil with paddy straw or locally available organic or inorganic material. Black polythene material would be essential to prevent excess evaporation.

Mulching in orchard

- Foliar spray of 2-4% Kaolin is recommended depending on the severity to reduce the transpiration. Two foliar spays of Potassium nitrate 1 – 1.5% may also be done at an interval of 15 days during April-May.

- Apply Copper oxychloride 50 WP @ 25g/10 litre water for controlling fruit blight infection.
- Water stress conditions often aggravate the mite problem during these months. Therefore, foliar application of Dicofol 18.5EC @27 ml or Propargite 57EC @ 20 ml or Ethion 50EC @20 ml in 10 litre water twice at 15 days interval is necessary during summer, particularly during the stress in late summer.
- The sudden rise in temperature has also triggered new vegetative flush in mango, which acted as powerful sink for assimilates than the fruits resulting severe fruit drop in mango. The fruit set also reduced due to minimal activity of pollinators owing to heat wave.
- Frequently irrigate citrus field to counter the effect of heat waves was suggested at many locations.

Technological options to mitigate the effect of heat wave on vegetables

Tomato

- Maintain soil moisture near to field capacity by frequent irrigation. In drip irrigated crop, system need be operated twice for half-an hour daily (morning and evening). Under surface irrigation system, tomato crop should be irrigated twice a week with 4 cm water each time.
- Use organic mulch of 5-7 cm thickness around the plant to maintain congenial soil and micro-climate nearby plants.
- Use 3-4 rows of maize as border crop to reduce the impact of heat wave on main crop. Border crop should be repeated at every 20-25 m distance.
- Two sprays of plant growth substances such as Salicylic acid (250 µmol/ lit) or Sodium nitroprusside (SNP @ 25 µmol/ lit) is also helpful in improving fruit set and size.
- Cultivate high temperature tolerant hybrids such as, Kashi Tapas and Kashi Adbhut.

Cucurbitaceous vegetables (Sponge gourd, Cucumber, Muskmelon)

- Soil moisture management, application of organic mulch and maize as border crop as in the case of tomato is recommended.
- Use shading net of 50% (1.5-2.0 m above the field surface) to reduce the intensity of solar radiation.
- Make 2-3 sprays of pesticides (Lambda Cyhalothrin 2.5% EC @ 1 ml/lit or mixture of Acetamiprid (0.5 g) + Pyriproxyfen (1 ml/ lit).

Radish

- Maintain higher soil moisture in the field by frequent irrigations.
- Use shading net of 50% (1.0-1.5 m above the field surface) to reduce the intensity of solar radiation.
- Growing of high temperature tolerant variety such as Kashi Rituraj.
- Make two sprays of water-soluble NPK (18:18:18) @ 4 g/lit to enhance plant growth.

Okra

- Maintain higher soil moisture in the field by frequent irrigations.
- Organic mulch of 5-7 cm thickness and frequent irrigation to make micro-climate favourable
- Make 2-3 sprays of Lambda Cyhalothrin 2.5% EC @ 1ml/lit or mixture of Acetamiprid (0.5 g) + Pyriproxyfen (1 ml/ lit) for control of Jassids and white flies.
- Use 3-4 rows of maize as border crop to reduce the impact of heat wave on main crop.

Cowpea

- Maintain higher soil moisture in the field by frequent irrigations.
- Use 3-4 rows of maize as border crop to reduce the impact of heat wave on main crop.

5.3 Livestock

Animals play a major role for providing subsidiary income to the farmers and major income to the land less laborers. Heat wave affects livestock sector as animals are more vulnerable to heatwaves. Heat wave results in low milk yields and meat productivity, reduce reproduction rate and mortality. To overcome these impacts various technological options were suggested.

- Provide insulation on top of the shed with sprinklers and use of foggers in animal sheds to sprinkle the water on animals and maintain optimum body temperature conditions.
- Install fans and coolers in animal sheds to bring down the temperatures and to reduce the impact of heat stress.
- Use shade nets for animal sheds to reduce the direct sun light and reduce the heat stress.

