Original article

Effect of modified atmosphere and ethylene absorbers on extension of storage life of 'Kolikuttu' banana at ambient temperature

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Abstract — Introduction. In Sri Lanka, bananas of 'Kolikuttu', an indigenous cultivar, are sold more expensive than those of the other cultivars, due to their pleasing taste. Early ripening, an inherent character of these fruits, shortens their post-harvest life. **Materials and methods**. Mature 'Kolikuttu' banana hands, enclosed in low density polyethylene (LDPE) bags of 75 µm thickness to create a modified atmosphere (MA), were stored at room temperature (25 ± 2 °C) and 85 ± 1 % relative humidity. The effectiveness of clay bricks impregnated with potassium permanganate as ethylene absorbers (EA) was studied. During storage, carbon dioxide, oxygen and ethylene contents in the packages were measured. The packages were opened after MA storage, and the banana hands ripened naturally under ambient conditions. Weight loss, changes in total soluble solids (TSS), titrable acidity (TA), pH, firmness, sugar-acid ratio and peel colour, during / or after storage, were determined. **Results**. Compared to the samples packed without EA, those packed with EA had significantly lower in-package ethylene and carbon dioxide contents, higher oxygen contents and minimum changes in firmness and TSS content; their weight loss, TA and pH little varied during MA storage. The modified atmosphere created inside the LDPE packages with EA was effective in extending the green life of 'Kolikuttu' banana up to 20 d. The fruits ripened naturally within 4 d after the end of storage. **Discussion**. Packaging of 'Kolikuttu' banana as individual hands in LDPE bags with a wrapped ethylene absorber could be recommended to extend their shelf life at ambient temperature. This could be of considerable economic importance in countries where cold storage is not readily available or expensive. The technology is not complicated and could be easily adopted by the farmers to minimize post-harvest losses of bananas. © Éditions scientifiques et médicales Elsevier SAS

Sri Lanka / *Musa* (fruits) / packing (process) / controlled atmosphere storage / postharvest life duration

Effet de l'atmosphère modifiée (AM) et de l'utilisation d'absorbeurs d'éthylène (AE) sur la prolongation de la durée de vie de bananes 'Kolikuttu' à la température ambiante.

Résumé — Introduction. Au Sri Lanka, les bananes du cultivar indigène 'Kolikuttu' sont vendues plus chères que celles des autres cultivars en raison de leur goût agréable. Leur maturation précoce, caractère inhérent de ces fruits, raccourcit leur durée de vie après récolte. **Matériel et méthodes**. Des mains de bananes 'Kolikuttu' mûres, introduites dans des sachets en polyéthylène de faible densité (LDPE) de 75 µm d'épaisseur créant les conditions de AM, ont été stockées à 25 ± 2 °C et 85 ± 1 % d'humidité relative. L'efficacité de briques d'argile imbibées de permanganate de potassium utilisées comme AE a été étudiée. Pendant le stockage, les concentrations en CO_2, O_2 et C_4H_2 ont été mesurées dans les sachets. Après stockage en AM, les sachets ont été ouverts et les bananes ont mûri naturellement dans les conditions ambiantes. La perte de poids, les changements d'extraits secs solubles (ESS), d'acidité titrable (AT), de pH, de fermeté, du rapport [sucre/acidité] et de couleur de la peau, pendant / ou après le stockage, ont été déterminés. **Résultats**. Comparés aux échantillons emballés sans AE, ceux emballés avec AE ont eu, à l'intérieur des sacs, des concentrations en C_4H_2 et en CO_2 sensiblement inférieures, des taux plus élevés en O_2 et des changements minimes de fermeté et de teneur en ESS ; leur perte de poids, AT et pH ont peu changé pendant le stockage en AM. L'AM créée à l'intérieur des sacs en LDPE munis d'AE a prolongé la vie verte des bananes du cultivar 'Kolikuttu' jusqu' à 20 d. Les fruits ont mûri naturellement en moins de 4 d après la fin du stockage. **Discussion**. L'emballage de bananes 'Kolikuttu', sous forme de mains individuelles, dans des sacs en LDPE munis d'AE, pourrait être recommandé pour prolonger leur durée de conservation à la température ambiante. Cette technologie, apte à présenter une importance économique considérable dans les pays où le stockage au froid est cher ou peu facile, n'est pas compliquée. Elle pourrait être facilement adoptée par les planteurs pour réduire au minimum les pertes après récolte des bananes. © Éditions scientifiques et médicales Elsevier SAS

