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Research article

Postharvest Management Options to Improve Tomato Value Chain in Cambodia

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Abstract Tomato (cv. Mongal) value chain practices of a farmers' cooperative as pilot model in Siem Reap, Cambodia, were assessed and improved through the introduction of postharvest technologies and best practices. The existing value chain (EVC) practices included harvesting tomatoes at the breaker stage, use of harvesting container with smooth surface (plastic pail), use of plastic crate in hauling harvested tomatoes to the farmers' house where packaging in ordinary plastic bags at 10 kg fruit per bag was done. No sorting and special storage were practiced except for overnight storage at ambient when harvesting was done in the afternoon. The packed fruit were then transported to the city market about 12 km from the farm or 30-45 minutes ride using a motorcycle-driven carrier (locally named 'TukTuk'). Marketing tomatoes usually took half day. Using the cooperative's simple packhouse which linked farm production and marketing, improved value chain (IVC) practices were introduced, including sorting to ensure more uniform quality and damage-free fruit, sanitizing with 0.01% calcinated calcium (non-chlorine sanitizer) by dipping fruit in the solution for 3 minutes, modified atmosphere packaging (MAP) using perforated 50 µm thick low-density polyethylene bag at 10 kg fruit per bag, and transporting and direct retailing in ice box using a dedicated motorcycle-driven carrier. In another set of trials, three-day storage simulating extended period of distribution and marketing was included using ambient condition in the EVC while in the IVC, three storage options were introduced: ice box (3 kg ice per box with about 25 kg fruit replenished every day); low-cost cold storage using the Coolbot chamber; or evaporative cooler (EC). Results revealed that without storage (direct marketing after harvest) total postharvest loss was about 14% in the EVC; this was remarkably reduced to 4% in the IVC. IVC fruit were also firmer, had higher soluble solids and much reduced microbial load than EVC fruit. No pesticide residue was detected in both EVC and IVC fruit. With the three-day storage, the three storage options in the IVC did not differ much in reducing postharvest loss to about 3-6% from 22% in the EVC. IVC fruit also ripened slowly resulting in higher firmness than EVC fruit. Other quality attributes were not affected. Vitamin C content was slightly higher in IVC fruit than in EVC fruit. From the results, there is potential for integrating postharvest management options in value chains to reduce postharvest loss and enhance quality of tomatoes.

Keywords *Solanum lycopersicum*, value chain improvement, farm-packhouse-market model, postharvest loss reduction

INTRODUCTION

Tomato (*Solanum lycopersicum*) is a major fruit-vegetable in Cambodia with production continually expanding as a result of the introduction of improved varieties and production techniques as well as increased market demand and entry of modern market outlets (e.g. supermarkets, hotels and restaurants) due to the flourishing tourism industry (Buntong et al., 2012). However, poor postharvest practices are a serious problem resulting in poor quality perception and high postharvest losses (Genova et al., 2006; AVRDC-The World Vegetable Center, 2016). Postharvest losses vary with type of produce, location, growing season and the value chain stage (Weinberger and Acedo, 2011; Acedo and Easdown, 2015). Postharvest losses of tomato in Cambodia were estimated at 11-35% in Kandal province (Genova et al., 2006), 23% in traditional and modern supply chains in Kandal and Kampong Speu provinces (Buntong et al., 2012) and 26% in Battambang and Siem Reap provinces (AVRDC-The World Vegetable Center, 2016). Aside from poor postharvest practices and the perishable nature of fresh produce, other factors contributing to losses include the fragmented and unorganized supply chains and the hot and humid tropical climate. Postharvest losses are often absorbed by farmers as reduced farm gate prices and by consumers through an increased purchase price. Postharvest losses contribute to Cambodia's high dependence on vegetable imports from Vietnam and Thailand estimated at about 80% of domestic consumption (Millar, 2017). As part of Cambodia's strategic priorities to achieve inclusive and sustainable development, domestic production and marketing of all kinds of vegetable are being promoted in order to substitute imports (Royal Government of Cambodia, 2018).

