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Effects of Calcium Carbide and 2-Chloroethylphosphonic Acid on Fruit Quality of Thai Mangoes under Various Postharvest Ripening Regimes

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Summary

Calcium carbide (CaC_2) and 2-chloroethylphosphonic acid (CEPA) are commonly applied in Thailand on wholesale markets and by the fruit processing industry to accelerate postharvest ripening of mangoes. Aiming at systematic investigation of the effects that the ripening accelerators exert on the development of chemical and physical fruit quality attributes, the impact of these agents and temperature on postharvest ripening of three Thai cultivars of prime commercial relevance were evaluated. Mature-green fruits of cvs. 'Nam Dokmai', 'Kaew', and 'Chok Anan' were ripened under daily monitoring for 7 days at 24±2 °C and 33±2 °C, representative for ambient temperature during fruit distribution in Europe and Thailand. At the applied dose (10 g kg^{-1} of fruit), CaC_2 showed a significant effect only on firmness and peel colouration, except for peel colour of 'Nam Dokmai'. Mangoes treated with CaC_2 were softer and therefore more sensitive to mechanical damage during handling and processing. Apart from minor differences in the contents of titratable acids of 'Nam Dokmai' and 'Kaew' observed at some days, no influence of the treatment with CEPA at a solution concentration of 200 mg kg^{-1} on fruit firmness, colour of peel and mesocarp, and chemical fruit quality was observed. When eating ripeness was defined based on the characteristic developments of total soluble solids and the sugar/acid ratio, the required ripening time was not affected by the chemical treatments, whereas exposure to the higher temperature resulted in shortening by one day. Consequently, the use of the ripening agents was not justified from an economic point of view. Depending on the physiological maturity at the time of application, they may even worsen overall fruit quality through different enhancement of external and inner quality parameters with exclusive stimulation of fruit softening and peel colour changes.

Key words. Ethylene – fruit – *Mangifera indica* L. – fruit quality – postharvest – ripening

Introduction

Thailand is among the three leading mango producers with an annual production of 1.8 million tons, but less than 2 % of the production is sold on the world market (FAOSTAT 2006). Processed mangoes include juice, pulp, as well as canned and dehydrated mango slices. Since mango is a climacteric fruit, its quality is greatly affected by postharvest ripening processes (LESHAM et al. 1986; VÁSQUEZ-CAICEDO et al. 2005). Common methods used in Thailand to accelerate ripening include the application of the ethylene-releasing 2-chloroethylphosphonic acid (CEPA) and calcium carbide (CaC_2) that decomposes to acetylene being an ethylene-action analogue. Their application is mainly ascribed to the improved stimulation of a yellow peel colouration. On the other hand, VÁSQUEZ-CAICEDO et al. (2002) showed that the peel colour did not necessarily correlate with mango fruit ripeness of all Thai cultivars. Since highly diluted aqueous solutions of ethylene-releasing compounds are not reusable, ripening costs are high and sophisticated waste-water treatment is required. Thus, effectiveness of such ripening procedures is of general economic interest as regards optimised handling of mango fruits in fresh fruit marketing and industrial processing.

Ethylene-releasing compounds are occasionally applied preharvest to enhance ripening of fruits and vegetables on the plant, e.g. in apple, tomato, melon, pepper, and coffee (CHESWORTH et al. 1998). In the postharvest phase, endogenous ethylene accelerates ripening and subsequent senescence of fruit tissues by stimulating physiological processes such as respiration, softening, and chlorophyll degradation, the latter with concomitant yellowing of peel and pulp in case of mango (ABELES et al. 1992; LALEL et al. 2003). As an ethylene-action analogue, acetylene induces ethylene-like responses (CHESWORTH et al. 1998). As commercial formulations, CEPA and CaC_2 are widely applied to induce ripening postharvest. CEPA is known under various trade names such as Ethrel®, Ride®, and ethephon. In mango, heterogeneity of fruits in ripeness and quality within commercial consignments is

frequently observed as a result of variations in physiological maturities at harvest. Equalisation is enabled both by acetylene and ethylene treatments postharvest through initiation of simultaneous ripening, as reported for mango cv. 'Tommy Atkins' ripened at 25 °C (MEDLICOTT et al. 1988). Depending on doses of the applied agents, cultivars, and the ripening conditions, a broad range of quality attributes, such as peel colour, firmness, total soluble solids (TSS), titratable acids (TA), contents of carotenoids and vitamin C, is affected (CENTURIÓN YAH et al. 1998; JOHNSON et al. 1997; PAL 1998).

By investigating the impact of CEPA and CaC_2 on the physical and chemical changes in mesocarp and peel of Thai mangoes, the intention of this study was to evaluate their effectiveness at different ripening temperatures with respect to fruit quality and ripening times, aiming at improved ripening procedures for these cultivars. Resulting recommendations for fruit handling and turnover periods were expected to contribute to optimised fruit distribution and utilisation by retailers and processors.

Materials and Methods

Materials

Fruits of the cultivars 'Nam Dokmai', 'Kaew', and 'Chok Anan' were purchased from the central fruit market in Nakhon Pathom, Thailand, randomly selecting 420 mature-green mangoes per cultivar with a specific gravity above 1.00 kg L^{-1} and devoid of visual damages or diseases. Fruits were transported to the laboratory at Silpakorn University within 10 min. Weight per fruit ranged between 300–420 g for 'Nam Dokmai', 245–350 g for 'Kaew' and 185–280 g for 'Chok Anan'. According to the information of the supplier, the fruits had not been exposed to any ripening accelerator, whereas such treatments are usually limited to preclimacteric mango fruits intended for selling at the ripe stage. For the repetition of the whole ripening experiment 8–9 days later, a second batch of 420 mature-green mango fruits was obtained per cultivar from the same supplier by analogy.

