ENHANCED PRESERVATION OF FRUITS USING NANOTECHNOLOGY (CIFSRF- PHASE II)

IDRC PROJECT NUMBER: 107847

RESEARCH ORGANIZATIONS INVOLVED IN THE STUDY:

1. University of Guelph, Guelph, Canada
2. Tamilnadu Agricultural University, Coimbatore, India
3. Industrial Technology Institute, Colombo, Sri Lanka
4. University of Nairobi, Nairobi, Kenya
5. Sokoine University of Agriculture, Morogoro, Tanzania.
6. University of West Indies, St. Augustine, Trinidad and Tobago.

LOCATION OF STUDY:

1. Milton, Elora, Campbellsville, Simcoe, Vineland and Different locations in the Niagara Peninsula, Ontario, Canada
2. Theni and Dharmapuri Districts, State of Tamilnadu, India
3. Colombo , Ellawala, Dambulla, Udawallawe, Vavunia and Jaffna Provinces , Sri Lanka
4. Muranga, Meru and Machokos counties, Kenya
5. Coast, Tanga, Morogoro regions, Tanzania
6. Carnbee, Orange Hill, Richmond in Tobago/Morugo, Arima and Mt. Hope in Trinidad

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LIST OF ACRONYMS

3MT: 3 Minute Thesis
AFS: Agriculture and Food security
AMAGRO: Association of Mango Growers
BFW: Banana fibre Fruit wrap
CEC: County Executive Chief
CEPA**:** Center for Excellence in Poverty Analysis
CFIA: Canadian Food Inspection Agency
CBO: Community Based Organisations
CHC: Canadian High Commissioner
DOA: Department of Agriculture
DBH: Days before Harvest
GRAS: Generally Regarded As Safe
EFF: Enhanced Freshness Formulations
FGD: Focussed Group Discussions
FPO: Farmer Producer Organization
FR: Financial Report
FRSC: Farmers Resource & Service Centre
FSSAI: Food Safety and Standards Authority of India
FTIR: Fourier Transform Infrared Spectroscopy
HICM: Hexanal Incorporated Composite Material
HSDS: Hexanal Smart Delivery System
IICA: Inter-American Institute for Cooperation on Agriculture
INR: Indian Rupee
IPHT: Institute of Post-Harvest Technology
ITI: Industrial Technology Institute
JKUAT: Jumo Kenyatta University for Agriculture and Technology
KALRO: Kenyan Agricultural and Livestock Research Organization
KEPHIS: Kenya Plant health inspectorate service
KTW: Knowledge Transfer Workshop
M&E: monitoring and Evaluation
MOU: Memorandum of Understanding
MOF: Metal Organic Framework
MPG: Mango Producer Group
MYRADA**:** Mysore Resettlement and Development Agency
NABARD: National Bank for Agriculture and Rural Development
NAMDEVCO: National Agricultural Marketing and Development Corporation
NFC: Nano Film Cellulose
NPFVGA**:** Niagara Peninsula Fruit and Vegetable Growers
OTFMB**:** Ontario Tender Fruit Marketing Board
PCPB: Pest Control Products Board
PLD: Phospholipase D
PRM: Project Review Meeting
REB: Research Ethics Board
RTE: Ready to Eat
RTS: Ready to Serve
SE: Socio Economic Report
SEM: Scanning Electron Microscope
SFAC: Small Farmers Agribusiness Consortium
SUA: Sokoine University of Agriculture
TFF: Tree Fresh Formulation
T&T: Trinidad and Tobago

TAHA: Tanzanian Horticultural Association
TAS: Tobago Agricultural Society
TNAU: Tamilnadu Agricultural University
UG: University of Guelph
UNGA: United Nations General Assembly
UNDP: United Nations Development Programme
UoN: University of Nairobi
US: United States
UWI: University of West Indies
VCS: Venture Capital Scheme
VKRC: Village Knowledge Resource Center
VRIC: Vineland Research and Innovation Centre

EXECUTIVE SUMMARY:

Post-harvest losses contribute several billions of dollars worldwide, in both developed and developing nations. Fruits and vegetables are one of the most highly perishable produce due to their tenderness that results in very short shelf life. Most fruits develop some sort of post-harvest 'disease' that accelerates the deterioration. In incidents where such disease incidences are prevented, fruits tend to shrivel and their taste attributes start to decline. Thus, minimising membrane damage can lead to extended post-harvest shelf life. Research at the University of Guelph lead to the discovery that a key enzyme called phospholipase D (PLD) triggers the onset of membrane deterioration. Further research in this field lead to the discovery of a key natural product, called hexanal that can inhibit the action of PLD dramatically. Based on these discoveries, a spray formulation with hexanal as the key ingredient (named as Enhanced Freshness Formulation or EFF), was developed and tested on many fruit crops as a pre- harvest spray as well as a post-harvest dip treatment. The results revealed that in addition to the anticipated extension of post-harvest shelf life, fruits in the treated trees were also retained for an additional period. These results made a significant impact with the fruit growers who tested these products, as they could generate a 10-15% additional income, depending on the crop. We have developed prototypes that could deliver hexanal at very small doses and in a sustained manner using 'green nanotechnology'. Through these technologies, the post- harvest shelf life could be extended from more than one point of intervention. As a result of this project, the awareness in this EFF technology has increased from zero farmers in 2012 to over 27,000 farmers in 2017. More than 80% of the farmers who were involved in testing approved the technology and 51% of the farmers got premium price in the market for mango and banana in India. This technology also generated 12-17 days of additional employment for women, due to longer availability of fruits during the season and more packaging opportunities. As an effective outcome of this project, 33 graduate students (15 Male: 18 Female) and 13 research associates/research fellows (3:10, Male: Female) were trained resulting in a sustained pool of highly qualified personnel. The salient results/outcomes during the 40 months of the project are:

1. The 9 Nano technological solutions to enhance the shelf life of fruits were tried in 6 countries and in 15 types of fruits. Irrespective of the crop, varieties and location the products continue to enhance the shelf life of fruits.
2. Seventeen Master's thesis and one PhD thesis have defended or submitted. Four or more MS thesis will be submitted by summer of 2018 (***Annex 1***)
3. Graduate students working in this global project won many national awards including a full scholarship to Cornell University for pursuing PhD.(***Annex 2***)
4. With the research and results from this project so far the team had produced 30+ refereed publications and nearly 60 conference presentations. Some of the publications are provided in the links below and detailed list I n A***nnex 3***.
   https://www.dropbox.com/sh/vf32fpu8x3dbmfy/AACuvB0oOKDWDeYxpCyS4aXta?dl=0
   DOI: 10.1080/15440478.2015.1029195 ,
   https://doi.org/10.17660/ActaHortic.2018.1201.8
   https://www.nature.com/articles/hortres201742
   http://dx.doi.org/10.1139/CJPS-2016-0351.
   http://dx.doi.org/10.1016/j.scienta.2017.10.031
   http://www.bioone.org/doi/abs/10.1139/cjps-2017-0365

