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Managing impact of climatic vagaries on the productivity of wheat and mustard in India

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सार – भारत के, विशेषकर अर्ध-शुष्क और शुष्क क्षेत्रों में गेहूँ और सरसों की फसलें अतिसंवेदनशील हैं। कार्बन डाईऑक्साइड और तापमान के परिवर्तनशील पैटर्न व वर्षा के परिणामस्वरूप उत्पन्न होने वाली ऊष्मा और सूखे जैसी प्रक्रियाओं के कारण जलवायु उष्ण होती जा रही है। गेहूँ की बुआई के दौरान तापमान में बढ़ोतरी के प्रभाव से अनाज की पैदावार में भारी कमी आई है। सरसों में फली आने और बीज विकसित होने की अवस्था के दौरान न्यून तापमान के प्रभाव से बीजों के कड़ेपन को नुकसान पहुँचा है और बीज की उपज में काफी हद तक कमी आई है। इस समीक्षा पत्र में गेहूँ और सरसों की फसल की पैदावार पर पड़ने वाले तापमान और आर्द्रता बल के प्रभावों को कम करने के लिए बुआई, प्रतिरोधी जुताई, पलवारना, बीज डालने, लवणों के पर्णीय छिड़काव, अतिरिक्त सिंचाई के लिए जल का उपयोग, सूक्ष्म पोषक तत्वों के पणीर्य छिड़काव, छिड़काव, पवनरोधी आदि जैसे प्रबंधन तथा मौसम की चरम घटनाओं से गेहूँ और सरसों की फसल पर पड़ने वाली प्रतिक्रियाओं पर भी विचार-विमर्श किया गया। प्रत्येक चरण में जल के बढ़ते हुए दबाव के साथ गेहूँ की फसल के भूमि से ऊपर शुष्क भार और इसके दर में कमी आई है। संकलित किए गए क्षतिग्रास्त थ्रेशहोल्ड तापमान के औसत मान गेहूँ में पुष्प आने के समय 31° से और दाना बनने के समय 35° से. थे। दक्षिण आस्ट्रेलिया में अधिकतम औसत तापमान में प्रत्येक 1 डिग्री वृद्धि के लिए क्रमश: 518 कि.गा./है.। और 1140 कि.ग्रा./है. की फसल पैदावार पर गेहूँ में फूल आने और दाना आने के समय अधिकतम दैनिक औसत तापमान में परिवर्तन का नकारात्मक प्रभाव था। पूर्वी क्षेत्र उसके बाद मध्य और उत्तरी भारत में तापमान का बढ़ना फसल के लिए बहुत ही हानिकारक हो सकता हैं। जहां पर शीत ऋतु में तापमान उत्तरी क्षेत्र की अपेक्षा अधिक रहता है। दो अन्य क्षेत्रों मध्य और पूर्वी भारत की अपेक्षा उत्तरी भारत में वर्षा पर आधारित सरसों तापमान वृद्धि के प्रति कम संवेदनशील है। वायुमंडलीय तापमान में वृद्धि से पर्णक्षेत्र सूचकांक, अनाज की मात्रा के साथ-साथ अनाज की मात्रा में कमी आई है। जिसका प्रभाव सरसों की फसल के पैदावार पर दिखाई दिया। सरसों के तने को आगे बढ़ाने, फूल आने और पोद विकास के दौरान जल की कम उपलब्धता से बीज पैदावार में कमी आई है। मौरिंगा जल तत्व और एसकार्बे के प्राइम्रिग पोधे के टिशू की स्थिति, सिल्लिका, स्थिरता, गैस अंतरण, जल उत्पादन में काफी सुधार हुआ है। फसल पककर तेयार हाने की अवस्था में देर से बोए गए गेहूँ की फसल को तापमान के उच्च दबाव का सामना करना पड़ता है। अनाज भराव की अवधि में देर से की गई बुआई जुताई की अवधि को कम करता है। गेहूँ में दाना आने की अवधि की संकटपूर्ण अवधि में गर्म मौसम बलपूर्वक परिपकवता की ओर ले जाता है जिससे अनाज की पैदावार में कमी आती है। गेहूँ में घास-पात के प्रयोग से गेहूँ की कम मात्रा के साथ अनाज की पैदावार अधिक होती है। गैर ऑर्गेनिक घास-पात की अपेक्षा ऑर्गेनिक घास-पात बायोमास, जड़ वृद्धि पर्णक्षेत्र सूचकांक और अनाज की पैदावार में बेहतर मृदा जल स्तर और उन्नत पौद केनोपी उपलब्ध कराता है। 50 प्रतिशत फूल आने की अवस्था में स्पष्ट पर्ण छिड़काव, एनथैसिस अवस्था में 1.0 प्रतिशत, छिड़काव दाना आने की अवस्था में अतिरिक्त सिंचाई जल से उच्च तापमान दबाव के तहत गेहूँ के उत्पादन में वृद्धि हुई है।

पाला पड़ने की घटना से एक दिन पहले सरसों की फसल में कम सिंचाई करने से उन्नत ऊष्मा अंतरण और ऊष्मा क्षमता द्वारा पाले से क्षति होने से सुरक्षा मिलती है। प्लास्टिक घास-पात, खरपतवार मृदा में लगभग 10° से मृदा के सतही तापमान को बढ़ाता है। धुंए के कण सामान्यत: आधार में 1 um से भी कम होता है, दृथ्य विकिरण को प्रतिबिंबित करते है किंतु दीर्घतंरग विकिरण को रोकते हैं और भूमि के निकट सतह के तीव्र गति से शीतलन को रोकने में प्रभावी हैं। सही मात्रा में वायु और तरल पदार्थों को मिश्रित करते हुए उत्पन्न किए गए बहुत से छोटे बेलों से न्यून उष्मीय संचालकता सहित झाग उत्पन्न होता है। आर्गेनिक घास-पात (घास-फूस और बुरादा धूसर घास-पात में बहतर मृदा जल की स्थिति उपलब्ध करता है।

ABSTRACT. Wheat and mustard crop is highly vulnerable, particularly in the semi-arid and arid regions of India. The climate is warming through the processes such as CO_2 and changed pattern of temperature and precipitation resulting in heat and drought stresses, respectively. The effect of increasing temperature during grain filling stage of wheat causes substantial reduction in grain yield. The effect of low temperature (frost) during podding and seed development stage in mustard causes freezing injury in seeds and sizable reduction in seed yield. In this review paper response of wheat and mustard crop to weather extremes and management practices such as time of sowing, selection of resistance cultivars, mulching, seed priming, foliar spray of salts, use of extra irrigation water, foliar spray of micronutrients, sprinkler, wind barrier etc. to mitigate the temperature and moisture stress effect on the productivity of wheat and mustard crop have been discussed. Above ground dry weight of wheat and its rate decreased with increasing water stress at each stage. The averaged values of damage threshold temperatures compiled from the literature were 31 °C for flowering and 35 °C for grain filling of wheat. Changes in average daily maximum temperature during flowering and grain filling had a negative effect on grain yield of 518 kg/ha and 1140 kg/ha, respectively for every 1 degree increase in average maximum temperature in South Australia. Temperature rise would be most harmful for the crop in eastern region, followed by central and northern India, where winter season temperature is comparatively higher than northern region. Rainfed mustard was less vulnerable to temperature rise in northern India as compared to other two central and eastern India. Rise in atmospheric temperature reduced leaf area index, grain number as well as weight of grains which was in turn reflected in yield of mustard crop. Seed yield reduction occurred by low water availability during stem elongation, flowering and pod development in mustard. Priming with moringa water extract and ascorbate substantially improved the tissue water status, membrane stability, gas exchange, water productivity of the plant. Late sown wheat crop faces high temperature stress during ripening phase. Delayed sowing reduces the tillering period and hot weather during critical period of grain filling lead to forced maturity thereby reduces the grain yield. Application of mulches in wheat produced higher grain yield over without much wheat. Organic mulches provided better soil water status and improved plant canopy in terms of biomass, root growth, leaf area index and grain yield as compared to inorganic mulch. The foliar spray of KNO_3 (0.5%) at 50 per cent flowering stage, 1.0 per cent KNO_3 during anthesis stage, 2.5 mM of arginine, spray of zinc, extra irrigation water during grain filling stage increased the productivity of wheat under high temperature stress.