Postharvest ripening experiments

According to the 6 ripening procedures studied per cultivar, the fruits of each batch were washed with subsequent removal of surface water by immediate air drying of the fruits at ambient temperature and randomly partitioned into 6 lots of 70 fruits. Using paper as cushioning material and cover sheets, the fruits of each lot were ripened in paper-covered plastic baskets for 7 days or less if visual spoilage required termination of the monitoring. Three lots per cultivar were subjected to ripening at 24±2 °C and a relative humidity (RH) of 45–60 % representing temperate climate conditions (level 1). The conditions used for the other three lots (level 2: 33±2 °C, 50–70 % RH) corresponded to the local subtropical climate during the peak harvesting season. At each temperature level, the three lots studied were subjected to one of the following ripening methods:

(i) natural ripening (control),
(ii) ripening with 10 g of CaC_2 per kg of mango fruit, and
(iii) dipping of mango fruits into an aqueous solution of CEPA with an active ingredient dose of 200 mg kg^{-1} for 3 min as recommended by the distributor of the commercial CEPA-preparation (48 % w/v, Ride®, S&P Formulator, Bangkok, Thailand).

According to local practice, CaC_2 wrapped with paper was placed between the fruits in the plastic baskets. For monitoring of the physical and chemical quality changes during ripening, daily samples of ten fruits were collected per variant.

Determination of ripeness parameters

For each fruit of a daily sample, firmness, defined by the maximum penetration force (F_{PN}) until breakage, was determined at the two opposite cheek sides of the fruit with a texture analyser (TA-XT2i, Stable Micro Systems, Surrey, UK), using a plunger with a diameter of 8 mm at a penetration velocity of 0.5 mm s^{-1} (n=20 measurements per daily sample and variant). Prior to texture analysis, colour of the peel was determined at the centre of each cheek side per fruit (n=20 measurements per daily sample and variant), using a Colour-view 9000 spectrometer (BYK-Gardner, Columbia, USA) on the basis of the CIELAB colour space with its Cartesian coordinates L*, a*, b* and its polar coordinates L*, C*, H° (HUTCHINGS 1999; HOPPE et al. 2006). Characterising colour intensity, chroma (C*) describes the length of the colour vector in the rectangular $a^* \times b^*$ space, where the hue axes a* and b* range from a^- (green) to a^+ (red) and from b^- (blue) to b^+ (yellow). Specifying the aspect of the hue, the hue angle

$$H° = 180° \cdot \pi^{-1} \cdot \arctan[b^* \cdot (a^*)^{-1}]$$

indicates the position of the colour vector, with H°=0° representing pure red and H°=90° pure yellow. After manual peeling, mesocarp colour was determined by analogy. Peeled mangoes were randomly subdivided into two groups of five fruits each, sliced and homogenised for chemical analysis of the pulp in duplicate. The pH of the pulp was determined using a pH-meter (Radiometer Analytical SAS, Lyon, France). Juice pressed from the pulp was subjected to quantification of TSS (LMBG 2002) with a hand-held refractometer (Atago Co. Ltd., Tokyo, Japan). TA was determined by titration with 0.1 N sodium hydroxide to pH 8.1 and expressed as percentage of anhydrous citric acid (LMBG 2002). The sugar/acid ratio (TSS/TA) was calculated from the contents of TSS and TA.

Statistical analysis

The effects of ripening accelerators, ripening temperatures and ripening times on each quality attribute were assessed by analysis of variance with the General Linear Model (GLM), using the Statistical Package for Social and Sciences software (SPSS) version 11.5 for Windows (SPSS Inc., Chicago, USA). Least significant differences (LSD) were calculated at P=0.05, following significant F-tests for mean comparison.

Results

Irrespective of the applied temperature and humidity, the ripening process of the three cultivars over seven days could be characterised by typical changes of fruit quality, comprising turning of peel colour from green to yellow,