5. A full set of publications (12) are in the typeset form to be published as a special issue in the journal Tropical agriculture, a first for a CIFSRF project (***Annex 4***)
6. Apart from these research outputs in the scientific community, the team had a solid communication output, through which the product (EFF) has reached more than **25,000 farmers directly**) and **30+** government and policy makers, globally.
7. Pre-harvest spray of EFF had extended shelf-life by 14-21 days in mango, 5-6 days in guava, and 4-5 days in grapes under ambient storage conditions. In Tanzania pre harvest spray has reduced the fruit drop in mango by 40%. In India, for Mangoes, the cost benefit ratio is 1:5/tree.
8. Post-harvest dipping of fruits (mango, banana and papaya) in 2% EFF extends shelf-life by 12-18 days which was confirmed in different geographical locations and reduced the disease incidence by 80%
9. Nano products such as nano sticker, sachet or film extend the shelf life of tropical fruits (mango or banana) by 12-18 days.
10. More awareness and acceptance of the product has been created in East Africa- A huge step from inception. In spite of delay in getting the hexanal in East Africa, EFF pre- harvest spray in sweet oranges reduced the fruit drop by up to 50% and reduced fruit drop (45.4 %) and increased fruit retention in mango. This can give significant economic and nutritional boost to Tanzania as their mango production is off season to other mango producing giants like India.
11. In Trinidad and Tobago, using EFF spray the farmers can stagger the time of harvesting papaya, so they could better manage their harvesting time and labour availability.
12. For school nutrition program in T&T, substituting green papayas (with the help of EFF) in place of potatoes would have implications for **national food security and sovereignty, while also supporting farmers** with assured market as the institutional (school board) demand for green papayas is 2746 lbs/month (But the supply is less than 2000 lbs).
13. Electrospun nano-fibre matrix fortified with hexanal (Sticker) and β cyclodextrin inclusion complex (Sachet) have been developed to minimize the post-harvest fruits damage during transport. The cost of technology is around INR.5 (~10 Cents) per piece to protect the fruit box carrying 2-3 kg.
14. Hexanal Incorporated Composite Material (HICM) maintained the marketability of the mango fruits for 21 days and Banana fibre Fruit Wrap (BFW) can be used as an ecofriendly cushioning in packaging as a substitute of Styrofoam.
15. EFF pre harvest spray in Nectarine increased the fruit retention by 15-17% in addition to higher firmness and reduced physiological disorders. This will fetch better price in Canada as against imported fruits from US. Volatile analyses provided conclusive evidence for the presence of hexanal in the fruit and its sustained presence after treating with EFF, thereby resulting in greater membrane integrity.
16. EFF as pre- harvest spray increased the shelf life in berry fruits: Strawberry (up to 9 days), Raspberry (6 days) which make huge impact in the marketability of these soft berries.
17. In hexanal response screening trials, a delay in mold growth and softening in strawberries is noted. Green aroma was also noted in nectarine and peaches which is due to naturally occurring hexanal trapped in the headspace of the packaging/wrap, which is important for preservation and shelf-life extension
18. As reported by Mango farmers in India, they could earn an additional income of INR. 14 000 (CAD 280) per acre with two weeks delay in their crop. This is in addition to the increased yield due to high retention (INR 10000= CAD 200).
19. Pack house meetings and trainings benefited more than 6000 women mango growers and value addition training in Mango to empower women entrepreneurship generated 17-man days of additional employment to women during crop season.
20. There are 90 Mango Producers' Group (MPGs) in the IDRC project sites, of which more than 60 per cent are represented by women compared to 2-5 per cent in other existing Community Based Organizations(CBOs).
21. About 15 per cent of women in MPGs revealed that they were able to partly convince men partners in the farm level decision making.
22. Two major events addressing packers (banana and mango) and growers (mango) were conducted with 120 packers each covering 80-100 farmers (representing over 10000 banana farmers) and 500 mango growers in Tamil Nadu, India.
23. In 2017 season alone, 2000 litres of EFF concentrate (equivalent to 100,000 litres of spray formulations) was produced and supplied to mango growers across the major mango growing domains of Tamil Nadu, Andhra Pradesh and Karnataka.
24. More than 2000 model farms have been set to disseminate the technologies. They represent all the five mango growing districts in Tamil Nadu besides Andhra Pradesh and Karnataka.
25. TNAU received request from 3122 farmers for the supply of EFF to undertake pre-harvest spray covering six major mango growing domains, of which small and marginal farmers constitute 81% (2526 farmers).
26. In India the technologies results in 12-17 days of additional employment for women during the cropping seasons, especially in the packing side. Also with three FRSCs, a total of 4360 farm advisory services were offered in which **32% of beneficiaries were farm women**. 44 Value added trainings given with 83% women participants (926 Women and 183 Men), 35% of the women became small entrepreneurs. Value addition products in Mango alone got an additional income of INR 19200 (CAD 384) per acre

27. The project was showcased in the Market Place, a side event of UN General Assembly in September 2015
28. The project was presented in the Invited talk "Healthy Goats and Tougher Fruits" at GAC, December 2015 and attended by policy makers, representatives from different consulates and high level government officials.
29. With GAC's help, the lead PI was able to give a webinar organized by IICA (Inter-American Institute for Cooperation on Agriculture, Canadian Chapter) which had 160 registrants from 17 countries.
30. During this project's tenure, the team had the opportunity to interact and update the project's progress with Canadian High Commissioner, Trinidad and Tobago, Sri Lanka, Tanzania and Canadian Consulate General, Bengaluru
31. The team has done extensive research and progress in the entrapment of hexanal and smart delivery of hexanal through various nano packaging materials such as sheets, sachets and stickers. US patent (PCT/CA2015/000027) was filed for a nano product developed in UG. A patent application by TNAU for the nano-sticker is currently being evaluated.
32. 'Smart Harvest'- a new licensee from Canada- hired consultants to clear the regulatory hurdles in US, Guatemala, Costa Rica with their existing partners. Focus is more on dip as it presents relatively lesser regulatory constraints.
33. Smart Harvest signed a MOU with TNAU on March 15, 2018 for commercial production and marketing of EFF. Hayley's in Sri Lanka received DOA (Department of Agriculture) clearance and launched their products (Tree Fresh Formulation and Bio wax) on March 22, 2018. These two events were attended by their respective CHC/Canadian Consul General (***Annex 5)***
34. In July 2016 this grant (project) sponsored a session on Food Security and Sustainability in *Joint* Annual conference for the Canadian Society of Agronomy /Canadian Society for Horticultural Science, Montreal, Canada. We also cosponsored the IIHS conference at Kandy in April 2017 and National Banana festival in India (July 21-23, 2017). This event was well attended by 10000 farmers, state ministers, and state and federal policy makers.
35. Skill demonstration on dip treatment of banana at the major banana growing area of Tamilnadu. This event also well attended by five project coordinator for supply chain management, 300 farmers and five policy makers.
36. A two day National conference on Nanotechnology for evergreen revolution was organized by TNAU in October 2017, which was again co-sponsored by this project funds. This conference was inaugurated by Dr. Anindya Chatterjee, Regional director, IDRC, Asia. The PO and lead PI of the project also attended the event.
37. In Trinidad and Tobago, World Food Day (October 16,2017) had a themed celebration "Change the future of migration - invest in food security" organised by Division of Food Production Forestry and Fisheries (DFPFF) attended by policy makers from Tobago
38. Dissemination meetings and events conducted in all project sites and was well received and attended by 2500 people including farmers, extension agents and policy makers.(***Annex 6***)
39. Book on "Postharvest Biology and Nanotechnology of Fruits, Vegetables and Flowers" edited by Gopinadhan Paliyath, Jayasankar Subramanian, Loong-Tak Lim, Avtar Handa, Autar Mattoo and K.S. Subramanian was submitted to Wiley-Blackwell Publishers in January 2018 and expected to release in Summer 2018 (***Annex 7)***
40. The project produced various informal non-scientific outcomes like pamphlets and 3-5 min videos from various project locations (Project output section of this report)

