Ensuring a Sustainable Tropical Fruit Industry in the Midst of Climate Change
The India Story

Dr. Prakash Patil
Project Coordinator (Fruits)
pcfruits@gmail.com

ICAR- Indian Institute of Horticultural Research
A premier Institute of Indian Council of Agricultural Research
भारतीय बागवानी अनुसंधान संस्थान

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Outline

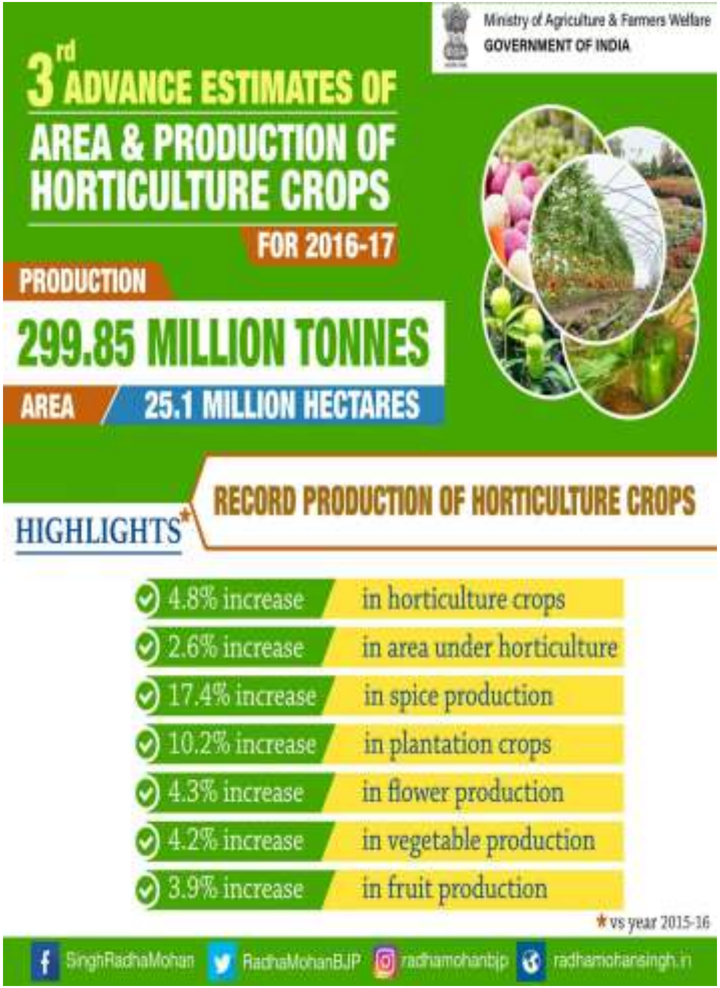
- Background:
  - ➢ Horticulture / Climate change
- Climate change in India
- Climate change effects in fruit crops
- Review of research results on climate change:
  - ➢ Climate change Vs TF Production
  - ➢ Climate change Vs Pests
- Conclusion

India Horticulture

- Horticulture - means of diversification, enhances efficient use of land and natural resources
- Fruits and vegetables contribute nearly **90%** to the total horticulture production in India
- Globally, India stands **second** in the production of fruits and vegetables

- To realize higher yields: Perfect match between **climate** of the **growing region** and the **crop species** is essential
- **Hindrances in** realization of potential yields: Biotic and abiotic stresses

- **Horticulture sector - driving force in Indian agriculture**
- **Its share in the agriculture GDP is more than 30%**
- **Latest 3rd Advance estimates for 2016-17 indicate production of 299.85 million tonnes from 25.1 million ha area**
- **Production of horticultural crops has outpaced production of food grains since 2012-13**
- **The special thrust given to horticulture sector through various schemes, NHM, HMNEH and MIDH has paid rich dividends**



Climate Change ?????

Climate change - Major Threat

Implications : global environment, ecosystems, biodiversity, water availability, natural resources, agriculture, economy and society.

United Nations Intergovernmental Panel on Climate Change (IPCC)

Reports : Scientific evidence on anthropogenic influence on climate ***through emissions of green-house gases***

IPCC report (AR5)

Unprecedented warming of the earth's atmosphere in last few decades.

Global temperatures

Increase of 0.85 °C during the period 1880-2012

Climate Change - Implications

- Worldwide environmental stresses primarily cause **yield losses > 50%** for the major crops (Bray et al. 2000)
- Productivity is primarily determined by **occurrence of abiotic stresses at sensitive phenophases**
- Under climate change conditions **periodicity** of various **abiotic stresses** is likely to ↑
- Meeting increasing demand for fruits and vegetables is a challenge
- Sustained and enhanced yields could be obtained through implementation of appropriate adaptation strategies

Climate Change in India

An Interim Report ESSO-Indian Institute of Tropical Meteorology, **Centre for Climate Change Research, July 2017**

Land temperatures over India

Shown unequivocal warming

Annual average temperatures over the Indian landmass

Increasing trend of about 0.6 °C (100 yrs) …1901-2010.

