Alleviating the intra-seasonal high and low temperature effects on field crops

Diwan Singh

headagmet@hau.ernet.in

Dept of Agril Meteorology

CCS Haryana Agril University

Hisar-125 004, India



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- **Plants are immobile**
- **Temperature variability during the intra-season is an important determinant of the yield of annual crops**
- **Except for transpirational cooling, plants are unable to adjust their tissue temperatures to any significant extent at intra-seasonal level**

Energy exchange of water due to cooling, heating & phase changes

PROCESS	ENERGY
Water cooling	+ 4.1868 J g^{-1} $°C^{-1}$
Freezing (liquid freezing at 0°C)	**+ 334.5 J g^{-1}**
Ice cooling	+ 2.1 J g^{-1} $°C^{-1}$
Water condensing (vapour to liquid) at 0°C	**+ 2501.0 J g^{-1}**
Water depositing (vapour to ice) at 0°C	+ 2835.5 J g^{-1}
Water sublimating (ice to vapour) at 0°C	**- 2835.5 J g^{-1}**
Water evaporating (water to vapour) at 0°C	- 2501.0 J g^{-1}
Ice warming	**- 2.1 J g^{-1} $°C^{-1}$**
Fusion (ice melting at 0°C)	- 334.5 J g^{-1}
Water warming	**- 4.1868 J g^{-1} $°C^{-1}$**

Effect of **intra-seasonal** high temp on field crops

- **Rise in soil temperature**
- **Desiccation of protoplasm**
- **Enzyme denaturation**
- **Increase in canopy temperature**
- **Premature death of plants**
- **High ET demand**
- **Impaired reproductive development (sterile pollen, no flowers or flowers without fruit or seed setting)**

Heat Wave

Daily maximum temp of more than 5 consecutive days exceeds the maximum temp normal by 5°C

High temp effects on major field crops

Corn

- **Temperature > 36°C causes pollen to lose viability**

Soybean

- **Soil temperature > 35°C at planting causes seedling death**
- Very sensitive to temp > 35°C during first three weeks after bloom
- **Great ability to recover from temperature stress at other times**

Cotton

- **Temp > 40°C for more that 6 hours causes bolls to abort**
- **Relatively tolerant to temperatures < 40°C**

High temp and Rice

- **High temp at flowering inhibit swelling of the pollen grains, which is the driving force behind anther dehiscence in rice**
- **High temp at flowering induce floret sterility and limit grain yield**
- **High night temp, the average grain weight of the whole plant and panicle decreased by 7-11% & 5-6%, respectively**
- **Cold damage at flowering or panicle initiation stage leading to panicle sterility**
- **Lowering the night/day temperature by 5°C from the optimum has been shown to reduce plant growth by**

High temp and Wheat

- **Hastening of crop maturity**
- Grain set is reduced by temperatures warmer than 30°C during the period from the onset of meiosis in the male generative tissue to the completion of anthesis.
- **Temp >30°C at floret formation cause complete sterility**
- High temp (31°C) after anthesis decrease rate of grain filling.
- **High temp episodes occurring near to anthesis can reduce the number of grains per ear and the subsequent rate of increase in harvest index, resulting in smaller grain yields**