RESEARCH PROBLEM:

Post-harvest loss in fruits adds to several billion dollars worldwide. Decreasing the post-harvest losses can significantly improve the economic return for the farmers. A large proportion of women are directly or indirectly involved in the production and post production related activities (e.g. harvesting, sorting, packing, vending and accounting) in Asia, Africa and The Caribbean. Preventing these losses will ensure increased availability of nutrient-rich fruits and enhance the food security in these countries., Scientists at University of Guelph have identified that hexanal, a GRAS (Generally Regarded As Safe) compound that is produced by plants can help to extend post-harvest shelf life of fruits. This IDRC-CIFSRF project aims to reduce the post-harvest fruit losses using a nanotechnology based hexanal smart delivery system (HSDS). Since the project started, it was clear that hexanal can also be used to retain the fruits in the trees longer. This aspect was deemed very helpful to manage the limited farm labor availability in certain areas. Further, observations by participating farmers revealed the hitherto unknown benefits of this intervention in keeping pests and diseases at bay, indirectly by improving the health of the tree and fruits. As a result of these observations the project evolved into a pre- and post-harvest shelf life enhancing mechanism. The impact of such delay in harvest on the socio-economic impact was also studied.

Although at the start we envisaged only post-harvest shelf life, research during this CIFSRF funded work evolved into a two- pronged approach. Hexanal also helped to retain fruits for longer period, especially in mango and evolved as a powerful mechanism to keep banana fresh for much longer than usual. These observations lead to the adoption of the EFF technology by the mango and banana farmers (including packers). Downstream players in the market stream opine that a steady supply of certain varieties will help to reduce price fluctuation and make fruits available for a longer period. This also opens export market opportunities for countries like India, Kenya and Tanzania. Based on the output and outcome stories that emerged, the use of EFF has been added as a highly

recommended practice to mango growers by the State Department of Agriculture in Tamilnadu, India. In 2012 when the project started, hardly anyone- including researchers- knew hexanal in India. At the end of the project (Mar 2018) the technology has reached ~12,000 farmers. During this project over 60 HQP (graduate students, research associates and research technicians) were trained across the 6 countries. In addition, 2 patents on smart delivery of hexanal using Nano technological approaches have been filed in India.

MILESTONE PROGRESS

Refer **annex 7A** for detailed report on the project's progress over 40 months

SYNTHESIS OF RESEARCH RESULTS AND DEVELOPMENT OUTCOMES:

Nine Nano technological solutions to enhance the shelf life of fruits were tried on 15 types of fruits in 6 countries. Refer to the outcome story, "Nano technological solution to tackle post-harvest loses in fruits" (**Annex 10**). Important facts about these nine nano technological solutions are:

- Enhanced Freshness Formulation (EFF) carrying hexanal as an active ingredient can be delivered in horticulture systems as pre-harvest spray, post-harvest dip and vapor form preserves fruits for 2-3 weeks under ambient storage conditions. The technology is economical and eco-friendly and enabling farmers to earn 15-20% higher income
- Farmers in North America, Asia, Africa and Caribbean can use **pre-harvest spray** of EFF to retain the fruits for 2-3 weeks on trees and extend the shelf-life for another 2-3 weeks in storage conditions. The technology is working well for both tropical and temperate fruits. It was unequivocally demonstrated that treated fruits had lower incidence of post-harvest diseases
- In pack houses and exporters can use EFF **dipping technology** alone or in combination with wax formulation as an intervention within the sequence of dipping treatments to reduce the post-harvest losses. Huge quantity of fruits can be treated in 5 minutes. A solution that is easy for the farmers to adopt.
- **Vapour** form of hexanal is equally effective and various dispensing systems such as nano-stickers, nano-wrappers and nano-sachet were developed, validated and patents filed. This is simple and large quantities can be treated without any associated ill-effects.
- More than 12,000 farmers in India adopted the technology and our survey suggested that 80% of them either benefited from the delayed harvest and higher incomes
- The hexanal technology is not unique to a particular fruit or vegetable and thus it can be fine-tuned to suit a wide array of perishables. The technology is quite robust and powerful to help address the global challenge of post-harvest losses.

Key results for each project specific objectives were analysed and presented below (and in the table)

1*. Test pre- and post-harvest applications of "Enhanced Freshness Formulation", a combination of hexanal and anti-oxidants, in sprays and dips for extension of fruit retention and improved shelf-life of treated fruit.*

EFF has been tested on a range of temperate and tropical fruits in several countries. EFF has worked well as a preharvest spray (usually 2 sprays before ripening) on fruits such as mango, nectarines where the fruits have a thinner outer skin that permits the EFF to penetrate the fruit. On thicker skinned fruit such as banana and papaya which ripen continuously, the dip treatment has been very effective. Results for mango and banana have been consistent over different varieties in the partner countries. Shelf-life has been extended between 12 and 18 days for mango and 10 to 21 days for banana. When other fruits such as guava, grapes, papaya, and lime were sprayed with EFF, the shelf-life was extended and several other positive outcomes were reported including less fruit drop and longer retention of fruit on the tree, improved colour.

The post-harvest dip was able to extend the shelf-life of mango, banana, plantain and papaya while delaying the development of full colour in the fruits. This has significantly extended the window for marketing a fruit such as banana.

Exposure to EFF as a spray or dip had the added benefit of creating firmer fruit with no negative side effects on other quality measurements such as flavour or total soluble solids.

2. *Test exposure of fruit to hexanal as a vapour for longer post-harvest shelf-life.*

EFF can also be applied as a vapour by placing the hexanal in an air tight space and allowing it to volatilize. On strawberry the vapour treatment helped to maintain the integrity of membranes which contributed to a longer shelf life. When used as a vapour treatment on banana, EFF destroyed the spores of important diseases in banana that would affect both pre- and post-harvest quality. This reduction in disease presence and severity has also been noted with other types of applications of EFF in the field.