Highest trend

In-post monsoon season 0.79°C (100 yrs)

Lowest trend

Monsoon season 0.43 °C (100 yrs)

Trends in Temperature change India

*Table 1.1: Trends in all-India average seasonal mean, maximum and minimum temperatures for two time periods 1951-2015 and 1981-2015 * indicates significance at 5% level.*

	1951-2015			1981-2015		
	Tmean	Tmax	Tmin	Tmean	Tmax	Tmin
Annual	0.086	0.24	-0.10	0.58*	0.6*	0.51*
DJF	-0.24	-0.28*	-0.20	0.39*	0.47*	0.30*
MAM	-0.11	0.081	-0.33*	0.92*	1.06*	0.71*
JJAS	0.24	0.53*	-0.076	0.37*	0.32*	0.38*
ON	0.44*	0.57*	0.28*	0.85*	0.69*	0.94*

Annual Mean Temp (0.16 °C per decade),

Annual Max. Temp (0.17 °C per decade)

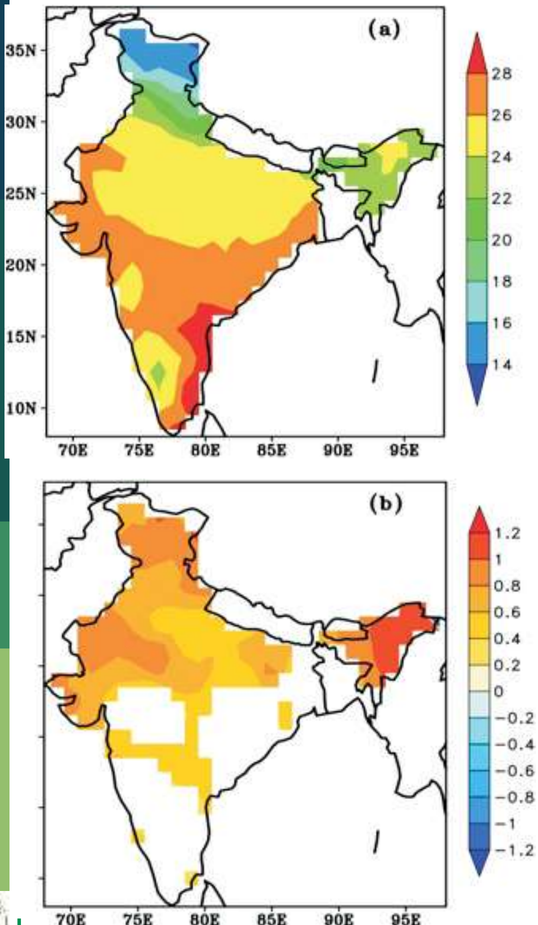
Annual Min. Temp (0.14 °C per decade)

Significant warming trend since 1981

Climate Change Facts in India

Maximum warming trend	Post-monsoon season
Annual Average Temp	⬆ in the region by 20 °N
Warm days and warm nights	⬆ over the last 35 years
Annual + seasonal RF June through September	Significant ⬇ trend Core monsoon zone North-Eastern parts Southern parts of west coast
Total number of consecutive dry days (spell length >than 5 days)	Has ⬆ significantly
Total number of consecutive wet days	Has shown significant ⬇

Spatial maps



(a) Annual climatological mean temperature over the Indian landmass

(b) Linear trend of annual temperature over the Indian landmass

- ***The temperature data : 1981-2015***
- ***Trends : Change over 35 years Shading denotes significant trend. Note that the <u>warming trends</u> are Significant in the region to the <u>north of 20° N</u>***
- ***Over North-West India : Warming is more pronounced***

(~ 0.6° -1°C in the recent 35 years)

Projected changes in India

Table 2.2 CORDEX South Asia multi-RCM reliability ensemble average (REA) estimate of projected changes in annual mean surface air temperature over India and the associated uncertainty range. The values in parenthesis show the uncertainty in percent for the REA estimate.

Scenario	Annual Mean Temperature (°C)		
	2030s	2050s	2080s
RCP2.6	1.08 ± 0.12 *(11.1%)*	1.35 ± 0.18 *(13.3%)*	1.35 ± 0.23 *(17.0%)*
RCP4.5	1.28 ± 0.20 *(15.6%)*	1.92 ± 0.28 *(14.6%)*	2.41 ± 0.40 *(16.6%)*
RCP8.5	1.44 ± 0.17 *(11.8%)*	2.41 ± 0.28 *(11.6%)*	4.19 ± 0.46 *(11.0%)*

Significance of rainfall variability assessment

Indian 75% - annual rainfall

Summer monsoon
South-West monsoon
Jun - Sept

- **Vital role in agriculture,**
- **Water resource management**
- **Power management**

Year-to-year monsoons variability
•Years of excess
•Years of deficit

Adverse effects on crops (B'cos variability and changes in rainfall)
Good or excess monsoons do not compensate for the loss due droughts

Climate Change Vs Peculiarities of Fruit Crops

- Perennial
- Constantly exposed to the climate variables
- One or the other phenological stage is influenced
- Have deep root system
- Can adapt phenological stages depending : climatic conditions
- Responses Studies (perennial crops to changing environmental conditions) are of short duration and with seedlings or juvenile plant materials

Temperature Effects in Fruit Crop

Optimum temp range for growth 24-30 °C,

(tolerate up to 48°C)

- Vegetative bias becomes stronger with increasing Temp.

Mango has limited cold tolerance	
Temp < 0 °C for few hours	• **kill the young trees**
Temp = 15 °C	• **Cessation in shoot growth**

△ Day and night Temp from 20/15 °C to 30/25 °C	↑ Vegetative flushes ↑ Number of leaves ↑ Leaf size	Affected photosynthesis

- Monoembrynic cultivars have greater tolerance Vs polyembryonic cultivars
- B'cos differences in their evolutionary centers

Flowering Vs Climatic effects in India

Subtropics	**Mean temp during panicle growth 12-15°C**
Panicles (male/ hermaphrodite flowers ratio)	**Temperature dependent**
South Indian cultivars	**Less hermaphrodite flowers under North Indian conditions**
Late emerging panicles	**Higher number of hermaphrodite flowers (than early emerging panicles)**

Mango floral biology

- **Relation between vegetative and reproductive development**

A period of stress	Promotes strong flowering (once stress is released … tree can grow)
Temp in subtropics	Strong environmental stimulus for flowering
Low temperatures	Promoted reproductive morphogensis (Experimented)
For sustainable panicle growth & development	Needs Temperatures < 15 °C
Base temperature for panicle growth	12.5 °C

