SALIENT RESEARCH ACHIEVEMENTS

Physiology of growth and development

- In okra, fruits on middle nodes are strong sinks for photo-assimilates. Seeds from these nodes had higher germination percentage.
- In capsicum fruit, first flowering node acts as the major sink up to 20 days which later becomes a weak sink as neighbouring fruits compete for assimilates. Night temperature plays an important role in plant growth and fruit set in capsicum.
- In Alphonso mango, fruit bud differentiation is found to occur during November to December under Bangalore conditions.
- Hormonal imbalance marked by reduction in IAA, free cytokinins- DHZR and ZR and polyamines coupled with an increase in ABA and ethylene are associated with high incidence of fruitlet drop in mango during early phase of fruit development.
- Night temperatures greater than 17 °C during the flower induction period (October to December) is detrimental to flowering in mango. The effects of high night temperature on flowering were accentuated by rainfall during September – December. Temperature of around 15 °C is vital for inducing floral bud morphogenesis.
- Leaf water potential, ABA and phenols are negatively related to seedling vigour of polyembrynic mango cultivars. p-Hydroxybenozoic acid followed by cinnamic acid and vanillic acid are major phenolic acids in the leaves of polyembryonic cultivars, and their levels were negatively related to seedling vigour.
- The growth inhibitory responses of paclobutrazol is due to reduction in the xylem sap yield, radial width of xylem, stomatal density, stomatal conductance and leaf IAA levels concomitant with increases in leaf water potential, ABA, phenols, chlorophyll, polyamines, cytokinins-*t*-ZR and DHZR.

Crop responses to abiotic stresses

a) Water stress

- In okra, genotype BO-1 having short plant stature is found to perform better under water stress.
- In onion, the genotypes with small bulb size and erect leaf orientation (eg. MS-11 and MS-39) are found to perform better under water stress conditions.
- Based on the cell membrane stability test, chilli genotypes, G-4, CM-334, VN-2 and EG-12 are classified as water stress tolerant and these are included in the breeding programme on water stress tolerance in chilli. The critical level of stress for seed germination in chilli varied from -0.4MPa to -0.6MPa.
- Following the changes in morpho-physiological characters, hormonal content and yield attributes, cvs. Contender in French bean, Arka Ajit in peas and Arka Kalyan in onion are characterized as water stress tolerant to cultivars.

b) High temperature stress

- In capsicum, cvs. Arka Gaurav, Indra and Sweet ban showed better performance under high temperature. High levels of IAA, cytokinin-ZR and polyamines-spermidine and spermine in the reproductive parts are found important attributes of high temperature tolerance in cv. Arka Gaurav. The induction of 70 and 90 KDa Hsps is also related to high temperature tolerance in capsicum cultivars.

- The high temperature induced abscission of floral organs in capsicum is related to an increase in the levels of ethylene and its precursor ACC, ABA and a decline in IAA and cytokinins in the flower buds and open flowers.

c) Salinity

- Grape rootstocks endowed with higher ABA, glycine betaine and polyamines-spermine and spermidine are found to accumulate less Na+ content. These rootstocks maintained low Na:K ratio, high osmotic potential, good root growth and high root:shoot dry mass ratio under salinity conditions.
- The salinity tolerant grape rootstocks showed greater induction in the activities of SOD, catalase and peroxidase, and accumulation in 11, 42.7, 66.4, 70.1 and 89.4 KDa proteins under salinity conditions.
- The grape rootstock, 110R is found to be relatively salinity tolerant rootstock.
- The soil application of mixture of VAM (*Glomus* species) + bacterial consortium is found improve the salinity tolerance of Dogridge rootstock by improving root:shoot ratio and root K:Na ratio, and inducing accumulation of polyamines and ABA.
- Under alkaline soils, the better performance of mango rootstocks, Kurukan and 13-1 is due to higher water use efficiency and induction in sugar and ABA accumulation in the roots. Analyses of root sugars is found to have potential to serve as biochemical marker for discriminating rootstocks for alkalinity tolerance.

Crop responses to biotic stresses

a) Fungal diseases

- In chilli, the anthracnose resistant cv. AR-24 had significantly higher polygalacturonase inhibitor protein (PGIP) activity in maturing fruits as compared to susceptible cv. Byadgi.
- In rose, foliar application of KH2PO4 led to enhanced activities of peroxidase and polyphenol oxidase (PPO) enzymes as compared to control. Higher activities of antioxidant enzymes were maintained up to a period of 15 days. The level of jasmonic acid in KH2PO4 treated leaves of rose increased steeply by 10.3 times as compared to control.

b) Insects

- Volatile compounds, namely, caryophyllene oxide, limonene, linalool and 1-hexanol identified in the volatile fraction are found to be responsible for insect repellant action of neem cake.
- The resistance mechanism of chayote to melon fly infestation is due to antibiosis mediated by the production of reactive oxygen species and not due to antixenosis.