3. *Develop hexanal impregnated biowax, bio-nanoparticles-based sachets and packaging materials for maintaining freshness of fruit during packaging and shipping.*

Hexanal has successfully been incorporated into sheets of fibres that will act as a vapour treatment for the fruit once the hexanal is released. This release pattern and the triggers for release are being studied now. The shelf-life of banana and mango was extended by 6 and 12 days respectively, when the hexanal was incorporated in a 'sticker' that was affixed to the inside of a carton. Marketability of hexanal incorporated bio was 84% when compared to its control. Similarly HICM helps to increase the marketability of mango up to 21 days at 13.5 ^{o}C.

4. *Assess risks from hexanal-based nano-applications.*

Hexanal and the vehicles used to carry it are all biodegradable and pose no threat to the environment. The hexanal applied as a vapour dissipates very quickly and is broken down to hexanoic acid. Extensive study on the biosafety of hexanal has been studied. It is safer to beneficial microbes, natural enemies, honey bees, earthworms and humans. Biodiversity of the orchard ecosystem is conserved without any ill effects. All these nano products have been evaluated for their suitability to qualify under green nanotechnology. All the products matched the major part of the criteria apart from flammability and energy requirement. Refer to the outcome stories "Biosafety" (***Annex 11***) and "Green Nanotechnologies" (***Annex 12***)

5. *Develop and implement a marketing strategy to ensure that applications reach a large number of small-holder producers.*

The marketing strategy began with exposing as many large and small farmers to the EFF technology as possible. With mangoes it has been effective to target grower organizations who represent many large and small growers. However, with banana, which are brought to central locations by small farmers in each small region, it has been best to target these collection points because each one deals with 100 or more small farmers. In some countries that state agency responsible for extension has been included as a KTW partner. These organizations are able to run local workshops in populated and remote areas. EFF usage in India 2014 was only 720 farmers, but with constant dissemination and trails, the usage rose to 12074 farmers in 2017. Feedback from the users revealed that post-harvest losses had been reduced by 10-12% in the EFF sprayed fields in comparison to control. Farmers got additional 24% income/acre directly due to increased retention (10%) and two weeks delay in harvest (14%). Based on the usage and cost benefit analysis, The Canadian Company, Smart Harvest, signed a MOU with TNAU in March 2018 to commercially produce and distribute EFF in India. In Sri Lanka, Hayley's sublicensed two products (EFF and Bio wax) and the products were launched in March 2018. Refer to outcome stories "EFF delivery at farm gate" (***Annex 13***), "Hexanal technology Cost Benefit Analysis" (***Annex 14***) and "Technology Transfer Experience in Sri Lanka" (***Annex 15***).

6. *Monitor socio-economic impacts on small-scale and marginal fruit growers, particularly women engaged in post-harvest operations*

In India the technologies results in 12-17 days of additional employment for women during the cropping seasons, especially in the packing side which reduces the drudgery, since they work in shade. Also with three FRSCs, a total of 7245 farm advisory services were offered in which **32% of beneficiaries were farm women**. 44 Value added trainings given with 83% women participants (926 Women and 183 Men), 35% of the women become small entrepreneurs. Value addition products in Mango alone got an additional income of Rs 19200 ($384) per hectare (Value Addition Training in ***annex 17***). In 2017 Mango season alone 3122 farmers were supplied with pre-harvest spray covering six major mango growing domains of India, of which small and marginal farmers constitute 81% (2526 farmers). In Trinidad and Tobago trials of EFF spray for papaya demonstrate potential benefits for actors across the value chain, including small-scale producers, processors, caterers, and consumers, due to the potential to use green papaya as a potato substitute. EFF spray slows the ripening of the fruit, retaining the green colour that processors want to see when buying papaya to make value-added products. For the country, the increased use of green papaya has the benefit of reducing dependence on imported goods and lowering national food bills, while supporting local farmers and their livelihoods. In Sri Lanka, Impregnating banana paper with EFF technologies allows it to do double duty – protecting fruit from injury during transportation over long distances, and increasing shelf life. Results from simulated transportation and storage trials carried out at the Industrial Technology Institute (ITI), Sri Lanka, showed no significant difference in fruit quality between polyethylene sleeves and banana fibre-based wraps. Even better, this technology adds further value through employment and income-generating opportunities, especially for women who otherwise have limited *employment options.* (Value Chain Actors in ***annex 16***).

SYNTHESIS OF RESULTS FOR EACH TECHNOLOGY, COUNTRY AND THEIR CROPS

#	Technology/ Country	India	Sri Lanka	Kenya	Tanzania	Trinidad and Tobago	Canada
	Crop	Mango, Guava, Grapes and Banana	Mango and Papaya	Banana and Papaya	Mango and Citrus	Banana and Plantain Papaya and Lime	Strawberry, Raspberry, Blueberry, Haskap and Nectarines, Apple
1	EFF pre Harvest Spray	**Mango**: Additional two weeks retention and Delayed harvest nets better price (up to 40% more) in the market 50% Reduction in fungal disease incidence on fruits Additional net fruit yield of 5 kg per tree (200 kg per acre) Extended shelf- life of fruits in ambient (2-3 weeks) and cold (4-6 weeks) storage Treated fruits are shiny and firm that enable long distance transport and export Amount invested 1 CAD per tree and amount gained 5 CAD per tree **Guava**: One Spray (2%), 30 days before harvest extended the shelf life by 6 days (Ambient) and 21 days (Cold Storage). Despite the shelf-life extension is shorter, it assists the farmers to transport the fruits to farthest market **Grapes**: One spray (1.0%) 15 days before	**Mango**:EFF 2% spray with three treatments: 20,40,60 DBH on varieties TJC & KK Retained consistent firmness for 4 weeks. Harvesting season of KK variety of mango and TJC variety of mango could be extended up to 4 weeks and 6 weeks respectively using 3 time EFF spray treatment.	**Banana**: 2% pre harvest spray (15&30 DBH) had delayed fruit ripening, 14 days delay in fruit retention and 6 days delay in shelf life after harvest. Also delay in peel softening **Papaya**: 2% pre harvest spray (15&30 DBH) had delayed fruit ripening, 13 days delay in fruit retention and 6 days delay in shelf life after harvest. Also showed better color development before & after harvest, increased firmness, titratable acidity, enhanced Beta Carotene, and reduced ethylene peaks. Also noted less incidence of diseases. Hence more farmers in Machakos County have deep interest in this technology	**Mango**:EFF 2% & 4% Spray reduced the fruit drop 10.4% (Apple Var), 40% (Palmer), pest incidence 10.8% (Apple), 19.49 % (Keitt). Increased the Marketable yield 13.45 % (Apple), 23% (Palmer), Shelf life Increased by 7 days. Also noticed increased fruit firmness, reduced physiological weight loss (PWL) and nutritional value **Sweet Orange**: EFF 2% improved the quality and shelf life by 7 days in Ambient conditions. Increased fruit firmness and reduced physiological loos in weight when compared to control and smoke treatment (most commonly used in Tanzania)	**Papaya**: 2% EFF spray resulted in fruit retention in trees for 2 months and significant reduction of post-harvest diseases **Lime**: 4% EFF pre-harvest sprays biweekly or weekly with 30 days of harvest extended the fruit retention to 99 days. Senescence (color change from green to yellow) took in excess of 120 days.	**Strawberry**: EFF spray did not significantly slow down ripening, but fruits from the sprayed plants were firmer and kept at least 2-3 days more than untreated. Genetic analysis revealed that several genes involved in ripening regulation were slowed down as a result of EFF spray. EFF reduced the transcript levels of Phospholipase D (PLD) **Raspberry**: No significant slowdown of ripening but fruits from the sprayed plants were firmer and kept at least 2-3 days more than untreated. Genetic analysis revealed that several genes involved in ripening regulation were slowed down as a result of EFF spray. A key finding of this study was the involvement of calcium in delaying the ripening process. Induced calcium depositions which helps in maintaining membrane integrity. **Blueberry**: Increase in firmness and soluble solids. Metabolomics revealed that genes involved in carbohydrate and stress response pathways were upregulated (increased) and genes involved in ethylene synthesis and cell wall integrity were decreased (downregulated). **Nectarines**: EFF 2% spray extended the shelf life by 9 - 12 days, reduced internal browning and mealiness by

