Journal of Food Science and Engineering 11 (2021) 9-22
doi: 10.17265/2159-5828/2021.01.002

Development of Cold-Chain for Postharvest Loss Reduction of Chinese Cabbage (*Brassica campestris* L. ssp. *Pekinensis*)

Rathana Nai[1], Buntong Borarin[2], Tong Socheath[2], Jessie L. Vipham[3], Glenn M. Young[4] and Karen LeGrand[4,5]

1. Faculty of Agro-Industry, Royal University of Agriculture, Phnom Penh 12000-12401, Cambodia

2. Division of Research and Extension, Royal University of Agriculture, Phnom Penh 12000-12401, Cambodia

3. Mid-Campus Drive North, Kansas State University, Weber Hall, Manhattan, KS 66506-8028, United States

4. Department of Food Science and Technology, College of Agricultural and Environmental Science, University of California-Davis, 595 Hilgard Lane, Davis, CA 95616, United States

5. Science and Mathematics Division, Department of Biology, Sierra College, 5100 Sierra College Boulevard, Rocklin, CA 95677, United States

Abstract: Cold-chain is a well-known method for reducing postharvest losses and low-cost cooling technology has not previously been tested as part of postharvest handling in Cambodia. The objective of this study was to measure postharvest loss, quality changes, and safety concerns of Chinese cabbage (*Brassica campestris* L. ssp. *pekinensis*), during transportation using a cold-chain and compared to current farmers' employing ambient-chain practices . The quality and safety of Chinese cabbage were further evaluated by using ambient storage and Coolbot-powered cold chamber storage with and without modified atmosphere packaging (MAP). The samples were transported from farm sources in Battambang Province to a Phnom Penh specialty wholesale market. Postharvest loss was evaluated by measuring weight loss and visual quality measurements, in addition to various physiochemical and nutritional quality measurements. In addition, food safety was evaluated by quantifying total coliforms and *Enterobacteriaceae*, as well as the *Salmonella spcies*, and *Escherichia coli*. The results revealed that the cold-chain avoided postharvest loss, as indicated by produce weight gain of 14% on market arrival due to rehydration while inside the ice box during transport. In contrast, the traditional practice of ambient transport (28-31 °C, 62-78% relative humidity) resulted in very high postharvest loss, comprising 11% weight loss and 10% visual quality loss, for a total loss of 21%. Moreover, leaf yellowing found no marked influence on shelf life as L*, a* and b* values did not greatly differ with treatment. The total soluble solids (TSS), titratable acidity (TA), pH and vitamin C content were not significantly affected during storage. Food safety indicators (coliforms, *Enterobacteriaceae*, *Salmonella* and *Escherichia coli*) were lower in cold-chain storage than ambient-chain with lower counts of coliform bacteria, *Enterobacteriaceae*, and *Salmonella* spp. than traditionally handled produce. *Escherichia coli* was detected only in cold-chain produce. MAP had no effect on these food safety indicators.

Key words: Chinese cabbage, postharvest practices, postharvest loss, Coolbot storage, ice box packaging, MAP, food safety.

1. Introduction

Postharvest losses of vegetables vary with commodity, location, value chain system and value chain actor. The loss estimates vary considerably, with maximum average losses of up to 50% or higher in developing countries [1, 2]. In South East Asia, vegetable loss is approximately 17% of total harvest with the greatest burden of physical loss to farmers. The same situation exists in Cambodia [3]. Cambodia has a more complex supply chain than neighboring nations and is observed to have the highest postharvest loss [4].

One example is in the tomato supply chain where postharvest losses were 23% for the traditional transport chain (from farmers in Kandal Province to

Corresponding author: Buntong Borarin, PhD of postharvest technology, director, research fields: postharvest technology of fruits and vegetables.

traditional wet markets in Phnom Penh) and 22.5% for the more modernized chain (from Kampong Speu farmers to supermarket in Phnom Penh) [5].

Maintaining quality and prolonging shelf life of leafy vegetables is especially challenging. Within a few hours from harvest, leaf wilting sets in due to rapid water loss [6].

Water loss is the main cause of weight loss (loss in saleable weight) which contributes to quantitative postharvest loss. A loss of 5-10% of fresh weight makes leafy vegetables appear wilted and unmarketable [7]. Water loss also induces degradation of nutritional components (e.g. vitamin C loss) and imposes stress (i.e. water stress) that increases respiration and ethylene production. Bok Choy is a model leafy vegetable and it has been shown water loss primarily occurs through the stomata at a rate of 2.8% per hour at 35 °C, which is a common field condition in the tropics [8]. A review of postharvest technology for fruits and vegetables in South Asia (SA) illustrated the huge postharvest losses in SA countries generated by poor pre- and postharvest practices that lacked appropriate technique for extending shelf life. The causes of African indigenous leafy vegetables (ALVs) postharvest loss and reduced shelf-life along the supply chain include poor harvesting techniques, poor handling, inappropriate packaging, lack of cold storage facilities, poor roads, and unhygienic market conditions [9]. Therefore, considerable improvement of low cost and easy-to-operate postharvest systems should be introduced into the food chain. For instance, providing stallholders at produce markets with improved containers, low or zero energy cool storage facilities, insulated field packaging and small cool rooms may be important ways to extend shelf life and reduce postharvest losses [10].

Cold-chain is a well-known method for reducing food losses and improving food safety. Cold-chain is the uninterrupted handling of produce within a low temperature environment during the postharvest steps of the value chain including harvest, collection, packing, storage, transport and marketing until it reaches the final consumer [11]. Simple and low-cost cooling technologies that can be used in cold-chain systems include the use of a simple hydrocooler, Coolbot cold storage, icebox packaging and transport, as well as evaporative cooling storage [12]. Modified atmosphere packaging (MAP) is an available technology that modifies gas concentration. It offers the possibility of lowering respiration rate and extending shelf-life of fresh fruits and vegetables [13]. The combination of MAP and lower temperature (refrigeration temperatures) plays a crucial role for safer storage. Fresh produce can face microbial contamination with foodborne pathogens at any point along the food chain which is a concerning health issue [14]. Increased food safety from farm to fork within the food chain prevents foodborne illness by eliminating microbial pathogens from routine preparation, handling, and storage practices. The effectiveness of measures intended to reduce contamination can be measured as decreased numbers of *Escherichia coli* (*E. coli*) O157:H7 and *Salmonella* in samples of fresh produce [15].

