Kumar et al., *Cogent Food & Agriculture* (2018), 4: 1461731
https://doi.org/10.1080/23311932.2018.1461731

cogent food & agriculture

Received: 11 January 2018
Accepted: 31 March 2018
First Published: 08 May 2018

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FOOD SCIENCE & TECHNOLOGY | RESEARCH ARTICLE

Science-based horticultural interventions for improving vegetable productivity in the state of Karnataka, India

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Abstract: Scientifically based agricultural interventions to improve vegetable productivity were carried out in four districts (Chikkamagalur, Raichur, Vijayapura and Tumkur) of Karnataka State in India, under the Government of Karnataka (GoK)-sponsored Bhoo Samruddhi project (improving the farm productivity and livelihood of smallholder farmers of Karnataka). The activities included, the demonstration of improved practices under protected cultivation (polyroof and shade nethouses), use of grafted seedlings in tomatoes, IPM methods to address tomato leaf miner damage, introduction of mungbean and vegetable cowpea as rotations or intercrops. As a postharvest strategy, we have demonstrated solar drying process and, good agricultural practices to reduce pesticide use & residues in chili. Our interventions have been successful not only in the target farms, the neighbouring farmers have also started adopting them and with the support of the Departments of Agriculture and Horticulture, GoK, the scaling up of these interventions has commenced.

Subjects: Environment & Agriculture; Environmental Studies & Management; Food Science & Technology; Development Studies; Environment; Social Work; Urban Studies

ABOUT THE AUTHOR

The WorldVeg team undertakes both research and developmental-driven projects in its attempt to provide methodical solutions to the problems associated with vegetables and their production systems. The project team particularly in this context, helped in bringing new technologies, demonstrated their value and worked with farmers and Department (agriculture/horticulture) staff to set a stage for the State government to scaling up these interventions. Further the team has also helped the project partners to successfully test them and showing through local adoption that the wider uptake was not only likely but much needed for any extension-linked project to prosper.

PUBLIC INTEREST STATEMENT

The World Vegetable Center, South Asia, with its science-led interventions focused to improve vegetable productivity and production system in four target districts of Karnataka state, India. These interventions comprise; improved practices under protected cultivation, grafted seedlings in tomatoes, Integrated Pest Management (IPM) methods for insect control, introduction of legume crops (rotation or inter-crops), solar drying process and good agricultural practices (reduce pesticide use & residues in chili). They have been successful and gained appreciation from the farming community. Through its network, WorldVeg also helped project beneficiaries to get the required inputs (seeds/seedlings, agro-chemicals, fertilizers and small field equipment, etc.) on time. Now the stage has set that farmers have started adopting these practices and with the support of the Departments of Agriculture and Horticulture of the Karnataka State, scaling up of these interventions has begun to reap the benefits.

Keywords: Improved cultivation practices; intercrop; IPM; pesticide residue; protected cultivation; solar drying and vegetable nursery

1. Introduction

Agriculture is the largest sector in the economy of Karnataka, a fast developing state of India. A total of 123,100 km^2 of land is cultivated, constituting 25% of the total geographical area and including a wide range of enterprises (Karnataka Agri Business and Food Processing Policy, 2015). According to the 2011 census, farmers and agricultural labourers formed about 60% of the state's workforce. Agriculture in Karnataka is heavily dependent on the southwest monsoon since the extent of arid land in the state is second only to Rajasthan in India (Karnataka Human Development Report, 2005). Only 26% of the cultivated area is irrigated (30,900 km^2). The state has three agricultural seasons—*Kharif* (April–September), *Rabi* (October–December) and summer (January–March). Horticultural crops are grown in an area of 16,300 km^2 and the annual production is about 9.58 million tonnes. The income generated from horticulture constitutes over 40% of income generated from agriculture and accounts for about 14.7% of the state's GDP (Karnataka Agri Business and Food Processing Policy, 2015; Karnataka Annual Report, 2017). Karnataka is the largest producer of coarse cereals, coffee, raw silk and tomatoes among the states in India.

In 2013, the Government of Karnataka (GoK)—CGIAR (Consultative Group on International Agricultural Research) Consortium Initiative was commenced to improve the livelihoods of small and marginal farmers in the state by improving agricultural productivity and farm income. The World Vegetable Center commenced its efforts as a part of this Consortium in two districts (Chikkamagalur and Raichur) and later in Tumkur and Vijayapura districts.

The four project districts provided contrasting environments for improving productivity and incomes from vegetable production. Chikkamagalur district has three agro climatic zones; southern transition, hilly and central dry zones. This diversity of agro-climatic conditions makes it ideally suited for the cultivation of a wide variety of fruits, vegetables, flowers, and plantation crops. The geographical area of the district is 722,075 ha, of which 319,790 ha (44%) is cultivable. A total of 112930ha (35%) of this cultivable area grows horticultural crops (excluding coffee, tea) (Karnataka Annual Report, 2017). Raichur district is known as the Rice Bowl of India and the major vegetables grown in the district are tomato, brinjal and chili (Annual Report, Department of Horticulture, GoK, 2014). Tumkur district is situated in southern Karnataka and has a total geographical area of 10,597 sq.km. The total cultivable area is 705,446 ha, of which 227,352 ha (32%) grows horticultural crops. Vijayapura district is situated on the northern corner of the state and pomegranate, lemon, onion are the important horticultural crops, and the vegetable area is 25,845 ha (Karnataka Annual Report, 2017).