Sri Lanka / *Musa* (fruit) / emballage (traitement) / stockage en atmosphère controlée / durée de vie postrécolte

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1. introduction

In Sri Lanka, many banana cultivars are indigenous to the country. Among these, 'Embul' (AAB) is the most abundant dessert clone, while 'Kolikuttu' and 'Suwandal' (AAB) are the most popular [1]. The cultivar 'Kolikuttu' receives a higher price than that of the other cultivars due to the pleasing taste of its fruit. It is cultivated mainly in the dry and intermediate zones of Sri Lanka. After harvesting, 'Kolikuttu' banana ripens faster than that of 'Cavendish' type resulting in a shorter post-harvest life. Ripening is initiated either by the endogenous ethylene evolved as the fruit reaches full maturity or by the exogenous ethylene applied commercially [2]. Thus, the suppression of ethylene synthesis and/or removal of endogenous ethylene could delay the ripening process.

In Sri Lanka, post-harvest losses of banana are reported being about 20 to 80 % [3]. These losses are mainly due to improper handling during harvesting and transport, poor transport facilities, lack of storage facilities and processing, and post-harvest diseases or disorders.

Modified atmosphere (MA) packaging is recognized as an easy and inexpensive method of extending the shelf-life of fresh fruits and vegetables compared to controlled atmosphere (CA) storage [4–8]. Modified atmosphere is created when fruits are sealed in packaging films with intermediary permeability to gases. When fruit respires, in-package gaseous composition is altered. Therefore, metabolic activities decreased, thereby extending post-harvest life of fruits.

Extention of post-harvest life of 'Cavendish' [9] and 'Williams' banana [10] under MA conditions at different temperatures has been reported. This study describes the development of a modified atmosphere packaging system to extend the storage life of 'Kolikuttu' banana at the room temperature. The effect of MA conditions on the eating quality of the fruit was studied. The effectiveness of the potassium permanganate as an ethylene absorber in further extending the storage life was also tested.

2. materials and methods

2.1 storage

Mature 'Kolikuttu' banana ('3/4 full') bunches harvested from farming fields in the Kurunagala District were transported to the laboratory at Peradeniya (Sri Lanka). Damage free hands with 12 to 14 fingers of uniform size were selected; washed with running water and air-dried at 25 ± 2 °C. The crown area of each hand was dipped in 0.1 % benomyl solution and air-dried. A saturated solution of potassium permanganate (50 mL) was absorbed on to individual clay bricks (9 × 4.5 × 4.5 cm) and dried in the sun for 4 h until the surface of the brick was completely dry; then the brick was used as ethylene absorbers. Fifteen bricks impregnated with potassium permanganate were wrapped individually with high-density polyethylene bags (17 × 12 cm) of 20 µm thickness and used as wrapped ethylene absorbers to prevent staining of the peel by direct contact of the fruits with the potassium impregnated the brick. Modified atmospheres were created by using LDPE (75 µm) bags. This film, recommended by the Varna Ltd., Ratmalana, a leading packaging manufacturer in Sri Lanka, provides the barrier properties required for developing MAP for fresh commodities, while being available and affordable. Oxygen, carbon dioxide and water vapour permeability rates of the material were 0.026 $mL \cdot m^{-2} \cdot h^{-1} \cdot atm^{-1}$, 0.11 $mL \cdot m^{-2} \cdot h^{-1} \cdot atm^{-1}$ and 185 $g \cdot m^{-2} \cdot h^{-1} \cdot atm^{-1}$, respectively. Fifteen individual hands were enclosed in fifteen LDPE (75 µm) bags of 1.2:1 surface to weight ratio ($cm^2 \cdot g^{-1}$) (treatment 1). Another 15 individual hands were packed in the same manner with 15 unwrapped ethylene absorbers in each bag (treatment 2). Similarly 15 more hands were packed individually with 15 wrapped ethylene absorbers in each bag (treatment 3). Self-sealing septums were fixed on to the packages to facilitate gas measurements. Three hands were enclosed in perforated LDPE bags and used as the control. All the packages were tied tightly with rubber bands and stored at room temperature (25 ± 2 °C) and 85 ± 1 % relative humidity.