Flowering and Fruiting in Mango

- Influenced by environmental as well as tree factors
- Vegetative growth is never continuous but in flushes
- Each flush takes 20-30 days for complete expansion
- Number of flushes: Varies with age, cultivar and prevailing weather condition
- **Temperature: Important environmental factor**
- Increase in temperature : Vegetative growth becomes stronger + increased flushes
- **Low temperature:** Powerful floral inducing factor in mango
- **Critical for induction <20 °C (day) and 15 °C (night) + high VPD ---- induction is faster**

Mango Flowering Contd…

Low temperature	Increases starch concentration by reducing the vegetative growth
High starch in roots, trunk and leaves	Showed positive correlation with flowering intensity and fruit retention
Low temperatures	High partitioning towards roots compared to shoots
Altered Temp duration (20/10 °C)	Starch was not related to flowering
If Temp (15/10 °C)	Flowering occurred at the same starch conc.
At low temperature	High starch cause reduction in vegetative growth Hormones mainly by lower GA and higher ABA and ethylene concentration in shoots

Fruit set

Weather parameters

Flower sex ratio

Mango productivity

Flowering

Pests and diseases

Cultural practices

Effect of Time of flower bud initiation---?

Productivity traits

Flowering intensity

Perfect flowers / inflorescence

Matured fruits per inflorescence

Early fruit set

Environmental factors

Genetic

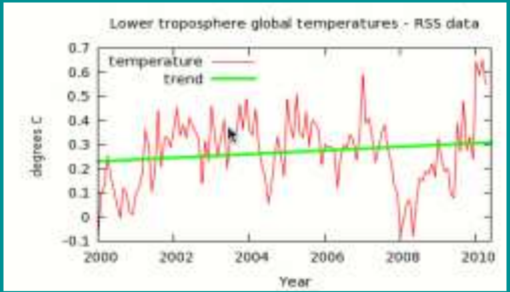
Flower sex ratio - Temperature

- ❖ Low temperature (10°C – 15°C) during flowering resulted in predominantly male flowers,
- ❖ **High temperatures** favored a **<u>higher % hermaphrodite </u>(bisexual)** flowers

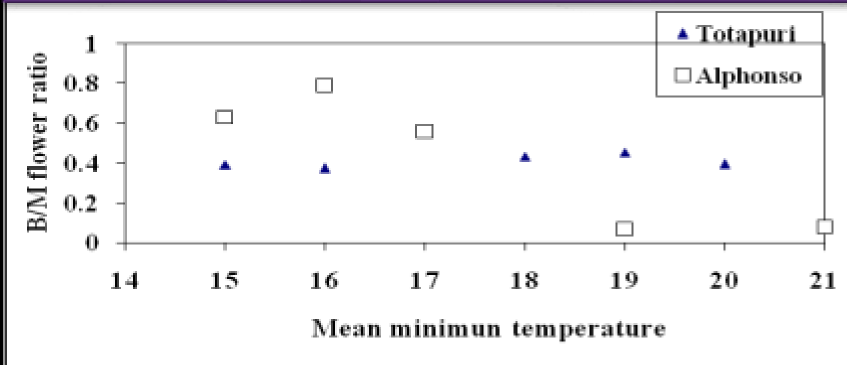
  (Tsang & change, 1983; Singh et al, 1966; Naik & Mohan rao, 1943; Singh, 1990)
- ❖ A positive linear correlation

  Bisexual flowers Vs daily average Min. Temp. - Kate mangos Shi-jin *et al*, 2007- (Japan)

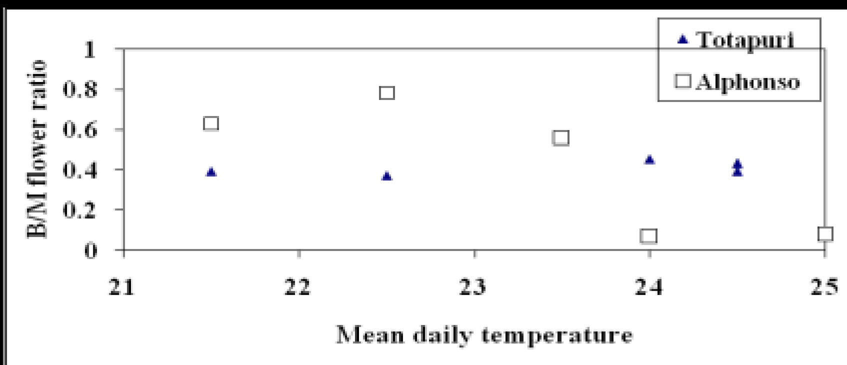
- ❖ In controlled environment studies, Whiley et al. (1995) found that low temperatures (15°C day/ 10°C night) during inflorescence morphogenesis reduced the proportion of perfect flowers



Temperature Vs Production of bisexual flowers



Bisexual to male flower ratio in Alphonso and Totapuri mangoes & the **<u>mean minimum temperature</u>** for 15 days prior to first flower opening



Bisexual to male flower ratio in Alphonso and Totapuri mangoes & the **<u>mean daily temperature</u>** for 15 days prior to first flower opening

Production of bisexual flowers ..good
Av. Min Temp.
15-16°C- Alphonso
18-19°C- Totapuri

⬇ further with △ Min. Temp

Influence of Temperature on banana

- Most of banana cultivation areas : 30° latitude N and S of the equator
- Large banana and plantain growing areas:

  In tropics between 20 °N and S latitude
- Non-limiting water; Temp determines rate of growth and fruit maturity time
- Optimum Temp for foliar growth

  26 and 28 °C (Ganry, 1980)
- Optimum Temp for fruit growth : 29-30 °C
- Greatest leaf area production

  at 33 °C day & 26 °C night (Turner & Lahav, 1983)

Influence of Temperature on banana Contd..