c) Weeds

- Allelopathic weed management improved the soil physical, chemical, and biological parameters. Rotation of crops with the medicinal legume cover crops, *Mucuna utilis* and *Dolichos* with other vegetable crops is found to be effective in reducing the population of the noxious weed *Cyperus.*
- The following herbicides are recommended for management of weeds in various horticultural crops :

Recommended herbicides and their dosages in vegetable crops

Herbicides and their dosages (Kg a.i./ha)	Amount of formulated product to be used (kg/ha)	Crops	Time and method of application	No. of sprays	Weeds controlled and their effective duration
Alachlor (2.0) or Butachlor (2.0)	4.0	Tomato, Chilli, Capsicum, Okra, Pumpkin, Ashgourd, Watermelon, Muskmelon, Squash, Ridgegourd, Bittergourd, Potato, Beetroot, French beans, Dolichos, Radish, Carrot	One day after / before sowing seeds/ transplanting	1	Controls all dicot and monocot (except Cyperus, Cynodon) for 45 to 60 days
Fluchloralin (1.125)	2.25	Cabbage, Cauliflower, Knol-khol, Brinjal, Onion, Garlic, Peas	One day after /before sowing /transplanting	1	Controls all dicot and monocot (except Cyperus, Cynodon) for 45 to 60 days
Fluazifopbutyl (1.0)	8.0	Leafy vegetables	One day after /before sowing seeds	1	Controls all dicot and monocot (except Cyperus, Cynodon) for 45to 60 days

Recommended herbicides and their dosages in fruit crops

Herbicides and their dosages (Kg a.i./ha)	Amount of formulated product to be used (kg/ha)	Crops	Time and method of application	No. of sprays	Weeds controlled and their effective duration
Diuron (2.0)	2.2	Nurseries of Mango, Citrus, Grapes, Custard apple, Ber, Pome granate, Banana	Just after planting suckers/ cuttings/stones	1	All type of weeds for 4-5 months
Atrazine (2.0)	4.0	Nurseries of Mango, Grape,	Just after planting cuttings/stones	1	All type of weeds for 4-5 months
Paraquat (2.0)	8.0 (7ml/litre)	Orchards of Mango, Grape, Custard Apple, Ber, Banana, Pomegranate	6 months after spray of Diuron	2	All type of weeds for 50-60 days
Glyphosate (2.0)	4.0	Orchards of Mango, Grape,	6 months after spray of Diuron	2	All type of weeds for 4-5 months

Herbicides and their dosages (Kg a.i./ha)	Amount of formulated product to be used (kg/ha)	Crops	Time and method of application	No. of sprays	Weeds controlled and their effective duration
	(5-7ml/litre)	Custard Apple, Ber, Banana, Pomegranate			

Recommended herbicides and their dosages in ornamental crops

Herbicides and their dosages (Kg a.i./ha)	Amount of formulated product to be used (kg/ha)	Crops	Time and method of application	No. of Sprays	Weeds controlled and their effective duration
Alachlor (2.0)	4.0	Gladiolus, Tube rose, Chrysanthemum, Crossandra, China aster	One day after planting the corms / Cormels/ transplants	1	Controls dicot weeds for 90 days and grassy weeds for 60 days
Diuron (1.0)	1.2	Rose	One day after transplanting the plants or one day after pruning	1	Control both dicot and monocot (except Cyperus & Cynodon) weeds for 100 days
Glyphosate (2.0)	4.0 (5-7ml/ litre)	Rose	After pruning	1	All weeds for 4-5 months

Pesticide dynamics studies

a) During processing of tomato

A washing under running water dislodges chlorantraniliprole, chlorpyriphos and imidacloprid to the extent of 63 to74% of deposited residues in tomato. Boiling of juice to puree/sauce is the major step to eliminate pesticides. During this step, the level of residues of chlorantraniliprole and chlorpyriphos decreased by over 90%, whereas the rate of decrease of imidacloprid residues was slow with a degradation of only 37% of theoretical concentration. Pesticide residues can be mitigated by incubation the tomato juice at 40 ± 2 °C. Five days of incubation rendered the disappearance of half of the applied pesticides. The slow rate of degradation for imidacloprid in comparison to chlorantraniliprole was observed here also. During the processing of tomato, imidacloprid was degraded to different compounds, which were chracterised as imidacloprid urea (I), imidacloprid guanidine (II), *N*-methyl nitrosoguanidine (III), 6-chloro nicotinaldehyde (IV), deschloroimidaclopridguanidine(V), and 6-chloro nicotinicacid (VI) (Fig. X).