Postharvest losses have significant economic, social, and environmental consequences. Globally, food loss amounts to about one-third of total production valued at almost one trillion US dollars in annual economic losses; contributes to hunger and malnutrition; represents about 25% of water used by agriculture; requires cropland area the size of China; and generates about 8% of global greenhouse gas emissions (GHG) which is the third largest after China and USA (FAO, 2013; HLPE, 2014). Reducing postharvest losses is a global agenda embedded in the United Nations Sustainable Development Goal (SDG) 12.3 which targets reducing food waste including postharvest losses by 50% by 2030 (https://sustainabledevelopment.un.org/). About half of the global food losses can be prevented with a more efficient supply chain and the saved food can feed about one billion extra people, thereby reducing the pressure to raise more food to feed an additional two billion people by 2050. Postharvest technologies play a vital role toward this end and can enable developing countries to improve the quality and competitiveness of their horticultural produce in domestic and international markets as they integrate into the world economy and global value chains proliferate. Additionally in Cambodia, reducing postharvest losses could potentially contribute to vegetable import substitution and self-sufficiency.

Postharvest management (PHM) is vital to reduce postharvest losses and contribute to improved food and nutrition security through three different pathways: (1) increasing the availability of food at farm-gate and market level, (2) reducing the price of food and thus enhancing potential access, and (3) reducing the volatility and quality of food availability (Van Gogh et al., 2017). PHM also contributes to food safety which is the most critical dimension of food quality. If the quality has deteriorated to a level that the food is no longer safe for human health, the food needs to be removed resulting in quantitative food loss (Bin Liu, 2016). Economic revenues of improved PHM include both efficiency (positive benefit-cost ratio) and effectiveness (incentives for supply chain stakeholders to engage in PHM activities). Furthermore, PHM increases employment as farmers and other value chain agents are engaged in postharvest loss reduction activities. PHM can also reduce GHG emission and global warming.

A value chain approach on PHM is important to effectively reduce postharvest losses (Batt and Cadilhon, 2007; Van Gogh, 2017). It should target smallholders who are the dominant players in supply chains in developing countries including Cambodia; otherwise, they would be further disadvantaged and marginalized (Van der Meer, 2006; Chan, 2009). PHM can overcome the underperformance in postharvest chains in terms of the loss of quantity and quality of the harvested produce, and hence the loss of revenues and resources. Postharvest losses are not caused by one or two specific links in the chain but are the result of an entire value chain. Tackling these losses therefore requires a value chain approach rather than actions from a single stakeholder or a single solution approach. The value chain approach specifies that the costs incurred in specific parts of the chain to create the added value will be sufficiently compensated by the revenues from the entire value chain. PHM measures are stimulated when there is good prospect of obtaining the revenues in exchange for the costs and risk of investment.

Reducing postharvest losses is context specific, and strategies to developing competitive and sustainable value chains have to be tailored to the socioeconomic and ecological environment in which the value chain operates. The root causes of postharvest losses can be generalizable; however, the magnitude and causes of losses and the measures to reduce losses will differ with supply chain. Attempting one-size-fits-all approaches can create more challenges than they address. In improving value chains, PHM measures need to be tested before commercialization. For example, in the cabbage supply chain in Central Philippines, postharvest loss in the traditional chain was estimated at 34% and introduction of 3-4 wrapper leaf retention and plastic crate packaging at the farm level; 2-3 wrapper leaf retention, 15% alum treatment for bacterial soft rot control and plastic crate packaging prior to transport to market; and 15% alum treatment prior to retail reduced losses to 3%, 6% and 11%, respectively, or a total loss of 20% (Gonzales and Acedo 2016). In the modern chain involving supermarkets, total loss was 25%, and introduction of 3-4 wrapper leaf retention and plastic crate packaging at the farm level; 2-3 wrapper leaf retention, 15% alum treatment and plastic crate packaging prior to transport to market; and 15% alum treatment and individual plastic film wrapping prior to supermarket display reduced losses to 3%, 7% and 6%, respectively, or a total loss of 16%. With the introduction of the different PHM measures, net income and return on investment increased. In Cambodia's tomato traditional chain in Kandal province, improved packaging (20 kg capacity plastic crate with modified atmosphere packaging or MAP using 50 µm-thick low density polyethylene or LDPE), precooling (5 min dip in 5°C water) and sanitizing (2 min dip in 200 ppm chlorine solution) at the farm level decreased fruit damage at the wholesale and retail stages and reduced weight loss at the retail stage by about two-fold compared to that of fruit conventionally packed in 20 kg capacity 50 µm-thick high density polyethylene (HDPE) and without precooling and chlorine treatments (Buntong et al., 2013). In the tomato modern chain in Kampong Speu province wherein only one intermediary (collector-wholesaler) was involved between farmers and supermarkets, MAP was only required, with 11 µm-thick film overwrap being more effective than LDPE in reducing weight loss and retarding fruit ripening.