		harvest extended the shelf life by 4 (ambient) and 31 days (cold storage). One of the significant observation made was greenness of the fruit stalk and retention of fruits that facilitate intact of fruit bunch and enables long-term transport.					8-10 days, Further EFF shifts all the volatiles by few days longer thus keeping them 'fresh'. **Haskap:** Very inconclusive with Haskap a new berry crop of Canada, because identifying the right stage of harvesting is tough as haskap turns dark even when it is unripe. EFF did delay the fruit drop from the bushes which can help the haskap growers. **Apple**: Fruit retention was very compelling and the grower also attests to the fact that the fruits in the sprayed trees had very less bitter pits. EFF treated apples also stored very well – into March 2018 (after harvesting in Sep 2017), which was a welcome result for apple growers
2	EFF Post Harvest dip	Dipping EFF (2%) for 5 mins & shade dried for 30 mins extended the shelf-life of mango, banana, guava and grapes, 13-15, 11-12, 4-6, 2-4 days respectively under ambient storage conditions. The EFF dipping works well for green banana where chips makers wish to take advantage of the fruit preservation.	N/A	Banana:2% EFF dipping for 5 minutes increased the shelf life to 9 days. Also increase in physical and chemical parameters tested (firmness, ethylene production, respiration, total titratable acidity and total soluble solids.) Papaya: EFF (1&2%) dip for 5 mins increased the shelf life by 6 days, retained fruit firmness (9 days), decrease in color break down, Vitamin C degradation		Banana: EFF dip 2% and 4% in commercial banana (William) firmness extended by 3 days. Papaya: 2% EFF dip delayed shelf life by 14 days, reduced post-harvest diseases and increased sugar (ideal for packers)	N/A
3	EFF vapour	Hexanal vapour at 800 ppm for 3 hrs totally reduced anthracnose and stem end rot in	N/A		N/A		Helps to keep the membrane integrity in greenhouse grown strawberries, thus enhancing shelf life.

		Banana. In Mango and banana extended the shelf life for 15-20 days.					
4	Electro Spun Wrapper	N/A	N/A	N/A	N/A	N/A	Simultaneous release hexanal, benzaldehyde, and/or salicylaldehyde from their precursors are effective in delaying the delaying the ripening of pear and nectarine fruits.
5	Hexanal entrapped Sachet (cyclodextrin inclusion complex)	58% hexanal entrapment using (MOFs)". Microwave synthesis took less time to get the crystals of MOFs. MOFs were made as pellets and each pellet of 1g can preserve a pack of fruit (2-3 kg)	N/A	N/A	N/A	N/A	N/A
6	Sticker (Electrospun nano-fibre matrix)	Nano-fiber matrix (developed through electrospinning which traps hexanal) 5 x 5 cm was affixed in a box of fruits (2-3 Kgs). The shelf-life extended by 6 (Mango) and 12 (Banana) days, under ambient storage conditions.	N/A	N/A	N/A	N/A	N/A
7	Banana fibre nano-film (Nano Fibre Cellulose) NFC	A combination of 5% polyvinyl alcohol, 5% poly acrylic acid and 1% NFC resulted in perfect biodegradable nano-film. This extends shelf life of tomatoes up to 18 days under ambient storage.	N/A	N/A	N/A	N/A	N/A
8	Bio wax	N/A	**Mango & Papaya:** storage life of bio-wax treated papaya	N/A	N/A	N/A	N/A

			could be extended for more than 21 days. Marketability of bio wax treated TJC Mango fruits was 84 % compare to 58 % of un-waxed fruits				
9	HICM (Hexanal Incorporated Composite Material)	N/A	**Mango:** HICM helps to increase the marketability of mango up to 21 days at 13.5 ° C.	N/A	N/A	N/A	N/A

Summary statement: EFF has really taken off well and is expected to be available commercially in India and Sri Lanka in 2018-19 season itself. In Canada and US it is expected to be made available in late 2019 or 2020 as the regulatory process will take that long. In Africa it requires some more data for regulatory clearance and a suitable partner to produce it commercially. This is for both spray as well as dip treatments. Hexanal impregnated nano-sachet and nano-sticker technologies have been filed for patent in India and once the patent is issued it is expected to be commercially produced and made available to packers. This technology is expected to reach other countries also as there is no direct contact of hexanal with the fruits and hence the regulations will be much less than EFF spray or dip. Electrospun wrapper is waiting for patent clearance and already the technology is being discussed with prospective suitors in Canada. Once the patent is issued this may be taken up for commercial production in Canada and other places. Biowax is commercially available in Sri Lanka from next year onwards hexanal impregnated biowax is also expected to be made available through Hayleys, it is licensee.

We anticipate that the overall 'hexanal nanotechnology' adoption will take up in the coming years. As of now the EFF is popular in India (only one state) and Sri Lanka, other than Canada and about 12000 farmers are adopting. This is mainly because of the delay in regulatory process that is beyond our reach. The demand for the farmers is quite high and once the regulatory hurdles are removed and the product is produced for distribution in the entire country, we can anticipate at least about 100-150000 farmers/packers using it in various parts of the country. This is a very modest estimate that was developed based on the statistics provided by State Horticultural Department, whose personnel look after the spread of such technologies. It must also be noted that this is a technology for fruits which is only a small percentage of total crops grown and in no way, can be compared with grain crops like wheat, soy or millets for that matter. In short, the demand from farmers, the scientific data from researchers, the licensee to produce it commercially are all there for a substantial growth of this technology. Only thing to be cleared is the regulatory hurdles and an y help to accelerate this process will be of immense use.

RESEARCH PARTNERSHIPS

The team has partnered with many institutions to conduct their field trials, socio economic work and for disseminations.