2.2. gaseous composition

In-package concentrations of oxygen and carbon dioxide were measured on the 10th, 14th, 17th and 20th day of storage using portable gas meters (Riken Keiki Co. Japan, Model OX-226 and Model RI-411A, respectively). In-package concentration of ethylene was measured at similar time intervals using a gas chromatograph (Shimadzu, Model GC-14B). For ethylene measurement, a Poropak Q column, a flame ionization detector, nitrogen career gas at a flow rate of 70 mL·min^{-1}, and column, injector and detector temperatures of 65 °C, 100 °C and 120 °C, respectively, were used.

2.3. physico-chemical properties

Weight loss (%) of each hand was calculated at the end of storage period.

Physico-chemical properties of the fruit were measured in triplicates after opening the packages on 10, 14, 17 and 20-days. Firmness of the pulp was measured by using a fruit firmness tester (AST Everwell Co.). Total soluble sugars (TSS), pH and titrable acidity (TA) were estimated on finely cut flesh tissue (5 g), homogenized with 5 mL of distilled water using a mortar and pestle. The mortar and pestle was washed twice with 5 mL each of distilled water. The pooled fractions were centrifuged (Himac CR 21 E, Hitachi) at 13 000 × *g* at 4 °C for 10 min. The TSS of the supernatant was measured using a hand held refratometer (Reichert), and the pH was measured using a pH meter (IM-40S TOA Electronics). The supernatant diluted twice was titrated against 0.1N sodium hydroxide until the pH was 8.1, and the TA was expressed as percentage malic acid.

The optimum storage period under different MA conditions was determined based on physico-chemical properties of the fruits and the in-package concentration of oxygen and carbon dioxide. The packages were opened, and the banana hands were allowed to ripen naturally under ambient conditions until the table ripe stage. The time taken for ripening was noted. Yellowness of the peel was measured by using a colour difference meter (2E 2000 Nippon Denshuku), and the values were expressed as the 'b' coefficient (Hunter colour system), which measures the 'yellow saturation index', and compared with the control fruits. The firmness, TA, TSS, pH and sugar-acid ratio of ripened banana after MA storage were determined and compared with the ripened fruits that were not subjected to MA storage.

2.4. experimental design and statistical analyses

The banana hands were subjected to three treatments namely, enclosing in LDPE (75 µm) without ethylene absorbers, with wrapped and unwrapped ethylene absorbers, in a randomised completely block design (RCBD) nested with three replicates. Samples packed in perforated packages were used as the control. The data were subjected to variance analysis using the SAS package [11]. Treatments were compared at $p < 0.05$ according to the Fisher's protected Least Square Difference (LSD) test. The data obtained for ripened fruits were analyzed using ANOVA, and the means were separated using the Duncan's multiple range test.

3. results

3.1. changes in gaseous composition

The in-package ethylene concentrations of samples packed with ethylene absorbers were significantly different from those packed without ethylene absorbers (*figure 1*). The unwrapped absorber was more successful in removing ethylene than that of the wrapped absorbers as indicated by 71 ppb and 98 ppb of in-package ethylene on day 20. At room temperature and within 10 d of storage, the oxygen content reduced to 6 % in packages with the unwrapped absorbers, 4 % when wrapped absorbers were present and 3 % in packages without absorbers (*figure 1*). Further changes were observed during storage for 20 d. Increase in oxygen concentration could be due to an experimental error or low precision of the portable gas meter. Within 10 d of storage,