Silage feeding to dairy animals

- Proper ventilation and air circulation must be ensured in the animal sheds which can minimise heat stress.
- Provide proper ration including concentrates during morning and evening to increase the feed intake.
- Proper feed supplementation with mineral mixture @ 50 g/day/animal and UMMB blocks to be taken up to provide sufficient nutrients and to enhance the milk yields up to 1-1.5 l/day/animal.
- Encourage indoor feeding with green fodder instead of outdoor grazing to reduce the heat stress and increase the feed intake
- Water bath to lactating animals to reduce the sun stroke.

5.4 Poultry

Variation in ambient temperature and humidity are the most important environmental variables which influence the production of poultry. As the chicken is homoeothermic and the thermoregulation is a physiological limitation, sudden variation in temperature adversely affect the performance and wellbeing of the poultry. Chicken remains comfortable in a temperature range of 17 to 25°C. A gradual variation in these environmental variables may marginally influence the bird performance, but sudden and steep variation is very harmful for birds.

Measures to minimize the losses during heat stress

- Poultry house temperature can be reduced up to 3-5°C by providing insulation on top of the roof with water sprinklers, providing foggers inside the house with forced ventilation, providing side curtains and sprinkling water on the curtains are some approaches to minimize the losses.
- Increase the nutrient density (primarily energy and amino acids) of diets by about 10% to compensate the reduced feed (nutrient) intake during heat stress.
- Feed the birds during early morning (before 5 AM) and late evening (after 5 PM) to increase feed intake and avoid production of metabolic heat during peak hours of high ambient temperature.
- Provide cool water during hotter part of the day to keep the body temperature under control.

Gramapriya poultry breed

- Provide osmolytes (betaine, potassium), anti-oxidant vitamins (vitamin C, E, A), trace minerals (Z, Cu, Mn, Se, Cr, etc.), electrolytes and herbal extracts in diet and or water.
- Environmental control of house with tunnel ventilation (air velocity of 350 feet per minute) will reduce the house temperature to the tune of 10 to 12°C compared to the ambient temperature.
- Supplementation of ashwagandha extract (0.75%), turmeric extract (0.1%) and amla powder (1.0%) in the diet improved the performance of birds by alleviating heat stress during summer season.
- Betaine hydrochloride (natural osmolyte) @ 0.2% or selenium and chromium @ 0.3 ppm were found to improve the antioxidant status and alleviate summer stress in commercial broilers.
- A customized electrolyte mixture containing potassium chloride (40.0%), sodium citrate (7.5%), sodium dihydrogen phosphate (2.0%), disodium hydrogen phosphate (2.0%) and sodium bicarbonate (48.5%) through feed is recommended at the dose of 1.0 kg per ton of feed to withstand heat stress in poultry birds.

5.5 Fisheries

Rainbow trout farming is prominent in the cold-water regions of India. The total trout production is estimated to be around 2500 tons (approximately) from different hill states. The ideal water temperature for production of trout is one that does not rise too high beyond 18°C. The best possible water supply is one in which the temperature remains in the range of 13-18°C for as long as possible. The temperature of water supply should never exceed 18^{0}°C. There are cumulative effects of heat waves, which influence the growth and survival of growing trout. For example, increasing water temperature directly affects to fish as well as reduces the dissolved oxygen content in pond water.

Possible interventions for minimizing the impacts of heat wave or increasing water temperature

- To hold one ton of fish, nearly 3-4 LPS (180-240 LPM) of water flow is required at an average temperature of 15°C. In higher water temperature, water flow should be increased as 300-350 LPM to maintain sufficient level of dissolved oxygen i.e > 7 ppm.
- Water depth in the fish pond should be raised from 0.8 m to 1.0 m by adding fresh water.
- Thinning of the growing stock should be done @ 10-15 kg/m^3 compared to 15-20 kg/m^3 under normal condition.
- Reduce the quantity of feed by 10-20% compared to normal condition.