After a series of workshops with staff of department of horticulture, GoK, farmers, and field visits to the project locations, the key production constraints were identified. In Chikkamagalur district, the major issues were low productivity and income from coconut and arecanut plantations, overuse of fertilizers and pesticides in vegetable cultivation and unreliable prices for farm products due to poor market access. The major constraints/issues in Raichur district included poor crop diversification due to overreliance on rice as a monocrop, overuse of pesticides by vegetable growers and unreliable prices for farm products due to poor market access. In Tumkur, there was an issue of converting non-agriculture areas into vegetable production belts (some taluks) and providing improved production practices with proper IPM in open fields. In Vijayapura, a lack of good vegetable production practices in poly/net houses was evident along with poor postharvest handling of vegetables. Farmers were also aspiring to grow some vegetable between their annual sugarcane crops.

The role of the World Vegetable Center (WorldVeg) was to bring in new technologies, demonstrate their value and to work with farmers and the government to set the stage for government officers to then take these innovations on to scale them up. So the main focus was on identifying new technologies, successfully testing them and showing through local adaption and adoption that wider uptake was not only likely but needed and thereby to assist the government departments in their extension work.

In response to the key issues identified, we undertook the following activities:

1. **Demonstration of improved polyroof and shadenet practices in farmers' fields**: The objective of this activity was to provide farmers with an option to grow high value crops during the off-season so that they could increase their income. In addition, this method of farming would help to reduce the overuse of pesticides.

2. **Grafted tomatoes to address plant diseases**: Bacterial wilt disease caused by *Ralstonia solanacearum* is one of the most destructive diseases of economically important crops, and is soil-borne. Field surveys undertaken in major tomato growing districts of Karnataka had previously showed an incidence of up to 39% (Vanitha, Niranjana, Mortensen, & Umesha, 2009). Early blight (*Alternaria solani*), late blight (*Phytropthora parasistica*) and powdery mildew (*Leveillula taurica*) are other major fungal diseases of tomato that under the right conditions can also devastate crops (Gajanana, Krishna Moorthy, Anupama, Raghunatha, & Prasanna Kumar, 2006; Krishna Moorthy, Krishna Kumar, Ganeshan, Sadashiva, & Hebbar, 2003a). Grafting disease-resistant scions onto rootstocks with complementary disease resistance boosted the overall disease resistance compared to that possible with a single variety.

3. **IPM techniques to tackle tomato leaf miner attack**: South American tomato pinworm, *Tuta absoluta* (Chidege et al., 2016), also known as the tomato leaf miner is a destructive invasive pest, which was observed in India for the first time in Maharashtra in 2014 (Sridhar et al., 2014; Maneno Chidege et al., 2016). Plants are damaged by larvae feeding on leaves, stems, buds, calyxes, young fruit, or ripe fruit and by the invasion of secondary pathogens which enter through the wounds made by the pest. It can cause up to 90% loss of yield and fruit quality under both greenhouse and field conditions. Following its sighting in Maharashtra, recent surveys conducted by University of Agricultural Sciences, Bengaluru and ICAR-NBAIR, Bengaluru in January 2015 confirmed the presence of this pest in Kolar and Bengaluru districts of Karnataka (www.icar.org.in/en/node/8600). To address this menace, we conducted a few field trials using IPM practices with pheromone traps (TLM-Lure) and coloured sticky & water traps developed by the Pest Control of India (PCI), Bengaluru.

4. **Introduction of legume crops in rice fallows and as a rotation crop with sugarcane**: The rice-based farming systems in South Asia are characterized by low system productivity and declining soil fertility. Diversification of the rice based farming system with suitable crop species would help improve productivity, profitability and mitigate effects of climate change (Lal et al., 2017). Introducing short duration (60 days) legume crops such as mungbean (green gram) and vegetable cowpea can improve the productivity of rice systems and generate significant additional income and improve the nutrition of resource-poor populations. Legume crops also break pest and disease cycles, provide feed for livestock as well as improving soil fertility (Ramakrishna, Anders, & Flower, 2013). This is also one of the strategies to address the shortage of pulses in the country (Singh, Singh, Prakash, Kumar, & Dwivedi, 2015).

5. **Post-harvest—solar dryer**: In Karnataka, only about 1% of the total vegetables are being processed into different products (value-added) (www.horticulture.kar.nic.in/horticulture development scenari.htm) and there is a need to improve the quality of on-farm processing. This is particularly important for chili (one of the important commercial crops) which is largely sun-dried often under unhygienic open (air) conditions.

6. **Post-harvest—Chili with less pesticide residue**: To improve the quality of chilies (dry), it is important to reduce the quantity of pesticides use through IPM practices from seedling to harvesting, and to effectively manage the post harvesting stages to get high-quality chilies with less pesticide residue.

2. Science-driven successful interventions (case studies)

2.1. Demonstration of improved protected cultivation (polyroof and shadenet) practices in farmers' fields

Globally, vegetable production faces several constraints, both biotic (insect pests, diseases and weeds), and abiotic (drought, floods, and low soil fertility). This increased environmental dependency resulted in a seasonal shortage in the supply of produce (Chatterjee, Mahanta, & Pal, 2013; Deininger & Byerlee, 2010). In their review, Thibault et al. (2017) highlighted that protected cultivation systems could be an answer to address these issues and suggested it requires considerable changes in crop management, since cultural practices are to be adapted to exploit the opportunities.

In this study, 14 polyroof and shadenethouses were constructed during March 2015 to demonstrate the effectiveness of protected cultivation practices in Chikkamagalur and Raichur districts and became fully operational in May 2015. These small nethouse units were important steps towards promoting protected cultivation for small and marginal farmers. Wind damage to some units during the initial monsoon period was rectified and a modified design was incorporated to enhance the structures' capacity to withstand high wind conditions. Grafted capsicum seedlings were transplanted in all 14 polyroof and nethouse units during this period. Improved practices like mulching, inline drip irrigation and fertigation, staking and IPM practices were adopted in the net houses to demonstrate the integration of the technologies for effective protected cultivation of vegetables. In Vijayapura district, WorldVeg initiated trials of four indeterminate tomato varieties under protected cultivation with the assistance of the Indian Institute of Horticulture Research (IIHR). The trials conducted under shade nets in four farmer fields in Angadageri, Aheri, Devar and Nimbaragi villages allowed an extended fruiting period and increased yield potential. Improved practices like mulching, fertigation, in-line drip irrigation, and IPM practices were demonstrated in these nethouses.