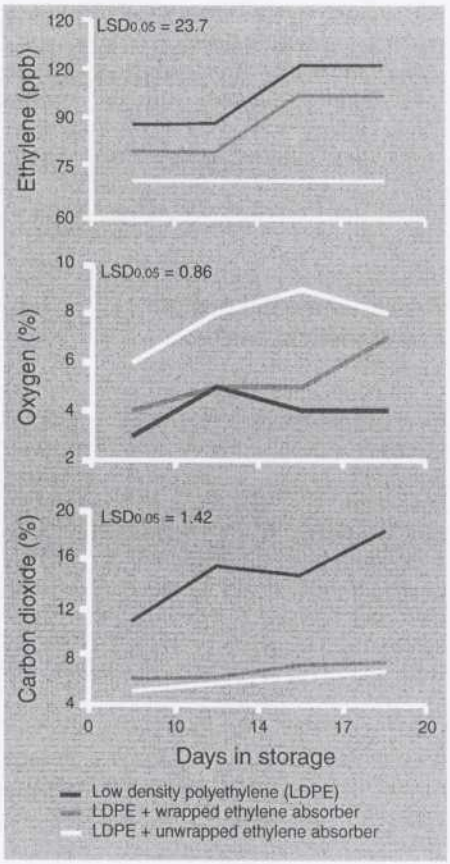

Figure 1.
In-package concentrations of ethylene, oxygen and carbon dioxide during storage of 'Kolikuttu' banana at ambient temperature. Each point represents the mean of three replications.

in-package carbon dioxide concentrations increased to 5 %, 6 % and 10.8 % in the packages with unwrapped absorbers, wrapped absorbers and without absorbers, respectively (*figure 1*). These values did not increase significantly with storage in the samples packed with ethylene absorbers. However, carbon dioxide levels increased to 18 % within 20 d in samples packed without ethylene absorbers.

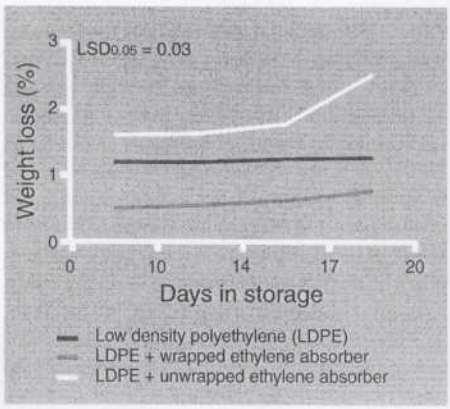

Figure 2.
Weight loss in 'Kolikuttu' banana at ambient temperature. Each point represents the mean of three replications.

3.2. weight loss

After 10 d, a weight loss of 4.1 % was noted for the fruits packed in perforated bags (results not shown). It did not change significantly in the samples packed with the wrapped absorbers and without absorbers. However, the samples packed with unwrapped absorbers showed a weight loss of 1.8 % in 10 d and increased thereafter up to about 2.4 % in 20 d (*figure 2*).

3.3. changes in physicochemical properties during storage

The changes in firmness of the fruits during storage for 20 d in LDPE with ethylene absorbers were not significant (*figure 3*). In the absence of ethylene absorbers, the firmness decreased significantly. The TSS content of all the samples subjected to MA storage changed significantly (*figure 3*). The presence of ethylene absorbers lowered these changes. Percentage TA and pH of the pulp of all the samples showed no significant change during MA storage (*figure 3*).

3.4. physicochemical properties of ripened banana

The optimum storage period of the samples packed in LDPE was 10 d (*table I*). Further increase in storage period by 10 d was possible on introducing the ethylene absorbers. There were no differences in firmness, TA and TSS between the MA stored banana and the control (*table I*). The pH value of the samples packed with the unwrapped ethylene absorber was similar to the control and was slightly higher than that of the samples packed with the wrapped absorber. The highest 'b' value for peel colour was obtained for the samples packed with the wrapped absorbers and the lowest value for samples packed in LDPE alone. There was no difference in the 'b' value between the samples packed with the unwrapped absorber and the control.

Sugar-acid ratio of the samples packed with the ethylene absorbers and the control was similar. The lowest sugar-acid ratio was obtained for the samples packed in LDPE alone.

4. discussion

'Kolikuttu' banana harvested at '3/4 full' maturity stage ripened within 6 d after harvesting at room temperature. After storage, the samples packed in LDPE without and with ethylene absorbers for 10 d and 20 d, respectively, ripened naturally within 4 d at room temperature. Delaying of ripening of MA stored banana may be due to decrease in rate respiration and other biochemical processes under high carbon dioxide atmospheres (*figure 1*) as indicated by non-significant changes in pH and % TA during storage (*figure 3*). Since carbon dioxide is a product of the respiratory process, rate of respiration would decrease, as carbon dioxide level surrounding the plant tissues is increased [12–15]. Low oxygen levels developed inside the packages may also have contributed to reduced rate of respiration and delaying ethylene production as indicated by low in-package variation of ethylene between 71 ppb and 107 ppb during MA storage (*figure 1*). Delaying climacteric rise under low oxygen conditions [16] and delaying ethylene production as a result of inactivation of 1–aminocyclopropane–1–carboxylic acid oxidase under MA conditions [9] have been reported for 'Cavendish' banana. Moreover, extension of postharvest life of 'Cavendish' banana by using 1–methylcyclopropane, an antiethylene compound, in combination with polythene bags has been reported [17].