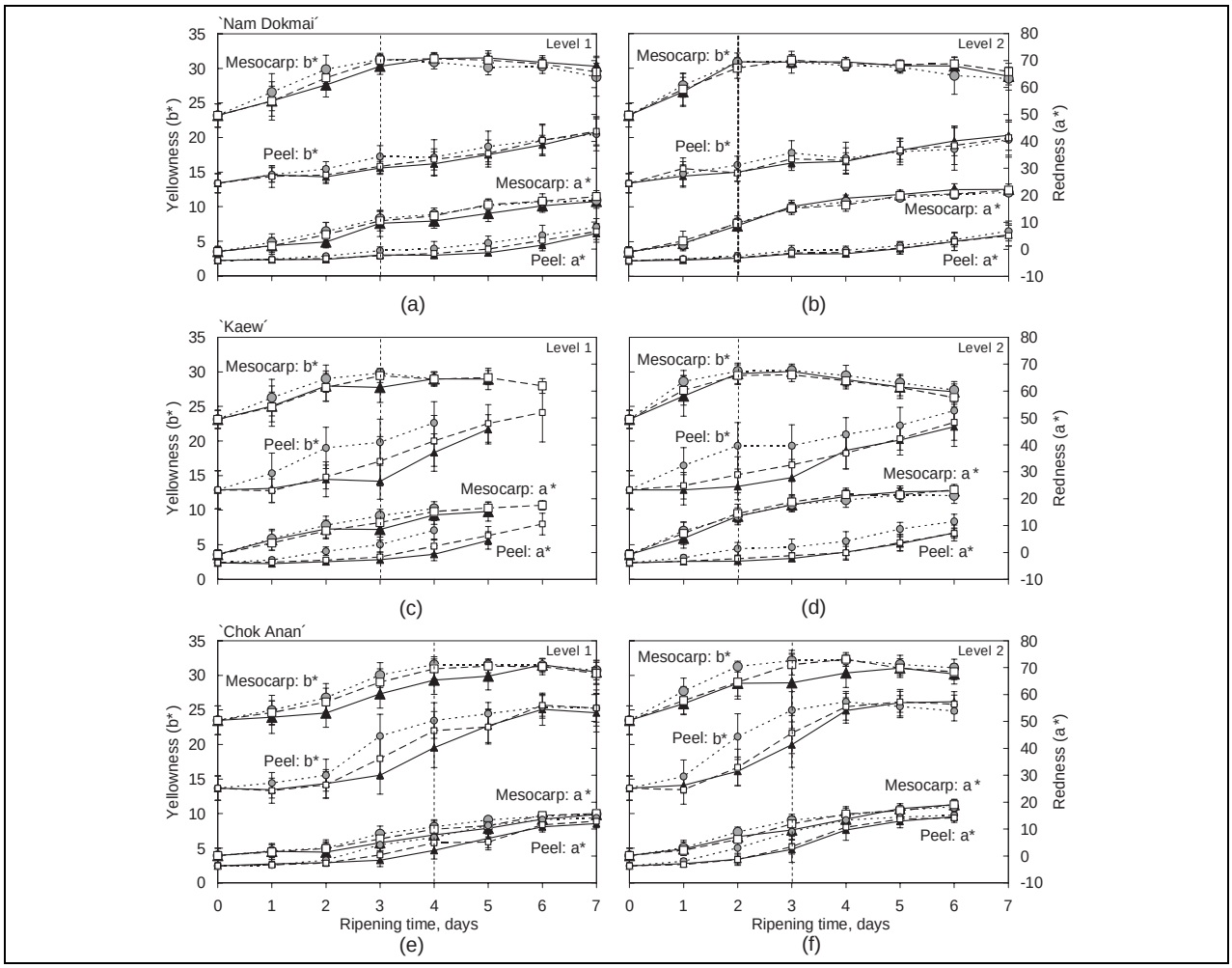


Fig. 1. Colour of peel and mesocarp, expressed by the CIE hue coordinates a* and b*, during postharvest ripening of mangoes cv. 'Nam Dokmai' (a, b), 'Kaew' (c, d) and 'Chok Anan' (e, f) at different conditions (temperature level 1: 24 °C, 45–60 % RH; level 2: 33 °C, 50–70 % RH; –▲– control; ···●··· CaC_2; --□-- CEPA). Total means with standard deviation of all measurements from two ripening experiments per cultivar, temperature level, and treatment. Dotted vertical lines indicate optimum ripening time until eating ripeness as deduced from Fig. 3.

intensification of yellow mesocarp colouration, loss in firmness, as well as decrease in TA, increase in TSS, pH and sugar-acid ratio (Fig. 1–3).

Impact on peel colour

Loss of green peel colour was indicated by increasing values of the green-red hue coordinate a* throughout ripening, mostly accompanied by a nearly parallel development of the yellow coordinate b* (Fig. 1). In this study, peel colour (particularly b*) of ripening 'Nam Dokmai' fruits was neither affected by CaC_2 and nor by CEPA (Fig. 1a, b), whereas CaC_2 provoked an accelerated change of the peel colour of 'Kaew' and 'Chok Anan' fruits with a faster rise in a* and b* (Fig. 1c–f). Redness (a*) of 'Chok Anan' peel subjected to 33 °C was more rapidly intensified than after ripening at 24 °C, but this temperature effect was not observed for the other two cultivars. The strongest acceleration of colour development was induced in 'Chok Anan' peel by the combination of CaC_2 and high temperature (33 °C), resulting in elevated a* and b* values especially from the second to the fourth day of ripening (Fig. 1f).

Impact on mesocarp colour

At the beginning, colouration of the fruit flesh was faster than degreening of the peel (Fig. 1). Moreover, unlike the steadily increasing a* coordinate, the b* value of the mesocarp passed through a characteristic maximum due to their different responsiveness to the changing pigment pattern involving chlorophylls and carotenoids. Irrespective of the treatment with ripening accelerators, similar degreening of the mesocarp occurred, as indicated by the uniform development of almost equal a* values per cultivar and temperature level (Fig. 1a–f). Consistently, the corresponding mesocarp hue angle (H°), which may reflect the colour impression best, declined from 92±4 ° to 50±4 ° in 'Kaew', from 93±4 ° to 55±3 ° in 'Nam Dokmai', and from 90±7 ° to 58±3 ° in 'Chok Anan' during the first