No	Country	Team	Partnered With
1	India	TNAU	MYRADA-Mysore Resettlement and Development Agency
2	Sri Lanka	ITI	CEPA-Center for Excellence in Poverty Analysis IPHT- Institute of Post-Harvest Technology*
3	Kenya	UoN	KALRO-Kenyan Agricultural and Livestock Research Organization JKUAT- Jomo Kenyatta University for Agriculture and Technology Meru farmers Association* and Kevian (Largest Indigenous Fruit Juice Processor in Kenya)*
4	Tanzania	SUA	AMAGRO- Association of Mango Growers TAHA-Tanzanian Horticultural Association
5	Trinidad and Tobago	UWI	NAMDEVCO- National Agricultural Marketing and Development Corporation Division of Food Production, Forestry and Fisheries, Tobago House of Assembly
6	Canada	UG	OTFMB- Ontario Tender Fruit Marketing Board* NPFVGA- Niagara Peninsula Fruit and Vegetable Growers* VRIC- Vineland Research and Innovation Center*

(*) Public and Private Sector Partnerships\

Results of research conducted by University Guelph in temperate fruits enabled the adaptation of EFF spray and dip technology in India, Sri Lanka, Kenya, Tanzania and the Caribbean. Based on the results in India, similar trials were conducted in Sri Lanka (TNAU and ITI). Hexanal entrapped Sachet, a nano technological intervention developed by TNAU will be sent out to Kenya to study the effect in Papaya (TNAU and UoN). Smart Harvest, a Canadian company had signed a MOU with TNAU on March 15, 2018 to commercially produce EFF in larger scale. Similarly, Hayley's in Sri Lanka, sublicensed for the commercial production of EFF and Bio wax for their market.
All the teams have been benefited from capacity building in terms of equipment and human resources (through RA's, Post docs and graduate students). As an effective outcome of this project, 33 graduate students (15 Male: 18 Female) and 13 research associates/research fellows (3:10, Male: Female) were trained resulting in a sustained pool of highly qualified personnel

Younger team members from TNAU and ITI had their training and lab exposure at Canadian University (UG). These researchers are being trained in the fields of horticulture, post-harvest science and nanoscience that would help them in career growth. With a consistent and solid financial support for the past four years, the TNAU team is well positioned to take a lead in nanotechnology in India.
The ITI is now collaborating with the Institute of Post-Harvest Technology (IPHT) Sri Lanka, to expand the scope of the EFF spray treatment and the Bio-Wax application for use on limes (to extend the crop season and post-harvest loss). The IPHT will also promote the use of the fruit wrap paper in the collection and distribution centres in place of the Styrofoam sleeves currently being used to protect fruits from abrasion and vibration damage. UoN is in the process of making a partnership with Kevian, Kenya, a largest indigenous fruit juice processor and with Meru farmers association to procure and process the fruits.
Graduate from UoN, Ms. Peninah M. Yumbya working in this project had been awarded Kshs. 2 Million from the Kenya National Council for Science and Technology to support her future work. Dr .K. S. Subramanian, PI of TNAU team has been awarded the position as the NABARD Chair Professor since April 17, 2017 to take forward the

emerging technologies beyond the project period. Graduate students from this project won several national and international awards (***Annex 2***)

Partnering Institutes benefitted greatly through this project. Apart from financial benefits, researchers-especially students- from these countries were exposed to the functioning of large, multinational project which helped them immensely in their career development. Several students working on this project, won awards and scholarships at International levels as detailed in the output section. This has also helped for newer partnerships which are taking place between different countries as there are joint project proposals submitted for taking these result to next level. In Asia EFF demonstrated through this project is expected to be available commercially soon. In Africa, further research proposals have been submitted to expand this work so as the regulatory hurdles will be cleared and the product will be available for commercial use. TNAU is continuing to work on spin-off technology such as sachet and sticker for further use. This project has helped UoN and TNAU to forge better collaborations with UG and possible student exchange can happen soon.

Governance: This project provides plenty of opportunities for the women to get involved in cutting-edge research that help them in career building. The selection is purely on merit basis and the outcome of their theses are being published or presented in international conferences.

Research ethics: The project follows their respective Institutional Ethics Board and is already in place. All the personal information gathered with consent as per the stipulated guidelines.

Use of research results: In mango and banana, had made a deep impact on the entire value chain in India and Sri Lanka. Because of the overwhelming impact mango farmers, banana packers, banana chip industry and exporters are eagerly awaiting the availability of the product in the market. At the end of the project, EFF has been launched as a commercial product through a private company in Sri Lanka and a MoU has been signed to produce EFF for limited use in India.

In Kenya, Tanzania and West Indies, hexanal was not something that is known to even researchers till the inception of this project. Currently fruit growers have been sensitized through on farm trials and are convinced of the benefits of hexanal for improving fruit growing and shipping in those countries. In Trinidad, green papaya is being substituted in the school meals instead of potato (which tends to be expensive there) and EFF plays a key role in keeping papaya from ripening for an extended duration.

It is anticipated that EFF will be available and used by well over 100000 fruit farmers in India alone within the next 3 years. We also anticipate that the sensitization of growers in Africa and Caribbean will lead to a commercial product (EFF) within the next three years.

SYNTHESIS TOWARDS AFS THEMES

This project focused on the research towards outcomes developed for improvements in food, income and nutrition security. Considerable progress has been done in the following directions:

NEW AND IMPROVED AGRICULTURAL SOLUTIONS THAT INCREASE FOOD PRODUCTIVITY, IMPROVED INCOME OPPORTUNITIES AND IMPROVING GENDER SPECIFIC CONSTRAINTS

EFF interventions have improved food productivity both directly and indirectly. Farmers can get better price for their produce, since they are able to exercise better control of fruit harvest and ripening. Another advantage for growers stems from quality improvement—uniform ripening, better appearance and fruit maturity parameters (e.g. color and size) will allow farmers to fetch premium price.

For example in India, in mango cultivation with Good Agricultural Practices (GAP) along with EFF intervention demonstrated at 2000 model farms in Tamilnadu. In addition to EFF spray on model farms, farmers have been trained to use nets and hooks to harvest fruits (GAP), in order to minimize losses related to falling and bruising.