Few studies on cold-chain, MAP and their effect on food safety have been conducted in Cambodia. Notably lacking is postharvest handling studies of Chinese cabbage, *Brassica campestris* L. ssp. *pekinensis*. This is a well-known leafy vegetable crop that has been a key vegetable for consumption in East, Northeast Asia and Southeast, especially Cambodia, for many decades [16, 17]. Specifically, value chain practices and postharvest loss of Chinese cabbage grown in Battambang Province have not been investigated. This study evaluates the effect of cold storage and MAP on food safety and postharvest loss of Chinese cabbage transported from farms in Battambang Province to markets in Phnom Penh.

2. Materials and Methods

2.1 Transport Study

Farmer's practice: Chinese cabbage (*Brassica* *campestris* L. ssp. *pekinensis*) was brought from the field to farmers' houses and held at ambient temperature with no washing or other special treatment after harvest. The vegetable was packed at the same dimension in paperboard box (44.5 × 37 × 23.2 cm) and each containing 15 kg Chinese cabbage. Cold-chain system: vegetable was brought to the packhouse located nearby the farm and was washed with tap water followed by air-drying. Foam box (49 × 37 × 31.5 cm) was used for packing vegetables with about 1.2 kg tube ice (20-23 °C and 75-90% relative humidity (RH) in the ice foam box). Each ice foam box contained 7 kg of Chinese cabbage. While waiting for transport, the vegetable was held in the Coolbot chamber (15-18 °C, 66-76% RH) in the packinghouse. Transportation: paperboard and ice foam boxes of Chinese cabbage were transported in a bus at ambient conditions to REMIC market in Phnom Penh, about 330 km from the farm source in Battambang or about 6-7 hours ride. Each process of transportation represented one replicate, for a total of 4 replicates. Each replicate was used for the storage study.

2.2 Storage Study

The two treatment groups (farmers' practice and cold-chain system) from the transport study were subdivided into 4 treatments, namely, ambient storage (temperature range from 28.9-31 °C, 62-78% RH) with and without MAP and Coolbot storage (15.5-18.5 °C, 67-76% RH) with and without MAP. MAP used polyethylene plastic bag (50 μm thick) with holes. The study was conducted in triplicate, using three samples for each treatment. Each sample was weighted using a precision scale and contained 60 g.

2.3 Parameters Measured from Transport and Storage Studies

2.3.1 Postharvest Loss, Physicochemical and Nutritional Quality Measurements

Data on postharvest loss, physicochemical and nutritional quality were gathered daily for transport and storage studies. Temperature and RH also were recorded by using Temperature-RH meter (model HTC-1). Postharvest loss: the percentage of weight loss at market arrival in Phnom Penh compared with the initial weight taken at the farm. Physicochemical quality of the initial and after-market-arrival, the measurement of color, total soluble solids (TSS), titratable acidity (TA) and pH were taken. Visual quality was evaluated by 5 trained panelists using a visual quality rating (VQR) of 9 to 1, with 9 as excellent, field fresh and no defect, 7 as good with minor defects, 5 as fair with moderate defects, 3 as limit of marketable and 1 as inedible under usual condition. For color measurements, a Minolta Color Reader CR-10 was used and the L*, a* and b* values of the leaf blade (green color part of the leaf) and leaf petiole (white stem based and midrib) were recorded. TSS was determined using a digital refractometer (Brix). TA was analyzed by the titrimetric method using 0.1 N NaOH and 1% phenolphthalein as indicator. pH was measured using a compact pH meter (Horiba Laquatwin). Nutritional quality: vitamin C content was analyzed at the farm (initial) and after-market-arrival following the 2,6-Dichloroindophenol Titrimetric method and the result reported as mg/100 g fresh weight of vegetable [18, 19].

2.3.2 Safety Measurement

Safety attributes of Chinese cabbage were determined by quantifying coliforms, *Enterobacteriaceae*, *E. coli* and *Salmonella* spp. by plate quantification method, where detection was reported as presumptive positive for corresponding samples. Microbes were enumerated from the vegetable at the initial day (harvest from the farm), at the time of market arrival and on day 4 of the storage study. This study used 4 replicates as indicated for the transport and storage studies with the addition of double plate repeats for each sample.

Samples were prepared by weight, 10 g of cut Chinese cabbage in 90 mL of 0.1% peptone water and hand-stomached for 60 s (initial rinse bag).

E. coli and coliforms were enumerated by the plate quantification method. From the initial rinse bag, appropriate dilutions were prepared by transferring 1 mL of homogenized sample (rinse bag) into 0.1% peptone water. Then 1 mL of each dilution was plated onto 3M™ Petrifilm™ *E. coli* and coliform count (ECC) plates and incubated at 37 ± 2 °C for 24 ± 2 h. After 24 h, counts of all red and blue colonies entrapped with gas were recorded as total coliforms while blue colonies with entrapped gas were recorded as *E. coli*. ECC count plates were incubated at 37 ± 2.0 °C for another 24 ± 2 h to observe color change of colonies. Within this validated incubation period, again blue colonies associated with gas were recorded as *E. coli*. Total colonies were counted and used to calculate the concentration of coliforms and *E. coli* per ECC manufacturer's guidelines. The total number of counted colonies ranged from 15-150 colonies per plate. If count was below 15 colonies on the lowest dilution, it represented half the limit of detection while a plate with over 150 colonies was recommended as too numerous to count [20].