Green capsicum seedlings were transplanted in 8 of 10 polyroof and shadenet units in Chikkamagalur in season-1 (2015–2016) and in all 4 shadenets of Raichur (2015). However, in Chikkamagalur, in season-2 (2016), three out of the eight farmers chose to grow capsicum only and the rest grew other vegetables such as tomato, beans and white cucumber (as crop-2) (Tables 1 and 2). In Raichur, all four farmers continued to grow grafted capsicum again for the next season (Table 2). Improved practices like mulching, inline drip irrigation and fertigation, staking and IPM practices were adopted to validate the integration of these technologies as a critical component of the protected cultivation package. In Chikkamagalur, there was an average cost: benefit ratio of 1:15 when growing capsicum under protected cultivation (season-1, crop-1). However, during season-2 (crop-2, tomato), a cost: benefit ration of only 1:1.7 was witnessed (largely attributed to bad rains and a dry climate all through the season). For common beans, there was a cost: benefit ratio of 1:10 even through rain was scanty and irregular; the short duration of the crop might have helped in producing an economic yield.

In Raichur, a cost: benefit ratio 1:11 was obtained from growing capsicum in season-1 and 1:8.5 in season-2. However, these are individual case studies and a more comprehensive review of a wider range of crops over different seasons is needed to give a full analysis of the economics of protected cultivation (Bhoosamrudhi Progress Report, 2016). Further economic analyses are currently underway, based on a standard protected cultivation production unit of 2000 m^2 (half an acre), which the Agriculture and Horticulture departments of the government of Karnataka are promoting at subsidized rates to farmers.

Table 1. Field demonstrations of the effective use of protected cultivation in improving vegetable yields and income levels of farmers (Chikkamagalur Dist, 2015–16)

	Cost income details 2015									Cost income details 2016						
Sl #	**Farmer name/ Crop**	**Structure**	**Yield (kg)**	**CoC**	**Net income**	**Derived yield (2000 m^2)**	**Derived NI (2000 m^2)**	**% increase yield**	**% increase NI**	**Farmer**	**Crop**	**Yield (kg)**	**CoC**	**Net income**	**Derived yield (2000 m^2)**	**NI (2000 m^2)**
	Capsicum															
1	Farmer 1	P	3960	15700	27860	49500	348250			1	Tomato	1540	8650	6750	19250	84375
2	Farmer 2	P	1750	10050	10950	21875	136875			2	Tomato	1190	9130	2770	14875	34625
3	Farmer 3	P	2359	10850	15069	29488	188363									
4	Farmer 4	P	2385	11300	14935	29813	186688									
5	Farmer 5	P	2660	11400	20562	33250	257025			5	Tomato	930	8070	300	11625	3750
6	Farmer 6	P	2552	10900	17172	31900	214650									
	Average		**2611**	**11700**	**17758**	**32638**	**221975**	**341**	**1650**			**1220**	**8617**	**3273**	**15250**	**40917**
7	Farmer 7	N	2710	11700	18110	33875	226375			7	Beans	560	4440	3960	7000	49500
8	Farmer 8	N	2255	11650	13160	28188	164500			8	Capsicum	1047	9250	5408	13088	67600
	Average		**2483**	**11675**	**15635**	**31031**	**195438**	**319**	**1440**							
	Farmer 5	OF	560	4862	500	7000	6250									
	Farmer 1	OF	624	6264	1530	7800	19125									
	Average		**592**	**5563**	**1015**	**7400**	**12688**									
	Cucumber															
9	Farmer 9	N	900	8800	11000	11250	137500			9	Cucumber	630	6250	6350	7875	79375
10	Farmer 10	N	1140	9450	14490	14250	181125									
	Average		**1020**	**9125**	**12745**	**12750**	**159313**									
	Tomato															
11	Farmer 11	OF	850	3665	2288	10625	28600									

(Continued)

Table 1. (*Continued*)

Cost income details 2015										Cost income details 2016						
Sl #	**Farmer name/ Crop**	**Structure**	**Yield (kg)**	**CoC**	**Net income**	**Derived yield (2000 m^2)**	**Derived NI (2000 m^2)**	**% increase yield**	**% increase NI**	**Farmer**	**Crop**	**Yield (kg)**	**CoC**	**Net income**	**Derived yield (2000 m^2)**	**NI (2000 m^2)**
12	Farmer 12	OF	638	3576	1531	7975	19138									
	Average		**744**	**3621**	**1910**	**9300**	**23869**									
Cost income details 2016-2017																
	Beans															
	Farmer 7	OF	128	2232	400	1600	5000									

Table 2. Field demonstrations of the effective use of protected cultivation (nethouse) in improving vegetable yields and income levels of farmers (Raichur Dist, Karnataka, 2015–16)

Farmer	Structure	Yield (kg)	CoC	Net income	Yield (2000 m^2)	NI (2000 m^2)	%incYld	% inc NI	Farmer	Yield (kg)	CoC	Net income	Yield (2000 m^2)	NI (2000 m^2)	%incYld	% inc NI
1	N	1750	2500	19200	21875	240000			1	1400	2500	14500	17500	181250		
2	N	1200	2300	15700	15000	196250			2	1000	2500	12500	12500	156250		
3	N	1785	3950	19150	22313	239375			3	1450	4000	15000	18125	187500		
4	N	1700	2500	17900	21250	223750			4	1520	3000	13400	19000	167500		
		1609	**2813**	**17988**	**20109**	**224844**	**120**	**859**		**1343**	**3000**	**13850**	**16781**	**173125**	**84**	**639**
1	OF	850	1500	1650	10625	18750										
2	OF	610	1650	2100	7625	20625										
		730	**1575**	**1875**	**9125**	**19688**										

Net area (160 m^2), P—Polyroof house, N—Nethouse, OF—Open field, NI—Net Income, CoC—Cost of Cultivation, Derived yield (for 2000 m^2 or 0.5 Acre).