Variability of mean temp in October during 1996-2006

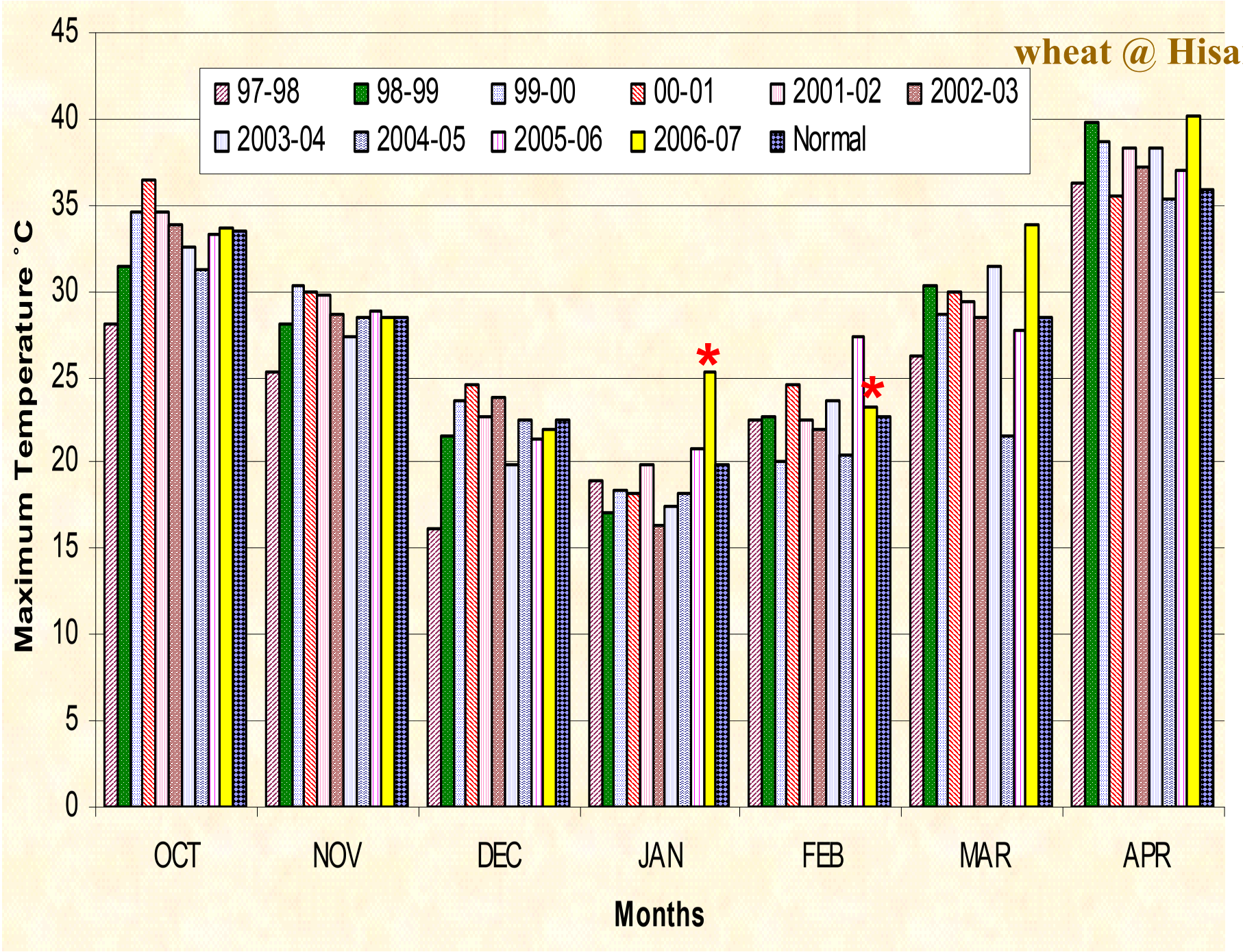
wheat @ Hisar

Julian date	Mean Temp (°C)											
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Normal
25th Oct	20.7	21.1	25.3	23.1	23.8	24.7	21.3	23.1	20.0	23.4	22.4	22.7
26th Oct	23.2	19.6	24.3	23.4	22.8	26.0	22.7	23.0	21.3	22.8	22.1	22.8
27th Oct	22.3.	19.7	24.4	22.8	23.0	25.8	22.6	22.2	21.9	23.0	22.3	22.9
28th Oct	22.4	20.0	23.9	23.6	22.4	26.6	22.8	23.0	21.3	22.2	23.5	22.9
29th Oct	22.1	20.1	22.8	23.7	23.2	26.6	23.5	22.0	20.9	20.5	23.0	22.7
30th Oct	21.3	17.9	22.8	23.6	24.5	25.4	26.0	21.6	19.2	20..4	22.3	22.4
31st Oct	22.0	19.6	22.4	24.3	22.7	25.6	24.8	21.3	19.0	21.0	23.1	21.9
18-24 Oct	24.6	20.8	24.1	24.8	25.4	24.9	24.0	22.7	23.9	22.9	24.5	23.8
25-31st Oct	22.0	19.7	23.7	23.5	23.2	25.8	23.4	22.3	20.5	21.9	22.6	22.6

Variability of mean temp during 1997-2006.

wheat @ Hisar

Julian year	Mean Temp (°C)		
	3rd Week (Oct)	4th Week (Oct)	1st Week (Nov)
1997	20.8	19.7	20.2
1998	24.1	23.7	21.6
1999	24.8	23.5	24.3
2000	25.4	23.2	22.1
2001	24.9	25.8	23.8
2002	24.0	23.4	22.4
2003	22.7	22.3	21.9
2004	23.9	20.5	18.6
2005	22.9	21.9	21.3
2006	24.5	22.6	21.9
Normal	23.8	22.6	21.3


wheat @ Hisar
97-98
98-99
99-00
00-01
2001-02
2002-03
2003-04
2004-05
2005-06
2006-07
Normal
Maximum Temperature °C
0
5
10
15
20
25
30
35
40
45
OCT
NOV
DEC
JAN
FEB
MAR
APR
Months
*
*