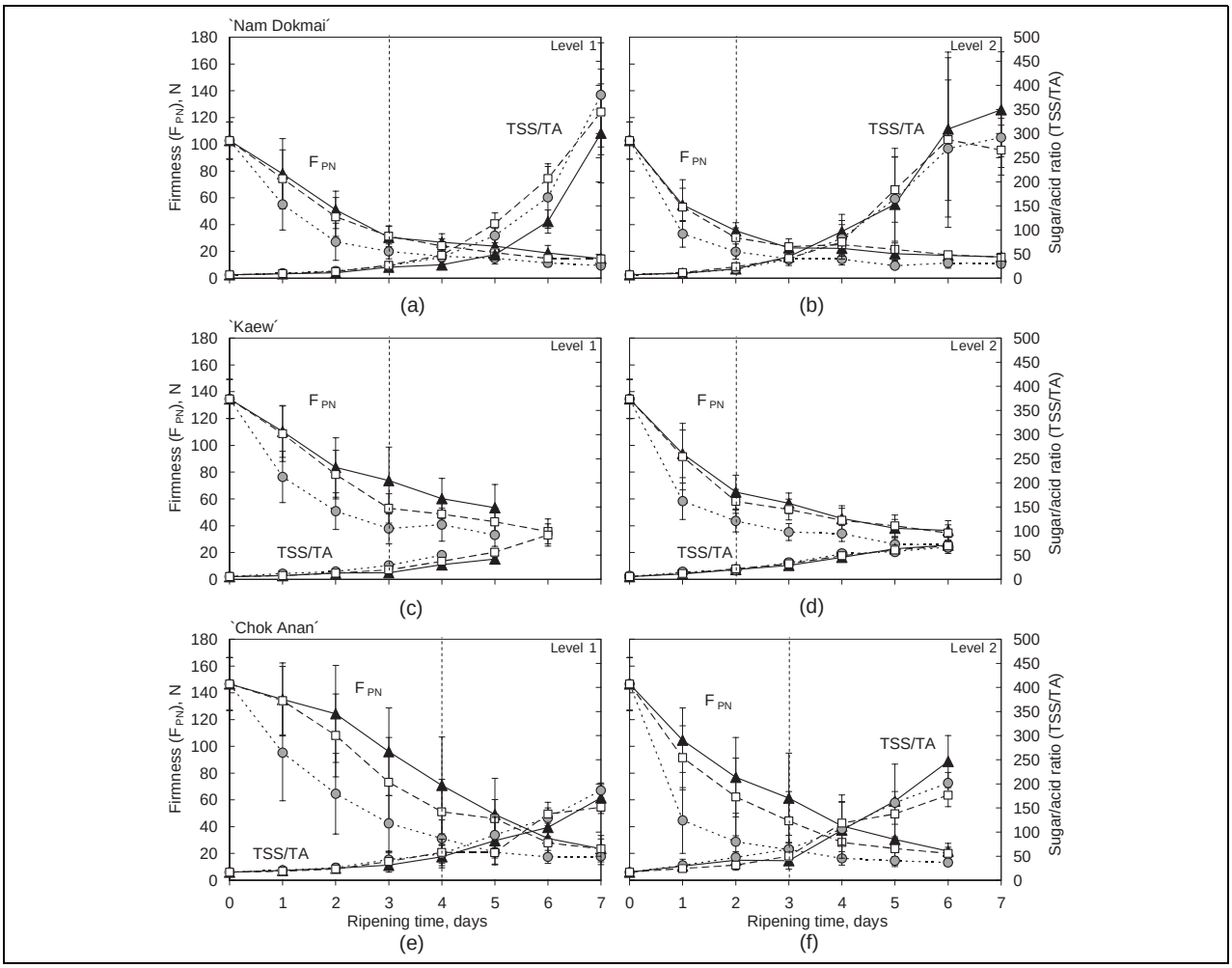


Fig. 2. Fruit firmness (F_{PN}) and sugar/acid ratio (TSS/TA) of mangoes cv. 'Nam Dokmai' (a, b), 'Kaew' (c, d) and 'Chok Anan' (e, f) during postharvest ripening at different conditions (temperature level 1: 24 °C, 45–60 % RH; level 2: 33 °C, 50–70 % RH; –▲– control; ···●··· CaC_2; --□-- CEPA). Total means with standard deviation of all measurements from two ripening experiments per cultivar, temperature level, and treatment. Dotted vertical lines indicate optimum ripening time until eating ripeness as deduced from Fig. 3.

six days of ripening at 33 °C, irrespective of the treatment. In contrast, the changes of mesocarp colour greatly depended on cultivar and temperature/humidity. At each day, redness (a*) of fruit flesh ripened at 33 °C was more intense than at the lower temperature, especially for 'Nam Dokmai' and 'Kaew'. At 33 °C, the maximum of flesh yellowness (b*) was reached one day earlier than at 24 °C.

Impact on fruit firmness

With respect to the initial firmness of mango fruits, 'Chok Anan' fruits were the firmest, followed by 'Kaew' and 'Nam Dokmai' (Fig. 2). A significant decrease in firmness occurred during the first 2–3 days in cvs. 'Kaew' and 'Nam Dokmai', but during 4–5 days in cv. 'Chok Anan'. Especially during the initial two days of ripening, both the treatment with CaC_2 and increasing ripening temperature provoked significant differences in softening ($P=0.05$), irrespective of the cultivar (Fig. 2). Consistently, softening of fruits ripened with CaC_2 at 33 °C was approximately 1.3 to 2-fold faster at the first day of ripening than that of batches ripened at 24 °C due to a synergistic effect. In contrast, reduction of fruit firmness after application of CEPA did not significantly differ from the control.