Our investigation indicated that protected cultivation systems are promising technologies to expand the supply of vegetables all year round; however, scaling up requires effective application to overcome agronomic constraints and suits socio-economic need of the producers (Thibault et al., 2017).

Inferences:

(1) With an initial investment of 1.4 lakhs (USD 2090, exchange 1USD = INR 67) for a polyroof house and 1.1 lakh (USD 1642) for a nethouse (to be covered from the subsidies from the government or a funding body) with an area of 160 m^2, protected cultivation seems to be profitable (Tables 1 and 2) and investments can be recovered more quickly.

(2) Growing capsicum under protected cultivation in Chikkamagalur district resulted in around a 300% increase in the harvestable yield and approximately 1400% increase in net incomes compared to growing the same crop in the open field. Growing capsicum under protected cultivation in Raichur district increased yields by 100% and incomes by about 750%.

(3) There was an apparent reduced-use of pesticides under protected cultivation compared to open fields with two to three, less sprays. If it continues, such reduction will have positive impact on the health of farmers, consumers and the environment.

(4) An intensive crop rotation in protection cultivation based on at least three crops per year is needed to make sufficient profits to offset the initial infrastructure costs keeping a watch on pests and diseases outbreak. A judicious choice of crops and off season timing can makes a large difference to the cash returns.

(5) We have derived the economics of protected cultivation based on a unit-dimension of 2000 m^2 (half an acre), but the Government of Karnataka has not yet finalized the preferred size of structures to be subsidized in the future.

(6) Farmers claimed to be able to harvest higher quality fruits of both capsicum and tomatoes from poly/nethouses as compared to the open fields.

2.2. Grafted tomatoes to combat diseases

Grafting of tomatoes is a well-proven technology promoted earlier by WorldVeg that has been successfully adopted in many previous projects (WorldVeg Technical report, 2016). In one of the recent opinion reviews, Youssef, Marios, and Giuseppe (2018) described that the vegetable crops grown under greenhouse and especially open field conditions are faced with multiple biotic and abiotic constraints, which hamper crop growth and productivity. Further, to overcome this threat authors suggested vegetative grafting as one the feasible approaches. The effectiveness of grafting in imparting tolerance/resistance to vegetable crops against abiotic and biotic stresses has been attributed to several improved traits of grafted plants, such as more vigorous root system, improved water and nutrient uptake mechanisms and enhanced photosynthetic efficiency/carbon fixation and water relations, etc. The soil borne disease such as bacterial wilt cause serious damage to Solanaceous vegetables like tomato, chili and brinjal in Karnataka. To overcome this, grafting of scions of high yielding commercial F_1 hybrids/varieties onto resistant root stocks was trialled to tackle this problem in Chikkamagalur and Tumkur districts during November-December 2014. Grafted capsicum seedlings procured from Kerala Agricultural University (KAU) were supplied to farmers of target districts for use in both nethouses and open field cultivations. Around 500 grafted tomato seedlings were introduced to farmers in Chikkamagalur district in November 2014 followed by another 500 grafted tomato and 500 grafted chili seedlings to a total of 11 farmers in Chikkamagalur and Tumkur districts in December 2014.

In April 2015, 1000 grafted capsicum seedlings were procured to grow in 10 polyroof nethouses in Chikkamagalur. At the same time, farmers in Tumkur district were provided with grafted chili seedlings and exposed to their benefits through a field-based training program. Grafted tomato seedlings were also introduced to farmers in Kurkunda village of Manvi taluk in Raichur and in Hiregundagal village in Tumkur. We had also used grafted seedlings in the polyroof and net houses for tomato cultivation. In Tumkur district, trials were conducted in five farmer fields to compare the yield of grafted and non-grafted tomatoes. Planting was done during the first week of August 2015. Yield per plant was recorded from 10 randomly selected plants from both grafted and non-grafted fields.

Results from the use of grafted tomato seedlings were encouraging. Grafting increased crop yields by 10% and net income by 35% as compared with growing non-grafted tomato crops. The yields from grafted tomatoes were significantly higher ($P < 0.0001$) than those of the non-grafted crops. An added advantage was that while there was no crop loss in the grafted tomato field, there was a 15% loss of seedlings in the non-grafted field due to bacterial wilt disease. Demand from farmers for grafted seedlings has grown since this activity was initiated in November 2014. Farmers were exposed to the benefits of grafted seedlings and the demand for these seedlings has increased since project inception.

The initiative of grafted seedling has made a good progress with high acceptability in all four target districts, which also encouraged couple of young farmers in two districts (Chikkamagalur and Raichur) to come forward to take up vegetable grafting as a new business enterprise (Survey feedback, Dept of Agriculture, Chikkamagalur). For instance, in 2016, in Raichur district WorldVeg field staff procured grafted tomato seedlings from KAU and distributed them to farmers. Raichur taluk received most (17,000), followed by Lingsugur (14,000), Manvi (13,000) and 12,000 that were supplied to Devadurga. Based on a request from the state government, efforts were also made to transfer skills through training in the grafting of seedlings so that they could be produced from local nurseries.

