Eur Food Res Technol (2007) 225:723–732
DOI 10.1007/s00217-006-0475-x

ORIGINAL PAPER

Effects of variety, ripening condition and ripening stage on the quality of sulphite-free dried mango slices

Busarakorn Mahayothee · Sybille Neidhart · Reinhold Carle · Werner Mühlbauer

Received: 3 April 2006 / Revised: 31 August 2006 / Accepted: 6 September 2006 / Published online: 9 November 2006

Abstract The influence of cultivar and fruit ripeness on sensory properties and *all-trans*-β-carotene contents of dried mango slices was evaluated. Different ripeness stages, quantitatively defined by a ripening index (*RPI*), were generated from a single lot per cultivar by subjecting mature-green mangoes of the cultivars 'Nam Dokmai', 'Kaew', and 'Chok Anan' to different postharvest ripening regimes. Fruits were ripened for 2 and 3 days at 24 ± 2 °C/45–60% relative humidity (RH) and 33 ± 2 °C/50–70% RH, with application of calcium carbide (CaC_2) or 2-chloroethylphosphonic acid (CEPA, Ride®) beside the control, terminating postharvest ripening when fruit firmness allowed proper peeling and slicing. After ripening, fruits were washed, peeled, sliced and subsequently dried in a conventional tray dryer at 70 °C for 8–10 h, until the water activity of the dried fruits was below 0.65. Mangoes cv. 'Kaew', followed by 'Chok Anan', were more suitable for drying than cv. 'Nam Dokmai' because of superior *all-trans*-β-carotene contents of the products. Maximum β-carotene contents of dried mango slices from cvs. 'Chok Anan' and 'Kaew' corresponded to retinol equivalents of 333–383 and 483–905 per 100 g of edible portion (dry weight), meeting daily mean requirements of vitamin A for adults according to FAO/WHO. Similar to the fresh fruit, exponential rise of *all-trans*-β-carotene contents with increasing fruit ripeness was also observed for the dried products of cvs. 'Nam Dokmai' and 'Chok Anan'. Consistently, accelerated ripening at 33 °C, instead of 24 °C, resulted in higher *all-trans*-β-carotene contents of dried fruits. Both good sensory acceptance and cultivar-specific maximum *all-trans*-β-carotene contents of 13–16 and 20–23 mg kg^{-1} usually characterised the products of 'Nam Dokmai' and 'Chok Anan' fruits with *RPI* levels between 3 and 4. Conversely, fruits cv. 'Kaew' of *RPI* levels above 6 generally yielded products inferior in sensory acceptance and β-carotene contents, while superior product quality was found at higher *RPI* levels than for the other two cultivars.

Keywords β-Carotene · Calcium carbide · Drying · Ethephon · *Mangifera indica* L. · Postharvest ripening · Sensory quality

B. Mahayothee · W. Mühlbauer
Institute for Agricultural Engineering in the Tropics and Subtropics, Hohenheim University,
Garbenstrasse 9,
70599 Stuttgart, Germany

S. Neidhart (✉) · R. Carle
Institute of Food Technology, Section Plant Foodstuff Technology, Hohenheim University,
August-von-Hartmann-Strasse 3,
70599 Stuttgart, Germany
e-mail: neidhasy@uni-hohenheim.de

Present address:
B. Mahayothee
Department of Food Technology, Faculty of Engineering and Industrial Technology, Silpakorn University,
Sanamchandra Palace Campus, Nakhon Pathom 73000, Thailand

Introduction

Dried tropical fruits such as mangoes, papayas, pineapples, and bananas are currently well known in industrialised countries as ingredients of breakfast cereals [1]. They are also considered as potential health snacks in developing countries, since mango and papaya are reported to be good sources of pro-vitamin A [2].

Thailand, the Philippines and Malaysia are the major suppliers of dehydrated exotic fruit products. Although consumers prefer health, low-caloric, natural products, dried tropical fruits are still osmotically dehydrated with

concentrated sugar syrups for sweetening and sulphited to improve colour retention [1]. These procedures result in a loss of typical aroma and natural taste of the fruits. According to the recent investigations by Pott et al. [3], sulphite-free dried mango with natural levels of sugar is a promising product, satisfying consumers' attitudes as to health benefits and nutritive value. However, most research has been conducted on the optimisation of pre-treatment and drying parameters such as drying temperature and drying time for osmotic dehydrated mango slices [4–6]. Apparently, limited studies were dealing with the impact of postharvest ripening and fruit maturity on the quality of dried products [7, 8]. Sagar and Khurdiya [8] reported that the highest sensory score was attributed to osmotically dehydrated mango slices cv. 'Dashehari' after 6 days of natural ripening at 33–35.5 °C. Overripe mangoes were not suitable for drying because of textural degradation, thus impeding peeling and slicing. On the other hand, unripe mangoes had weak aroma and plain taste. Furthermore, John et al. [9] found that the mango flesh of cv. 'Badami' with unripe, partially ripe and fully ripe stages had various amounts of total carotenoids (pro-vitamin A) with 0.41, 33.6 and 89.2 mg kg^{-1} of fresh weight, respectively. Total carotenoids vary quantitatively according to cultivar [10, 11] and postharvest temperature [12]. Storage temperatures below 25 °C would adversely affect the development of typical aroma, flavour and carotenoids in mango fruits cv. 'Alphonso' during ripening [12]. Thus, control of quality and ripeness of raw materials and the ripening conditions prior to the drying process are crucial.