Quantification and detection methods were applied for *Salmonella* enumeration. *Salmonella* quantification followed the procedure for detection of *Salmonella enterica* with slight adjustment [21]. Firstly, ten-fold serial dilutions from the initial rinse bag were prepared. Then 1 mL of each dilution was plated onto 3M™ Petrifilm™ *Enterobacteriaceae* count (EB) plates and incubated at 37 ± 2.0 °C for 24 ± 2 h. After 24 h, all red colonies associated with entrapped gas, and red colonies with both yellow zones and entrapped gas were counted. These were characterized as *Enterobacteriaceae* [22]. Straightway, EB count plates were transferred to Xylose Lysine Tergitol-4 (XLT-4) agar small plates. This process involved removing the petrifilm and gently pressing it onto the surface of an XLT-4 agar plate to replicate colonies present on the EB count plates. Transferred plates were incubated at 37 ± 2.0 °C for 24 ± 2 h. After incubation, yellow and clear colonies with dark centers were collected and tested by *Salmonella* latex agglutination kit. The colonies which were not agglutinated nor had morphology atypical of *Salmonella enterica* on XLT-4 agar plate were counted, and the number deducted from the initial total plate count. This was recorded as the concentration of presumptive positive *Salmonella* spp. per EB manufacturer's guidelines. If the total number of colonies was below 15 colonies (< 5 CFU/g), it corresponded to half of the limit of detection (below the limit quantification). *Salmonella* detection was also confirmed by methods adapted from Bacteriological Analytical Manual (BAM) [23]. For pre-enrichment, 1 mL from the rinse bag was transferred into a conical tube containing 9 mL of Tryptic Soy Broth (TSB) and incubated at 37 ± 2 °C for 24 ± 2 h. After incubation, the pre-enrichment (TSB broth) was aliquoted and 1 mL transferred into 9 mL of each of two selective enrichment broths (Rapport-Vassiliadis (RV) broth and Tetrathionate (TT) broth). Both selective enrichments were incubated at 37 ± 2 °C for 24 ± 2 h. After 24 h, 1 µL loopful of selective enrichment was used to streak onto XLT-4 agar and Brilliant green sulfur (BGS) agar plates and incubated at 37 ± 2 °C for 24 ± 2 h. After incubation, yellow and clear colonies with dark centers were further analyzed by *Salmonella* latex agglutination kit to confirm *Salmonella* spp. as presumptive positive.

Meanwhile, *E. coli* detection was performed similar to *Salmonella* spp. detection but selective enrichment was done using *E. coli* (EC) broth instead. After incubation at 37 ± 2 °C for 24 ± 2 h, EC selective enrichment was streaked onto Rainbow agar and incubated at 37 ± 2 °C for 24 ± 2 h. Presumptive colonies (pale green colonies with no precipitation, dark purple-blue colonies with precipitation, light purple colonies with precipitation, light pink colonies with precipitation, dark pink colonies with precipitation, grey colonies with no precipitation, and cream colonies with no precipitation) were selected to test with *E. coli* latex agglutination kit for confirming of presumptive positive *E. coli*.

2.4 Data Processing and Analysis

The results were transferred and analyzed by SPSS statistics version 25.0 software. Descriptive statistics and univariate analysis of variance were used to determine the significant differences of different treatments for transport, storage and with or without packing. To describe changes in vegetable safety, Excel and CFU/g were used.

3. Results and Discussion

3.1 Transport Study

In Table 1, the results of the transport study comparing the cold-chain system and the existing farmers' practices are shown. The cold-chain system prevented postharvest loss, and in fact resulted in weight gain (negative weight loss) of 14% on arrival in the Phnom Penh (PHN) market. In contrast, produce handled following the farmers' practices lost weight of 11%. Produce from the farmers' practice had lower visual quality resulting in higher price reduction and additional loss of 10% compared to cold-chain system which had only 5% price reduction due to visual quality loss. Overall, the total postharvest loss in the farmers' practice was 21% whereas the cold-chain system had no loss, instead a net gain in weight of 9%. The gain in weight in the cold-chain system indicates rehydration of produce while inside the ice box package during transport as there was free water when the ice melted inside the box in addition to the high RH inside the box. Water application by sprinkling or dipping is usually practiced to rehydrate and restore the turgid appearance of leafy vegetables [24]. Postharvest loss from the traditional practice was high due to weight loss and visual quality loss after transport to market. Weight loss was mainly due to water loss through the process of transpiration. In an earlier study on leafy mustard produced in Battambang and Siem Reap, total postharvest loss obtained was higher (29%) than that of Chinese cabbage in the present study (21%). However, the present study measured the actual loss after transport from the farm in Battambang to Phnom Penh market whereas the study on leafy mustard was the sum of loss as perceived by farmers, collectors, wholesalers, and retailers [25]. It also agrees with a current study on tomato, integrating cooling techniques in value chain comprising Coolbot storage at 14-17 °C with 73-100% RH and ice box packaging (20-23 °C, 85-100% RH) during transport and retailing greatly reduced postharvest loss to only 2.5%; without cooling techniques (ambient storage and handling), postharvest loss was 21.6% [26].

Physicochemical quality did not differ much between produce from the cold-chain system and that from the farmers' practice. Colorimetric L*, a* and b* values of the green leaf blade and white leaf petiole at market arrival were comparable to that of produce at the farm. Similarly, TSS, TA and pH of produce from the cold-chain system and farmers' practice were almost the same, except that the TSS content (4.2-4.4%) was lower than that at the farm (5.4%). Vitamin C content as a nutritional quality indicator did not widely vary between the two treatments (8.59-8.71 mg/100 g FW), which was slightly lower than that at the farm (9.04 mg/100 g FW). This finding is similar to results obtained in tomato in which fruit with and without cooling had comparable TSS, pH and vitamin C content [26].