The in-package carbon dioxide concentration of the samples packed without ethylene absorbers increased to 10.8 % within 10 d of storage (*figure 1*). This is beyond the maximum tolerable levels of 8 % [4] as indicated by significant decrease in firmness of the samples packed without ethylene absorbers (*figure 3*). However, in-package carbon dioxide concentration of the fruits packed in LDPE with wrapped and unwrapped ethylene absorbers were 7.4 % and 6.7 %, respectively, on the 20th day of storage. The oxygen concentrations in the packages with ethylene absorbers did not decrease below 2–3 %, which is considered the minimum tolerable level for most fruits and vegetables [4]. This indicates that use of ethylene absorbers helped not only in controlling the in-package ethylene concentration but also in keeping the in-package carbon dioxide concentration below the injury level and oxygen above the injury level.

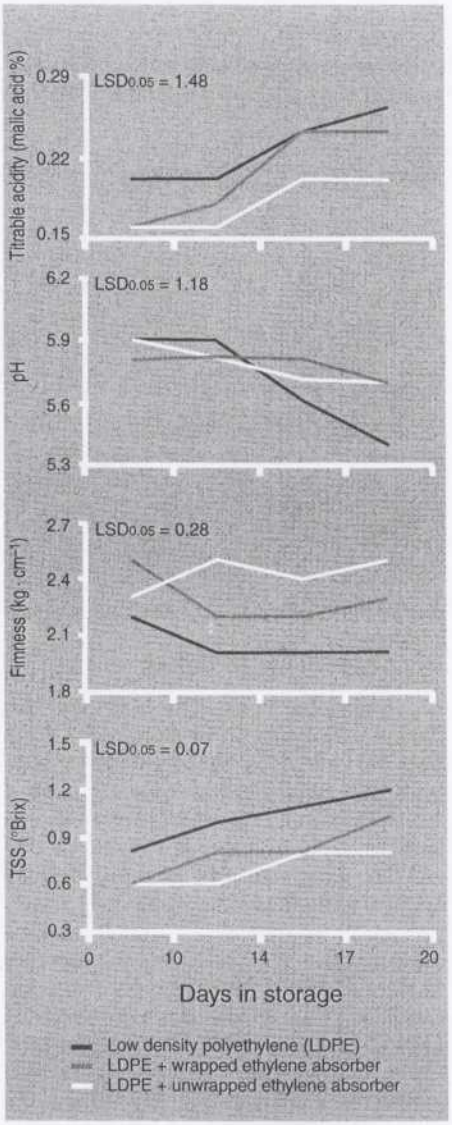

Figure 3.
Changes in physico-chemical properties of 'Kolikuttu' banana at ambient temperature. Each point represents the mean of three replications.

Table I.
Physico-chemical properties of 'Kolikuttu' banana at the table-ripe stage, after storage under different conditions at 25 ± 2 °C and 85 ± 1 % relative humidity.

Storage condition	Storage period (d)	Firmness ($kg \cdot m^{-1}$)	Titrable acidity (% malic acid)	Total soluble solids (°Brix)	pH	Ratio [sugar/acid]	Peel colour 'b' value
Control	6	1.90	0.80	4.70	4.38	4.80 ab	27.47 b
LDPE[1]	10	1.80	0.80	4.50	4.32	4.60 b	26.82 c
LDPE + wea[2]	20	1.90	0.76	4.40	4.31	4.80 ab	29.47 a
LDPE + uwea[3]	20	2.00	0.76	4.60	4.39	5.00 a	27.42 b
Test significance	–	ns	ns	ns	ns	**	**
Duncan's critical value	–	0.29	0.08	0.30	0.20	0.20	0.15

[1] LDPE: low density polyethylene.
[2] wea: wrapped ethylene absorber.
[3] uwea: unwrapped ethylene absorber.
Each value represents the mean of three replications.
Duncan's test, $p < 0.05$; ns: means not significantly different; ** Means significantly different; a, b, c: groups of means significantly different.