Tropical climate	Foliar emission for the taller Cavendish varieties stops below 16 °C and All growth stops : at about 10 °C (Aubert, 1971)
Min Temp <14.5 °C	Fruit growth reduce + would have effect on bunch maturity
Impact of temperature on fruit number	More during bunch differentiation period (greater root growth and dry matter production)

Effect of growing seasons & regions (India) on fruit quality parameters in different banana cultivars

- Fruit quality - variation in the antioxidant potential

  is affected ---cultivars, extraction procedures, geographical location and existing conditions

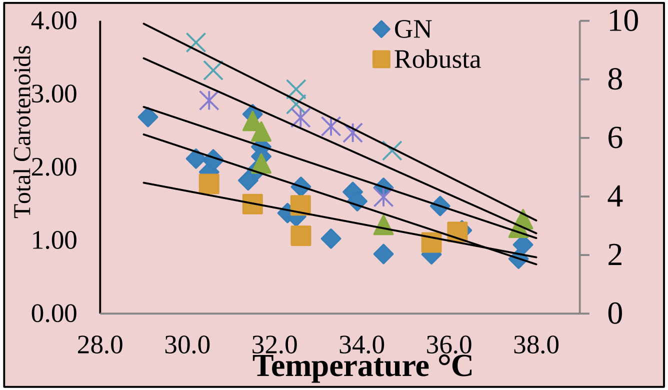
  soil, temperature, sunlight, agro-techniques

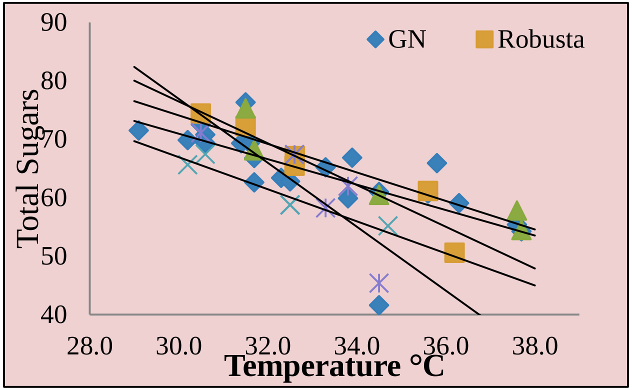
- Temperature --- **fruit growth and ripening**

  affects the quality of ripe fruit
  the marketable life of banana fruit

Shivashankara *et al* 2016

Total carotenoids & Total sugars Vs temperature Banana cultivars - Indian regions





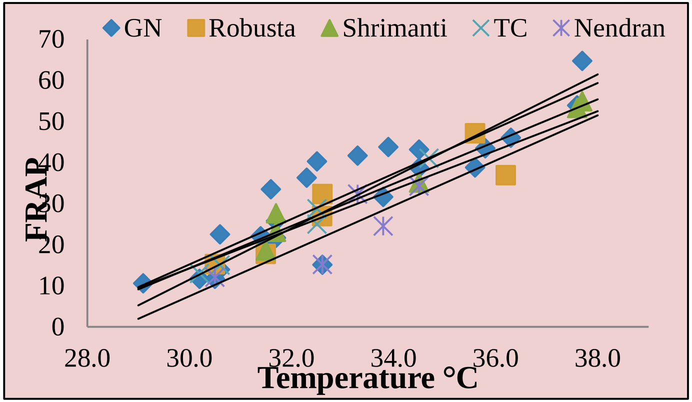
GrandNaine ($y=-0.197x+8.165$; $R^2=0.673$), Robusta ($y=-0.113x+5.077$; $R^2=0.677$), Shrimanti ($y=-0.199x+8.605$; $R^2=0.775$), Tella Chekkerakeli ($y=-0.298x+12.62$; $R^2=0.949$) and Nendran ($y=-0.664x+27.99$; $R^2=0.653$)

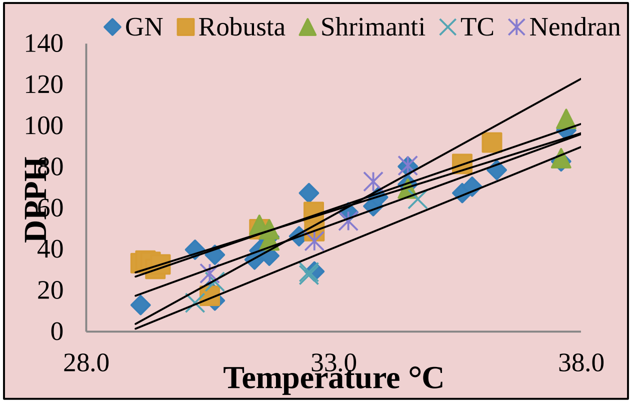
GrandNaine ($y=-2.177x+136.2$; $R^2=0.498$), Robusta ($y=-3.575x+183.7$; $R^2=0.890$), Shrimanti ($y=-0.199x+8.605$; $R^2=0.775$), Tella Chekkerakeli ($y=-2.742x+149.1$; $R^2=0.907$) and Nendran ($y=-5.468x+240.9$; $R^2=0.711$)

Factors	Attributes
⇧ Temp - fruit growth period	In all varieties ⇩Total carotenoids ⇩total sugars
Max R^2 value	Tella Chekkerakeli