Heat Strokes @ Hisar – An Example

- 13 May – 09 June, 1998
- 23 days with Tmax > 40 ^{0}C
- 14 days with Tmax > 45 ^{0}C and above
- Max temp (47.5 ^{0}C) on 27 & 29 May, 1998 (Record)
- Occurrence of heat wave during abnormal monsoon seasons - a normal feature

Alleviation (*Short-term*)

- **Mulching**
- **Use of anti-transpirants**
- **Wind breaks and shelterbelts**
- **Irrigation**
- **Selection of resistant cultivars/ species**
- **Reducing the *evaporation* losses of farm ponds by applying cetyl alcohol films**

Alleviation *(Long-term)*

Mechanism of Heat Tolerance

- **Plants have evolved several mechanisms that enable them to tolerate higher temp**
- **These adaptive thermo-tolerant mechanisms reflect the environment in which a species has evolved and they largely dictate the environment where a crop may be grown**
- **These measures require relatively longer periods**

Frost & Frost injury

- **Occurrence of temp ≤ 0°C in a 'Stevenson Screen' shelter at a height between 1.25 & 2.0 m**

- **Crops of tropical origin experience physiological damage when subjected to temp < 12.5 °C**
- **Extra-cellular ice formation**

Freezing and Chilling injury

- **Crops of tropical origin experience physiological damage when subjected to temperatures below about +12.5 °C. However, damage above 0°C is chilling injury rather than freeze injury**
- **Freezing injury occurs due to ice formation in plants**
- **Rupturing and burst of cell wall**
- **Leakage of cell sap**
- **Death of cell followed by plant parts and plant**

Intra-seasonal low temp effects on field crops

- **Freezing and chilling injury**
- **Frost injury**

Explanation of frost/freeze warnings:		
Warning	**Air temp**	**Wind speed**
Frost	**> 32°F**	**< 10 mph**
Frost/Freeze	**< 32°F**	**< 10 mph**
Freeze	**< 32°F**	**> 10 mph**

Freezing injury in Maize

- **Seed: swelled seed could be chilled depending on how low soil temps drop delaying germination; un-swelled seed should be OK**
- **Spike to 4 leaf (generally tolerates freezing temp of short duration) leaf or tip burn usually doesn't kill the plant**
- **5-6 leaf (more likely to have plant death if exposed growing point is subjected to temperatures below freezing)**

Frost injury in *Dicots*

- **During flowering plants are affected by -2 to -3 °C while those in the pod formation stage are a bit more tolerant but will be damaged by -3 to -4 °C.**
- **During early pod fill/grain-formation frost can cause discoloration and deformation of seeds.**
- **Frost damaged seeds will be water soaked and no longer firm as they start to 'leak'. Heavily damaged pods will have a rubbery wilted appearance.**
- **As pulses often mature from the bottom of the plant toward the top, frost injury may be much greater on plant tops. Seeds near the ground may have no frost damage and care should be taken to focus harvest efforts on these seeds**

Temperatures that cause injury to spring wheat at growth stages and symptoms and yield effect of freeze injury			
Growth Stage	~ Temperature Injurious (2 hrs.)	Primary Symptoms	Yield Effect
Tillering	12 °F (-11°C)	Leaf chlorosis; burning of leaf tips; silage odor; blue cast to fields	Slight to moderate
Jointing	24 °F (-4° C)	Death of growing point; leaf yellowing or burning; lesions, splitting or bending of lower stem; odor	Moderate to severe
Boot	28 °F (-2 °C)	Floret sterility; head trapped in boot; damage to lower stem; leaf discoloration; odor	Moderate to severe
Heading	30 °F (-1 °C)	Floret sterility; white awns or white heads; damage to lower stem; leaf discoloration	Severe
Flowering	28 °F (-1 °C)	Floret sterility; white awns or white heads; damage to lower stem; leaf discoloration	Severe
Milk	28 °F (-2 °C)	White awns or white heads; damage to lower stems; leaf discoloration; shrunken, roughened or discolored kernels	Moderate to severe
Dough	28 °F (-2 °C)	Shriveled, discolored kernels; poor germination	Slight to moderate





Burning and yellowing of leaf tips are common spring freeze symptoms at tillering stage

More severe freeze damage causes the entire leaf to turn yellowish-white and the plants to be limp or flacid. A silage odor may be detected after several days