5.6 Groundwater

Increase in temperature increases atmospheric water demand for crops and creates stress on groundwater usage. Groundwater is the major source of irrigation for *rabi* crops. Providing protective irrigations during heat wave situations can minimise the effects of heat stress and minimise the yield loss.

Technological options to increase ground water level and reduce adverse effect of heat wave by providing irrigation

- Providing irrigations in multiple times, through efficient irrigation systems minimise water loss and enhance water use efficiency.
- Focus on enhancing storage by renovation/construction of rain water harvesting structures, well recharge structures to increase the ground water which can be used for irrigation.
- Increasing the efficiency of irrigation water use with technologies such as laser land leveling, raised beds, mulching, etc. which reduces pressure on ground water.

5.7 Humans

Higher temperatures and intense heat have a devastating impact on human health particularly the farmers and agricultural workers who are exposed to the heat. To minimise the impact during the heat wave, the following measures are to be followed

- Avoid going out in the sun, especially between 12.00 noon and 3.00 p.m.
- Farmers have to avoid strenuous activities when the outside temperature is high. Schedule farm operations either morning or evening hours to reduce the heat stress.
- While leaving to field, use a damp cloth on head, neck, face and limbs.
- Wear appropriate clothing which are light weight, loose fitting cotton clothing that allows ventilation of air to the body.
- While working in the field, farmers must drink small amount of water frequently throughout the day; avoid tea, coffee and carbonated soft drinks; avoid high-protein food; use ORS, homemade drinks like lassi, lemon water, buttermilk, etc.
- After returning to home from fields, take bath with cold water.
- If person feel faint or ill, consult doctor immediately.

6. Learnings from NICRA Project

National Innovations in Climate Resilient Agriculture (NICRA), a flagship project implemented by Indian Council of Agricultural Research, Ministry of Agriculture and Farmers' Welfare, Government of India aims at demonstration of promising climate resilient technologies to minimize the impacts of climate change on agriculture. Climate resilient technologies are being demonstrated in 151 village clusters representing very high- and high-risk prone districts. An enabling environment is created in the village for enhancing the adoption of these technologies so as to increase resilience of farmers to climate change and variability. As part of the TDC of NICRA, several resilient practices were identified which are promising and can minimise the impact of climatic stresses. The impact of the technologies during the current heat wave is presented.

(i) Punjab

Terminal heat is an important climatic stress experienced by many districts of Punjab during 2022 which impacted wheat yield significantly. As part of the NICRA, resilient technologies are being demonstrated in Faridkot and Bathinda. During the third and fourth week of March 2022, maximum temperatures were higher by 4-5°C and higher temperatures prevailed for two weeks. Resilient technologies introduced significantly minimised the impact (Table 6).

Table 6: Promising technologies which minimized yield loss due to heat wave in wheat during 2022 (Normal yields during 2021 are 45-50 q/ha)

Technology	Yield (q/ha)
Early sowing of wheat during 20-30th Oct, 2022 after short duration rice	43-44 (95%)*
Timely sowing of wheat during 1st and 2nd week of November	43 (95%)
Heat tolerant wheat varieties PBW-803, DBW-187 and DBW-222	44-45 (97%)
Wheat sown with happy seeder	45-46 (97%)
Providing irrigation during heat stress	46-47 (98%)
Timely sowing with happy seeder	45-46 (97%)
Late sowing of wheat after Nov 15th 2022	41-42 (93%)

*Parenthesis values indicates the per cent yield obtained compared to normal year (2021)

Timely sowing of wheat significantly minimised the impact of heat stress and helped to realize normal yields in Punjab. Technologies such as direct seeding of rice with short duration varieties such as PR-121, 122, 124, 126,127 helped in timely sowing of wheat. Further, wheat sowing with happy seeder, super seeder with rice residue management such as baler cum knotter, chopper cum spreader, shredder, zero –till wheat sowing, rice residue incorporation followed by wheat sowing helped in quick sowing of wheat crop immediately after the harvest of rice which have realized wheat yields up to 97% of normal yields. Further, adoption of heat tolerant wheat varieties PBW-803, DBW-187 and DBW-222 and spray of KNO_3 @ 0.5% at boot leaf and anthesis stages further minimised yield loss.