2.3. IPM techniques to tackle tomato leaf miner attack

In Chikkamagalur and Tumkur district, trials were conducted with different types of traps to control infestations of the tomato leaf miner (*Tuta absoluta*) in 10 farmers' fields. In each district, four farmer fields had both yellow sticky traps and water traps, two had only yellow sticky traps, two had only water traps and two were the check plots without any traps. The yields per plant were recorded from 10 randomly selected plants from all the fields.

The first incidence of South American tomato leaf miner, *Tuta absoluta* in India (Karnataka) was reported by Sridhar et al. (2014) in Chikkamagalur district. The need for suitable management practices to manage the continuing spread of this invasive pest were emphasized by the high losses experienced by farmers and the lack of adequate controls available. Trials were conducted during 2015 in Chikkamagalur and Tumkur districts with different types of traps (supplied by Pest Control of India) to control the infestation of tomato leaf miner in 10 farmers' fields. In each district, four farmers' fields had both yellow sticky traps and water traps, two had only yellow sticky traps, two had only water traps and two were the check plots without any traps. In both Chikkamagalur and Tumkur districts, the combination of a yellow sticky trap and a water trap gave the highest yields (Table 3).

During 2016, yellow sticky traps and water traps with pheromone lures were installed on a total of 6 ha in 15 farmer fields in Chikkamagalur and on three farmers' fields in Tumkur districts to assess their performance. The results were positive and encouraging. After realizing this good and effective result, the Department of Horticulture officials recommended to the Karnataka government to scale up this intervention. In 2017, an area of 240 ha was treated with the same traps and lure to provide protection for 600 tomato growers in Chikkamagulur district.

2.4. Introduction of legume crops in rice fallows and as rotation crop with sugarcane

A large number of farmers in Raichur and in a few other locations cultivate paddy during the rainy season and leave the land fallow during the rest of the year. WorldVeg has promoted the cultivation of mungbean and vegetable cowpea in paddy fallows over the past three seasons in all four project districts. Mungbean and vegetable cowpea can also be successfully sown as an inter-crop in coconut plantations or in sugarcane. WorldVeg introduced short duration mungbean to be grown on residual moisture following paddy harvest, especially in Raichur. Starting in the

Table 3. Effect of traps on tomato yields in two districts in Karnataka

District	Trap Type	Tomato Yield (kg/m^2)
Chikkamagalur	Control	3.44
Chikkamagalur	W	4.00
Chikkamagalur	Y	3.78
Chikkamagalur	YW	6.00
Tumkur	Control	5.38
Tumkur	W	5.96
Tumkur	Y	6.09
Tumkur	YW	7.09

Y—Yellow sticky trap, W—water trap and YW—yellow sticky trap and water trap.

2013 season, 15 farmers were selected to test three varieties of mungbean; namely SML-668, PDM-139 and BGS-9 (a variety released by the University of Agricultural Sciences, Raichur). Yield data from 11 farmers were collected using crop-cuts from 5 m × 5 m sub plots. Among the three mungbean cultivars, SML-668 recorded a significantly (P = 0.05) higher grain yield (356 kg/ha) compared to PDM-139 (313 kg/ha) and BGS-9 (307 kg/ha). The yield levels obtained by farmers in these trials could be increased further by adopting improved cultural practices such as timely weeding.

Mungbean was raised as an intercrop in coconut and arecanut gardens in Chikkamagalur and Tumkur districts. The use of vegetable cowpeas in coconut plantations was promoted in Kadur Taluk of Chikkamagalur and as an inter-crop with sugarcane in Vijayapura district.

In the following year in 2014, WorldVeg in collaboration with IRRI (International Rice Research Institute) promoted the cultivation of mungbean and vegetable cowpea in paddy fallows in both Raichur and Chikkamagalur. Five Raichur farmers cultivated mungbean in 4 ha of paddy fallow (December sown) producing an average yield of 1250 kg/ha. The cultivation of vegetable cowpea in the paddy fallow was then adopted by 10 farmers in Raichur in December 2014 (Bhoosamrudhi Progress Report, 2016). In Chikkamagalur, 10 farmers also cultivated vegetable cowpea in 4 ha of paddy fallows. Vegetable cowpea matures in only 60–65 days and it was introduced as a rotation crop on one farm following the sugarcane harvest in December–January to provide additional income and to enrich soil fertility.

Interest in this innovation has grown among farmers because not only do the legumes supplement farmers' incomes they also improve soil fertility. An additional 15 farmers in Tumkur and 12 farmers in Vijayapura district have subsequently adopted this practice of growing both mungbean and vegetable cowpea in the paddy fallow and a good potential for further scaling up in rice growing regions of the state.

A total of 73 farmers in Chikkamagalur and Tumkur districts adopted mungbean cultivation across a total of 27 ha and 43 farmers adopted vegetable cowpea cultivation on 19 ha of land. The mungbean yield was between 330 and 480 kg/ha and the yield of vegetable cowpea ranged between 2.2 and 3 t/ha. WorldVeg has promoted the cultivation of mungbean and vegetable cowpea in paddy fallows over the past three seasons in all four project districts. Vegetable cowpea being a short-duration legume fitted well with main sugarcane crop.

In Vijayapura, after the sugarcane harvest during December–January, vegetable cowpea was introduced during 2015–2016 as a rotation crop to provide additional income to farmers. Data on the yields of vegetable cowpea and sugarcane in two seasons (before and after the vegetable cowpea crop), and the additional income due to vegetable cowpea were recorded from sites on six farms. The results shown (Table 4) suggest that farmers on an average obtained a cowpea yield of around 570 kg and an extra income of INR 0.13 lakhs (USD 194) by incorporating this crop into their sugarcane rotation. It is interesting to note that the second season (2016–2017, post vegetable cowpea introduction year), the sugarcane yield was 720 kg, a 1.8% increase on the previous year, which also fetched an additional income of INR ~0.25 lakhs (USD 373) (15.7% increase). This needs to be confirmed in further investigation.