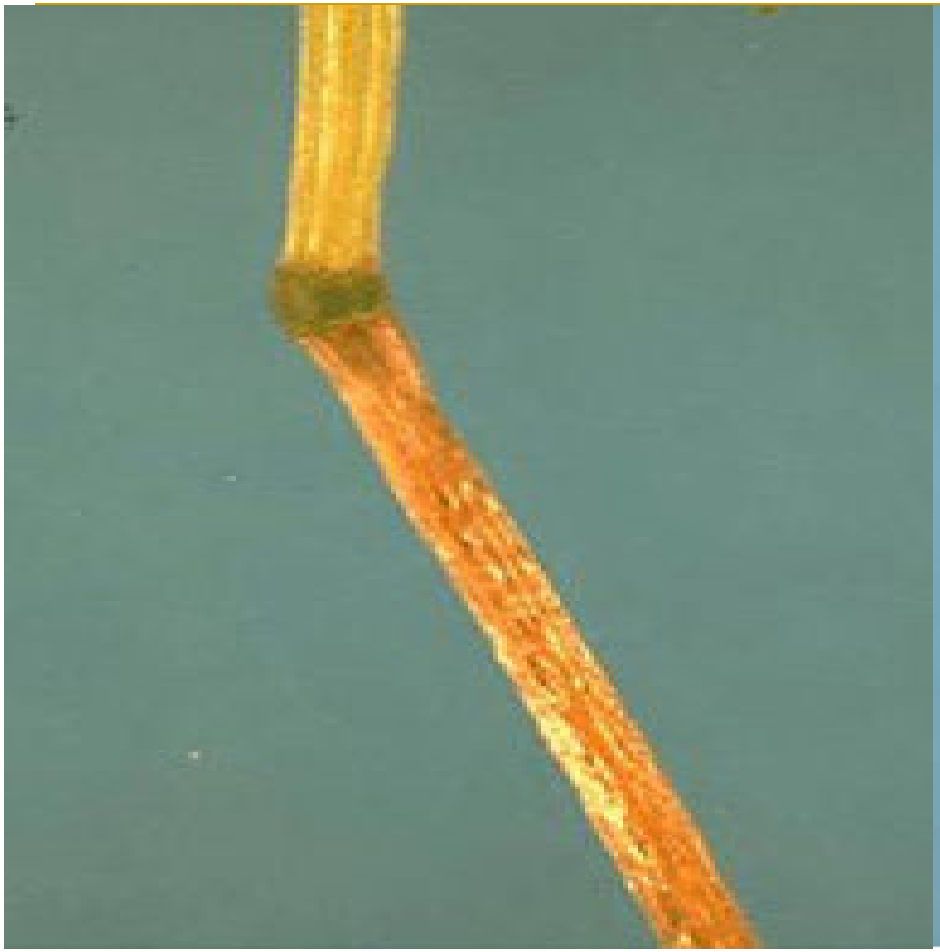


A yellow necrotic leaf emerging from the whorl indicates the growing point may be damaged.



Left: A healthy growing point has a crisp whitish-green appearance.

Right: A growing point that has been damaged loses its turgidity and greenish color within several days after a freeze. A hand lens will help detect subtle freeze damage symptoms.



Discoloring and roughening of the lower stem are symptoms of spring freeze damage.



Splitting of stem occurs with severe freeze damage.



Splitting of stem occurs with severe freeze damage.



Left: Spike had partially emerged when freezing occurred so only upper portion of the spike was damaged.
Middle: The awns were damaged while it was still in the boot stage.
Right: A twisted spike trapped in the boot and split out the side of the sheath.





Symptoms of slight freeze damage may occur only on the awns as the spike is emerging from the boot or after heading. Awns become twisted and bleached or white instead of their normal green color. There may be no other damage to the rest of the plant .



A whitish frost ring encircles the stem at the juncture of the stem and flag leaf at the time of the freeze



Damage may occur in different areas of the spike because flowering, which is the most sensitive stage to freeze, does not occur at the same time in all florets.

Strategies to avoid low temp include

- **Snow retention throughout the winter, which protects both the aerial and subterranean parts of the plants**
- **The biophysical effect of dense canopies, which shield part of the plant from the cold sky**
- **Artificial frost protection methods, which modify the microclimate of the plants (e g foams, covers and fogging)**

Tolerance of low temp can be achieved by

- **Avoiding freezing through a decrease of the freezing point or an increase in the degree of supercooling.**
- **Tolerance of extra-cellular freezing by reducing the amount of ice formed due to an increase of the concentration of solutes in the protoplasm.**
- **Tolerance of a higher degree of desiccation due to the plasmolysis of the protoplasm.**
- **Increasing the permeability of the plasma membrane to avoid intracellular freezing.**