Direct seeding of rice followed by timely sowing of wheat with ZT seed drill minimized yield loss at several locations of Punjab

In animals, foggers and proper ventilation and air circulation in the animal sheds minimised heat stress. This has stabilized milk yields at several locations. Similarly, installation of coolers was also taken up in few locations which have resulted in normal milk yields comparable to 2021. Feed supplementation with mineral mixture and UMMB blocks enhanced the milk yields up to 1-1.5 l/day/animal.

(ii) Uttar Pradesh

Terminal heat stress occurs frequenty over Bundelkhand region. As part of the NICRA, resilient technologies are being demonstrated in Baghpat, Jhansi, Hamirpur, Chitrakoot, Pratapgarh, Kaushambi, Bahraich, Gonda, Maharajganj, Gorakhpur, Kushinagar and Sonbhadra to minimise the impacts of climatic stresses. During the third and fourth week of March 2022 maximum temperatures are higher by 3-4^{o}C over the normal temperature which impacted yields of several crops (Table 7).

Table 7: Promising technologies which minimized yield loss due to heat wave during 2022 (Normal yields during 2021 for wheat 41-48 q/ha and mustard 21q/ha)

Technology	Yield (q/ha)
Baghpat	
Timely sowing of heat tolerant wheat variety DBW 173	45-46 (95%)*
Gorakhpur	
Early wheat sowing with ZT seed drill	41-42 (93%)
Early sowing of mustard with heat tolerant variety RH-749	17 (81%)
Gonda	
Timely wheat sowing with ZT seed drill (I fortnight of Nov.)	38 (92%)
Jhansi	
Timely sowing of heat tolerant wheat varieties Raj-4120, 4079	43 (94%)
Kushinagar	
Timely sowing with ZT wheat with varieties DBW-187, 252 (Ist fortnight of Nov.)	43 (94%)

*Parenthesis values indicates the per cent yield obtained compared to normal year (2021)

Technologies such as mulching in sugarcane, ridge and furrow conserved the soil moisture and minimised the stress. Heat tolerant wheat variety DBW 173, Raj 4120 and Raj 4079 has contributed to 94-95% yields and minimised the yield loss. In frequently flood prone areas of Gonda and Kushinagar districts, zero till sowing of wheat enabled timely sowing *i.e.* immediately after *kharif* rice and also in *kharif* fallows and minimized yield loss.

In livestock, feeding with green fodder, concentrates and mineral mixture @ 50 g/day along with providing shade has reduced the impact of heat stress on animals and minimized the milk yield loss compared to farmers’ practice at several locations in Uttar Pradesh.

Early wheat sowing with ZT seed drill in Gorakhpur

Heat tolerant wheat variety Raj 4079 in Jhansi

Low cost animal shelter to protect from heat stress in Kaushambi district

(iii) Bihar

Heat wave is the major constraint impacting the *rabi* crop yields in many districts of Bihar. During 2022, the third and fourth week of March, maximum temperatures reached 3-4^{0}C higher for two weeks impacting *rabi* crop yields. As part of the NICRA, resilient technologies are being demonstrated in Buxar and Supaul (Table 8).

Table 8: Promising technologies which minimized yield loss due to heat wave in wheat during 2022 (Normal yields during 2021 for wheat 28-37 q/ha)

Technology	Yield (q/ha)
Wheat sowing by 15-30 Oct, 2022	34-35 (91-95%)*
Wheat sowing during I fortnight of Nov, 2022	34 (91%)
ZT sowing of wheat with heat tolerant variety WR 5444	35 (95%)
Spray of KNO_3 @ 0.5% at boot leaf stage and flowering	36 (97%)
Providing irrigation during heat stress	36 (97%)
Timely wheat sowing (I fortnight of Nov.) + ZT sowing + Heat tolerant variety	35 (95%)
Wheat sowing during 15-30 Dec., 2022	34 (91%)
Short duration wheat varieties Sri Ram 303 and 304 under late sown condition (II fortnight of Dec.)	26 (88%)