Shivashankara *et al* 2016

Relationship with FRAP, DPPH Vs temperature
Banana cultivars - Indian regions





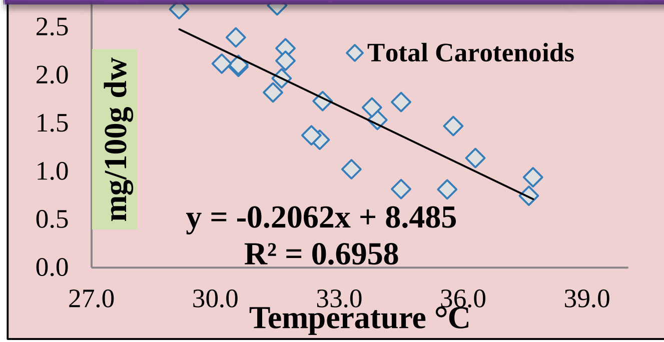
Grandnaine (y=5.520x-150.4; R^2=0.810),
Robusta (y=4.784x-129.2; R^2=0.810),
Shrimanti (y=5.142x-139.9; R^2=0.967),
TellaChekkerakeli (y=6.251x-176.0; R^2=0.986) and
Nendran (y=5.501x-157.5; R^2=0.718)

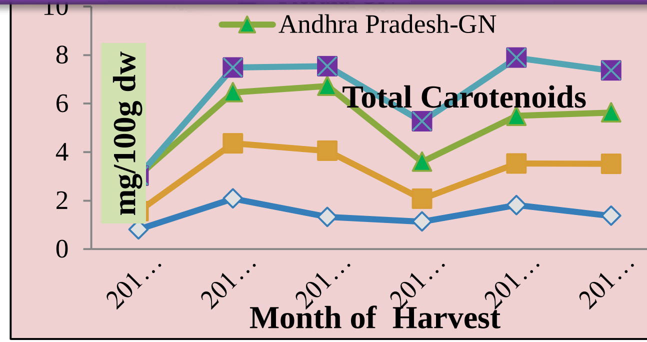
Grandnaine (y=8.726x-235.7; R^2=0.830),
Robusta (y=8.254x-212.7; R^2=0.872),
Shrimanti (y=7.505x-188.8; R^2=0.920),
TellaChekkerakeli (y=9.813x-283.2; R^2=0.853) and
Nendran (y=13.24x-380.3; R^2=0.904)

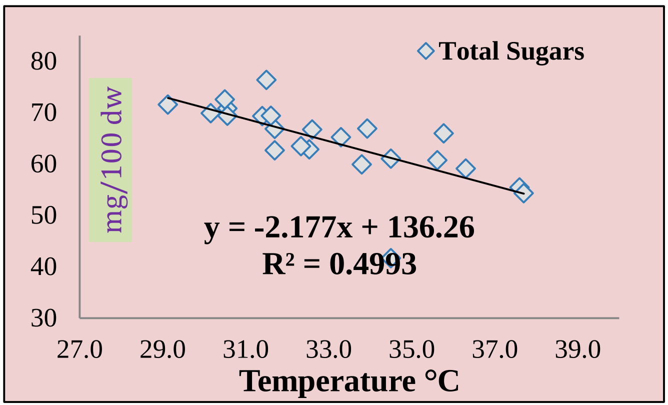
Factors	Antioxidant capacity (FRAP) and radical scavenging ability (DPPH)
Increasing temperature	More FRAP and DPPH
Max R^2 (Tella Chekkerakeli)	Correlated FRAP (+)
Max R^2 (Shrimanti)	Correlated DPPH (+)