Impact on the contents of sugars and acids

TSS, TA, and the sugar/acid ratio, which are important sensory attributes crucial for consumers' acceptance of fruits and fruit products, were not significantly affected by the application of CaC_2 and CEPA, irrespective of cultivars and ripening temperatures (Fig. 2, 3), apart from some minor differences in TA of 'Nam Dokmai' and 'Kaew' (Fig. 3a–d) and TSS/TA of 'Nam Dokmai' (Fig. 2a, b). Compared to CEPA treatment and control, CaC_2-treated fruits of cv. 'Kaew' underwent faster reduction of TA when ripened at 24 °C (Fig. 3c).

Initial contents of TSS at the green-mature stage were rather uniform for all cultivars, ranging from 9–11 °Brix. During the first two or three days of ripening at 33 °C and

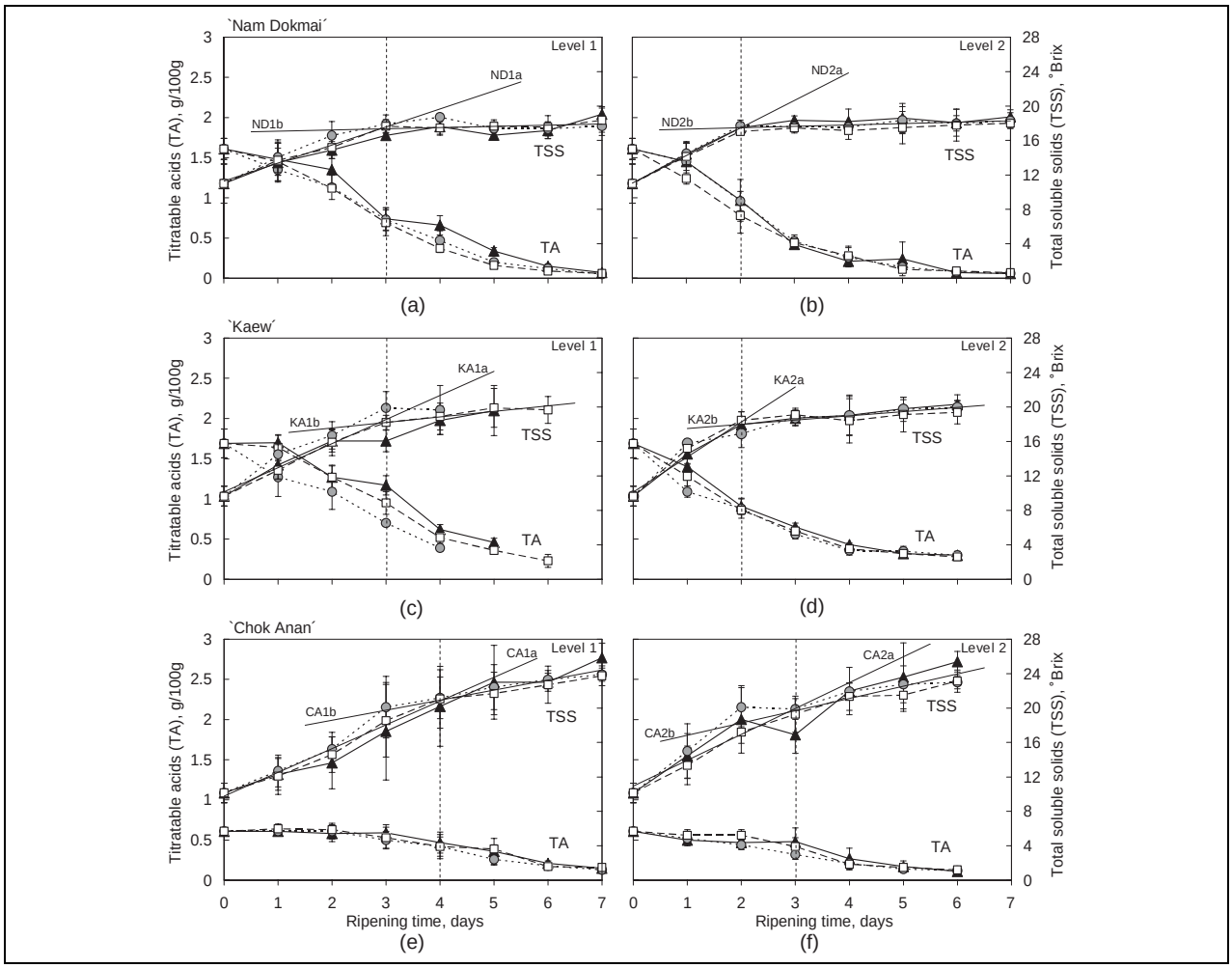


Fig. 3. Development of titratable acids (TA) and total soluble solids (TSS) in mangoes cv. 'Nam Dokmai' (a, b), 'Kaew' (c, d) and 'Chok Anan' (e, f) during ripening at different conditions (temperature level 1: 24 °C, 45–60 % RH; level 2: 33 °C, 50–70 % RH; –▲– control; ···●··· CaC_2; --□-- CEPA). Total means with standard deviation of all measurements from two ripening experiments per cultivar, temperature level, and treatment. Treatment-independent linear regression between TSS and ripening time (RT) of the type TSS = $s \cdot RT + c$, distinguishing two phases of TSS development at each temperature level (s, c, and coefficient of determination [R^2] in parentheses): ND1a (2.095; 11.27; 0.949), ND1b (0.140; 16.95; 0.093), ND2a (3.197; 11.05; 0.994), ND2b (0.164; 17.14; 0.347), KA1a (2.793; 10.16; 0.903), KA1b (0.647; 16.26; 0.299), KA2a (4.058; 10.14; 0.940), KA2b (0.490; 17.01; 0.707), CA1a (2.760; 9.77; 0.960), CA1b (1.166; 16.25; 0.809), CA2a (3.001; 10.94; 0.837), CA2b (1.428; 15.40; 0.754). Dotted vertical lines indicate optimum ripening time until eating ripeness as deduced from the intersection point of the TSS = f(RT) regression curves. [RT;TSS] intersection points were compiled in Table 1 for all cultivars and temperature levels studied.