Light irrigation in mustard crop one day before frost occurrence protects from frost damage by improving heat transfer and heat capacity. Plastic mulch raises the surface temperature of the soil nearly 10 °C over bare soil. Smoke particles are usually less than 1 µm in size, reflect visible radiation but trap the long wave radiation and so are effective in preventing rapid cooling of surface near ground. Mixing air and liquid materials in the right proportion to create many small bubbles is the secret to generate foam with low thermal conductivity. Organic mulches (straw and saw dust) provided better soil water status over ash mulch.

Key words – High temperature, Frost, Water deficit, Seed priming, Mulching, Wheat, Mustard, Fogging, Smoke Insulation, Chemical spray, Extreme weather.

1. Introduction

Professor John Monteith considered the question of climatic variation and the growth of crops in his presidential address to the U K Royal Meteorological Society in 1980. This topic continues to capture the imagination of agricultural scientists and agro-meteorologists. He concluded that the two largest climatic causes of variation in yield were temperature and rainfall and their independent effects were three to four times larger than caused by variation in how much light was incident on crops. Other causes of yield variation, notably management, contribute much more to yield variability than those factors beyond our control. However, increased variation and changes in mean temperature and precipitation are expected to dominate future changes in climate as they affect crop production. Therefore, it is certain that weather play a more determining role in global yield variability. The definition of what constitutes extreme weather differs for the properties of weather such as temperature, rainfall, wind speed etc. from crop to crop for a region. For example, temperature extremes (low temperature) abnormal for the mustard crop may be normal for wheat crop in North West India. Crop growth, development and yield are affected by climatic variability via linear and nonlinear responses to weather variables and the exceedance of well defined crop thresholds, particularly, temperature. Integrating the study of meteorological extremes and crop responses to weather thresholds, leads to an assessment of the possible impacts of changes in climatic variability on crop production and quality.

The diverse nature of extreme events leads to variable effects on different aspects of the crop growth cycle and associated field management. Extreme weather events can in fact impact crops both *via* negative impacts on plant physiological processes and direct physical damage, as well as by affecting the timing and conditions of field operations. For instance, above-threshold temperatures and precipitation leading to heat and drought stress, can negatively affect crop photosynthesis and transpiration (Wolf *et al*., 1996 and Porter and Semenov, 2005; Gerber, 1979), as well as increased pest and disease incidence. Extreme temperature events may also hinder fruit setting and development, critically lowering yield potential (Tubiello *et al*., 2007). On the other hand, heavy rain, hail storms and flooding lead to crop failures by physically damaging crop canopies, or *via* anoxic soil conditions limiting root and plant function. Extremely wet conditions can also delay key field operations such as planting and harvesting. Importantly, the same extreme events can have very different outcomes depending on the time of the year and the crop development stage. Understanding of how extreme events modify processes and interactions in agricultural production systems is therefore essential to devise appropriate management responses under currently and future climate regimes.

Indeed, future climate change conditions are likely to be characterized by increased frequency of extreme events and thus larger negative impacts on crop yields (Easterling *et al*., 2007). They analyzed modeling results and found that in low-latitude regions, a temperature increase of 1-2 °C is likely to have negative yield impacts for major cereals. The IPCC has projected a temperature increase of 0.5-1.2 °C by 2020, 0.88-3.16 °C by 2050 and 1.56-5.44 °C by 2080 for the Indian region, depending on the scenario of future development (IPCC, 2007). Himalayan glaciers and snow cover are projected to contract leading to much higher variability in irrigation water supplies. It is very likely that hot extremes, heat waves and heavy precipitation events will become more frequent. Overall, the temperature increases are likely to be much higher in winter season when crops such as mustard are grown. In this season, precipitation is also likely to decrease. There is a probability of 10–40% loss in crop production in India with increase in temperature by 2080-2100 (Fischer *et al*., 2007; Parry *et al*., 2004; IPCC, 2007).

There are a few Indian studies (Saseendran *et al*., 2000 and Aggarwal, 2008) which also confirm decline in the agricultural production with climate change. Winter crops are especially vulnerable to high temperature during reproductive stages. Mall *et al*. (2004) reported that crop production in winter season might become comparatively more vulnerable due to larger increase in temperature and higher uncertainties in rainfall.

Wheat is the main cereal crop in India. The total area under the crop is about 29.8 million hectares in the country. The production of wheat in the country has increased significantly from 75.81 million MT in 2006-07 to an all time record of 94.88 million MT in 2011-12 and productivity increased from 26.0 to 31.4 q/ha. India is among the top few vegetable oil economies of the world. Here, oilseeds are an important component of the agricultural economy, next to food grains, in terms of area, production and value. But still India is a net importer of vegetable oils and almost 40% of its annual edible oil needs are met by importation. In future, the demand for oilseeds production is likely to go up significantly due to increase in population and income. Finally, there is a consideration of how crops might be managed or be bred to adapt to variable conditions to minimize their effects.

2. Crop response to extreme weather

Abiotic stress includes any environmental conditions or combination of them that negatively affect the expression of genetic potential for growth, development and reproduction. Drought stress and heat stress frequently occur simultaneously, exacerbating one another. They are often accompanied by high solar irradiance and high winds. Under drought stress, the crop's stomata close, reducing transpiration and, consequently, raising plant temperatures. Flowering, pollination, and grain-filling of most grain crops are especially sensitive to water stress. The extent of crop damage depends on the duration of stress and crop developmental stage. Crop yields are most likely to suffer if the adverse weather conditions, especially high temperature and excess or deficit precipitation during critical developmental stages such as the early stages of plant reproduction (Miroslav Trnka *et al*., 2014).

2.1. *Wheat*

In India both temperature stress and moisture stress are important and affect the wheat productivity. Terminal stress (temperature and moisture) badly affects the wheat productivity especially in late sown wheat, which is a common practice in rice-wheat or cotton-wheat cropping system etc due to delayed maturity of rice and cotton crop.

2.1.1. *Temperature stress*

Extreme low temperature *viz*., frost, particularly damages wheat crop between flag leaf emergence and ten days after anthesis. The damage appears as an erratic occurrence of aborted spikelets at the base, centre or tip of the spikes. It is also manifested as sterile florets in parts of the entire spike. This is due to an initial supercooling of plant tissues and a later erratic spread of the freezing front through stems and ears. The damage during this period occurs at minimum temperature below 0 °C and tissue temperature of around -4 °C (Harding, *et al*., 1990) and is associated with radiative cooling in calm clear nights. The lethal low temperature reported for wheat is -17.2 °C (±1.2 °C) (Porter and Gawith, 1999) and must be considered together in the presence or absence of a snow cover layer. Gusta and Fowler, 1976 reported that minimum temperatures below -2 °C after the main growing stage dehardened the crop with reduction in the yield substantially. However wheat crop escapes from frost damage in India because the sensitive stage (grain filling) occurs mainly in second week of February, during this period frost is uncommon. Sometime early maturing wheat varieties are damaged if grain filling coincides with frost in last week of January.

Changes in average daily maximum temperature during flowering and grain filling had a negative effect on grain yield of 518 kg/ha and 1140 kg/ha, respectively for every 1 degree increase in average maximum temperature

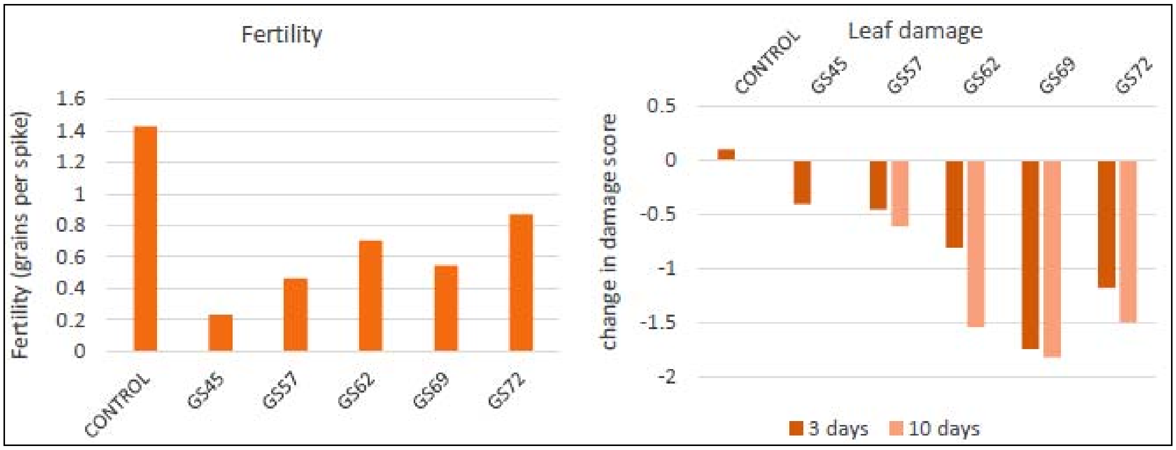


Fig. 1. Treatment mean responses for fertility (grains set per spike), and change in visual score 3 and 10 days after stressing (visual leaf score, based on the proportion of leaf area remaining viable) [Plants were placed in the chamber in growing environment with temperatures of 36 °C and 40 km/hr winds, for three consecutive eight hour days, 10 days after the main tiller had finished flowering (GS72), booting (GS45), three quarters head emergence (GS57), start of flowering (GS62) and the end of flowering (GS69)] (*Source* : Telfer *et al*., 2013)