WorldVeg also assisted in fostering the involvement of the private seed sector in 2014–2015 and facilitated the supply of 730 kg of the mungbean variety SML-668 and 790 kg of the vegetable cowpea variety Pragathi through Anand Biotech, a private Seed Company based in Indore, Madhya Pradesh, to supply farmers in different target districts. The successful adoption of mungbean and vegetable cowpea cultivation in the paddy fallows and as an inter-crop of all four districts has prompted the Department of Horticulture, to scale up this technology as a Departmental initiative in 2017–2018. The results from the present study highlight the multiple role of legumes for agricultural sustainability (Stagnari, Maggio, Galieni, & Pisante, 2017).

2.5. Postharvest—solar dryer

The World Vegetable Center in collaboration with national partners has developed and customized several types of small and large solar dryers which have worked well with chili, tomato, eggplant, cabbage and cauliflower in trials across Asia. Vegetables that need to be dried must be of top quality, drying will preserve most of the original flavour but will not improve food quality (Kordylas, 1990). Solar dryers accelerate drying, protect the produce from rain, avoid food safety hazards, and produce safer and better quality products. These solar dryers can maintain temperatures 15–35°C (at 12 noon) and 5–15°C (at 5pm) higher than found under open sun-drying conditions. In addition, it just takes only 1–3 days for drying vegetables, and dried chilies have a better colour and are more hygienic than sun-dried crops. For drying chili peppers, the small-sized solar dryer with 50 kg volume capacity is suitable for small test batches. These types of solar dryers were installed for farmer groups across Karnataka in 2015 to demonstrate hygienic drying methods and to familiarize farmers with the drying process (Figure 1; please refer line sketch of the structure also) (WorldVeg Reports, 2016). Fresh chili peppers can be dried to less than 10% moisture content in 3 days and farmers sell these dried chilies at a higher price than open sun-dried crops. To complement these on-farm trials, solar drying trials for tomato, onion and chili were conducted at WorldVeg regional headquarters in Hyderabad. A solar dryer with a rotary ventilator was tested using the tomato variety "Arka Saurabh" and the onion variety "Bhima Kiran". In the process of drying, the drying rate is greatly influenced by weather conditions such as: solar insolation, temperature, relative humidity, moisture content of the product and duration of drying period (Rajeshwari & Ramlingam, 2012). There have been many reports on the drying behaviour of vegetables such as, tomato (Yılmaz, Ozbalta, & Gungor, 1999), onion (Gallali, Abujnah, & Bannani, 2000), and red pepper (Doymaz & Pala, 2002).

Using customized solar dryers, higher temperatures and lower relative humidity (RH) could be maintained than in the open sun (Table 5). As a result, drying was faster in the solar dryer compared to outside (Table 6). The colour of the dried product measured in terms of colorimetric lightness values did not significantly differ with the drying treatment. The colour of the dried tomato was darker (lower lightness values) than that of fresh fruit while that of dried onion was similar to that of fresh produce. The rehydration ratio: a measure of the amount of water absorbed to increase the yield of the re-constituted product, was higher in the dried onion than open sun drying product from the two solar dryers.

For chili, two types of solar dryers were compared to open sun drying treatment: SDR (Solar Dryer with Rotary chimney) and a Greenhouse Solar Dryer (GSD) with black plastic film lining of the polycarbonate roofing. Drying temperatures were highest in the GSD and lowest in the open sun drying (Table 7). The Relative Humidity (RH) was lowest in the GSD and highest in open sun drying. As a result, drying was fastest in the GSD (4 days) followed by 6 days in SDR and slowest in open

Table 4. Comparative assessment of growing vegetable cowpea as a rotation crop with sugarcane in farmers' fields in Raichur district

Farmers	Sugarcane area (m^2)	Vegetable cowpea (kg/ha)	Vegetable cowpea total yld (kg)	Avg price/kg	Total income (INR)	Sugarcane yield (tonne/ha) (2015)	Sugarcane yield (tonne/ha) (2016)	Total income (INR)-sugarcane (2015)[a]	Total income (INR)-sugarcane (2016)[b]
1	8000	600	4800	12	14400	42	42.70	184163	213250
2	12000	580	6960	13	22620	38	38.80	250984	290625
3	8000	550	4400	11	12100	41	41.50	179198	207500
4	4000	620	2480	15	9300	42	43.00	92691	107250
5	4000	570	2280	12	6840	40	41.00	88303	102250
6	8000	490	3920	14	13720	38	38.30	165380	191500
Ave.	**7333.33**	**568.33**	**4168**	**12.83**	**13163.33**	**40.17**	**40.88**	**160120**	**185396**
Inc in Sugarcane yield (kg) & Income							**720**		**25276**
% inc in SugarcaneYld& Income							**1.78**		**15.79**

[a]Sugarcane price in 2015: INR 2159/tonne.
[b]Sugarcane price in 2016: INR 2500/tonne.

Figure 1. Customized solar dryers with rotary chimney (SDR units in Hyderabad and Raichur sites) and its line drawing.

Table 5. Temperature and RH levels under different drying conditions during the dehydration of tomato and onion

Parameter	SDR	Open sun
Tomato drying		
Temperature (°C)	33.4-39.9	29.0-34.6
RH (%)	34.5-50.0	42.0-60.8
Onion drying		
Temperature (°C)	38.2-44.2	32.1-40.9
RH (%)	31.7-46.8	34.7-53.7

sun drying (9 days). The higher temperature inside the solar dryers, could be a resultant of higher absorption of solar energy and likely prevention of heat loss from the dryer, which is in close agreement with the findings of Desai, Vijaykumar, and Anantachar (2009) in chili drying under a farm solar dryer. The colour of the dried product seemed to be better maintained in the SDR and SDB compared to sun-drying (WorldVeg Report, 2016). Based on the demands for the farmers, 15 SDRs were installed in their fields and necessary training on handling the units was provided by WorldVeg staff. The greenhouse solar dryer (1–1.5 tons) has great potential for drying commercial volumes of produce and could be adopted by smallholder farmer groups. Farmers' cooperatives or groups can establish community based GSD units and provide services (with minimal rental charge) of drying of local vegetables and fruits.