Food safety was examined by quantifying coliform bacteria, *Enterobacteriaceae*, *E. coli* and *Salmonella* spp., which are indicators of contamination and hygiene. Coliform bacteria are commonly used as an indicator of contamination and sanitary quality of foods which can be found in the aquatic environment, in soil and on vegetation. *Enterobacteriaceae* is a large group of biochemically and genetically related Gram-negative bacteria used to assess the general hygiene status of a food product. It includes many of the more familiar pathogens, such as *Salmonella*, *E. coli*, *Klebsiella*, and *Shigella*. *E. coli* is a commonly used faecal indicator organism. Its presence in food generally indicates direct or indirect faecal contamination. Substantial number of *E. coli* in food suggests a general lack of cleanliness in handling and improper storage. *Salmonella* sp. is found in the intestinal tract of man and animals. Food may be contaminated by *Salmonella* in animal faeces and cross-contamination may occur during preparation and processing. Satisfactory levels of these bacteria in foods considered safe include < 2.0 log CFU/g of coliform and *Enterobacteriaceae* while *E. coli* and *Salmonella* should not be detectable in 25 g sample [27]. The results of the present study showed that produce from both cold-chain system and farmers' practice had coliform bacteria (4.08-4.23 log CFU/g), *Enterobacteriaceae* (4.18-4.38 log CFU/g) and *Salmonella* spp. (2.98-3.53 log CFU/g) (Table 2). These levels exceeded satisfactory levels, indicating the uncooked produce was unsafe for human consumption if no antimicrobial or sanitizing treatment is applied. In a separate study, lettuce collected from Cambodian informal markets observed high prevalence and concentration of bacterial pathogens, including *Salmonellaenterica*, *E. coli* and coliforms concentration in lettuce was observed (5.66, 2.75 and 6.31 log CFU/g, respectively), which was higher than the present study found in the Battambang value chain. These findings indicate unsanitary handling of vegetables in the informal markets and contaminated irrigation water are likely contributors of contamination and should be the focus to improve food safety practices for vegetable value-chain actors [28].

Table 1 Postharvest loss and quality of Chinese cabbage transported from Battambang farm source to Phnom Penh market under cold-chain system and farmers' practice.

Particulars	Cold-chain system	Farmers' practice	F-test[1]
Postharvest loss			
Weight loss, %[2]	-13.7	10.9	ns
Visual quality loss			ns
Visual quality at farm (Batt.)[3]	9.0	9.0	
Visual quality at market arrival (PNH)[3]	8.2	7.3	
Price reduction due to visual quality loss, %	5.0	10.0	
Total postharvest loss, %	-8.7	20.9	
Physicochemical quality			
Leaf blade color at market arrival in PNH			ns
L* values (at farm in Batt.—39.6)	38.5	44.5	
a* values (at farm in Batt.—-4.6)	-4.3	-4.4	
b* values (at farm in Batt.—22.3)	21.3	23.3	
Leaf petiole color at market arrival in PNH			ns
L* values (at farm in Batt.—52.2)	55.4	54.8	
a* values (at farm in Batt.—1.1)	0.8	1.5	
b* values (at farm in Batt.—15.0)	12.7	12.2	
TSS, % (at farm in Batt.—5.4)	4.2	4.4	ns
TA, % (at farm in Batt.—1.4)	1.7	1.8	ns
pH (at farm in Batt.—6.18)	6.14	6.15	ns
Nutritional quality			
Vitamin C, mg/100 g FW (at farm in Batt.—9.04)	8.71	8.59	ns

[1] ns—not significant; * significant at 5%, ** highly significant (significant at 1%).

[2] Negative values indicate weight gain.

[3] Visual quality rating: 9—excellent, field fresh, no defect; 7—good, defects minor; 5—fair, defects moderate; 3—limit of marketability; 1—inedible.

Table 2 Food safety of Chinese cabbage transported from Battambang farm source to Phnom Penh market under cold-chain system and farmers' practice.

Particulars	Cold-chain system	Farmers' practice	F-test
Food safety parameters			
Coliform bacteria, log CFU/g (at farm in Batt.—4.00)	4.08	4.23	ns
Enterobacteriaceae, log CFU/g (at farm in Batt.—4.11)	4.18	4.38	ns
E. coli, log CFU/g (at farm in Batt.—0.75)	0.60	0.00	ns
Salmonella, log CFU/g (at farm in Batt.—3.00)	2.98	3.53	ns

ns: not significant; * significant at 5%, ** highly significant (significant at 1%).

Furthermore, to address this problem, a sanitizing treatment should be included, such as adding chlorine or non-chlorine sanitizer in the wash water used in cleaning the produce in the packhouse [29]. Previous studies demonstrate that chlorine or non-chlorine sanitizing could be effective in enhancing food safety and shelf life of vegetables [30-35].

3.2 Storage Study

Coolbot storage expectedly maintained lower temperatures than ambient temperatures. Average temperatures in the Coolbot measured at three times of the day (morning, afternoon and evening) during storage ranged from 15.5-18.5 °C while ambient ranged from 28.9-31.4 °C. RH in the Coolbot cold chamber and at ambient did not widely differ and was 76-78% in the morning, 66-73% in the afternoon and 62-67% in the evening as present in Fig. 1.

The produce from the cold-chain system performed better in storage with or without MAP and Coolbot storage compared to their counterparts from the farmers' practice (Fig. 2). Cold-chain packed in MAP and kept in the Coolbot chamber had the lowest rate of visual quality loss and had the longest storage of 5 days among all treatments. Without MAP and Coolbot storage, produce had the shortest storage period, about 3 days for cold-chain produce and 2 days for produce from farmer's practice. The same trend in the rate of visual quality loss was obtained. According to the findings, the relationship between weight loss and visual quality of fruit and vegetable showed that lettuce leaves had 4 to 5% weight loss with storage period of 4 days at 20 °C and 85 to 95% RH [36].

Weight loss was remarkably reduced by MAP regardless of whether the produce was held in the Coolbot chamber or at ambient (Fig. 3). This was evident throughout storage. After one day of storage, MAP produce lost less than 10% of their weight whereas those held in the open had 20% weight loss or higher. Weight loss increased with advancing period of storage but at a more reduced rate in MAP than in the open. Coolbot storage had no added advantage in