A previous study [18] indicated that 'Embul' banana could be stored for 12 d in polyethylene bags under ambient conditions without ethylene absorbers. Results of this study showed that shelf life of 'Kolikuttu' banana could be extended up to 20 d at ambient temperature by packing in LDPE (75 µm) with ethylene absorbers. The fruits ripened naturally within 4 d after opening the packages. Physico-chemical properties of ripened fruit (*table I*) stored under MA conditions were similar to the fruits ripened naturally within 6 d after harvesting, indicating that modified atmosphere created inside the packages did not impair the ripening process.

It was evident that packaging helped in controlling the weight loss (*figure 2*). However, the weight loss was more in the fruits packed with the unwrapped ethylene absorbers than those packed with the wrapped ethylene absorbers. This may be due to the absorption of moisture by the porous unwrapped ethylene absorbers. Use of unwrapped absorbers could also be limited due to staining of the peel by potassium permanganate, thereby reducing the consumer acceptance, as indicated by lower 'b' value for peel colour of fruits packed with the unwrapped absorbers than those packed with the wrapped absorbers (*table I*). Thus, packaging of 'Kolikuttu' banana as individual hands in LDPE (75 µm) bags of 1.2:1 surface to weight ratio ($cm^2 \cdot g^{-1}$) with a wrapped ethylene absorber could be recommended to extend shelf life of 'Kolikuttu' banana at ambient temperature. This could be of considerable economic importance in Sri Lanka as well as in other developing countries where cold storage is not readily available or expensive. The preparation of ethylene absorbers and enclosing banana hands in LDPE bags is not complicated. Therefore, the farmers themselves could easily adopt this technology to minimize post-harvest losses of banana.

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Efecto de la atmósfera modificada (AM) y de la utilización de absorbedores de etileno (AE) en la prolongación de la duración de vida de bananos 'Kolikutto' a temperatura ambiente.

Resumen — Introducción. En Sri Lanka, los bananos del cultivar autóctono 'Kolikutto' se venden más caros que los de los demás cultivares debido a su agradable sabor. Su maduración precoz, carácter inherente de estos frutos, reduce su duración de vida postcosecha. **Material y métodos**. Se almacenaron a 25 ± 2 °C y 85 ± 1 % de humedad relativa, manos de bananos 'Kolikutto' maduros en bolsas de polietileno de baja densidad (LDPE) de 75 µm de grosor creando condiciones de AM. Se estudió la eficacia de ladrillos de arcilla embebidos de permanganato de potasio utilizados como AE. Durante el almacenamiento se midieron las concentraciones de CO_2, O_2 y C_4H_2 en las bolsas. Tras almacenamiento en AM, se abrieron las

bolsas y los bananos maduraron naturalmente en atmósfera ambiente. Se determinó la pérdida de peso, los contenidos de sólidos solubles totales (SST), acidez titulable (AT), pH, textura, relación [azúcar/acidez] y color de la piel durante o después del almacenamiento. **Resultados**. Comparados con las muestras embolsadas sin AE, las muestras embolsadas con AE presentaron, dentro de las bolsas, concentraciones de C_4H_2 y CO_2 sensiblemente inferiores, tasas más altas de O_2 y cambios mínimos de textura y contenidos en SST. AT, PH y pérdida de peso cambiaron poco durante el almacenamiento en AM. La AM creada en el interior de las bolsas de LSPE con AE aumentó la vida verde de los bananos del cultivar 'Kolikuttu' hasta 20 d. Los frutos maduraron naturalmente en menos de 4 d tras el final del almacenamiento. **Discusión**. El empacado de bananos 'Kolikuttu', en manos individuales, en sacos de LDPE con AE, podría recomendarse para prolongar su duración de conservación a temperatura ambiente. Esta tecnología, capaz de presentar una importancia económica considerable en los países en los que el almacenamiento en frío es caro o difícil, no es complicada. Los agricultores podrán aplicarla fácilmente para reducir al mínimo las pérdidas postcosecha de los bananos.

Sri Lanka / *Musa* (fruta) / embalaje / almacenamiento / atmósfera controlada / duración de vida postcosecha