TABLE 1

Influence of temperature on wheat grain yield in field trials across six locations during in South Australia

Site	Grain yield (kg/ha)	Sowing date	Average maximum temperature (°C) during flowering	Average maximum temperature (°C) during grain fill
Angas Valley	1789	23 May	26.0	27.7
Booleroo	3119	17 May	24.7	26.3
Minnipa	2295	15 May	23.2	27.3
Pinnaroo	2318	28 May	24.1	27.4
Roseworthy	3489	17 May	21.9	26.3
Winulta	5222	10 May	20.2	24.8
Significance (p Value)			0.022	<0.001
Percent variation accounted for			77	98
Effect (kg/ha)			-518	-1140

Source : (Telfer *et al.*, 2013)

in South Australia (Table 1). During grain filling in particular, this accounted for a large component of the variation within the data set (98%). Interestingly this is larger than the variation accounted for by growing season rainfall (84%) (Huang *et al*., 2005).

A significant negative impact of heat stress on wheat grain yield in South Australia was reported by Telfer *et al.*, 2013. They also reported that growth stage 45 or booting showed the greatest decline in fertility compared to the control (Fig. 1).

Stress at this time corresponds to the formation of the pollen within the plant, which is very sensitive to stress, with the size of the effects decreasing as stress occurs later in the plant's development (Flowering is also known to be sensitive to abiotic stress, with the pollen aborting or having reduced viability when subjected to stress). However, the opposite effect was observed on leaf, with less leaf damage observed at the earlier growth stages, while the rate of leaf senescence was increased if heat stress occurred post flowering and during early grain filling.

Heat stress during anthesis increases floret abortion (Wardlaw and Wrigley, 1994). They also reported that heat stress during the reproductive phase between anthesis to grain maturity, caused reduction in grain yield (Fig. 2).

TABLE 2

Response of wheat to temperature stress at different phenophases

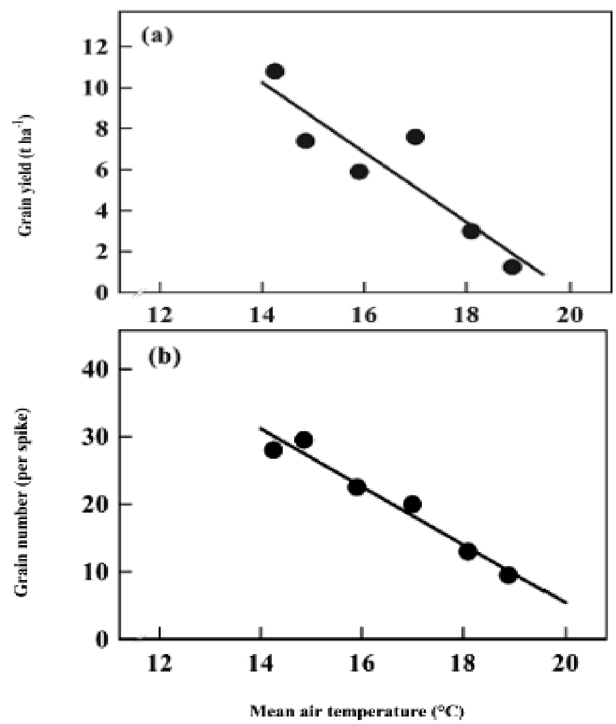
S. No.	Weather extremes	Effect on wheat	Weather extreme description – situation must occur at least once per season to be counted
1.	Late frost	Its occurrence after loss of the winter-hardiness leads to leaf chlorosis, burning of leaf tips, floret sterility, damage to lower stem and consequently medium to severe yield losses	Event is triggered when the minimum temperature is equal to or below -2 °C after the start of the following window, determined as the period when the mean air temperature is continuously 10 °C (for at least five days) and does not drop below 10 °C for more than two days in a row
2.	Heat stress during anthesis	Causes partial or complete sterility of the florets with a severe effect on yield	Event is triggered when the *T*max is above +31 °C for at least two days during the period ± 5 days around anthesis.
3.	Heat stress during grain-filling	Speeds up development and decreases yield until the growth stops, resulting in a substantial yield reduction	Event is triggered when the Tmax3 is above +35°C for at least three days during the period from five days after anthesis to maturity.

Source : Ruiz-Ramos, *et al.,* 2011

It is attributed to reduced time by heat stress to capture the resources. Isolated periods of extremely high temperatures around sensitive crop developmental stages such as flowering could reduce the grain yield considerably, and a continuous period of extreme high temperature can result in an almost total yield loss (Porter and Semenov, 2005).

The wheat yield could be limited by the low grain number, which is established to a large extent during the period around anthesis (flowering), which is known to be sensitive to high temperature stress (Ferris *et al*., 1998). If the crop is unstressed, it establishes the grain number and its potential size at sufficiently large values to accommodate the biomass that is produced during grain filling. Grain number and grain size can be substantially reduced if a heat-sensitive cultivar is exposed to a short period of high temperature around flowering, limiting the capacity of the grains to store newly produced biomass. Wheeler *et al*., 1996 a&b reported that temperatures between 27 °C to 31 °C or even higher (before and during anthesis resulted a high number of sterile grains and considerable yield losses.

Temperatures above 31 °C shortly after anthesis and during grain filling were shown to reduce the net assimilation, thus causing the production of smaller grains (Tashiro and Wardlaw, 1989) and increasing leaf senescence (Asseng *et al*., 2011). Although the rate of grain growth increases with temperature increase and an increase in the grain-filling rate compensates for the shorter grain-filling period, but this compensation does not occur at temperatures above 30 °C due to limited assimilated translocation from flag leaf to grain (Stone *et al*., 1995; Wardlaw *et al*., 1980). The averaged values of damage thresholds that were compiled from the literature by Porter and Gawith (1999) were 31 °C for flowering and 35 °C for grain filling and Ruiz-Ramos *et al.*, 2011 have used these values to define temperature



Figs. 2(a&b). Influence of mean temperatures from anthesis to harvest maturity on (a) grain yield and (b) number of grains per ear in winter wheat. (*Source* : Wheeler *et al*., 1996 a, b)

as an indicator to evaluate stress during flowering (anthesis) and grain filling (Table 2). Yield penalties are associated chronically with both high temperatures as well as heat shocks, at temperature greater than 32.0 °C during mid or late reproductive stages including grain filling (Wardlaw and Wrigley, 1994). High respiration rates especially during night due to high temperature can increase reactive oxygen species, leading to cell damage affecting pollen viability (Prasad *et al.*, 1999).

TABLE 3

Grain filling duration and final grain weight of wheat grown at four temperatures

S. No.	Crop growth mean temperature (°C)	Grainfilling mean temperature (°C)	Grainfilling duration[b] (days)	Final grain weight[b] (mg)	Grain filling per day (mg/kernel)
1.	12.2	17.0	28.5a	39.5a	1.39
2.	20.7	24.0	29.4a	28.9b	0.98
3.	23.9	25.6	26.5a	30.5b	1.15
4.	27.5	24.4	30.5a	27.6c	0.91

[a]Mean of 24 genotypes.
[b]Numbers followed by a different letter differ at P = 0.05.
Source: Acevedo *et al*., 1991b.