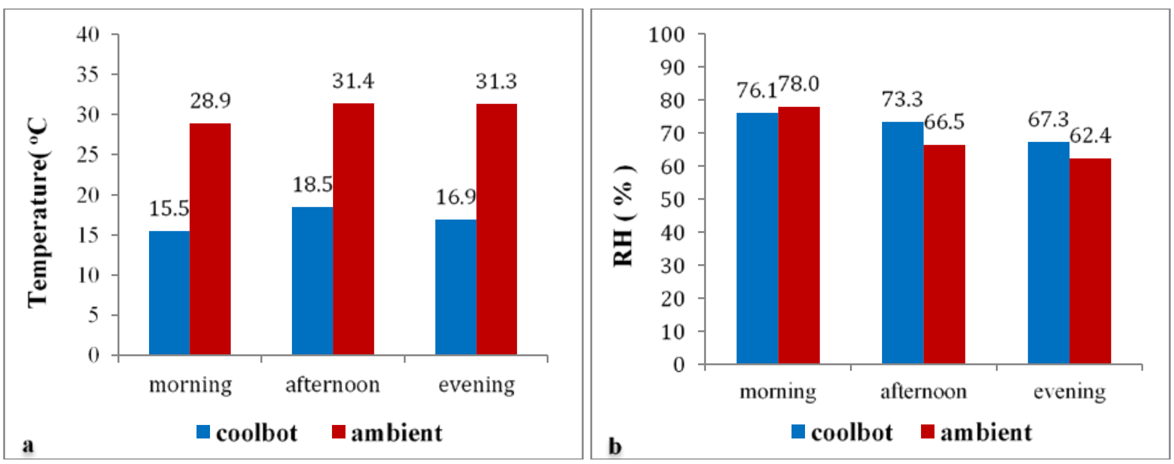

Fig. 1 Temperature and relative humidity (RH) during Coolbot and ambient storage of Chinese cabbage.

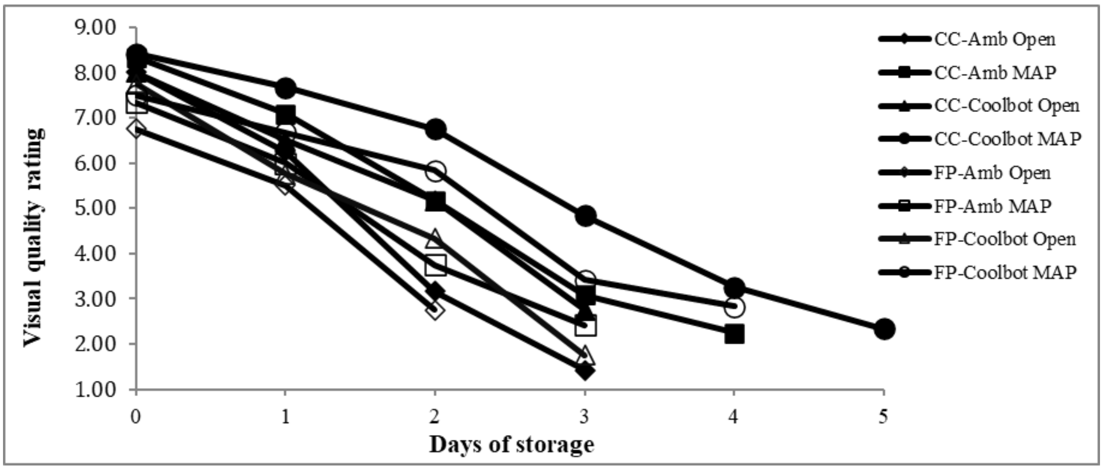

Fig. 2 Visual quality rating (VQR) of Chinese cabbage stored at ambient or Coolbot chamber with or without MAP after transport under cold-chain system (CC) or farmers' practice (FP).

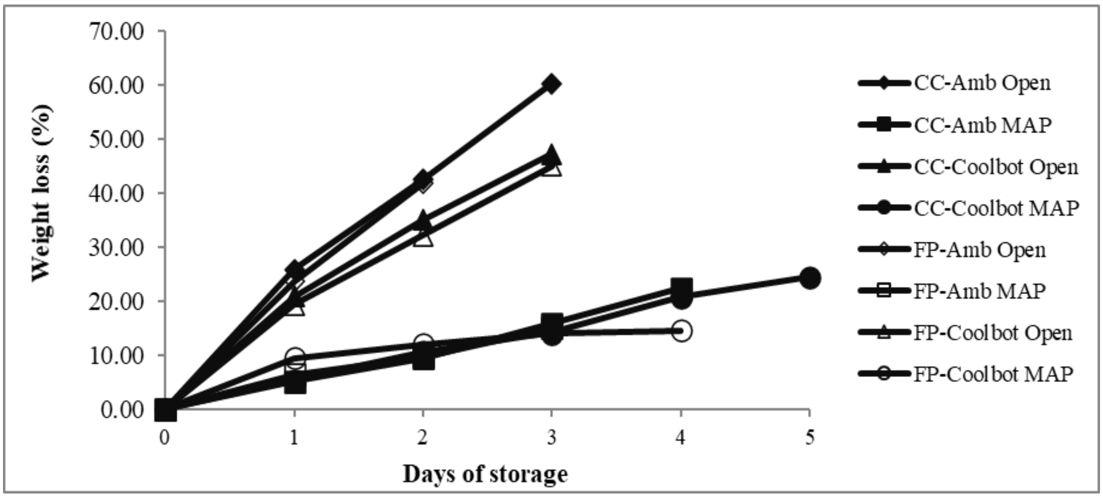

Fig. 3 Weight loss of Chinese cabbage stored at ambient or Coolbot chamber with or without MAP after transport under cold-chain system (CC) or farmers' practice (FP).

reducing weight loss in MAP produce. Without MAP, Coolbot-stored produce had lower weight loss than those stored at ambient. Furthermore, the handling system had no marked effect on weight loss as cold-chain produce and those from the farmers' practice had comparable weight loss. Color changes of the leaf blade and petiole were not greatly affected by the different treatments (Fig. 4). L* [white (100) to black (0)], a* [green (-) to red (+)] and b* [blue (-) to yellow (+)] values did not differ much from the initial levels. No consistent treatment effect was also obtained. In general, the leaf blade being green in color had lower L* and a* values and higher b* values than the white leaf petiole. These results indicate that color change did not contribute much to quality deterioration of Chinese cabbage during storage.

TSS content after one day of storage remained similar or slightly lower than the initial level of 4.8% (Fig. 5). It increased on the second day of storage but only in ambient-stored produce from both Cold-chain and farmers' practice handling systems, the latter reaching the limit of marketability (VQR 3) at this period. Coolbot-stored produce and those held in MAP in Coolbot chamber or at ambient had either similar or lower TSS content than that of the initial TSS content.