b) During processing of mango

A washing under running water dislodgedacephate, carbendazim and imidacloprid to the extent of 37 to over 95% of deposited residues in mango. The application of heat to the pulp was found as an effective step to decrease the load of pesticides. In ready-to-serve (RTS) formulation and mango bar, the level of all pesticides are considerably very low. During the preparation of osmotically dehydrated mango slice, pesticides were physically dislodged from the slice through osmosis.

c) During processing of moringa leaf

During the processing of moringa leaf to its dry powder, it was observed that pesticide residues did not dissipated much. Pesticide residues were also detected in the market samples. A hot water treatment of contaminated moringa dry leaf powder for 10 min removed deltamethrin and chlorpyriphos by 94 and 86%, respectively.

c) During processing of guava

In the experiment on processing of guava, it was found that the peeling of guava removed almost entire amount of applied pesticides including imidacloprid, deltamethrin and carbendazim. No pesticide residue was found in RTS, beverage and bar made from pesticide-treated guava.

Physiological disorders of fruit crops

a) Identification of the cause of spongy tissue formation in Alphonso mango

The cause of spongy tissue formation in Alphonso mango was identified for the first time in the world. Physiological and biochemical studies have firmly established that the disorder is caused due to the premature onset of germination-associated events in the seed during fruit maturation on the tree/ postharvest ripening stages. Radiotracer studies using tritiated water confirmed the increased mobilization of water from mesocarp to seed during spongy tissue formation. Preharvest application of GA3 to fruits during fruit development phase resulted in an increase of seed amylase activity, fruit respiratory rate and a proportionate increase of the incidence of spongy tissue while paclobutrazol application reduced the seed amylase activity, fruit respiration and spongy tissue incidence further confirming the fact that the formation of spongy tissue in Alphonso mango is influenced by the activity of seed.

Studies conducted on stone weevil affected fruits of Alphonso mango clearly established the decisive role played by the seed in the formation of spongy tissue.

An eco-friendly formulation is developed and tested in farmers' fields in the Konkan region for the successful control of the disorder.

b) Aril Browning in Pomegranate

- The causative factor of aril browning in pomegranate has been identified. Hormonal studies on developing fruits have confirmed the role of seed in initiating the disorder. Preharvest application of plant growth regulators could reduce the incidence of aril browning significantly.

c) Chilling injury in mango

- Fatty acid desaturation is more in Dashehari and Alphonso compared to Banganapalli, indicating that Dashehari may tolerate low temperature better than other varieties.

d) Flowering in mango

- Completely defoliated and girdled branches of both Totapuri (regular bearer) and Alphonso (irregular bearer) showed no flowering in comparison with girdled branches with one leaf retained or untreated control, proving that floral signals originate from leaves.
- The expression of the flowering genes – *FT, SOC1, AP1* and *LFY* – were higher in the leaves, bark and buds of Totapuri compared to Alphonso; a possible explanation for the consistent flowering observed in the former.

Nutritive value of fruits and vegetables

a**) Antioxidant capacity of fruits and vegetables**

- In tomato, dark red types with high total carotenoids, lycopene and total phenols showed high antioxidant and radical scavenging capacities. Wild varieties recorded high ascorbic acids.

- Dark red small onions have very high antioxidant capacity due to higher anthocyanins and flavonoids. White onions possessed lowest antioxidant capacity.
- Frying in oil is found to be better method for retaining the antioxidant capacity of cauliflowers followed by microwave cooking and boiling in water. Genotypic variability is observed in the antioxidant capacity, oxalates and nitrates. In carrot, variation in antioxidant capacity is related to the total phenols and carotene contents.
- The high antioxidant capacity in cv. Pusa Navrang fresh fruits is found to be due to high anthocyanins. Black grapes have higher antioxidant values than green grapes. Seeds and peel contribute relatively more to the high antioxidant activity in grapes.
- Mulberry fruits show higher antioxidant and radical scavenging ability when compared to other fruits like pomegranate, mango, grapes and papaya mainly due high anthocyanin content. Jamun fruits have high antioxidant capacity due to anthocyanins and total phenols. Aonla fruits shows very high antioxidant capacity due to their high phenols and vitamin C contents.
- Cultivar Alphonso possesses higher vitamin A, vitamin C, antioxidant and radical scavenging abilities compared to Totapuri, Banganapalli, Fazli, Dashehari, Langra and Suvarnarekha. Mango kernel is found to have very high antioxidant capacity mainly due to higher polyphenols. This can be commercially exploited for food additives for enhancing antioxidant values.
- Ripened jackfruit collections were evaluated for its nutritional value (carotenoids, phenol, flavonoid, sugar, acidity, ascorbic acid, vitamins and antioxidant activities) and aroma which helped in selection of nutrient rich lines.
- Kokum accessions were characterized for hydroxycitric acid (HCA), anthocyanin, phenol and antioxidant activities which gave us a better understanding about kokum as a functional food.
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b) Biochemical properties

- Biochemical basis of host-plant resistance to shoot and fruit borer, *Diaphania caesalis* Wlk. in jackfruit (*Artocarpus heterophyllus* Lam.) was studied and a combination of biochemical attributes like wax, phenol and DPPH activity might be use as markers in selection of resistant jackfruit sources against the target pest.