TABLE 4

Effect of moisture stress on wheat crop

S. No.	Moisture stress	Effect on wheat	Moisture stress description – situation must occur at least once per season to be counted
1.	Extremely wet early season	Restricts growth and reduces yield through the occurrence of diseases, nitrogen leaching, logging and root anoxia	Event is triggered if the soil moisture is at or above the field capacity for more than 60 days from sowing to anthesis. Days with a mean temperature below 3°C are not counted
2.	Severe drought (sowing - anthesis)	Causes a severe reduction of growth or crop die back	Event is triggered if ETa/ETr is less than 0.15 for at least ten consecutive days between sowing and anthesis; the days with a mean temperature below 3°C are not considered
3.	Severe drought (anthesis-maturity)	Causes a severe reduction of growth or crop die back	Event is triggered if ETa/ETr is less than 0.15 for at least ten consecutive days between anthesis and maturity
4.	Severe dry season (sowing-maturity)	Causes severe reduction of growth or crop die back	Event is triggered if ETa/ETr is less than 0.15 for at least 21 days during the period from sowing to maturity; the days with a mean temperature below 3°C are not considered
5.	Adverse conditions at harvest	Restricts the ability to harvest at the most appropriate time	Event is triggered when soil moisture in the top layer below 85% and rain on the given day is below 0.5 mm and not more than 5 mm on the preceding day

Eta and ETr are the actual and reference evapotranspirations
Source : Trnka, *et al.,* 2014 *et al*., 2003

In hot environments, however, the maximum soil temperature in the top centimeters soil may exceed maximum air temperature by 10 °C to 15 °C if the soil surface is bare and dry and radiation intensity is high. Under such conditions, maximum soil temperature may reach 40 °C to 45 °C with serious effects on seedling emergence. The initial plant population may fall below 100 plants/m considered to be deleterious to crop yield (Acevedo *et al.*, 1991b). They also reported a mean reduction of 4 percent in grain weight per degree increase in mean temperature during grain filling (Table 3). Crop growth mean temperature increase from 12.2 °C to 27.5 °C caused 34.5 per cent reduction in grain filling in wheat crop.

2.1.2. *Moisture stress*

Water excess (logging) and deficit are both detrimental to wheat crop. The occurrence of water logging due to exceedingly wet conditions between sowing and the end of tillering can reduce the number of kernels per head, the number of tillers per plant, plant height and finally grain yield. The risk of unusually wet conditions during the period from sowing to anthesis was based on number of days with the soil water content in the top soil layer at field capacity. The risk of dry conditions during the period from sowing to maturity was based on number of days with the top soil layer unable to meet crop water demand (Table 4). Grain yield and its attributes were reduced significantly under water stress conditions. The percent reduction in grain yield was 23.8 and 57.6 over non stress in mild (two irrigation) and severe stress (no irrigation) conditions, respectively (Sharma *et al.*, 2003).

Rong-hua *et al.*, 2006 reported that the values of chlorophyll content in drought tolerance genotypes of barley were significantly higher than those in drought sensitive genotypes under moisture stress. Although stress depresses grain yield (Hsiao, 1973) and it can elevate the

TABLE 5

Above ground matter dry weight of winter wheat under water stress condition

Irrigation levels	Precipitation (mm)	Irrigation (mm)	Jointing stage (g/plant)	Heading stage (g/plant)	Mature Stage (g/plant)	Jointing to heading stage (g/plant)	The percent of decrease in comparison with control (%)	Heading to mature stage (g/plant)	Decreasing percentage of in comparison with control (%)
1	66.70	300.00	0.15	0.72	2.84	0.57	1	2.12	—
2	66.70	262.52	0.14	0.57	1.64	0.43	24.84	1.07	49.51
3	66.70	225.04	0.16	0.62	1.64	0.45	21.00	1.02	51.74
4	66.70	187.48	0.13	0.44	1.21	0.31	45.59	0.77	63.60
5	66.70	150.00	0.14	0.58	1.10	0.44	23.68	0.52	75.4

(*Source* : Zhao, *et al*. 2009)

value of other components of the economic yield, such as quality of grain (Guttieri *at al*., 2000). Siddique *et al*., 2000 reported a reverse relationship of photosynthetic rate with leaf water potential of wheat plants, which decreases with water stress (Fig. 3).

Above ground dry weight of single plant decreased at each stage and the increment of biomass reduced under the increasing water stress (Zhao *et al*., 2009). Furthermore, the cumulative biomass in later stage was more than the earlier stage (Table 5). The increment of biomass of the 2nd to 5th irrigation plans in later stage reduced by 41.9%, 15.4%, 31.5% and 38.6% compared with the first irrigation plan, respectively. This indicates that spike growth was affected seriously by water stress. The wheat product decreased obviously under high water stress in later stage, whereas, the yield under slight water stress in jointing stage was more than other irrigation levels.

Drought stress reduced the number of days to heading, grain filling, and maturity, plant height, number of spike per m^2, peduncle length, spike length, number of grains per spike, 1000 grain weight of genotypes while it increased the chlorophyll content and grain protein content. Spikelets per spike were not affected by drought stress (Kiliç and Yağbasanlar, 2010; Paknejad *et al*., 2007). Kılıç *et al*. (1999) has reported that the number of days to heading, number of spike per m^2, 1000 grain weight and grain yield of durum wheat is reduced in the drought and terminal heat stress conditions. Severe water stress from the seedling stage to maturity reportedly reduced all grain yield components, particularly the number of fertile ears per unit area by 60% and grain number per head by 48% (Giuanta *et al*., 1993).

2.2. *Mustard*

Mustard is much sensitive to climatic variables and hence weather extremes could have significant effect on

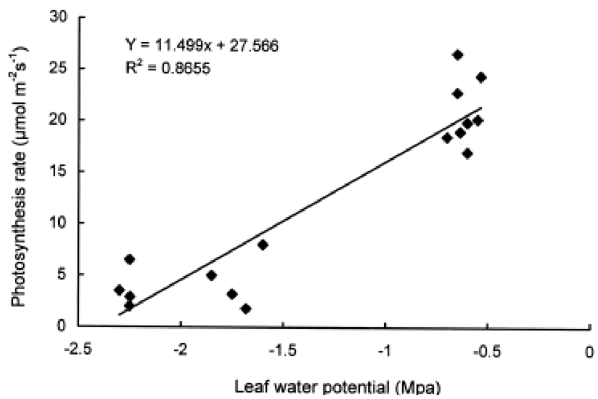


Fig. 3. Relationship of leaf water potential and photosynthetic rate with drought at anthesis of wheat cultivars. (*Source* : Siddique *et al*., 2000)

its production. Apart of the decline and/or stagnation in mustard yields negative growth rate in India from 1997 was observed possibly due to unfavorable monsoon which created moisture stress (drought and excess rainfall) and temperature increase (Kumar, 2005). High temperature during mustard crop establishment (mid September to early November), cold spell, fog and intermittent rains during crop growth also affect the crop adversely and causes considerable yield losses. Frost is the most important weather extreme for mustard cultivation as it causes a great loss to seed yield through direct injury to seed during seed development phase.

2.2.1. *Temperature stress*

Increasing temperatures reduce days to flowering and maturity, which in turn reduces total crop duration. In plants, warmer temperature accelerates growth and development leading to less time for carbon fixation and biomass accumulation before seed set resulting in poor yield (Rawson, 1992).

TABLE 6

Impact of current and adaptation measures on percentage yield gain loss of irrigated mustard in different climate change scenarios

India	2020	2050	2080
Northern			
Current	−3.2	−6.6	−15.7
S1	1.0	−0.4	−9.4
S2	−3.0	−2.6	−8.6
Central			
Current	−1.4	−2.1	−16.5
S1	−0.5	−1.9	−7.7
S2	−1.1	−2.1	−6.9
Eastern			
Current	−9.9	−37.4	−63.1
S1	−1.8	−29.6	−69.6
S2	−3.6	−31.4	−71.7

S1 – late sowing by 7 days and S2 – long-duration variety (Boomiraja, *et al*., 2010)

Boomiraja *et al*., 2010 used InfoCrop model for simulating mustard yield with different increments of temperature. Under irrigated condition, the grain yield dropped steeply with rise in temperature in eastern India. In this region, yield reduction was maximum (86.6%) with 5 °C rise in temperature. Rise in temperature at same level of CO_2 decreased yield reduction to 82.4 and 79.4% respectively. In north India, temperature rise by 5 °C, with no rise in CO_2 reduced mustard yield by 34.7%.