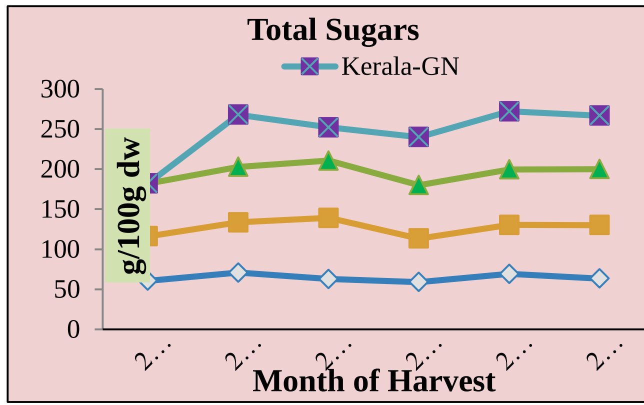
Shivashankara *et al* 2016

Temperature Vs Total carotenoids & total sugars cv. Grand Naine banana







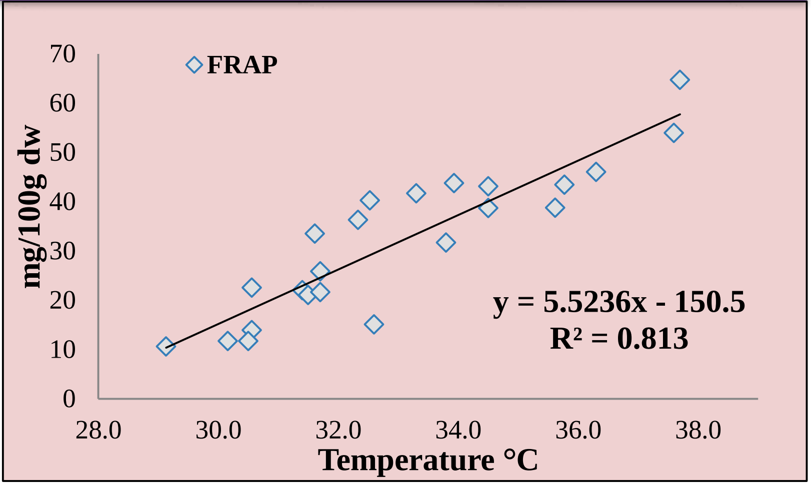


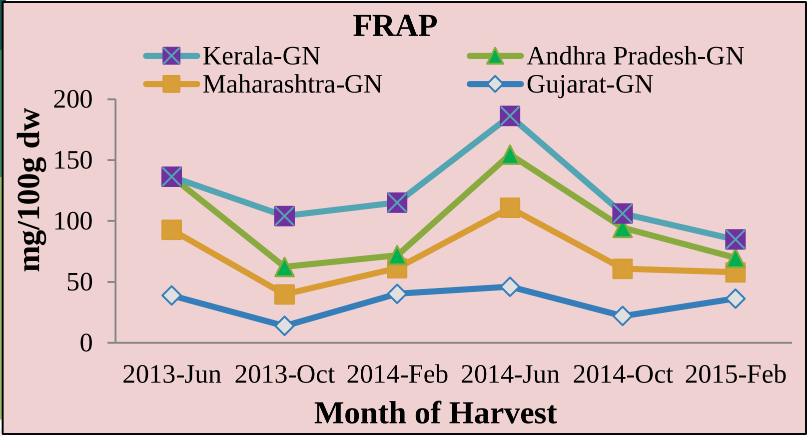
Attribute	Inferences
Total carotenoids Vs Temp	r = -0.816
Total sugars Vs Temp	r = -0.689
Higher total carotenoids and total sugars	February harvest (Maharashtra and Andhra Pradesh) October harvest (Gujarat and Kerala)

Temperature Vs fruit FRAP and DPPH

Grand Naine Banana

Antioxidant capacity (FRAP)
Radical scavenging ability (DPPH)





Attribute	Inferences
FRAP Vs Temp	r =0.889
DPPH Vs Temp	r = 0.902
Better in Grand Naine total antioxidant capacity and radical scavenging abilities	June harvest (Gujarat, Maharashtra , AP and Kerala)

Shivashankara *et al* 2016

UPLC data of carotenoids pigments in different cultivars of banana grown at various regions

Regions	Varieties	α-Crypto xanthin	Auro xanthin	Mutato xanthin	Luteo xanthin	β-Carotene	α-Carotene	Phytoene
		µg/100g dw						
Gujarat	Grand Naine	331.81	0.47	8.61	21.84	615.31	5.87	91.92
	Robusta	341.39	0.43	11.49	23.05	864.18	11.77	99.33
Maharashtra	Grand Naine	221.97	6.13	27.97	48.99	1166.93	17.58	83.34
	Shrimanti	210.63	7.68	21.46	48.47	795.28	16.32	102.71
Andhra Pradesh	Grand Naine	403.14	1.41	9.2	27.66	439.71	6.22	124.71
	Tella Chekkerakeli	110.95	2.76	16.46	20.94	2563.26	45.25	66.25
Kerala	Grand Naine	328.37	4.99	14.25	37.5	608.8	5.96	110.75
	Nendran	539.98	59.32	70.96	160.22	5683.2	45.66	65.72
Mean		**311.03**	**10.40**	**22.55**	**48.58**	**1592.08**	**19.33**	**93.09**

- **Seven** compounds were identified namely, *α*-Cryptoxanthin, Auroxanthin, Mutatoxanthin, Luteoxanthin, *β*-carotene, *α*-carotene and Phytoene.
- Carotenoids like ***β*-carotene and cryptoxanthin** were the **major pigments** in all the varieties. Among the cultivars, *β*-carotene and cryptoxanthin were maximum in Nendran (Kerala) and minimum in Grand Naine (Andhra Pradesh) and TellaChekkerakeli (Andhra Pradesh).

Optimum temperature (Topt) ranges for different phenophases of Citrus

- T-opt increases with the progression of Citrus growth and development

Phenophase	Topt
Dormancy stage has a Topt range of	−4°C to 14°C Includes two sub-stages: hardening (−4°C to 8°C) pre-bloom (0 to 14°C).
Flowering	10–27°C
Fruit set	22–27°C
Fruit growth	20–33°C

Temperature ranges for different phenophases of Citrus

Temp	Effects
T opt 13–27°C	Maturation + development of soluble sugars
T opt 8–18°C	Development of colour
T max. 35°C T min. 2°C	Temperature thresholds
T max. >38°C	Losses in citrus fruit set
T max. >48°C	50% loss
T max. >40°C	causes sunburn and increase in fruit drop

Temperature ranges for different phenophases of papaya

Base temperature 10 °C

Temp	Effects
<23 ºC or above 40 ºC	Severely affects germination
25-35 °C	Optimum for Photosynthesis
> 40°C	Drastic effect on photosynthesis
<14 ºC	Hermaphrodite flowers change to female flowers Misshapen fruits

Effects of water deficit

Effect of water deficit on growth depends on the stage of the crop

Citrus	Leaf initiation may stop leaf size gets reduced leathery leaves thick leaves (Levy, 1978)
Grapes	Flowers drop off before fruits set (stress induced abscission) Reduced the growth of berries (van Zyl, 1984)
Papaya	Arrested plant growth Leaf abscission Decreased photosynthetic rate

Impact of climate change on pests and pollinators in horticultural crops

Direct effects of climate change on pests (rise in temperature)

- **Expansion of habitat range of pests**

  In temperate regions, unfavorable areas becomes favorable to the pest with rise in temperature. Eg. Fruit fly, *Bactrocera dorsalis* expansion is expected by 100 km in North India (Sridhar *et al*., 2014).

- **Increase in the number of generations of pests**

  Insect and mite pest generations increase by 1-5/year causing more damage to various crops

Direct effects of climate change on pests (rise in temperature) Contd….

- **Changes in over wintering success**

  ↑ Temp » earlier infestation of *Helicoverpa armigera* (Hub.) and more damage on crops in North India resulting in ↑ crop loss (Sharma 2010) due to early breakdown of diapause

- **Changes in interaction between species**

  Eg. Newly introduced pest South American tomato moth, *Tuta absoluta* may compete more successfully over serpentine leaf miner, *Liriomyza trifolii*, on tomato at higher temperatures.