TA content increased with storage from an initial level of 1.7-1.9% (Fig. 6). After two days of storage, ambient-stored produce without MAP had more elevated TA levels than the other treatments. Coolbot-stored

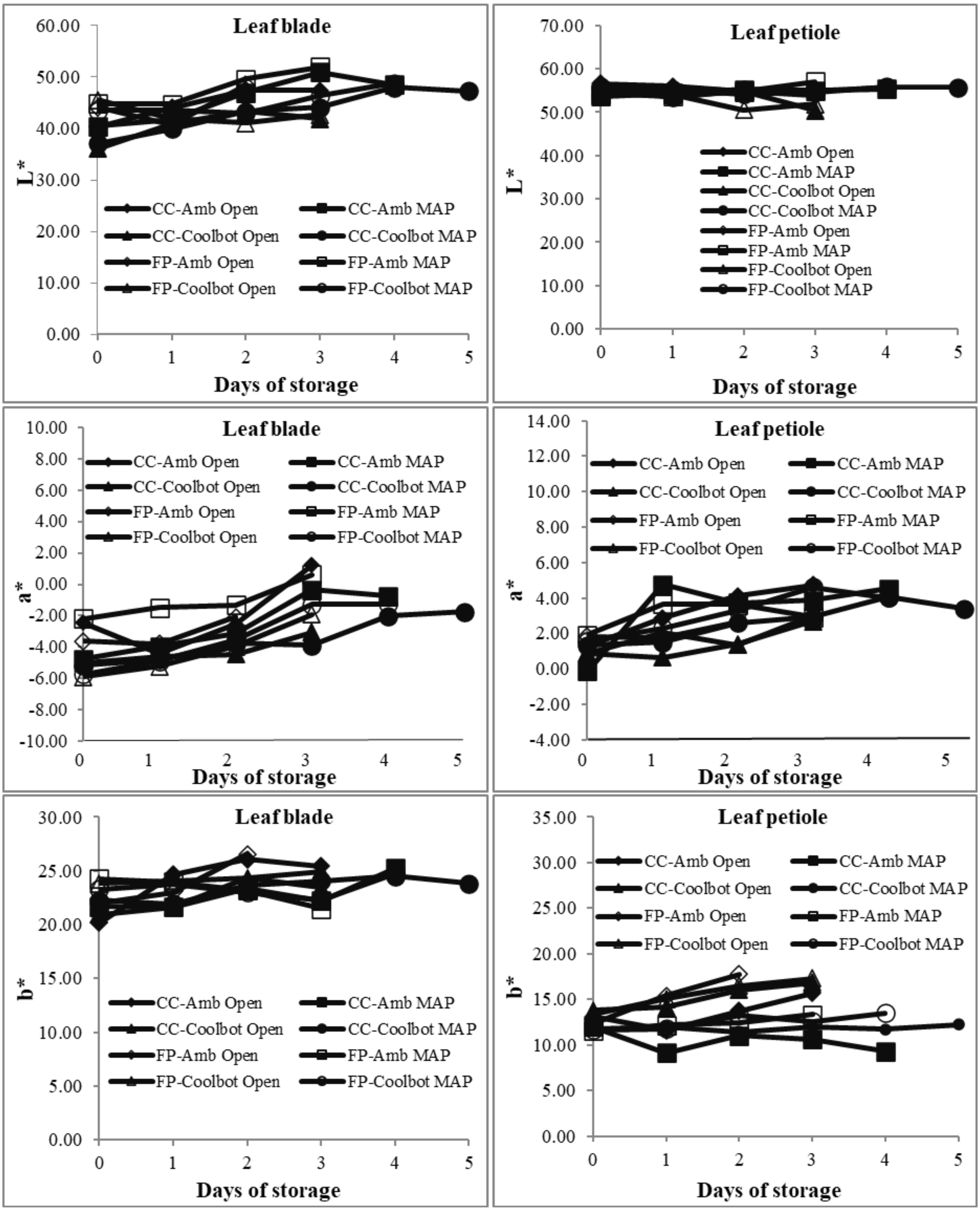

Fig. 4 L*, a* and b* of the leaf blade and petiole of Chinese cabbage stored at ambient or Coolbot chamber with or without MAP after transport under cold-chain system (CC) or farmers' practice (FP).

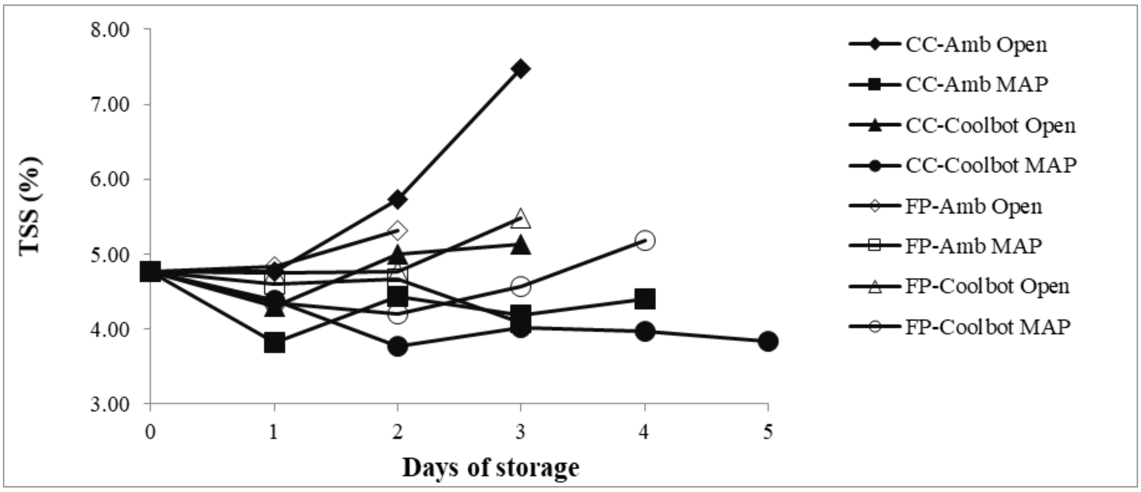

Fig. 5 TSS of Chinese cabbage stored at ambient or Coolbot chamber with or without MAP after transport under cold-chain system (CC) or farmers' practice (FP).