Mustard crop grown in central part of the country was also vulnerable to temperature rise, where substantial yield loss was observed. Temperature rise would be most harmful for the crop in eastern region, followed by central India, where winter season temperature is comparatively higher than northern region (Table 6). Similar to irrigated crop, rainfed mustard would be most affected by temperature rise in eastern India with yield loss of 78.4% with 5 °C rise in temperature at various enhanced level of CO_2. Increase in CO_2 Concentration at same temperature also caused reduction in grain yield. Elevated CO_2 and temperature caused more yield reduction under rain fed condition. Substantial yield loss occurred in central India with a loss of 40.2% (Fig. 4). Rainfed mustard was less vulnerable to temperature rise in northern India as compared to other two locations. Rise in atmospheric temperature reduced leaf area index, grain number as well as weight of grains which was in turn reflected in yield of the crop. According to Morison and Stewart, 2002 increased temperature during bolting to flowering period reduced yield of all Brassica spp.

Low temperature extremes (frost) after flowering and during pod filling will cause significant yield reductions and possible down grading. However, it is also very likely to suffer freeze injury caused by frost. Frost could induce significant pigment and water loss, structural injuries, and impaired light capture capability of photo systems at the cellular scale (Oksanen *et al*., 2005). Furthermore, it would cause dehydrated or withered leaf blade and even canopy structure alteration. Winter rape due to large-leaf crop with high water content in the leaves, is more vulnerable to freeze injury. Winter oil seed rape growing exuberantly or with premature development has more risk of damage by frost (Gu *et al*., 2008).

Various research studies have shown that both *B. napus* and *B. rapa* canola will imbibe water and germinate at constant temperatures of 2 °C. Sustained low temperatures for both *B. napus* and *B. rapa*, however, damage the seed embryo, which reduces germination and growth. Low temperature impairs the production of proteins required for proper germination and early seedling development through reduced metabolic processes. Acharya *et al*., 1983 found that 4 °C or higher temperature had little effect on total percent germination in *B. napus*, however, the number of days to 50% germination increased dramatically at temperatures below 6 °C. The number of days to 50% germination in *B. napus* was only three days at 8 °C compared to nearly 13 days at 2 °C. This low temperature effect of slower and lower germination was even more pronounced with *B. rapa* canola (Fig. 5). In *B. rapa*, there was greatly reduced germination at 3 °C and 2 °C, even after 20 days, 50% emergence was not reached.

2.2.2. *Moisture stress*

Moisture stress is common in rain fed mustard crop in North West India during the month of February when winter rain fails. At this time mustard is in podding and seed development stage, is adversely affected by soil moisture deficit and it causes reduction in oilseed production.

The soil covered by straw mulch conserved more soil water followed by saw dust and ash over bare soil (Fig. 6). The variation in soil moisture retention was found in similar order at one month later. However the moisture content was about 2 - 3% less at this stage irrespective of the mulches applied (Awal and Sultana, 2011).

Mirzael *et al*., 2013 reported that moisture stress(Full irrigation, stress at flowering, pod developing and seed forming stages) had significant affect on seed yield, number of seeds/pod, number pod per plant, number of branches per plant, 1000 - seed weight, plant height and

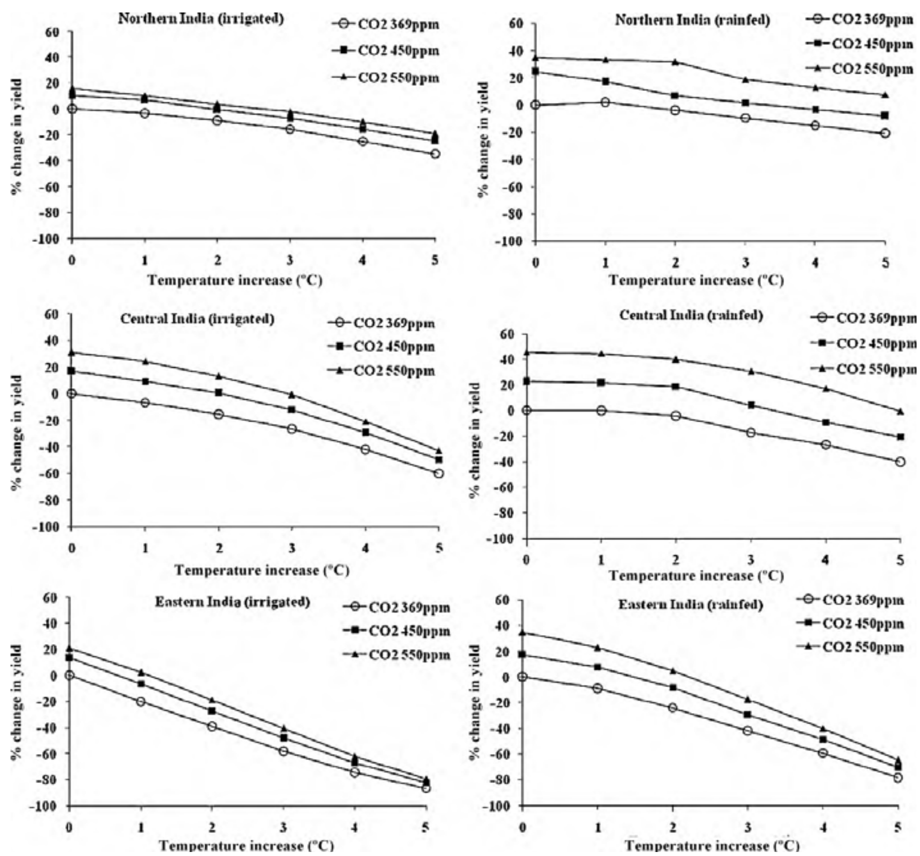


Fig. 4. Effect of CO_2 and temperature on simulated yield of irrigated and rainfed mustard in different locations in India (Boomiraja *et al*., 2010)

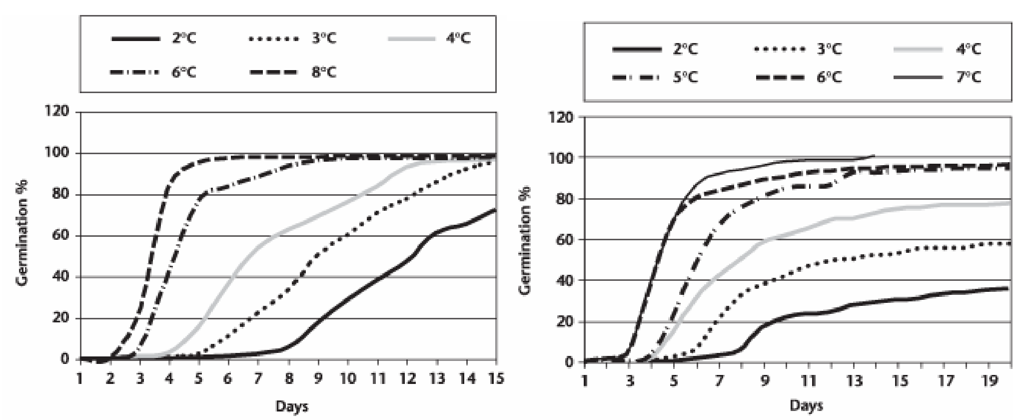
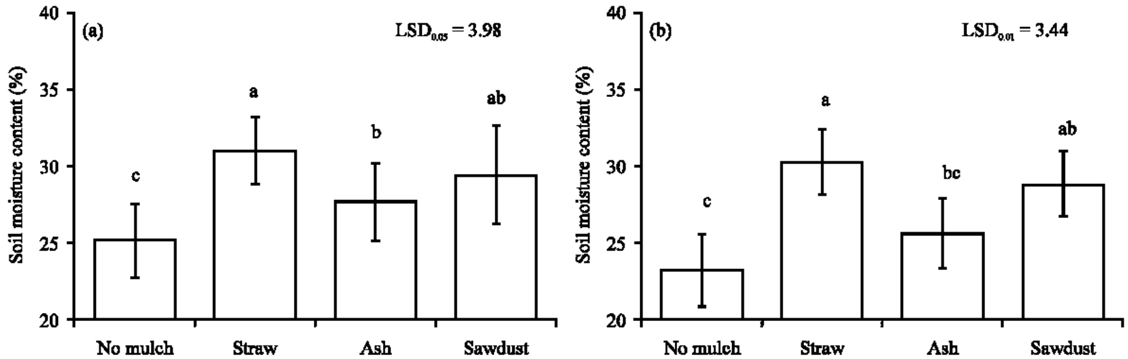


Fig. 5. Effects of temperature on germination of B. napus and B. rapa (*Source* : Acharya *et al*., 1983)

oil content of cultivars (Hyola401, Hyola308, Zarfam and PF) in Iran. Seed forming stage was the most sensitive stage, because 1000 - seed weight and oil content were decreased in this stage. The highest (3151.25 kg/ha) and lowest (2377.08 kg ha^{-1}) seed yield belonged to full irrigation and stress at flowering stage, respectively.