- With EFF technology there is increased harvest of at least 5 kg fruits per tree which gives a net gain of INR 10000/acre ($200). Additionally delayed harvest (EFF keep fruit fresh for 2 weeks) assists in additional income due to late arrivals in the market. According to farmers 1-day delay = INR. 1000 gain (CAD20/day) and 2 weeks delay = INR. 14,000 gain (CAD280)

- The post-harvest dipping of banana in EFF extended shelf-life up to 2 weeks under ambient and 4 weeks under cold storage conditions. At least 15% of fruits rejected at the pack houses can be avoided with EFF dipping. Such delayed ripening circumvents price volatility while ensuring higher farm income.
- EFF intervention in banana is almost exclusively done by women, round the year, whose families are farm families. In mango farms spraying is done by men while sorting, grading and packing are done by women. Thus, the technologies provide improved livelihood for these farmer families, women included.
- Continued availability of fruits for an extended time due to EFF intervention (spray or dip) directly results in additional employment especially for women between12-17 days during each cropping season. Since, pack houses would primarily be women's jobs, there is increased employment opportunities for women.
- The potential for farmers, particularly smaller-scale farmers, to generate additional income streams from fruit species they have previously avoided. Since the fruits such as banana, mango and papaya are highly perishable the short shelf-life deters smaller-scale farmers to grow it. EFF interventions are beginning to convince such small scale farmers, especially in Africa to re-think and expand fruit growing in these regions. Keeping color as in limes or green papaya can help to expand growing these crops where there is such need (e.g. the Caribbean).
- Value-addition training has potential for women to make use of the additional fruit availability for which the team has given 44 value addition training with 83% women participants (926 Women and 183 Men), 35% of the women become small entrepreneurs. Value addition products in Mango alone got an additional income of INR 7500 (CAD150) per acre.
- In Sri Lanka training programs on banana cultivation and fibre production were conducted, with the goal of enhancing income for products as well as generating new income through selling banana stems for fiber production (SLR 15,000/acre- CAD150.00/acre). Further expansion of banana fiber paper production will lead to additional employment for women and utilize the bio-waste produced.

CONTRIBUTING TO ENVIRONMENTAL SUSTAINABILITY, AND CONSIDERING THE POTENTIAL ENVIRONMENTAL IMPACTS, BOTH POSITIVE AND NEGATIVE, OF THE APPLICATIONS BEING DEVELOPED.

Hexanal is a natural product produced by all plants. It is a GRAS (Generally Regarded as Safe) compound and has no known or observed ill effects on the environment. Further due to its volatile nature, the product evaporates within 24 hrs leaving no trace in the fruits as well as gets broken down quickly into basic molecules in the atmosphere. Risk assessment and environmental safety studies were done in detail using subjects from various trophic levels -microbes, predators, parasitoids, honey bees, earthworms, zebra fish and human cells and none of them was affected by hexanal even at 300% more concentrations than we recommend (Paliyath and Subramanian, 2008). The tests were done for some of the organisms till F1 generation. The results have clearly demonstrated that the EFF formulation is quite safe to all trophic levels even at three times of concentrations recommended for pre-harvest spray or post-harvest dip. A book encompassing the results has been released already which will help the scientific community, industry and policy makers. Further honeybee and other beneficial insect activity improved in the treated farms.

Banana fiber paper and tray produced is a value-added product from the waste which minimizes post-harvest loss during transportation and distribution by protecting fruit from physical injury. The products are ecofriendly and the fruit wrap is expected to replace the Styrofoam sieving currently used to protect fruits during storage and transport. Thus this eco-friendly product will have a huge positive bearing on the environment.

The project also contributes to environmental sustainability as traditional methods for pre- and post-harvest treatments of fruits involve exposing to smoke in several countries, which requires the use of wood, and thus has negative implications in terms of deforestation. In addition, the traditional smoking method creates partially underground tunnels, which contributes to soil erosion. **Thus, EFF spray appears to have positive resource sustainability implications**. Moreover**, it reduces drudgery for women** because it would mean a reduced need for firewood (which women collect by walking long distances). Finally, crop smoking decreases air quality, which has implications for the health of farmers and their families.

IMPROVING ACCESS TO RESOURCES, AND/OR MARKETS AND INCOME (ACCESSIBILITY)

In India three Village Knowledge Resource Centers- VKRC (one each in Krishnagiri, Dharmapuri, and Theni Districts) were established. These VKRC provide essential tools to small and marginal fruit farmers thus enabling them to implement Good Agricultural Practices- GAP. Trainings were conducted on the importance of collective marketing, GAP, EFF interventions, and formation of model farms. The VKRC are serving as a "hub" to promote GAP for mango farmers, answer any concerns about EFF intervention and improve the adoptability of the technology. MYRADA (NGO) is using mobile phones to send SMS on the occurrence of pests and diseases besides price forecast.

IMPROVING NUTRITION

Given the diversity of types of farms (marginal, small-scale, medium-scale, large-scale) in the project, and their diverse sources of farm income, it is expected that household food security is variable. Those vulnerable to food insecurity are most likely to be the marginal and small-scale farmers who rely in farming as the sole or primary source of income. Our data in Sri Lanka suggests that **farmers and the workers of the banana fibre factory are the most vulnerable, and the project activities that are targeted to increase the sustainability of earnings among these groups will likely have significant outcomes for household food security.**

- In the Caribbean, bread fruit is one of the key crops to improve the food and nutrition security. With a shelf life of as little as twenty-four hours at full maturity under ambient conditions, this fruit suffers extremely high levels of wastage despite its potential. Further, the Trinidad and Tobago Government policy has dictated that relevant agencies find ways to utilize breadfruit in the School Feeding Program in which breakfast and lunch meals are provided free of charge to children attending local schools.
- Apart from its direct use as a starchy staple, the breadfruit can be processed into flour for use on its own or in a composite with wheat flour to make many items traditionally used in these meals. Delay in the ripening process will greatly facilitate processing into flour and will set a domino effect on the food, nutritional and economic security of the region. Preliminary test on breadfruit with EFF dip treatment gave promising results and further trails are ongoing.
- In Tanzania, Most farmers consume the banana they produce (99%): 42.1% on a daily basis, 41.3% few times in a week while 16.7% consume these fruits rarely. Enhancing shelf-life will have profound effects on banana consumption given that it is an annual and staple food. Also subsistence farmers can potentially apply the technologies sequentially to spread maturity (over time) thereby smoothing food consumption.
- In India, the best post-harvest management practices and adoption of EFF technology enhanced the availability of fruits per unit area which resulted in improved purchasing power. The consumption survey data suggest that minimized post-harvest losses enhanced the availability of fruits but hardly coincided with increased consumption. Instead, it provides purchasing power to get nutritionally rich foods.

INFORMING POLICY

- In Tamilnadu, in a state level policy decision, EFF technologies were incorporated to reduce losses at the post production stage (January 2016)
- The project was briefed to Canadian Consul General (June 2015) and to Dr. Harshvardhan, Minister for Science and Technology, India (September 2015)
- This project was show cased (one of the thirteen concepts invited) in Market Place, a side event of UN General Assembly in New York in September 2015. Dr. Jay Subramanian, Lead PI of the project explained the progress and its importance in global food security to many policy makers including Hon. Elissa Golberg, Assistant Deputy Minister, and Partnerships for Development Innovation, GAC.
- A presentation entitled 'Healthy Fruits' was delivered by the PI, Dr. Jay Subramanian at the GAC, Ottawa, which was attended by diplomats from several countries as well as policy makers from Canada – December 2015.