In the present study, the existing value chain of tomato in Siem Reap province was improved by introducing selected PHM techniques in two scenarios, with and without storage options to simulate temporary holding prior to marketing and immediate marketing after harvest, respectively. Postharvest loss was quantified and fruit quality (physicochemical and food safety attributes) was determined.

OBJECTIVE

The study aimed to determine the effectiveness of selected PHM techniques in improved value chain in reducing postharvest loss and enhancing physicochemical quality of tomato and assess the comparative advantage of improved value chain over the existing value chain with and without a storage component.

METHODOLOGY

Tomato fruits cv. Mongal at the breaker to turning stage were sourced from local farms of farmer-members of a cooperative in Siem Reap. The harvested fruit were placed in plastic crates and hauled either to the farmers' house representing the existing value chain (EVC) or to the cooperative's simple packhouse located nearby representing the improved value chain (IVC). Ten kg fruit were used for each treatment per replicate. Three replications were used.

Experimental Trials Without Storage Component

In the EVC, after arrival at the farmers' house, tomatoes were packed in ordinary plastic bags at 10 kg fruit per bag without sorting or grading as usually practiced. The bags of fruit were then transported to Siem Reap city wet market using 'TukTuk' (motorcycle-driven rickshaw) about 12 km away or 30-45 min travel time. After the usual half day marketing period, the fruit were assessed for losses and quality attributes.

In the IVC, after arrival at the simple packhouse, the fruit were sorted and only defect-free fruit were used. The sorted fruit were sanitized by dipping for 3 min in 0.01% (100 ppm) calcinated calcium (CCa) solution which was followed by rinsing in clean water and air-drying. The fruit were then packed in MAP (50 µm-thick LDPE) at 10 kg fruit per bag and placed in 25-kg (30 x 30 x 40 cm) Styrofoam box with 1 kg ice (ice box) for transport to Siem Reap in dedicated 'TukTuk' for direct retailing and after half day, the fruit were assessed for losses and quality attributes. All treatments were replicated three times.

Experimental Trials with Storage Options

The same procedure as in trials without storage component was followed except that a 3-day storage period was included prior to transport to Siem Reap market to simulate temporary holding before marketing. In the EVC, the 3-day storage period was done at ordinary ambient condition. In the IVC, three storage options were tested; low-cost cold storage using the Coolbot chamber, storage in evaporative cooler, and storage in 25-kg ice box with 1 kg ice per box per day. All treatments were replicated three times.

Data Gathered

Postharvest loss: This was determined as the sum of percent outright volume loss, percent weight loss and percent loss of damaged fruit which were still marketable. After the half day marketing period and storage (for trials with storage component), non-marketable fruit due to rotting, breakage and/or over-ripening were weighed and expressed as percentage of the initial weight to represent the outright volume losses. Weight loss was also taken as percentage of the initial weight. For damaged fruit that were still marketable, they were subjected to evaluation of price reduction by 5 trained panelists. The magnitude of price reduction was expressed as percentage of the price of sound or undamaged fruit to represent equivalent loss of damaged but still marketable fruit.

Fruit quality attributes: Red-ripe fruit were counted and expressed as percentage of the total number of fruit samples per replicate. Firmness was measured non-destructively using the Fruit Hardness Tester (TR Turoni, Italy). Total soluble solids of the fruit juice was determined using a digital refractometer while juice pH was measured using an electronic pH meter (Hanna Instruments). Vitamin C was analyzed following the 2, 6-Dichloroindophenol Titrimetric method and the result reported as mg/100g of tomato fruit (AOAC, 2006).

Food safety attributes: Pesticide residue analysis was performed using the GT Rapid Pesticide Test Kit (Bangkok, Thailand). Microbial analysis determined the total bacteria (total plate count), coliform and E. coli counts. Triplicate 25g fruit samples were placed in Stomacher for 2 min and then subjected to serial dilution using sterile distilled water under aseptic condition in a laminar flow cabinet. Triplicate aliquot of 0.1 ml was aseptically micropipette and placed in a petri dish with plate count agar. The petri dishes were then placed in an incubator at 35ºC for 24 hours and colony forming units (CFU) were counted. For coliform enumeration, violet red bile agar (VRBA) was used. The plates were incubated in 35 ± 2 ◦C for 24 hours and red colonies were counted. For E. coli analysis, 25g fruit samples were mixed with 225 ml saline water and placed in Stomacher for 2 min and added with 9 ml EC broth before serial dilution. Aliquots of 0.1 ml were aseptically pipetted out and placed in E. coli agar plates followed by incubation at 44ºC for 24 hours. Microbial counts were determined using dilution plates with 15–300 colonies expressed as colony forming units per ml (CFUml−1). When CFU exceeded 300 per plate, counts were taken from four 1-cm squares per plate. Logarithmic values of counts (logCFUml−1) were computed for every plate.