Gunasekara *et al*., 2006 reported the grain yield reduction of Brassica napus and Brasssica juncea due to drought stress. Seed yield reduction occurred by low water availability during stem elongation, flowering and pod development which caused reduction of pods per plant. Supplemental irrigation applied at grain-



Figs. 6(a&b). Effect of mulches on moisture content on weight basis at 5 to 15 cm soil depthat two growth stages (29 and 59 DAS) of mustard crop (*Source* : Awal and Sultana, 2011)

filling stage increased the grain yield (Wang *et al*., 2005). Hang *et al*., 2008 indicated that irrigation during stem elongation, increased grain yield in non-irrigation conditions.

Pandey *et al*., 2001 found that water stress during flowering stage, decreased seed yield due to reduction in seeds weights. Deloche (1980) reported that drought stress at seed filling stage caused fading of seeds. Decreasing seed weight under drought stress resulted from harmful effect of drought on producing biomass (Keati and Cooper, 1998). Poma *et al*., 1999 also indicated in their study on effect of irrigation treatments on canola yield that all seed yield components and seed yield decreased under drought condition. The highest 1000 - seed weight was in full irrigation and Hyola 401 cultivar and the lowest seeds per pod were in stress at seed forming stage and Zarfam cultivar.

Singh *et al*., 2011 found that overall mean performance of Brassica progenies was comparatively higher in irrigated environment for days to 50% flowering, days to maturity, fruiting zone length, main shoot length, siliquae on main shoot, siliquae per plant, 1000 seed weight, seed yield per plant and protein content. Lowest value of drought susceptibility index (DSI) indicates the highest level of drought tolerance and *vice-versa*. Values of DSI (Table 8) ranged from -0.139 (07-547) to 1.316 (07-827). The genotypes 07-547, 07-515 and 07-510 had lower DSI values (< or ~0.00), thus rated as drought tolerant.

3. Management of weather extremes

Temperature and moisture stress among the weather extremes are most important which control the productivity of mustard and wheat crop in India. Low temperature stress (frost) affects mustard crop adversely when it occurs in the month of January, but on the other hand it is beneficial for wheat crop results in better tillering. High temperature stress is most detrimental for wheat crop during grain developmental phase in the month of March but it is not as important in case of timely sown mustard as the crop matures by the first week of March. Moisture stress mainly deficit of water is determinantal for both wheat and mustard crop. Therefore management of temperature and moisture stress can minimize the crop losses to a considerable extent. Some of the approaches for managing weather vagaries adopted by many research workers are presented in following sub heads:

3.1. *Site selection*

Growers are usually aware that some spots are more prone to frost damage than others. The first step in selecting a site for a new planting is to talk with local people about what crops and varieties are appropriate for the area. Local growers and extension advisors often have a good feeling for which locations might be problematic. Typically, low spots in the local topography have colder temperatures and hence more damage.

3.2. *Effect seed priming*

A study evaluated the role of seed priming with inorganic salts ($CaCl_2$, KNO_3, KCl, plant water extracts (sorghum, moringa) and organic molecules (ascorbate, salicylicate, proline) in improving the wheat performance under heat and drought stresses (Muhammad *et al*., 2011). Stress treatments (optimal conditions, drought stress at 50% of the field capacity, heat stress (40.0 °C) higher than the ambient temperature and both drought and heat stress) substantially reduced the wheat performance and the effects were more severe when both the plants were exposed simultaneously to both the stresses. Priming treatments substantially improved the tissue water status, membrane stability, gas exchange and water productivity, however, priming with moringa water extract and ascorbate was better than other treatments in the respective group. Seed priming with water over night increased the number of spikes by 13.9% and seed yield by 29.4% over unprimed seed (Sharma and Kumar, 2009). This increase in yield was positively associated with chlorophyll content, canopy temperature depression and photosynthetic rate. Similar study was conducted by Hobbs, 1985.

3.3. *Dates of sowing and varieties*

Time of sowing is one of the most important non-monetary inputs for optimizing the growth according to prevailing agro-climatic conditions and genotypes. Adjustment in time of sowing can minimize the effect terminal heat stress in wheat. Timely sown wheat (in first fortnight of November) escapes from heat stress, caused by sudden rise in temperature in last week of March. But terminal heat stress is common in late sown wheat in North West India.

Sandhu *et al.* (1999) reported that planting dates affected grain yield significantly. The maximum grain yield (4456 kg ha^{-1}) was recorded when planting was done on 25th October, which decreased gradually and significantly to 2132 kg ha^{-1} when planting was done on 5th December. Averaged over sowing dates, PR-84 gave the highest grain yield (3835 kg ha^{-1}), which was followed by PR-85 with 3545 kg ha^{-1} grain yield. Thousand grains weight ranged from 34.8 g to 51.4 g (PR-87) (Table-VI) when planting was done on October 25th. As planting was delayed, gradual decrease took place in 1000-grains weight of all varieties/lines except PR-83 and PR-85 in which 1000-grains weight increased to 53 g and 46.8 g, respectively, when planting was done on 15th November and then decreased till 5th December. From 5th December sown crop, 1000-grains weight decreased in all varieties/lines except PR-83, PR-86 and thousand grains weight ranged from 24.8 g to 46.5 g (PR-83) when sowing was done on 5th December. Similar study was reported from Gurdaspur, Punjab (Sandhu *et al.*, 1993; Samra and Singh, 1987; Mohammad *et al.*, 2014). They found that crop sown on 15 October produced higher grain yield as compared to crop sown on 25 October, 4 and 14 November.

Boomiraja *et al.* (2010) taken adaptation measures: (S1- late sowing by 7 days and S2 - long-duration variety) and found to prevent yield loss to certain extent in mustard crop. Yield loss would be less with adaptation measures in central and northern India in all the future scenarios (Table 6). In eastern region, adoption of adaptation measures could prevent yield loss in 2020 and 2050, while in 2080 they could not prove to be beneficial. The adaptation strategy of sowing late could be able to increase yield by 1% compared to current in northern India in 2020, while in 2050 and 2080 it decreased mustard yield loss considerably.

TABLE 7

Drought susceptibility index of different characters in wheat genotypes

S. No.	Genotypes	Drought susceptibility index		
		Grains per spike	Biomass	Seed yield
1.	RWP 05-09	1.59	0.58	0.52
2.	WH 1012	0.50	0.49	0.18
3.	VL 899	1.50	0.74	0.73
4.	VL 902	1.00	0.36	0.07
5.	KYPO 425	0.53	0.07	0.18
6.	WH 736	0.61	0.39	0.50
7.	AKAW 3997	2.27	0.80	0.83
8.	C 306	0.00	0.49	0.73

(*Source* : Sharma and Kumar, 2010)

It is important to choose cultivars that bloom late to reduce the probability of damage due to freezing, and to select varieties that are more tolerant of freezing. For example, RH-30 variety is more tolerant to frost as compared to other mustard varieties. Yield loss was less in long variety in which maturity occurred later than that of the existing variety. Genotypes, RGN 197, PLM-2BPR-549-9, BPR-540-6 and BPR-349-9 showed tolerance to high temperature at terminal stage based on less reduction in seed yield, and medium transpiration rate (Singh *et al.*, 2014).

Cultivars of wheat: Raj 3765, WH 1021, etc. and mustard: RH 30, RH 0749 etc. are of low water requirement/ stress tolerant can be grown in rain fed and limited irrigation areas. Rain fed cultivated wheat crop encounters water stress during later stages of growth due to dry spell leading to progressive decrease in soil moisture received by winter rains.