- In October 2016, with GAC's help, a webinar on this project was organized by IICA (Inter-American Institute for Cooperation on Agriculture, Canadian Chapter) which had 160 registrants from 17 countries:
- The project and its benefits were explained to Canadian Consul General, Bengaluru, during her visit to TNAU in January 2017
- In February 2017 the seminar presented by Dr. Jay Subramanian at UWI, St. Augustine Campus was well received by Mr. Marlon Thompson, Trade Commissioner, CHC, Trinidad and Tobago and CHC is very much interested in the project updates and wants to involve herself in future events.
- Also during that time Dr. Jay along with few members of UG team and UWI PI/team met Assembly Man Mr. Spencer and explained the project and its implications in Tobago
- Presentation to the Secretary for Food Production, Forestry and Fisheries in Trinidad and Tobago; Tobago House of Assembly, and discussions with NAMDEVCO
- Collaborations with District Agriculture, Irrigation and Cooperative Offices in Tanzania
- Results shared with Kenyan Cabinet Secretary for Agriculture at a March 2017 conference.
- In March 2018, Consul General of Canada, Bengaluru presided the MOU signing event in TNAU and CHC, Sri Lanka, presided the product launch event in Sri Lanka.

PROJECT OUTPUTS:

1. Book on "Biosafety of Hexanal", written by the team members formerly released during the inception in January 2015, by Mr Sydney Frank, Canadian Consul General, Bengaluru (***Annex 18***)
2. Project was show cased in Market place, a side event of UN assembly in September, 2015
   https://www.uoguelph.ca/research/discover-our-research/photo-friday/2015-10-02
   https://www.guelphmercury.com/opinion-story/5962693-driving-toward-the-zero-hunger-generation-/
   Epoch Times: Canadian Innovations show cased in UN
   http://printarchive.epochtimes.com/a1/en/edition.php?dir=ca/yow/2015/10-Oct/02
3. In India: http://www.thehindu.com/todays-paper/tp-national/tp-tamilnadu/life-of-temperate-fruits-in-orchards-extended-thanks-to-nanotech/article8038916.ece
   http://www.thehindu.com/todays-paper/tp-national/tp-tamilnadu/new-technologies-will-enhance-income-of-farmers/article8038958.ece
4. In Sri Lanka: http://www.sundaytimes.lk/160508/news/longer-life-for-lankan-fruits-193250.html
   http://www.ft.lk/it-telecom-tech/Advancing-Dialog-s--Govi-Mithuru--service-in-partnership-with-Industrial-Technology-Institute/50-642946
5. In Tanzania: http://www.habarileo.co.tz/index.php/habari-za-kitaifa/368-dawa-kuzuia-matunda-kuoza-yaja (Swahili)
6. In Australian Broadcasting Center (Radio): http://www.abc.net.au/news/2015-03-17/nanotechnology-mangoes-india-srilanka-canada/6325346
7. IDRC Newsletters: https://www.idrc.ca/en/stories/mango-saving-molecule
8. In Vice Media: https://motherboard.vice.com/en_us/article/4xan8n/how-nanotechnology-will-keep-your-bananas-and-mangoes-from-rotting
9. In October 2016, with GAC's help a webinar on this project was organized by IICA (Inter-American Institute for Cooperation on Agriculture, Canadian Chapter) which had 160 registrants from 17 countries:
   http://www.iica.int/en/events/affordable-natural-product-extend-fruit-shelf-life
10. Nanotechnology makes mango farming more profitable in Krishnagiri, By Anupam Srivastava,IDRC Regional Office, New Delhi (***Annex 19***)
11. 10 things about Hexanal: https://www.uoguelph.ca/research/discover-our-research/publications/10-things-to-know
12. Hexanal Project: https://www.uoguelph.ca/research/discover-our-research/publications/strategically-themed-newsletters
13. Special Issue on Tropical Agriculture Journal, featuring 12 research articles from this project which will be formerly released in Trinidad and Tobago, with their CHC, in summer 2018 (***Annex 6***)

14. Book on "Postharvest Biology and Nanotechnology of Fruits, Vegetables and Flowers" edited by the team members and published by Wiley- Blackwell Publishers, expected in Summer 2018 (***Annex 5***)
15. Project coverage in Canadian National geography: http://idrc.canadiangeographic.ca/blog/stopping-rot-india.asp
16. Following dissemination videos in various project sites:

    Overall view of the project: https://youtu.be/KOMMXoiT_ZQ
    3MT National Winner Video: https://www.youtube.com/watch?v=TyibZdxfBDw
    Project impact in Trinidad and Tobago: https://uoguelphca-my.sharepoint.com/:v:/g/personal/jsubrama_uoguelph_ca/EePV3VL5iDJDvemHQ-gNkQEB3MzH323xsHAKV_Bu63yS-w?e=P9AoRr
    Project impact in Sri Lanka:
    https://drive.google.com/file/d/1lMy245cAuCMTzrJliuTJ9C8THxintJU8/view
    Project impact in Kenya:
    https://drive.google.com/file/d/0BzLNoLD6ommbMFNJeEVXMGRDLXc/view
    Project impact in India: https://www.youtube.com/watch?v=J2P-KpOJYKA

PROBLEMS AND CHALLENGES:

Staff recruitment and retention in a timely manner was an issue throughout the project. This stems mainly due to the unusual start and end dates, especially when student recruitment is concerned.
Lack of knowledge on clearing regulatory hurdles by all the parties involved. Researchers were not familiar with the regulatory process in various countries but tried their best to sort it out. Usually such regulatory processes will be taken up by licensee with technical help from researchers and we had our licensee only in the later stages of the project. We sought help from GAC in India, but it was even a challenge to them.
Availability of hexanal was an issue in Africa and Caribbean and this cost us almost 8 months to start the project as the company who supplied for Africa was not forthright. Eventually we had to acquire it in Canada and ship it to Africa at a cost.
Farmers were reluctant in Africa to take up anything that they perceive as 'chemicals' if it comes from the West. It took a while to convince farmers to participate in the trials. These are things that we did not anticipate in spite of sufficient planning.

OVERALL ASSESSMENT AND RECOMMENDATIONS:

Based on our project gained experience involving 6 countries with varied currencies, we recommend that in future programming, such multi-country projects may be restricted to 3 or 4 countries at best. Addition of more partners delays reporting which has a domino effect on the project and increases transaction cost to all organizations involved.
We also recommend that in a large project operating in 6 countries, some relaxation on budget and financial reporting would have been beneficial. It is not easy in most countries to get the FR every 6 months. In every place the PIs spent a considerable time with finance department consolidating these frequent reports. Holding back the entire team for one member's delay really set us back. Although we all understand this was a specific requirement for CIFSRF projects, yearly FR would have made everyone's life lot better.
Timing of the project start – December 1-is really an inconvenient time to initiate a project as we had to report in December, which will never be possible due to holidays, breaks etc. This also resulted in delays in reporting.
Given the complexity of the project, certain additional flexibility in budgeting would have been beneficial for the teams. Although IDRC grants provide flexibility to accommodate changes in the work plan when mutually agreed in advance, if at all possible ideally researchers should have the freedom to move funds vertically within the budget.

Student stipends are done differently in different institutions. In various cases students were not able to complete their programs within the project period. Flexibility to pay the students as required by the conditions of their program will help to recruit and retain top students.
We appreciate the efforts from IDRC to give recognition of students and research awardees in IDRC projects, as this will go a long way in their careers.