- Karonda accessions were evaluated for its biochemical properties (phenol, flavonoid, anthocyanin, antioxidant activities and sugars) to understand diversity.
- Tamarind collections were evaluated for total acidity, sugars and tartaric acid for the selection of elite lines.
- Seven clones of of both white and red pulped dragon fruit was characterized for nutritional and biochemical constituents.
- Three clones of unripe raw jackfruit were characterized for nutritional and biochemical constituents.
- Total dietary fibre content in five jackfruit varieties (table purpose) was quantified.
- Total carotenoids and phenolic content was determined in about 10 genotypes/varieties of marigold flowers

Development of molecular markers and Marker assisted selection in horticultural crops

- Developed SSR markers for Custard apple, Sapota and Jackfruit
- Developed genomic resources for banana, mango, okra and tomato based on transcriptome data and gene expression studies.
- Identification molecular marker linked to bacterial wilt resistance in eggplant; Phytopthora root rot, nematode and bacterial wilt resistance in chile; powdery mildew resistance in peas
- Validation of molecular markers linked male sterility in onion , carrot and CGMS system in chilli and integration in main stream breeding
- Development of linkage maps in watermelon, chile and eggplant
- Identification of multi disease resistance chile genotypes through genotyping
- Marker assisted selection in okra, cucumber, tomato: Involved in development of tomato hybrids ArkaAbhed, ArkaApeksha and ArkaVisesh.

DNA fingerprinting in released varieties/hybrids/registered genotypes

- DNA Fingerprinting of IIHR released varieties/hybrids/registered genotypes
- Diversity of mango, custard apple, sapota, and jackfruit has been studied
- DNA fingerprinting and markers based hybrid testing developments in vegetables and fruits
- Biodiversity and evolutionary studies of Papaya ringspot virus (PRSV) in India.

TILLING in Papaya

- Speed molecular breeding was initiated in papaya through the application of an important biotechnological tool, **T**argeted **I**nduced **L**ocal **L**esions **IN G**enomes (TILLING) to address shelf life and postharvest traits and disease resistance
- Several genes governing fruit shelf life through ethylene biosynthesis, perception and signal transduction, including ACC synthase, ACC oxidase, ethylene receptor (ETR1) and downstream pathway genes (pectatelyase, polygalacturonase etc.) were cloned and studied.
- SNPs were detected and cognate mutant lines were identified in papaya using RealTime Quantitative PCR (RT-PCR) based High Resolution MeltCurve (HRM) analysis. The selected promising lines were forwarded.
- Two highly promising Bt transgenic lines were identified in brinjal (cv. ArkaKeshav) and tomato (cv. ArkaVikas) with resistance to fruit borers.

- Interesting mutants and selections were identified in papaya and sandalwood using TILLING and Transcriptomics analysis.

RNAi for insect and pest resistance

- Development of RNAi based multiple virus resistance in tomato: Resistance to CaCV GBNV, CMV, and CVMV. (capsicum chlorosis virus, groundnut bud necrosis virus, cucumber mosaic virus and chilliveinal mottle virus)
- RNAi mediated resistance to fruit borer/bollworm *Helicoverpaarmigera*achieved in tomato
- DsRNA-mediated protection against Papaya ring spot virus through topical application of dsRNA in papaya.
- Developed and validated RNAi construct for Cucumber mosaic virus resistance in chilli

Transgenic development

- Gene pyramiding of dreb2 (from Sorghum) and vacuolar pyrophosphatase gene (from *Prosopis*) in tomato for enhanced drought and salinity tolerance.
- Metabolic engineering for enhance anthocyanin accumulation in tomato
- Developed transgenic banana with dual antimicrobial genes and anti-apoptosis gene constructs for Fusarium wilt disease resistance. The transformants showed tolerance to disease under pot condition. One event (pJAF 418-141) showed tolerance to wilt under containment net house condition.

Tissue culture

- Standardized *In vitro* screening technique of guava seedling for wilt resistance using toxin derived from Fusarium culture filtrate and screened six different species of guava for wilting response and evaluation of purple guava mutants for wilt resistance is under away
- Developed a technology for mass multiplication of banana (cvElakki bale) using Embryogenic Cell Suspensions and shoot tip culture.
- Developed *In vitro* shoot regeneration from nodal explants of pomegranate (*Punicagranatum* L.) cv Bhagwa

Genome Editing using CRISPR/Cas9

- CRISPR/Cas9 vectors for gene editing in tomato, chilli, banana and papaya have been developed for developing viral disease resistance in these crops.