24 °C, respectively, TSS of 'Nam Dokmai' and 'Kaew' quickly increased to reach a plateau at approximately 18 °Brix (Fig. 3a–d). In contrast, 'Chok Anan' showed a constant increase in TSS up to 3–4 days (Fig. 3e, f). Among all cultivars, 'Chok Anan' was characterised by the highest final TSS content (23–26 °Brix). Moreover, it was this cultivar only, where ripening at elevated temperature provoked significant higher sugar contents (1.1–1.4-fold) during the first two days of ripening (Fig. 3e, f). Nevertheless, irrespective of the ripening temperature, the same cultivar-specific TSS levels were finally reached.

The initial acidity of 'Nam Dokmai' and 'Kaew' at the green-ripe stage was approximately 3 times higher than in 'Chok Anan' (Fig. 3). The first-mentioned cultivar also showed the fastest acid degradation within the first four days. In fruits ripened at the higher temperature, the drop in acidity was more pronounced, irrespective of cultivars (Fig. 3). This became especially evident in fruits of cv. 'Chok Anan', where TA contents after 4 and 5 days of ripening were approximately 2 times lower than in respective fruits ripened at 24 °C (Fig. 3e, f). However, final TA levels were obviously only cultivar-specific. Consistent with acid degradation, the pH values of the fruit pulp steadily rose throughout ripening, irrespective of the treatments (data not shown). During the first six days at 33 °C, for example, pH values changed from 3.1±0.2 to 5.7±0.3 in 'Nam Dokmai', from 3.1±0.1 to 4.5±0.1 in 'Kaew', and from 3.8±0.1 to 5.4±0.1 in 'Chok Anan', whereas the pH values reached by 'Nam Dokmai' and

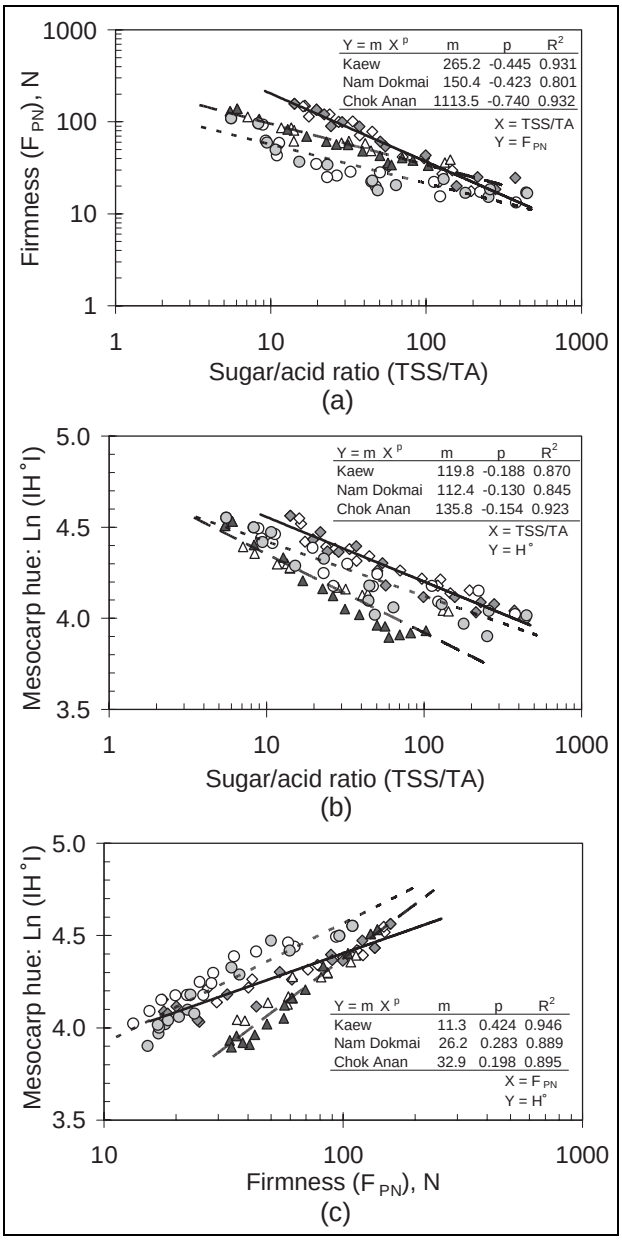


Fig. 4. Cultivar-specific relationships between major quality attributes (Y and X) of mangoes defining ripening stages. Fruit batches (2 per cultivar and ripening temperature): ◇ 'Chok Anan' (control, 24 °C); ◆ 'Chok Anan' (control, 33 °C); △ 'Kaew' (control, 24 °C); ▲ 'Kaew' (control, 33 °C); ○ 'Nam Dokmai' (control, 24 °C); ● 'Nam Dokmai' (control, 33 °C). Cultivar-specific power law regression curves of the type $Y=m \cdot X^p$ based on the data sets of the combined control batches investigated for each cultivar (independent of postharvest ripening temperature): ——— 'Chok Anan', — — — 'Kaew', - - - - 'Nam Dokmai'. R^2, coefficient of determination. H°, hue angle of the mesocarp in degree.