Comparison of minimum temp of soil surfaces under various types of floor management practices	
Bare, firm moist ground	Warmest
Shredded cover crop, moist ground	½ °F colder
Low cover crop, moist ground	1-3 °F colder
Dry, firm ground	2 °F colder
Freshly disked ground	2 °F colder
Higher cover crop	2-4 °F colder
In some instances where high cover crop restricts air drainage	6-8 °F colder

1. Biological (avoidance or resistance)

- ✓ **Induction of resistance to freezing without modifying plant genetics**
- ✓ **Treatment of the seeds with chemicals**
- ✓ **Plant selection and genetic improvement**
- ✓ **Selecting species for timing of phenological development**
- ✓ **Selecting planting dates for annual crops after the probability of freezing lessens in the spring**
- ✓ **Growth regulators and other chemical substances**
- ✓ **Hardening**

2. Ecological

- **Site selection for cropping**
- **Modification of the landscape and microclimate**
- **Controlling nutritional status**
- **Soil management**
- **Cover crop (weed) control and mulches**
- **Removing cover crops**
- **Soil covers**
- **Trunk painting and wraps**
- **Bacteria control**
- **Planting date for annual crops**

3. *Active Protection from Frost*

Covers and Radiation

- Organic materials
- Covers without supports
- Covers with supports

Water

- Over-plant sprinklers
- Under-plant sprinklers
- Micro sprinklers
- Surface irrigation
- Artificial fog

Wind machines

- Horizontal
- Vertical
- Helicopters

Heaters

- ✓ Solid fuel
- ✓ Liquid fuel
- ✓ Propane

4. Combinations

- **Fans and heaters**
- **Fans and water**

5. Chemical protectants

- **Seaweed extract (Maxicrop)**
- ***Glycine Betaine***
- **DEPEG and Teric 12A23B**

Four major aspects of thermo-tolerance studied widely till now

1. **Thermal dependence at biochemical & metabolic levels**
2. **Thermal tolerance in relation to membrane stability**
3. **Induced thermo-tolerance thro' gradual temperature increase *vis-a-vis* production of heat shock proteins**
4. **Photosynthesis & productivity during high temp stress**

Crop growth and development

- ✓ **All genotypes are sensitive to temp at one stage or another. Temp sensitivity, however, varies greatly with genotype**
- ✓ **Phenological stages differ in sensitivity to temperature**
- ✓ **Duration of phase from sowing to first spikelet initiation is less sensitive to change in temp than other phases, although genotypes do differ in thermo-tolerance during this phase**
- ✓ **Stages during which environment has greatest impact on yield are from first spikelet initiation or terminal spikelet formation until anthesis**
- ✓ **Spikelet number & floral number (potential grain number), both dominant yield contributing attributes, are established during these phases. Grain weight, on the other hand, appears to be much less sensitive to heat stress than is grain number**

Cold Facts of current winter @ Hisar

- Severest winter since 1970
- 2 months of chilly weather, with occasional relief during 16/12/07 – 13/02/08 (2 months)
- 30 days (1 month) with Minimum temp of < 2.0°C
- 17 days out of 30 had sub-zero temp (< 0°C)
- 7 days with Minimum temp between -1.0 to -3.2°C
- 22nd January, 2008 coldest night of season with -3.2°C
- 28 Frost events with spells of 2 to 9 days duration
- 5th February, 2008 coldest day with 9.1°C (Max) and 7.5°C (Min) temp

  (↓12°C) (↑ 2.5°C)


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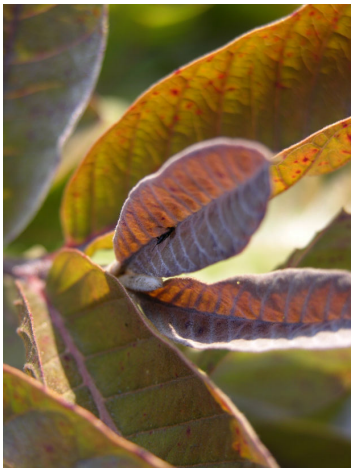





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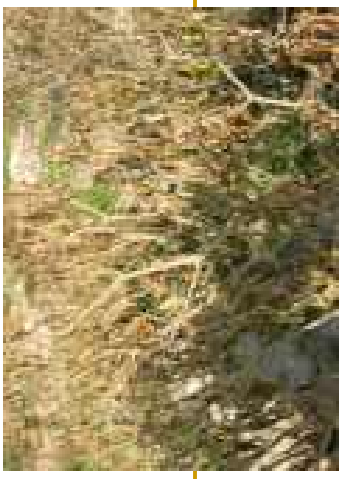






















Thank You All

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