Storage conditions: Temperature and relative humidity (RH) during storage were measured using an Infrared Temperature-RH meter.

Statistical Analysis

All experimental trials were conducted in completely randomized design with three replications. Data were subjected to analysis of variance and treatment mean comparison by least significant difference (LSD) test using the SAS Statistical Package.

RESULTS AND DISCUSSION

Value Chains without Storage Component

Postharvest loss: Postharvest loss in both EVC and IVC was due to the combination of weight loss, outright volume loss and equivalent loss of price reduction of damaged but still marketable fruit (Table 1). However, EVC had much higher weight loss (3.7%), outright volume loss (4.8%) and equivalent loss of damaged fruit (5.1%) compared to that of IVC (1.6%, 1% and 0.9%, respectively). Overall, the total postharvest loss in the EVC was 13.6%, which was about four times higher than that in the IVC (3.5%). Several factors contribute to the reduction of postharvest loss in the IVC. The temperature of the ice box (21ºC) used during transport of tomatoes to market was much lower while RH (100%) was much higher than that in the EVC (ambient, 29ºC and 60% RH). Low temperature and high humidity are known to reduce water loss which is mainly responsible for weight loss (Nunes, 2008; Holcroft, 2015). The ice box in the IVC may have also protected the fruit from damage more effectively being a more rigid container than the plastic bag in the EVC during transport and marketing. In addition, sorting, CCa sanitizing and MAP in IVC may have contributed to postharvest loss reduction as previous reports indicated (Kumar et al, 2015; Arah et al., 2016). Specifically in tomato, MAP has been found to be very effective in reducing weight loss (Gautam et al., 2017; Rahman et al., 2017; Seng et al., 2017).

Table 1 Postharvest loss of tomato in existing value chain (EVC) and improved value chain (IVC) without storage component

Parameter	EVC	IVC	ANOVA1
A. Weight loss, %	3.7	1.6	**
B. Outright volume loss, %	4.8	1.0	**
C. Damaged fruit, %	23.8	4.2	**
D. Price reduction of damaged fruit, %	21.0	21.0	
E. Equivalent loss of damaged fruit, %	5.1	0.9	**
F. Total postharvest loss (A+B+E), %	13.6	3.5	**

Fruit quality: No fruit turned full ripe in both EVC and IVC as transport and marketing were done on the same day of harvest (Table 2). Vitamin C content and pH were also statistically similar between EVC and IVC fruit. However, IVC fruit were significantly firmer than EVC fruit. Total soluble solids content was also significantly higher in IVC fruit than in EVC fruit. These responses suggest slowed metabolic activity in the IVC fruit which could have been induced by low temperature in the ice box and MAP as also found in earlier studies (Beckles, 2012; Facundes et al., 2015; Gautam et al., 2017; Rahman et al., 2017; Seng et al., 2017).

Food safety: No pesticide residue was detected in both EVC and IVC fruit (Table 2). However, microbial load was remarkably reduced in IVC fruit with aerobic bacteria (total plate count) of 2.95 log CFU/g and non-detectable level of coliform bacteria and E.coli. In contrast, EVC fruit had 4.02 log CFU/g aerobic bacteria, 2.85 log CFU/g coliform bacteria and 1.48 log CFU/g E. coli. Acceptable levels for food safety include <4.0 log CFU/g aerobic bacteria, <2.0 log CFU/g coliform and no E. coli. IVC fruit met these acceptable microbial levels for food safety while EVC fruit did not. This result can be attributed to the CCa sanitizing treatment in the IVC fruit. The effectiveness of CCa sanitizing in reducing the microbial load on tomato and other vegetables was obtained in previous studies (Ahmed et al, 2017a, 2017b; Rahman et al., 2017).

Table 2 Quality attributes of tomato in existing value chain (EVC) and improved value chain (IVC) without storage component

Parameter	EVC	IVC	ANOVA1
Full-ripe fruit, % of total	0	0	
Firmness, nondestructive, Shore	122	133	*
Total soluble solids, %	5.2	5.8	**
pH	4.3	4.4	ns
Vitamin C content, mg/100g FW	9.3	9.3	ns
Microbial load			
Total plate count, log CFU/g	4.02	2.95	**
Coliform, log CFU/g	2.85	<1.0 (0)	**
E. coli, log CFU/g	1.48	<1.0 (0)	**
Pesticide residue, GT Rapid Test	negative	negative	

Value Chains with Storage Options

Postharvest losses: Total postharvest loss was very high in the EVC (21.6%) due to high weight loss (11.1%), outright volume loss (7%) and equivalent loss of damaged fruit (3.5%) (Table 3). In the IVC, total loss was comparable among the three storage options and ranged from 2.5-6.1% consisting of 1.9-2.8% weight loss, 0-2.8% outright volume loss and 0.6-0.9% equivalent loss of damaged fruit.