'Chok Anan' at 24 °C within the same time were only 5.2±0.4 and 4.7±0.2, respectively.

An extreme rise in the sugar/acid ratio to a final value of 300 with an onset after 4 days was observed for 'Nam Dokmai' at both temperature levels. Thus, overripe fruits of 'Nam Dokmai' were characterised by very sweet taste and diminishing pulp acidity (Fig. 2a, b). Another pronounced rise in TSS/TA to final levels exceeding 100–120 only occurred in 'Chok Anan' fruits when ripened at 33 °C. At the same day of ripening, sugar/acid ratios of fruits stored at elevated temperature mostly exceeded those of fruits at the moderate temperature of 24 °C, as particularly shown by the fruits of 'Nam Dokmai' and 'Chok Anan' after 3 days.

Criteria specifying eating ripeness

Precise quantification of any accelerating effects on postharvest ripening requires the objective specification of the ripe stage of these cultivars for comparison of ripening times. Measurable ripeness criteria were to be deduced from the development of the major quality attributes for this purpose to describe the minimum ripeness for consumption, in this study referred to as "eating ripeness". This analytical definition of eating ripeness has to be distinguished from the understanding of eating ripeness in fruit marketing and processing, where this term, as part of a purpose-oriented product specification, may refer to a range of slightly different physiological ripeness stages, depending on the different sensory preferences, which exist among culture groups, and various processing property profiles required for different applications in mango processing.

The times required until eating ripeness were summarised in Table 1 for all three cultivars under each condition. The criterion used was the ripening time elapsed with linear increase of TSS, until its final level was approximately reached after the ripening time RT_{IP}, as indicated by the intersection point (IP) of the linear regression curves approximating the two-phase TSS development (Fig. 3). In the second phase, TSS levels showed no significant differences between days at P=0.05. Consequently, the concurrent, disproportionately high increase in sugar/acid ratio was solely due to ongoing acid degradation (Fig. 2, 3). Significant softening generally occurred until RT_{IP}, before firmness slowly approached to a final level in the second phase (Fig. 2).

By analogy with the findings of VÁSQUEZ-CAICEDO et al. (2004), each TSS/TA level reached during ripening corresponded to a special firmness (F_{PN}) and mesocarp colour (H°), as observable for each cultivar (Fig. 4a, b). Moreover, the present study showed that the cultivar-specific power law relationships were independent of the ripening temperature. Consequently, the ripening temperature had also no influence on the resulting relationships between fruit firmness and mesocarp colour (Fig. 4c). Because of the interaction between TSS/TA, fruit firmness and mesocarp colour as the major quality attributes of sensory importance, these relationships confirm the relevance of the sugar and acid metabolism used in the presented kinetic definition of eating ripeness.

Thus, the knowledge of the specific ripening kinetics of the quality attributes predominantly related to eating quality allowed to specify eating ripeness unambiguously, provided that the postharvest ripening process can be completely monitored. Irrespective of the ripening accelerators, fruits of cvs. 'Nam Dokmai' and 'Kaew' ripened at 33 °C needed 2 days until eating ripeness, while 'Chok Anan' required 3 days. Ripening at 24 °C slowed down the ripening process by approximately 1 day. The de-

Table 1. Ripening time (RT) of three Thai mango cultivars required until eating ripeness at two different ripening temperatures as well as respective quality attributes.

	24±2 °C, 45–60 % of RH			33±2 °C, 50–70 % of RH		
	'Nam Dokmai'	'Kaew'	'Chok Anan'	'Nam Dokmai'	'Kaew'	'Chok Anan'
Coordinates of the intersection points (IP) of TSS = f(RT) regression curves[a]:						
RT_{IP} [days]	3	3	4	2	2	3
TSS_{IP} [°Brix]	17.4	18.1	21.0	17.5	18.0	19.5
Quality profile of the mesocarp at eating ripeness[b]:						
TSS [°Brix]	17.4 ± 1.0	18.1 ± 2.1	20.8 ± 3.5	17.4 ± 0.6	17.8 ± 1.5	18.7 ± 2.2
TSS/TA	25 ± 6	21 ± 7	54 ± 23	21 ± 6	21 ± 3	52 ± 18
pH	3.8 ± 0.3	3.6 ± 0.2	4.1 ± 0.3	3.5 ± 2.0	3.6 ± 0.1	4.0 ± 0.2
Colour: b*	30.9 ± 1.1	29.0 ± 1.7	30.6 ± 1.8	30.6 ± 1.2	29.8 ± 1.2	30.9 ± 3.2
Colour: H° [°]	71.6 ± 6.7	69.5 ± 6.0	73.1 ± 5.0	73.1 ± 3.5	65.3 ± 4.4	69.7 ± 6.8

[a]Regression curves presented in Fig. 3
[b]Total mean ± standard deviation from all measurements performed at RT_{IP} per cultivar and temperature level within two ripening experiments, each with three process variants including control.

scribed procedure used to identify optimum ripening time was applicable to all fruit batches. The quality profiles of the fruits at eating ripeness were compiled in Table 1. Apart from TSS and TSS/TA, the yellowness of the mesocarp (b*) was included, because its maximum also occurred at RT_{IP} (Fig. 1). Despite the lack of similarly salient developments, the pH values and the hue angles (H°) of the mesocarp were additionally listed as catchy, easily accessible threshold parameters.