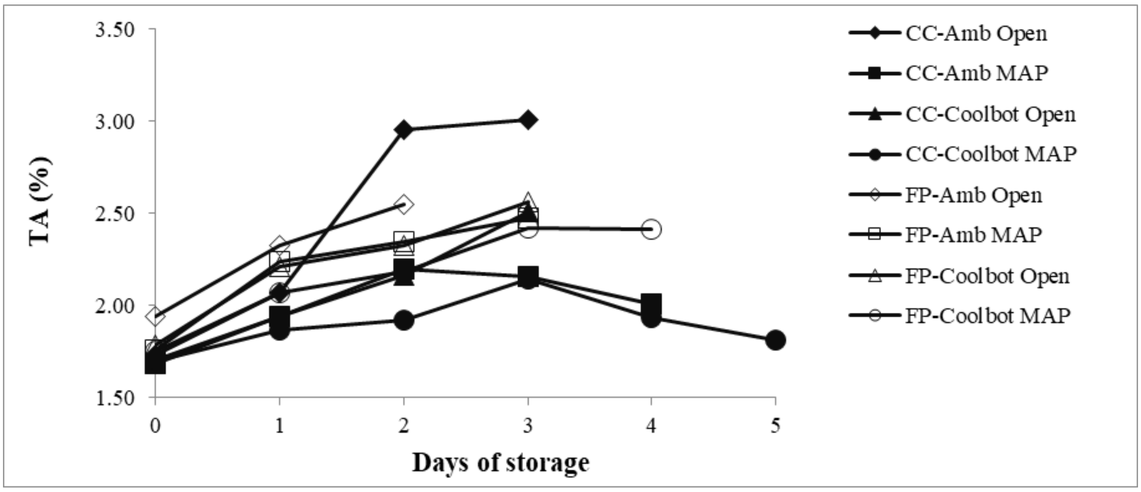

Fig. 6 TA of Chinese cabbage stored at ambient or Coolbot chamber with or without MAP after transport under cold-chain system (CC) or farmers' practice (FP).

produce in MAP had consistently the lowest TA level among treatments throughout its shelf life. The other treatments had intermediate TA levels. On the other hand, pH did not correlate with TA levels and no clear trend of treatment effect was apparent (Fig. 7). In general, pH ranged from 5.85-6.30 in all treatments throughout the storage period.

Vitamin C content remained almost similar to the initial content (8-9 mg/100 g FW) in all treatments during the first two days of storage (Fig. 8). On the third day of storage, it increased to more than 10 mg/100 g FW except in ambient-stored produce held in the open and MAP from the cold-chain system and farmers' practice, respectively. As the storage period advanced, vitamin C content further increased in cold-chain produce held in MAP at ambient or in Coolbot chamber.

Storage characteristics and shelf life of Chinese cabbage were largely determined by the storage conditions relative to the effect of handling system (cold-chain vs. traditional or farmers' practice). Combined low temperature (Coolbot storage) and MAP gave the longest shelf life, with the cold-chain produce having about one day longer shelf life than traditionally handled produce. As a single treatment, MAP appeared to be better in improving shelf life as it was more effective in reducing weight loss than low temperature storage. Weight loss (water loss) and

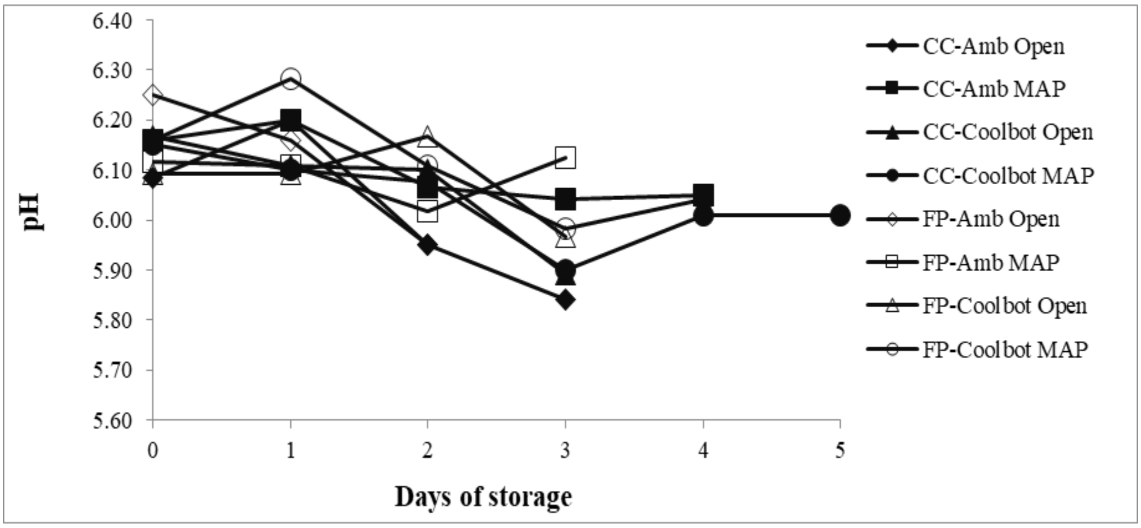

Fig. 7 pH of Chinese cabbage stored at ambient or Coolbot chamber with or without MAP after transport under Cold-chain system (CC) or farmers' practice (FP).