With the increasing demand from chili farmers for large-volume drying, World Vegetable Center examined the suitability of a 1.0 ton capacity greenhouse solar dryer at Zaheerabad Mandal, Sangareddi Dist, Telangana State, and found that chili with 80% initial moisture content can be dried to less than 10% moisture content within 3–4 days. Further, WorldVeg commissioned a community based greenhouse solar dryer with a drying capacity of 500 kg (0.5 ton). This was installed in Basavana Baghevadi (Onion growing belt), Taluk, Vijayapura district, especially for onion growers (Figure 2) who have been pleased to use the facility for onion drying in the 2018 season started from the final week of April.

Based on the results of these on-site trials and the proven success of solar dryers, the state government has approved the subsidized installation of 12 more 50 kg capacity solar dryers; six units to Chikkamagalur, four units to Raichur and two units to Tumkur. Additionally, one unit each of greenhouse solar dryer of about 1–1.5 ton capacity will be installed in Raichur and Chikkamagalur. The state is also planning to have similar units in other regions for chili and other high value horticulture produce.

2.6. Postharvest—chili with less pesticide residue
In Chikkamagalur, meetings were conducted with vegetable growers to establish a District Horticultural Producers' Cooperative Society. Two promoters from each taluk were identified to initiate membership and Paprika Oleos India (POI) Ltd., staff were invited to the region. In January

Table 6. Drying period, colour, rehydration ratio and vitamin-C content of dehydrated tomato and onion in solar dryer with rotary chimney (SDR) and open sun drying (SUN)

Vegetable	Drying method	Hours to < 10% moisture content	Lightness[a]	Rehydration ratio
Tomato	SUN	71	40.8	4.3
	SDR	47	39.6	4.1
Onion	SUN	72	58.6	9.2
	SDR	44	54.7	10.3

[a]Lightness values for fresh tomato and onion were 53.7 and 57.4, respectively.

Table 7. Temperature and RH in the greenhouse solar dryer (GSD), solar dryer with rotary chimney (SDR), and open sun drying; days to drying; and colour L* and a* values of the dried chili

Drying Condition	Temperature °C		RH, %		Days to drying	L* (lightness)		a* (red colour)	
	Min	Max	Min	Max		Fresh	Dried	Fresh	Dried
GSD	33.5	74.5	10.5	46.0	4	34.2	26.3	43.4	16.7
SDR	29.2	40.4	23.6	54.3	6		24.5		35.5
Sun drying	23.6	30.4	34.2	72.2	9		28.2		27.4

2014, the WorldVeg team along with POI conducted two trainings on Good Agricultural Practices, such as plastic mulching, inline drip irrigation, fertigation, IPM (Integrated Pest Management) and INM (Integrated Nutrient Management) interventions in chili. As a result, farmers started adopting IPM practices. Random samples were collected from the chili grown in the region and were analysed in the laboratory of the Spices Board.

During the project period, efforts were also made to link chili farmers with a major chili buyer, Paprika Oleos (India) Ltd. who was keen to source chili with low pesticide residues to meet the needs of high-priced markets. Following training and exposure to the potential price benefits of producing chili with lower pesticide residues, farmers started adopting the IPM practices prescribed by WorldVeg across a total of 24 ha. Random samples of locally produced chili (at the end of the season) for their pesticide residues by Central Spices Board Lab confirmed a lack of residues., Paprika Oleos (India) Ltd then decided to purchase local chilies at a premium price of INR 110–120 per kg (USD 1.64–1.79) (standard price of the day in the major chili markets), which was higher than the local market price (INR 70–80 per kg) (USD 1.04–1.19). Farmers were comfortable in dealing with Paprika Oleos (India) Ltd. The company subsequently appointed one extension officer for Chikkamagalur to guide the farmers to grow clean chili for the company with a buy back arrangement (WorldVeg Report, 2016). The company requested the WorldVeg team to select and accompany representative/progressive farmers to their processing plant and farms for training on chili cultivation, postharvest and buy back arrangements.

3. Capacity building activities: training and workshops on successful interventions

WorldVeg worked with staffs of horticulture department, Agricultural Technology Management Agency (ATMA) and scientists of University of Agricultural Sciences, Raichur and University of Horticultural Sciences, Bagalkot, Karnataka, India, to help build capacities of local farmers to sustain and expand the adoption of its interventions. WorldVeg provided practical insights to the farmers to help them adopt improved practices as a part of various project interventions. Periodic hands-on training was provided during the cropping season, coinciding with the critical stages of the various

Figure 2. Greenhouse solar dryer in farmers' field in Vijayapura district (both outside and inside views—with onion crop).

vegetable crops, so that farmers could immediately apply what they had learned. Such training also helped in promoting the lateral spread of technologies among the other farmers in the project villages.

Before the project, farmers had few ideas on how to reduce the cultivation costs of tomato, chili and capsicum (Personal Communication). Need-based training by WorldVeg (based on necessary feedback from Agriculture and Horticulture technical staff, GoK) on different aspects of vegetable cultivation helped in reducing the input costs of spraying, weeding and harvesting, thereby increasing the net returns of farmers. When the farmer trainees in the IPM courses were interviewed before training, they indicated that they were using chemicals that were mostly suggested by private pesticide dealers, at least twice in a week to manage serious pests like thrips and other sucking pests (WorldVeg Technical Report, 2017). Beneficiaries felt WorldVeg training helped them understand the importance of cultural practices to manage major insect pests; however, the effect of this training on-site farm needs to be witnessed.