*Parenthesis values indicates the per cent yield obtained compared to normal year (2021)

At Buxar, zero till helped in taking up of wheat crop during the third and fourth week of November, which is generally taken up immediately after the harvest of long duration paddy varieties (MTU-7029) which is widely grown. Heat tolerant variety WR 5444 has obtained 95% yields compared to normal year and reduced the yield loss. Spraying of Potassium Nitrate @ 0.5% at boot leaf stage and flowering has significantly minimized yield loss due to terminal heat stress. Further providing irrigation at milking stage significantly contributed to wheat yields. Short duration wheat varieties Sri Ram 303 and 304 are suitable options for late sown condition (II fortnight of December) compared to the farmers' practice.

Timely wheat sowing with Zero Till seed drill in rice fallows minimized yield loss in wheat in Bihar

Mineral mixture supplementation

In animals, providing shade, water bathing to animals, feeding with green fodder, concentrates and mineral mixture @ 50-70 g/day has reduced the impact of heat stress on animals and minimized the milk yield loss compared to farmers' practice at several locations of Bihar.

(iv) Madhya Pradesh

Several districts of Madhya Pradesh experienced heat wave like situation in the month of March. Maximum temperatures were higher by 3-4^{o}C for two weeks in March 2022 compared to the previous year. The abnormal rise in temperatures has adversely impacted crop yields. As part of the NICRA, resilient technologies are being demonstrated in Tikamgarh, Jhabua, Datia, Ratlam, Morena and Chhatarpur (Table 9).

Table 9: Promising technologies which minimized yield loss due to heat wave in wheat during 2022 (Normal yields during 2021 for wheat 37-42 q/ha)

Technology	Yield (q/ha)
Ratlam	
Heat tolerant wheat variety HI-1605	40 (95%)*
Tikamgarh	
ZT sowing of wheat	37 (97%)
Providing irrigation during heat stress	37 (95%)
Datia	
Heat tolerant wheat variety RVW-4106	41 (97%)
Dry sowing of wheat	40 (95%)
Heat tolerant and late sown variety of chick pea RVG202	20 (95%)
Timely sowing of mustard variety Pusa Bold	20 (95%)

*Parenthesis values indicates the per cent yield obtained compared to normal year (2021)

Heat tolerant wheat variety HI-1605 has significantly minimised the yield loss in Ratlam. Dry sowing of wheat helped farmers for sowing timely (before 20th Nov.) which is otherwise delayed by 8-10 days. Heat tolerant and late sown variety of chick pea RVG202 and timely sowing of mustard variety Pusa Bold escaped the heat stress at maturity.

In animals, installing foggers and fans, providing shade nets, water bath to animals can maintain optimum body temperature in animals. This has reduced the impact of heat stress on animals and minimised the milk yield loss compared to farmers' practice.

Heat tolerant wheat variety RVW-4106 in Datia

Use of foggers, fans and providing ventilation to reduce heat stress in animals

(v) Haryana

Many districts of Haryana experienced heat wave during the third and fourth week of March, 2022 impacting wheat yields significantly. As part of the NICRA, resilient technologies are being demonstrated in Sirsa. Sirsa experienced 3-5°C higher temperature when compared to previous year 2021(Table 10).

Table 10: Promising technologies which minimized yield loss due to heat wave in wheat during 2022 (Normal yields of wheat during 2021 are 48q/ha)

Technology	Yield (q/ha)
Early sowing of wheat during 20-30th Oct, 2022	44-46 (92-96%)*
Timely sowing of wheat during I Fortnight of November	44 (92%)
Wheat sown with happy seeder	46 (96%)
Providing irrigation during heat stress	46-47 (96-98%)
Timely sowing with happy seeder	47 (98%)
Late sowing of wheat after Nov 15th 2022	43-45 (90-94%)

*Parenthesis values indicates the per cent yield obtained compared to normal year (2021)

Timely sowing of wheat during the first fortnight of November, wheat sowing with happy seeder and super seeder with rice residue management helped in sowing of wheat crop immediately after the harvest of rice on residual soil moisture and irrigation during heat stress at anthesis and milking stages further minimized the yield loss.