Oriental fruit fly (*Bactrocera dorsalis*) potential distribution

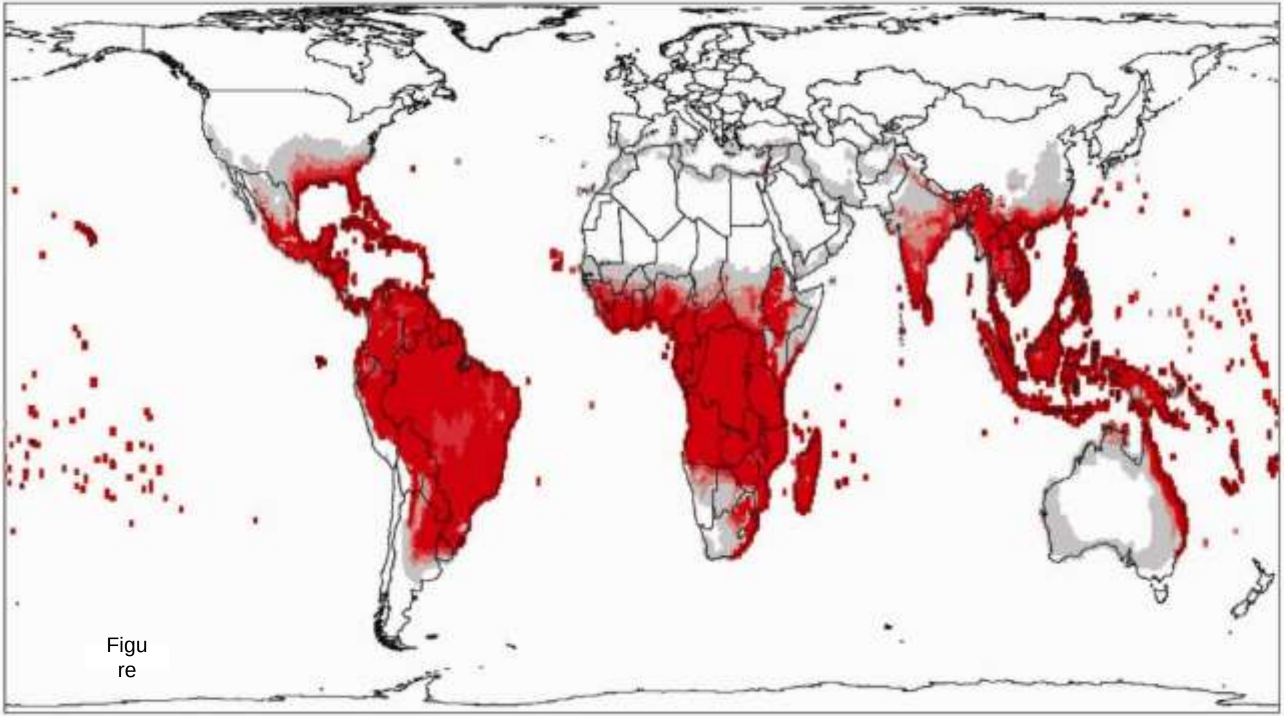
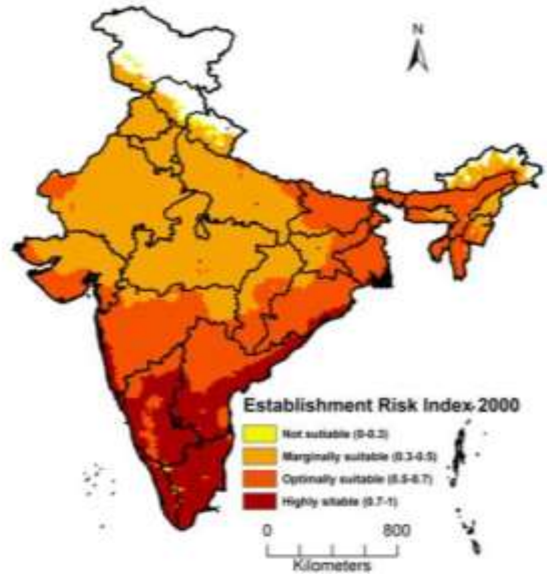
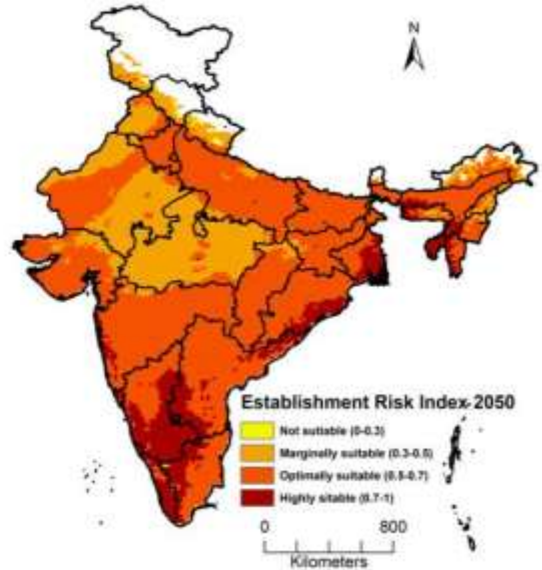


Figure 3. Current global distribution of OFF as modelled using CLIMEX. Ecoclimatic Index (EI) values: Unsuitable (0–0.99); Marginal (1–7.35); Suitable (7.35–13.7); Optimal (13.7–20); Highly suitable (20 +).