Nursery growers in the project districts had been raising vegetable seedlings for many years. WorldVeg found a number of shortfalls in their nursery management that led to unhealthy and weak seedlings, reducing the potential field yields. Realizing the need for producing healthy seedlings, WorldVeg through its technical partner, Kerala Agricultural University, arranged training in grafting for nursery growers and the value of well-managed protected cultivation of seedlings. Farmers who were introduced to protected cultivation through this project were trained on a weekly basis in their own polyhouses, which were visited by other farmers on a rotation basis. The WorldVeg team facilitated workshops and the sharing of experiences. This helped the practicing farmers in analysing the do's and don'ts in protected cultivation by themselves and to learn from each other. Farmers started visiting the polyhouses to learn by themselves. They also expanded the range of their questions to the WorldVeg team to understand the critical issues of their operation.

Postharvest is another area that has been neglected by vegetable farmers for decades. WorldVeg's interventions in postharvest management including the installation of solar dryers coupled with demonstrations and training helped farmers know how to plan production and post-production schedules. Chili farmers said that they had never used solar dryers before the project intervention and were losing their yields during storage, due to improper drying. The training on solar dryers helped them to dry their produce in a more effective way. WorldVeg's also developed four key case studies and two short videos (as success stories) for wider dissemination during this period (www.avrdc.org) and submitted to Departments of Agriculture and Horticulture, GoK for further utility.

4. Conclusion and moving forward

Under the Bhoo Samruddhi project funded by the Government of Karnataka, the World Vegetable Center has successfully demonstrated the following interventions over the four years (2013–2016) (WorldVeg Technical Report, 2017):

(1) The introduction and promotion of improved mungbean varieties in paddy fallows provided an additional income of about INR 1.0 lakh/ha to farmers. Promoting the cultivation of vegetable cowpea as an intercrop with sugarcane gave farmers an extra income of INR 25,000/ha.

(2) The adoption of improved agronomic practices such as staking and mulching in open field tomatoes resulted in yield increases of 14% and a reduction of labour costs by 35%. The cultivation of grafted seedlings of tomato, chili and capsicum under protected cultivation with improved production practices such as staking, mulching, inline drip fertigation and IPM measures (pheromone lures and sticky traps) enabled farmers to obtain yield increases ranging from 150 to 300%. In addition, growing under protected cultivation helped to reduce pesticide use by 70%.

(3) The linkage of chili growers to a large processing company which was willing to pay for reduced pesticide residues, helped farmers to get a better market price for their produce than the prevailing local rates. This was due to the adoption of WorldVeg prescribed Good Agricultural Practices and pesticide free produce.

(4) The promotion of solar dryers of varying drying capacity helped to improve the shelf life of vegetables and increased the options for smart trading and improved incomes.

(5) Skill-based training programmes, workshops, field days and exposure visits were conducted during the project period to accelerate the adoption rates of these interventions.

Based on the feedback from the farmers and endorsement of the Horticulture department officials of all the four districts, the GoK in its 2018–2019 work plan has sanctioned an additional grants in its budget for scaling up of these activities.

Achieved impact during the project period 2013–2017:

1	Area covered	~785 ha
2	Number of Farmer beneficiaries	~3400
3	Number of demo polyroof/ nethouses	20
4	Number of pilot and commercial scale solar dryers installed	6
5	Number of demonstrations/ trainings	~35

Proposed scaling up activities from gok (2018–19):

1	Commissioning of polyroof/ nethouses (area 100–160 sq m)	25
2	Pilot scale and commercial scale solar dryers (capacity 0.5 to 1.5 tons)	12 (15)
3	Distribution of IPM kits (sticky traps and lures)	~1500
4	Grafted seedlings distribution and production nursery	~30,000
5	Area under mungbean and vegetable cowpea	~300 ha
6	Number of Farmer beneficiaries (expected)	~10,000

Acknowledgements
WorldVeg project team acknowledges all the project partners of the consortium (special reference to ICRISAT), Department officials of the GoK, State Agricultural Universities, Dr. Narayanan Kutty of Kerala Agricultural University, ICAR-IIHR, ICAR-Krishi Vignan Kendras (KVKs), Pest Control India (PCI), Private Seed Companies, and the farming community for their complete support while implementing its interventions. The team hopes all stakeholders will continue to support scaling-up activities of the successful interventions. We recognize and acknowledge the project coordination support of Mr. Hemant Nitturkar, during the initial phases of the project.

Funding
This work was a part of the Govt. of Karnataka (GoK) funded project "Bhoo Samruddi" (CGIAR-GoK Consortium—Improving Rural Livelihoods through Innovative Scaling-up of Science-led Participatory Research for Development in Karnataka) led by ICRISAT. WorldVeg received a project grant from CGIAR-GoK consortium for this work. Core funding to support World Vegetable Center's activities worldwide is provided by the Republic of China (ROC), UK aid, the Australian Centre for International Agriculture Research (ACIAR), the United States Agency for International Development (USAID), Germany, Thailand, Philippines, Korea, and Japan.

Competing Interest
The authors declare no competing interests.

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Citation information
Cite this article as: Science-based horticultural interventions for improving vegetable productivity in the state of Karnataka, India, N. Kumar, D. Bharat, N. Amaresh, H. Shivakumar, R. Shivakumar, P. Arshad, R. Subramanian, W. Easdown, H. Bindumadhava & R. M. Nair, *Cogent Food & Agriculture* (2018), 4: 1461731.

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Cogent Food & Agriculture **(ISSN: 2331-1932) is published by Cogent OA, part of Taylor & Francis Group.**