Providing proper ventilation to animal sheds minimized heat stress and stabilized the milk yields. Increasing the availability of green fodder, feed supplementation with mineral mixture, timely vaccination was taken up to reduce dehydration in animals and providing enough nutrients enhanced milk yields up to 1-1.5 l/day/animal.

Timely sowing of wheat with happy seeder minimised yield loss in Haryana

Providing shade net to animals

(vi) Maharashtra

During March-April, Jalna experienced a maximum temperature of 39.6-42.8^{o}C and in Nandurbar the maximum temperature has increased upto 41.5-43.0^{o}C, higher by 4^{o}C compared to 2021. The sudden increase in temperatures has impacted horticultural crops.

Resilient technologies such as straw mulching in orchards has significantly reduced the impact of heat stress and minimized water use. Plastic mulching with frequent irrigations with drip helped in reducing the heat injury to fruit and vegetables and helped to realize normal yields. Covering the trees with shade nets and cotton cloth reduced sun scalding and scorching of leaves and stems and sunburn on fruits.

Straw mulching and covering with shade nets in Pomegranate, Mulberry and Grape orchards in Ahmednagar district of Maharashtra

In animals, installing foggers and fans, providing shade nets, water bath to animals has reduced the body temperature which helped to realize the normal milk yields. Feed supplementation with concentrates, silage has further enhanced the milk production compared to farmers' practice at various locations. These low-cost technologies can be scaled to overcome the heat stress in the entire state.

Water bath to animals, shade net to the animals and silage bags to minimise the impact of heat stress in Ahmednagar and Nandurbar districts of Maharashtra

7. Way Forward

Unlike the earlier heat wave events, the extreme heat during 2022 is widespread in occurrence covering several parts of the country. It is predicted that extreme events such as the current one is going to occur more frequently and severely in the years to come due to climate change. In view of this, concerted efforts are needed to forecast such events in advance, monitor their occurrence and to understand their impacts comprehensively. Though efforts are in place to develop crop varieties and technologies which can minimise the impact to multiple stresses, there is a need to intensify such efforts across agriculture, horticulture, livestock, fisheries and poultry sectors in view of the impending increase in frequency and severity of such extreme events.

Due to the efforts of the National Agricultural Research System, several technologies are currently available which can minimise the negative impacts of heat waves. As part of NICRA, technologies are being demonstrated in 151 risk prone districts of the country and promising technologies are identified for each of the districts. As presented in the bulletin, these technologies minimised the impact during the current heat wave and could achieve yields to the extent of 95-97% of the normal yields in case of wheat. There is a need to popularize the promising technologies so that they can reach large number of farmers.

There is a need to scale these technologies by way of integrating in the ongoing development programs. As contingency plans are prepared for all the districts of the country, the promising technologies needs to be included in the contingency plans. Promising heat stress tolerant varieties can be spread by integrating in to the ongoing developmental programs like National Food Security Mission (NFSM). Practices related to residue management by way of machinery can be scaled through custom hiring centers, farm machinery banks and through National Submission on Agricultural Mechanization (SMAM). Promising technologies related to horticulture can be integrated into the Mission for Integrated Development of Horticulture (MIDH). Similarly, other promising resilient practices which can minimize the impact of climatic stresses can be scaled through mainstreaming in to the ongoing developmental programmes for their largescale spread among the farming community.

There is also a need to strengthen the weather forecasts including extreme weather events and agro-advisory services so that farmers can take informed decisions about the impending weather. Strengthening the existing district agromet field units (DAMUs), issuance of agro-advisories based on downscaled forecast at the block level, disseminating advisories to large numbers of farmers is the need of the hour. Further, the spread of the promising technologies by KVKs, state extension departments, NGOs, etc. by integrating these technologies into their ongoing programs will help in their spread among the farming community. Largescale awareness and capacity building is also needed for enhancing adoption of promising technologies. Such efforts will enhance resilience of the various sectors of Indian agriculture to extreme events.

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