Sridhar *et al*., 2014

Change in establishment and future distribution of *B. zonata* in India based on establishment risk index





The major mango producing areas are predicted as marginally to highly suitable areas for establishment, abundance and spread of *B. zonata*

Bikas Das et al 2016

Variation in number of generations of *B. dorsalis* at mango fruiting season in 8 mango growing regions (India) under climate change scenario

Name of location	Current climate situation		Future climate change situation	
	Base line period generations (1961-1990)	Present period generations (1990-2015)	Near Future period generations (2021-2050)	Distant Future period generations (2071-2098)
Paria	4.69±0.20 **	4.84±0.11	5.22±0.19 **	5.75±0.21 **
Vengurle	4.30±0.17 NS	4.39±0.12	4.80±0.17 **	5.38±0.16 **
Lucknow	5.95±0.34 **	5.34±0.19	6.52±0.36 **	7.20±0.32 **
Sangareddy	5.08±0.23 **	5.25±3.56	5.61±0.29 **	6.31±0.31 **
Bhubaneswar	5.54±0.33 **	4.54±0.15	6.07±0.40 **	6.74±0.29 **
Ranchi	5.36±0.37 **	4.91±0.18	5.87±0.40 **	6.52±0.31 **
Bengaluru	4.12±0.28 NS	4.24±0.11	4.72±0.28 **	5.40±0.28 **
Mohanpur	5.64±0.36 **	4.98±0.14	6.14±0.40 **	6.77±0.31 **

Bikas Das et al 2016

Temperature Vs Predators

Temperature increase with climate change may encourage/discourage the predators.

Eg. Below 11°C (51.8°F), the pea aphid reproduction rate >> the rate at which the lady beetle, *Coccinella septempunctata* can consume it. Above 11°C (51.8°F), the situation is reversed.

Changes in migrating behavior Migratory pests will have direct impact with change in temperatures. In temperate regions, the winter mortality of adults of *Nezara viridula* is predicted to be ⬇ by 15% by each ⬆ of 10º C.

Effect on Host-pest-natural enemy interactions

Insects as vectors of diseases

Aphids transmits 50% of approximately 600 viruses with invertebrate vectors	
An increase of 2 ^{o}C	• Aphids can complete extra five generations (Yamamura and Kiritani, 1998) • Probability of transmitting diseases in plants will be more
Under high temperatures	• More generations -other vectors like whiteflies, thrips, hoppers

Impact of climate change on Pollinators

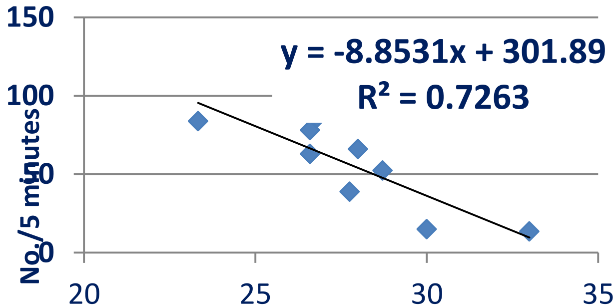
- **Direct effects … on biology and foraging behaviour**
- **Indirect effects …Through floral resources**
- **Climate change leads to phenological <u>asynchrony</u>**

  plants Vs pollinators
- **Vulnerability rate to pollination loss high among horticultural crops .. 25-40 % compared to other field crops**

Reddy *et al*., …….

Consequences of Elevated Temperature on pollinators

- **Insects – cold blooded**
- **The temperature of their surroundings determines their activity**
- **At higher ambient temperature, more efforts required to regulate body temperature which affects the foraging ability**



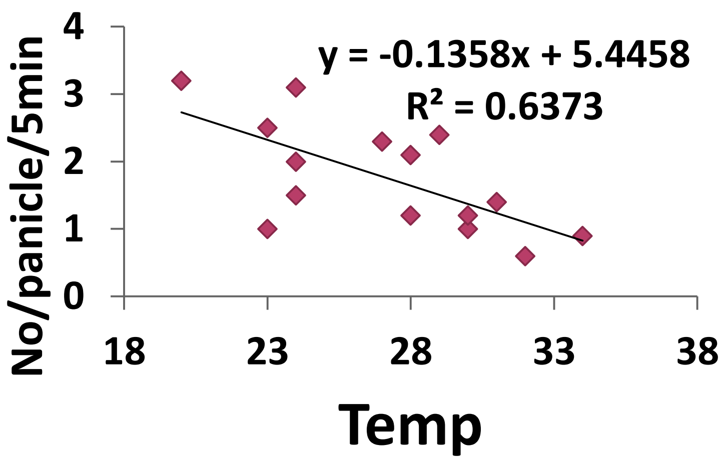
Maximum temperature on the out going foragers

- For example, number of worker bees moving out to forage is adversely affected by temperatures beyond 30°C

Reddy *et al*., …….

Temperature and foraging behaviour

In mango, total pollinator visitation was negatively affected by temperature (r= - 0.74)



- **Active foraging time per unit number of flowers comes down by 26-30 % with elevated temperature**

Reddy *et al*., …….

Mitigation options-pollinators

- Ensuring sufficient off-season flora (non-crop flowering resources
- Conserving native species
- Avoiding clean cultivation, wherever possible
- Minimizing toxic chemicals
- Maintaining and restoring native ecosystems
- Supplementing natural populations with reared pollinators/ honey bee colonies


Conclusion

- Temp for India in near term are = +1.08 to 1.44 °C.
- 🡅 in temperature and extreme rainfall = △fruit crops productivity
    - ❖ TF perennial in nature » influenced at various phenophases » altering the productivity
    - ❖ Alteration of pollinators and incidence of pests
    - ❖ shift in production zones
- National Innovations on Climate Resilient Agriculture (NICRA)- to intensify the research on climate change
- **Potential new TF under CC in India = Jackfruit**

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