Discussion

Ripening characteristics of the studied fruits were similar to the physical and chemical changes observed in seven commercially important Indian cultivars during ripening at 25±2 °C and 70±5 % RH (Selvaraj et al. 1989). Increasing temperature stimulated the postharvest development of the major quality parameters including fruit firmness, TSS/TA, and colour of peel and mesocarp, reducing the time required until eating ripeness. The prevailing soluble sugars in mango were reported to be glucose, fructose and sucrose (Selvaraj et al. 1989; Vásquez-Caicedo et al. 2002). The increase in sucrose contents during ripening was ascribed to starch degradation (Litz 1997). The observed TSS contents at eating ripeness were consistent with the average level of 16.6 °Brix and a range of 15.0–18.7 °Brix that were reported by Vásquez-Caicedo et al. (2002) for fully ripe Thai mangoes.

Owing to the first perception by consumers, peel colour is an important attribute of fruit maturity and quality (Medlicott et al. 1992). Peel colour of Thai cultivars turns from green to greenish-yellow, yellow, or orange during ripening, depending on cultivars (Vásquez-Caicedo et al. 2004). According to Medlicott et al. (1986), degreening and concomitant development of the yellow colour in the peel of mango cv. 'Tommy Atkins' ripened at 22±0.5 °C were caused by an almost complete loss of chlorophyll, especially chlorophyll a, and an approximately five-fold increase in carotenoids. Degradation of chlorophyll pigments to negligible amounts in ripe fruits was also reported for mango cv. 'Dashehari' (Kalra and Tandon 1983). With respect to the delayed development of peel redness in 'Chok Anan' at 24 °C, a similar effect of lower temperature on the peel of mango 'Kensington Pride' was reported by Nguyen et al. (2002), with ethylene-treated fruits ripened at 20 and 25 °C revealing less green skin colour than those ripened at 15 °C. However, the present study confirmed that the development of the peel colour did not reflect that of all attributes relevant for eating quality. Contrary to Fig. 4 showing the interactions among the latter attributes, no analogous relationship could be deduced between the corresponding hue angles of peel and mesocarp despite some correlations of the peel hue development (H°) with softening and the evolution of TSS/TA (data not shown).

In contrast to Medlicott et al. (1988), no effects of CaC_2 and CEPA on uniformity of ripening were found in this study. CaC_2 accelerated fruit softening and degreening of the peel, but showed no impact on TSS/TA ratios and mesocarp colour. Nguyen et al. (2002) also observed that ethylene-treated fruits softened more quickly than the control. Mango softening was ascribed to degradation of cell wall pectin to lower molecular weight fractions which were more soluble in water (Roe and Bruemmer 1981). However, in this study, softening of fruits did not increase when CEPA was applied. Consistently, Pal (1998) described better retention of pulp texture in 'Dashehari' mangoes treated with CEPA than following a CaC_2-treatment. Since firmer fruits are easier to handle during postharvest operations and to process into solid products, CaC_2-treatment was more disadvantageous, especially when applied to the comparably softer 'Nam Dokmai' fruits. As accelerated fruit softening occurred without an analogous stimulation of the development of the edible part in terms of colour and TSS/TA, the ripening characteristics documented by Fig. 4 were modified through CaC_2. Since mesocarp colour is closely related to provitamin A levels (Vásquez-Caicedo et al. 2005), CaC_2

application presumably prevented concomitant development of nutritive quality. CaC_2-induced softening and changes of peel colour rather gave the impression of accelerated ripening, which was not supported by the mesocarp properties.

In conclusion, the application of CaC_2 and 2-chloroethylphosphonic acid (CEPA) during fruit ripening was not justified with respect to the chemical and physiological changes related to the sensory performance of the fruits (TSS, TA and TSS/TA). This may be due to the application of both chemicals after the onset of natural ripening, when endogenous ethylene evolution already started to cause measurable quality changes. Accelerated fruit softening provoked by CaC_2 application at such a stage of maturity, especially at ambient temperatures of tropical countries, would be particularly counterproductive prior to mango processing into solid foods such as drying of mango slices and canning. Benefits of the ripening accelerators regarding fruit quality might only be expected for applications intended to induce uniform ripening directly after harvest of heterogeneous fruit batches including physiological maturity stages with insufficient endogenous ethylene levels. However, as illustrated by the present findings, later application in marketing or processing to accelerate ripening for short-term delivery on schedule may be economically useless or even detrimental to fruit quality because of different enhancement of major external and inner quality attributes. This may especially apply to fruits of unknown history, when artificial stimulation of ethylene synthesis at a previous stage cannot be excluded. Therefore, a general use, particularly of CaC_2, cannot be recommended.

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