The rainfed wheat plant had water deficit as indicated by more negative water potential but the decrease was relatively more in cultivar WH711 over Kauz star in comparison to non stress wheat (Sharma *et al.*, 2008). The leaves of cultivar Kauz star had higher chlorophyll content and less decrease in photosynthesis and transpiration rates under stress condition. Cultivar WH 147 maintained higher plant water status and higher

TABLE 8

Classification of advanced lines of *Brassica juncea* on the basis of Drought susceptibility index (DSI)

DSI value	Reaction	Genotype (s)
<0.0	Drought tolerant	07-547, 07-515 and 07-510
>0.0-1.0	Moderately tolerant	07-501, 07-502, 07-503, 07-504, 07-505, 07-507, 07-509, 07-511, 07-512, 07-513, 07-514, 516, 07-517, 07-518, 07-520, 07-520, 07-526, 07-527, 07-529, 07-531, 07-534, 07-535, 07-536, 07-537, 07-538, 07-540, 07-541, 07-542, 07-544, 07-875-1, 07-895-1
>1.0-1.5	Moderately susceptible	07-508, 07-519, 07-521, 07-523, 07-525, 07-528, 07-539, 07-543,07-548, 07-551, 07-552, 07-553, 07-555, 07-561, 07-606, 07-609, 07-728, 07-761, 07-763, 07-771, 07-773, 07-782, 07-788, 07-793, 07-883, 07-885, 07-895, 07-906, 07-925-1, 07-925-2, 07-885-1
>1.5	Susceptible	-

(*Source* : Singh *et al*. 2011)

rate of photosynthesis of flag leaf at anthesis than PBW 175, C 306, WH 711, WH 1024 and WH 1025 and also resulted in higher grain yield under rain fed conditions (Sharma and Kumar, 2009). Sharma and Kumar, 2010 computed the drought susceptibility index (DSI) of different characters in different wheat genotypes (Table 7; Sharma and Chakor, 1989). Drought Susceptibility Index (DSI) indicated that seed yield was determined by the biomass produced by an individual genotype. RWP 05-09, WH 1012, VL 899, VL 902, KYPO 425, WH 736, AKAW 3997 and C 306 showed tolerance in biomass and seed yield against drought. The tolerance in grains/spike was observed in WH 1012 KYPO 425, WH 736 AKAW 3997 and C 306 against moisture stress. Drought Susceptibility Index (DSI) was calculated for each mustard genotype as a criterion of drought tolerance (Table 8). The lowest value indicates the highest level of drought tolerance and *vice-versa* (Singh *et al*., 2011). The genotypes 07-547, 07-515 and 07-510 had lower DSI values (< or ~0.00), thus rated as drought tolerant.

3.4. *Fertilizer management*

Unhealthy trees are more susceptible to frost damage and fertilization improves plant health. However, nitrogen and phosphorus fertilization before a frost encourages growth and increases susceptibility to frost damage (Snyder and de Melo-Abreu, 2005). To enhance hardening of plants, avoid excess application of nitrogen fertilizer. However, phosphorus is also important for cell division and therefore is important for recovery of tissue after freezing. Potassium has a favorable effect on water regulation and photosynthesis in plants. An adaptation strategies such as 50% increase in recommended fertilizer (120 kg ha^{-1}) as basal as well as split dose (basal, 30 and 60 DAS) and increasing one more irrigation (1, 30, 60 DAS) did not help in improving mustard yield in future climate change scenarios (Boomiraja *et al*., 2010).

3.5. *Soil compacting*

Soil cultivation creates air spaces in the soil and it should be avoided during frost-prone periods. Air is a poor heat conductor and has a low specific heat, so soils with more and larger air spaces will tend to transfer and store less heat. If a soil is compacted and irrigated, will improve heat transfer and storage capacity. Bridley *et al*., 1965 attempted to reduce the frost damage by compacting the soil by roller in Australia.

3.6. *Irrigation*

When soils are dry, there are more air spaces, which inhibit heat transfer and storage. Therefore, in dry years, frost protection is improved by light irrigation. The goal is to maintain the soil water content near field capacity, 1 to 3 days following thorough irrigation. Wetting the soil will often make it darker, and increases absorption of solar radiation.

Irrigation by sprinkler increases long-wave radiation and sensible heat transfer to the plants relative to an unprotected crop. Over-plant sprinkler irrigation provides excellent frost protection down to near -7 °C if the application rates are sufficient and the application is uniform. Under windy conditions or when the air temperature falls so low that the application rate is inadequate to supply more heat than is lost to evaporation, the method can cause more damage than experienced by an unprotected crop. Cary, 1974 used sprinklers for frost protection under screen covering the crop field. Hang *et al*., 2008 indicated that irrigation during stem elongation, increased grain yield in non-irrigation conditions. Supplemental irrigation applied at grain-filling stage increased the grain yield (Wang *et al*., 2005).

TABLE 9

Effect of straw mulch and irrigation on evapotranspiration, soil water depletion, biomass and grain yield of wheat

Year	Yield (qha-1)	Treatments				
		No straw mulch and no irrigation	Straw mulch and no irrigation	No straw mulch and irrigation 15 mm	No straw mulch and irrigation 30 mm	No straw mulch and irrigation 45mm
1997	Biomass	3356+390	4584 + 350**	4500 + 364**	4903 + 510***	5556 + 493***
	Grain	818 + 125	1240 + 84**	1250 + 104**	1384 + 156***	1650 + 131***
	Evapotranspiration	239.2	219.5**	250.6 NSa	260.8**	271.1***
	Soil water depletion	58.1	38.4***	54.5 NSa	49.7***	45.0***
1998	Biomass	7120 + 310	8563 + 439**	9546 + 480***	10970 + 570***	12580 + 520***
	Grain	2061 + 199	2601 + 203**	2520 + 195**	2883 + 228***	3230 + 213***
	Evapotranspiration	369.6	355.3*	349.9**	338.8***	364.4 NSa
	Soil water depletion	91.2	76.9***	71.5***	60.4***	85.7 NSa

(*Source* : Huang, *et al*. 2005)
a Significance at p> 0.05 level,
* Significance at p< 0.05 level,
** Significance at p< 0.01 level,
*** Significance at p< 0.001, when compared to the t1 treatment

Singh *et al*., 2011 found that overall mean performance of Brassica progenies was comparatively higher in irrigated environment for days to 50% flowering, days to maturity, fruiting zone length, main shoot length, siliquae on main shoot, siliquae per plant, 1000 seed weight, seed yield per plant and protein content.

3.7. *Mulching*

Mulching has been proved to be useful in conserving moisture and increasing productivity in wheat (Chakraborty *et al*., 2008; Huang *et al*., 2005; Verma, 2004), which subsequently resulted in higher water and nitrogen uptake and their use efficiencies (Chakraborty *et al*., 2010). Mulch research has shown that use of surface mulch can result in storing more precipitation water in soil by reducing runoff, increasing infiltration and decreasing evaporation (Huang *et al*., 2005; Ji & Unger, 2001 and Smika & Unger, 1986)

Crop straw and plastic mulches are often used to warm the soil and increase protection. Clear plastic warms the soil more than black plastic and wetting the soil before applying the plastic further improves effectiveness. Fritton and Martsolf, 1981 covered soil by plastic and found that surface temperature of the soil covered with plastic was nearly 10 °C greater than that of bare soil.

Straw mulch in wheat crop increased the grain yield from 818 & 2062 (1997 and 1998) kg/ha (without mulch) to 1240 kg/ha under limited soil moisture conditions

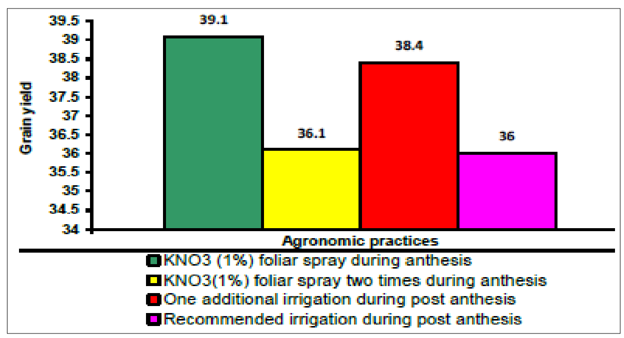


Fig. 7. Agronomic practices for managing heat stress on grain yield (q/ha) (*Source*: Singh, 2010)

(Table 9). Evapotranspiration was reduced by straw mulch over wheat crop without mulch by reducing the soil water depletion (Huang *et al*., 2005). Organic mulches (straw and saw dust) provided better soil water status (Fig. 6). Mustard crop with saw dust improved plant growth in terms of biomass over in organic mulch (ash) (Fig. 8).