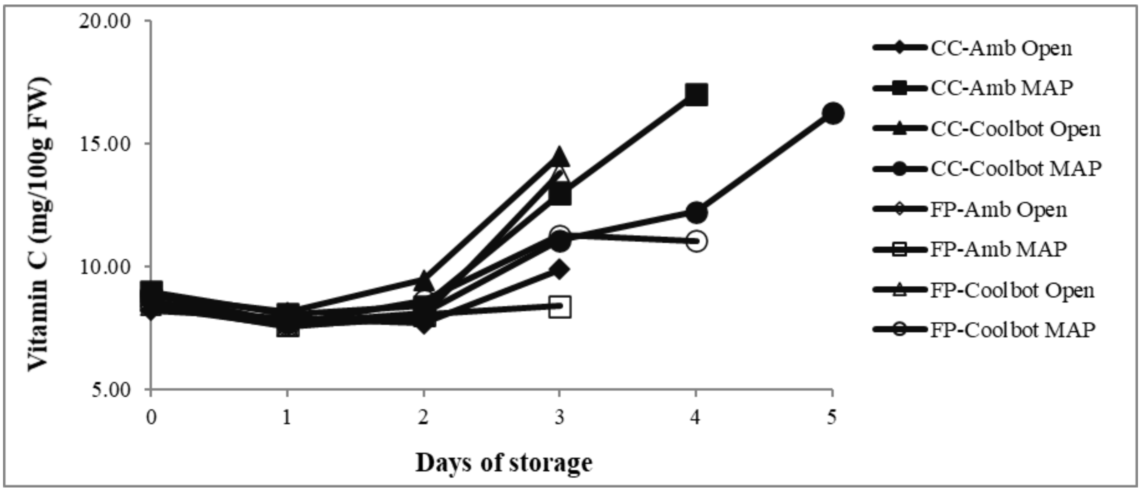

Fig. 8 Vitamin C content of Chinese cabbage stored at ambient or Coolbot chamber with or without MAP after transport under cold-chain system (CC) or farmers' practice (FP).

Table 3 Coliform, *Enterobacteriaceae*, *E. coli* and *Salmonella* counts at the end of shelf life of Chinese cabbage stored at ambient or Coolbot chamber with or without MAP after transport under cold-chain system (CC) or farmers' practice (FP).

Treatment	Coliform, log CFU/g	*Enterobacteriaceae*, log CFU/g	*E. coli*, log CFU/g	*Salmonella*, log CFU/g
Cold-chain system				
Ambient, open	4.67	5.11	0.67	4.11
Ambient, MAP	5.21	5.39	0.67	4.19
Coolbot, open	3.72	3.96	0.00	2.84
Coolbot, MAP	4.02	4.54	0.00	2.47
Farmers' practice				
Ambient, open	4.40	4.75	0.79	3.85
Ambient, MAP	5.12	5.51	0.85	3.42
Coolbot, open	4.18	4.42	0.00	2.49
Coolbot, MAP	3.47	3.57	0.00	2.99

Mean separation within columns by LSD, 5%.

associated leaf wilting were the main determinants of quality loss and shelf life. Leaf yellowing had no marked influence on shelf life evidenced by the colorimetric L*, a* and b* values which did not differ widely from the initial readings at the start of storage regardless of treatments. Chemical parameters including vitamin C content did not show consistent treatment effects. These results were consistent with previous findings on the effects of Coolbot storage and MAP on different types of vegetables [29-31, 37-40].

Microbiological quality was improved by Coolbot storage of produce from both the cold-chain system and farmers' practice (Table 3). Coolbot-stored produce had lower coliform, *Enterobacteriaceae* and *Salmonella* counts than ambient-stored produce with or without MAP. *E. coli* was not detected in Coolbot-stored produce while ambient-stored produce had 0.67-0.85 log CFU/g. The handling system (cold-chain vs. farmers' practice) and MAP had no consistent effect on these microbial parameters. Furthermore, low temperature storage was more effective than MAP in reducing indicator microbial population (coliforms, *Enterobacteriaceae*, *Salmonella* and *E. coli*). However, the colony counts exceeded the satisfactory levels for food safety implying as satisfactory level of bacteria in foods less than 2.0 log CFU/g coliform and *Enterobacteriaceae* while for *E. coli* and *Salmonella*, they should not be detectable in 25 g sample of the need to integrate sanitizing treatment to further improve the cold-chain and storage in enhancing the quality and food safety of Chinese cabbage [30].

4. Conclusion

The study shows the benefits of the cold-chain in reducing postharvest loss during transport and the effects of storage conditions on quality of Chinese cabbage. Postharvest practices of vegetable farmers were technology-deficient and the ambient handling and transport of produce from the farm source in Battambang Province to Phnom Penh market resulted in high postharvest loss of 21%.

Shelf life, defined as storage period, was the longest (more than 4 days) when Coolbot storage and MAP were combined. The shelf life of produce transported by the cold-chain system was about one day longer than traditionally handled produce. When applied as a single treatment, Coolbot storage or MAP resulted in a shorter shelf life than when treatments were combined but was longer than that of produce stored at ambient without MAP. Since shelf life was mainly determined by weight loss (water loss), MAP was more effective than Coolbot storage in extending shelf life.

The physicochemical and nutritional quality of produce from the cold-chain system did not differ much from that of produce traditionally handled and transported. TSS, TA, pH and vitamin C contents did not show consistent treatment effect during storage.

A notable outcome of this study is the effect of cold-chain on food safety. Produce stored and transported using cold chain practices had lower counts of food safety indicator organisms (coliform bacteria, *Enterobacteriaceae*, *E. coli* and *Salmonella* spp.) than traditionally handled produce. While both handling systems resulted in microbial counts that exceeded the satisfactory levels for food safety, this study indicates cold chain is an important tool for improving food safety.

Acknowledgement

This research is made possible by the generous support of the American People provided through the United States Agency for International Development (USAID) to the following: Building Safe Vegetable Value Chains in Cambodia Program through the Feed the Future Horticulture Innovation Lab for Collaborative Research at the University of California Davis, subaward No. 09-002945-130 to KL and GMY; the Borlaug Global Food Security Graduate Research Program as part of the U.S. government's global hunger and food security initiative called Feed the

Future, grant No. 13076416 to KL; and the Center of Excellence on Sustainable Agricultural Intensification and Nutrition (CE SAIN) of the Royal University of Agriculture through the Feed the Future Innovation Lab for Collaborative Research on Sustainable Intensification at Kansas State University (USAID) under Cooperative Agreement No. AID-OAA-L-14-00006. Additional support was provided by Sierra College and awards from the University of California President's and Chancellor's Postdoctoral Fellowship Program to KL.

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