Table 3 Postharvest loss of tomato in existing value chain (EVC) with 3-day ambient storage and improved value chain (IVC) with 3-day storage in ice box, Coolbot chamber or evaporative cooler (EC)

Parameter	EVC-ambient	IVC-ice box	IVC-Coolbot	IVC-EC
A. Weight loss, %	11.1a	2.4b	1.9b	2.8b
B. Outright volume loss, %	7.0a	2.8b	0.0b	0.0b
C. Damaged fruit, %	17.4a	4.7b	3.2b	3.0b
D. Price reduction of damaged fruit, %	21.0	21.0	21.0	21.0
E. Equivalent loss of damaged fruit, %	3.5	0.9	0.6	0.6
F. Total postharvest loss (A+B+E), %	21.6a	6.1b	2.5b	3.4b

Table 4 Temperature and relative humidity (RH) during 3-day storage at ambient in existing value chain (EVC) and in ice box, Coolbot chamber or evaporative cooler (EC) in improved value chain (IVC)

Value chain and storage option	Temperature (°C)	RH (%)
EVC – ambient storage	28-33	58-78
IVC – ice box storage	20-23	85-100
IVC – Coolbot storage	14-17	73-100
IVC – EC storage	21-26	79-100

Weight loss reduction in the IVC can again be attributed to the use of MAP as well as the lower temperature and higher RH in the three storage options (Table 4), which are conducive to fruit water retention as water loss is the primary cause of weight loss of fruit and vegetables. Other metabolic activities, particularly respiration rate are also reduced under MAP and low temperature conditions. Earlier, MAP and Coolbot storage were found to reduce weight loss of tomatoes (Gautam et al., 2017a; Rahman et al., 2017; Seng et al., 2017). The reduced outright volume loss and damage incidence in IVC fruit were due to fewer fruit that turned overripe and diseased during storage and lower incidence of mechanical damage compared to that of EVC fruit.

Fruit quality: The three storage options in IVC slowed the rate of ripening depicted as much lower number of fruit that fully ripened after storage (3.9-10.5%) as compared to EVC fruit (40.9%) (Table 5). Fruit firmness was higher in IVC with Coolbot or EC storage relative to that of EVC fruit and IVC with ice box storage. High firmness indicates lower degree of ripening in which softening is a major indicator. Total soluble solids, pH and vitamin C content did not significantly differ with value chain and storage option (Table 5). Total soluble solids ranged from 3.8-4.4%, pH from 4.3-4.4, and vitamin C content from 17.7-23.4 mg/100g fresh weight. The results show the remarkable effect of IVC with storage options was on the retardation of fruit ripening. Earlier studies showed that MAP in combination with Coolbot storage delayed ripening of tomatoes (Seng et al., 2017). MAP atmosphere of low oxygen and high carbon dioxide together with low temperature are known to inhibit physiological process including ripening in harvested produce.

Table 5 Quality attributes of tomato in existing value chain (EVC) with 3-day ambient storage and improved value chain (IVC) with 3-day storage in ice box, Coolbot chamber or evaporative cooler (EC)

Parameter	EVC-ambient	IVC-ice box	IVC-Coolbot	IVC-EC
Full-ripe fruit, % of total	40.9a	3.9b	3.9b	10.5b
Firmness, nondestructive, Shore	83.3b	96.9b	113.7a	114.2a
Total soluble solids, %	3.8	4.0	3.9	4.4
pH	4.3	4.4	4.3	4.4
Vitamin C content, mg/100g FW	17.7	20.7	23.4	21.9

CONCLUSION

Improving tomato value chains with the infusion of postharvest technologies and best practices, such as sorting, non-chlorine sanitizing using CCa, MAP, storage techniques, and cold packing for transport and marketing, proved to be highly promising in reducing postharvest losses and enhancing fruit quality and food safety. Considering that postharvest loss reduction is context specific, it is important to examine existing value chains and know the deficiencies in order to identify, test and adopt postharvest management measures.

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