3.8. *Foliar spray of chemical*

In recent past some encouraging results were obtained with post flowering foliar application of various nutrients on yield of wheat. The higher grain and straw yield of wheat by spraying 0.5 per cent KNO_3 at 50 per cent flowering stage of the crop was reported (Das and Sarkar, 1981). Wheat crop sown on 25 November sprayed with KNO_3 (1%) during anthesis produced highest grain

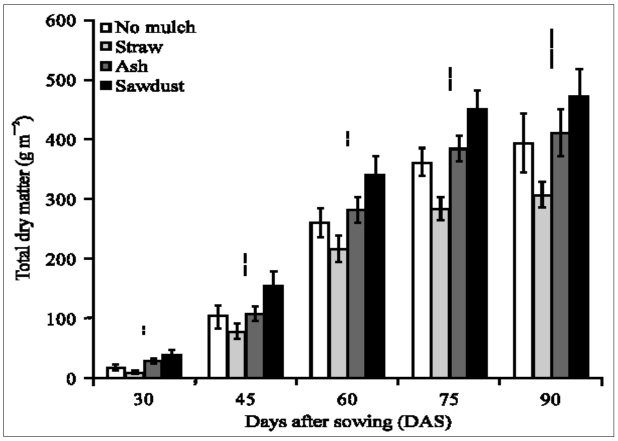


Fig. 8. Effect of mulches on dry matter of mustard crop (*Source* : Awal and Sultana, 2011)

yield followed by one additional irrigation during post anthesis, two foliar spray of KNO_3 (1%) during anthesis and recommended irrigation (Fig. 7) (Singh, 2010 and Singh *et al*., 2011). A study was designed to explore the role of arginine (0.0, 2.5 and 5.0 mM) in increasing the tolerance of wheat cultivar (Sids-93) to two late sowing (23/12 and 23/1) besides the normal sowing date (23/11) in Egypt (Hozayn *et al*., 2011). Foliar spray of 0.5 per cent KNO_3 at 50 per cent flowering stage or 1.0 per cent KNO_3 during anthesis, use of organic mulch, foliar spray of zinc, use of potassium fertilizer with waste water can alleviate the adverse impact of high temperature stress on wheat (Singh *et al*., 2011).

Highest grain and biological yield with normal irrigation and spraying with zinc were 62.4 and 143.0 q/ha, respectively and the lowest of 38.0 and 122.0 q/ha in the conditions of discontinuation of irrigation at flowering stage and lack of spraying zinc (Shahramlack *et al*., 2011). Sharma and Pannu, 2009 managed heat stress by frequent light irrigation followed by thiourea spray over control.

3.9. *Foliar spray of micronutrient*

One of the reasons of reduction of crop yield is insufficient supply of micronutrients. Zinc is one of those micronutrients which have an important role in metabolic activities of the most plants. On the other hand, its mobility is low under drought stress conditions, so this element can be sprayed to increase its intake in the plant. It showed that the highest grain and biological yield during the conditions of normal irrigation and spraying with the zinc is 62.40 and 143.00 qha^{-1}, respectively and the lowest of 38.00 and 122.00 qha^{-1} in the conditions of discontinuation of irrigation at flowering stage and lack of spraying zinc (Shahramlack *et al*., 2011). On the other hand, application of zinc spraying in drought conditions causes the increase in number of grains per spike, grain weight and harvest index, comparing with the lack of spraying. The spraying of zinc in normal irrigation conditions, especially in drought stress conditions have significant positive effects on yield and yield components of wheat.

3.10. *Bacterial control*

For freezing to occur, the ice formation process is mostly initiated by presence of ice nucleation active (INA) bacteria. The higher the concentration of the INA bacteria, the more likely that ice will form as it acts as a freezing nuclei (Steven *et al*., 1982). Bacterial ice nucleation on leaves can be detected at about -2 °C, whereas the leaves themselves, *i.e*., without INA bacteria, contain nuclei active only at much lower temperatures. The temperature at which injury to plants occurs is predictable on the basis of the ice nucleation activity of leaf discs, which in turn depends on the number and ice nucleation activity of their resident bacteria. After forming, it then propagates inside the plants through openings on the surface into the plant tissues. Commonly, pesticides (copper compounds) are used to kill the bacteria or competitive non-ice nucleation active (NINA) bacteria are applied to compete with and reduce concentrations of INA bacteria (Snyder and de Melo-Abreu, 2005). However, this frost protection method has not been widely used.

3.11. *Biomass residue burning/ heaters*

Heaters provide supplemental heat to help replace energy losses. Generally, heaters either raise the temperature of metal objects (*e.g.*, stack heaters) or operate as open fires. If sufficient heat is added to the crop volume so that all of the energy losses are replaced, the temperature will not fall to damaging levels. They are not economical in low valued crops (mustard).

Biomass residues (crop straw/waste) are also used for heating the crop environment, especially under windy conditions. Straw burning in windward creates a smoke layer over the crop surface and absorbs long wave radiation released by soil; thereby protect the mustard crop from frost by raising the ambient temperature. Mee and Bartholic, 1979 found that smoke particles are usually less than 1 µm in size, reflect visible radiation but are not permeable to long wave radiation and so are effective in preventing rapid cooling of surface near ground.

3.12. *Air mixing*

Wind machine breaks up micro-scale boundary layers over plant surfaces, which improves sensible heat transfer from the air to the plants. However, wind machine is effective if inversions between 2.0 and 10 m height are

TABLE 10

Wheat yield at indicated position from slat fence wind barrier, Manhattan, Kansas

Distance from shelter (H*)	Years			Average
	1971	1972	1973	
-12.5	-	41.5	33.3	37.4
-8.0	14.4	41.8	33.2	37.5
-4.5	-	43.0	34.0	38.9
-2.0	9.3	38.3	32.8	35.9
2.0	6.3	40.7	31.5	36.1
4.5	13.0	43.3	33.9	38.6
8.0	-	44.0	34.1	39.1
12.5	14.5	39.4	35.6	37.5

* Distance from barrier in barrier heights. Positive and negative indicate north and south sides of an east-west barrier, respectively. Prevailing wind direction was southerly. (Mc Martin *et al*., 1974)

at least 1.5 °C or greater on most frost nights. Generally, one large wind machine with a 65 to 75 kW power source is needed for each 4.0 to 4.5 ha. Wind machines are typically started when the air temperature reaches about 0 °C. Wind machines are not recommended when there is a wind of more than about 2.5 m/s (8 km/h). Bates, 1972 found that wind propeller system maintains safe temperature on frost nights but protection diminishes with distance from wind propeller.

3.13. *Insulation*

Application of foam insulation has been shown to increase the minimum temperature on the leaf surfaces by 10 °C over unprotected crops. However, the method has not been widely adopted by growers because of the cost of materials and as well as labor problems with covering large areas in short times. Mixing air and liquid materials in the right proportion to create many small bubbles is the secret to generate foam with low thermal conductivity. Siminovitch *et al*., 1972 covered the plants with nontoxic protein based foam material and found most effective under radiation frost conditions but less effective under adjective frost. Spray of 0.1 per cent of thiourea at 50 and 75 days after sowing significantly improved in yield attributes and grain yield over 0.1 H_2SO_4 and without spray mustard crop under frosty conditions (Meena *et al*., 2012).

3.14. *Shelter/ barrier*

Waggoner (1969) has demonstrated the importance of wind in water-stress relationships. Using wind barriers to decrease wind speed and potential evapotranspiration resulted an increase in yield and more efficient (though unchanged total) water use. Mc Martin *et al*., 1974 harvested spring wheat for 3 years from sample areas at regular intervals from 14 single-row shelterbelts in North Dakota. They found maximum yield at 5H. If the area occupied by the tree row was not included, the yield for the area 1H to 13H was the same as the check area. With favorable weather and absence of hot winds, the barrier influenced the yield of wheat due to modification of microclimate (Table 10). Reduction in winds in sheltered area decreased the evapotranspiration . Thereby soil/crop moisture status was improved, ultimately it contributed in grain yield. Yield data illustrate a possible trend lowest yielding positions were close to and far from the fence and highest yield at intermediate positions apparently was favorably influenced by modified microclimate of sheltered area due the barrier. Effect of barrier was observed on both sides but more beneficial effect was on the leeward side.

4. Conclusion

Based on the investigations of various research workers, it can be concluded that the adoption of cultural practices like seed priming with water and moringa water extract and ascorbate, timely sowing, mulching, additional light irrigation during post anthesis, foliar spray of 0.5 per cent KNO_3 at 50 per cent flowering stage or 1.0 per cent KNO_3 during anthesis, 2.5 mM of arginine, foliar spray of zinc can manage the adverse impact of terminal heat and moisture stress.

Air mixing, biomass residue burning/smoking in windward, light irrigation, spray of 0.1 per cent of thiourea and 0.1 H_2SO_4 at 50 and 75 days after sowing, spray of non-ice nucleation active (NINA) bacteria, avoid excess nitrogenous fertilizer and soil hoeing before frost, resistant variety, mulches and soil compaction can manage the crop losses due to frost damage.

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