Calcium carbide (CaC_2) and 2-chloroethylphosphonic acid (CEPA, ethephon) are widely used for induction and regulation of the ripening process in mango both in fruit marketing and processing. By inducing homogenous ripening, these agents also affect physical and chemical properties of mangoes such as peel colour, firmness, total soluble solids, total acidity, and total carotenoids. However, those parameters were found to depend on applied concentrations of the chemicals and ripening conditions [13–15]. Exogenous ethylene and acetylene treatments have been reported to improve the uniformity of 'Tommy Atkins' mangoes ripened at 25 °C without detrimental effects [16]. On the other hand, higher percentage of spoilage had been indicated in mango fruits cv. 'Rataul' treated with CaC_2 (3.5–3.6 g kg^{-1} of fruit) and ripened at 32–35 °C, 89–90% RH when compared to those treated with Ethrel® (CEPA) and control [17].

In our previous work, a ripening index (*RPI*) has been introduced connecting fruit firmness and the sugar/acid ratio to define postharvest ripeness unambiguously. It proved a valuable tool in monitoring cultivar-specific carotenogenesis during postharvest ripening of mangoes [18]. Therefore, the objective of this study was to systematically investigate the effects of variety and the stage of postharvest ripening, based on the use of *RPI*, on the quality of sulphite-free dried mango slices. The investigations involved three Thai mango cultivars of high commercial relevance. Different ripeness stages were generated by modulation of ripening through temperature, duration, and the application of CaC_2 and CEPA.

Materials and methods

Materials

Mature-green Thai mango cvs. 'Nam Dokmai', 'Kaew' and 'Chok Anan' with a specific gravity above 1.00 kg l^{-1} were selected, rejecting fruits with visual physical damages or diseases. Fruits were purchased from the central fruit market in Nakhon Pathom, Thailand, during peak season 2002. The fresh weight per fruit was in the range of 300–420, 245–350 and 185–280 g for cvs. 'Nam Dokmai', 'Kaew' and 'Chok Anan', respectively.

Methods

Postharvest ripening and drying of mango fruits

After washing, the fruits were either naturally (method A = control) or artificially ripened, applying one of two different ripening accelerators. For exposure of the fruits to 10 g of calcium carbide (CaC_2) per kg of mango (method B), CaC_2 was wrapped in paper and enclosed in plastic baskets with the fruits. Application of CEPA (method C) was performed by dipping the fruits for 3 min into an aqueous solution containing the active ingredient at 200 mg kg^{-1} as recommended by the manufacturer of the commercial ethephon (48% w/v, Ride®, S&P Formulator, Bangkok, Thailand). All ripening experiments were conducted at temperate climate conditions (24 ± 2 °C at a relative humidity (RH) of 45–60%) and at subtropical local climate (33 ± 2 °C, 50–70% RH) during the peak harvesting season in Thailand, using 70 fruits for monitoring of postharvest ripening in addition to approximately 20 kg of fruits, intended for fruit drying, per cultivar, temperature level and ripening method. In a previous study [7], the fruits after 2 and 3 days of ripening showed the optimum properties required for drying when compared to those ripened for 4 days. Extended ripening, as recommended by Sagar and Khurdiya [8], leads to excessive softening. Consequently, this will complicate peeling and slicing. Therefore, after 2 and 3 days, approximately 8–10 kg of fruits per product variant were washed, manually peeled, cut into slices of 8 mm and subsequently dried in a conventional tray dryer at 70 °C for 8–10 h, until the water activity of the dried products reached approximately 0.65. Water activity was determined by the use of a Rotronic AwVC instrument (Rotronic AG, Bassersdorf, Switzerland).

Dried fruits were packed into laminated aluminium pouches in units of approximately 150 g.

Physical and chemical analyses of fresh and dried fruits

Progress of postharvest ripening was monitored by daily analyses of fruit quality as described previously [7], focusing on fruit firmness, mesocarp colour, total soluble solids (*TSS*), titratable acids (*TA*) and the resulting sugar/acid ratio (*TSS/TA*). Daily samples of 10 fruits were collected for this purpose.

Quality analyses of the dried products included colour, β-carotene content and sensory evaluation. Colour of dried mangoes was measured according to the CIELAB colour system (L^*, a^*, b^*), using a Minolta colorimeter CR 110 (Tokyo, Japan). The polar hue coordinates H° (hue angle) and C^* (chroma indicating colour saturation) were calculated from the Cartesian hue coordinates a^* and b^*. H° was calculated in degree from arc tan (b^*/a^*), while C^* is defined as the square root of the sum of the squares of a^* and b^* for a given colour [19]. Per product variant, samples of 10 slices were used, measuring the colour on two points per slice. The analysis of β-carotene contents in dried fruits was performed using a HPLC method to quantify *all-trans*-β-carotene according to Marx et al. [20] and Pott et al. [3]. β-Carotene was extracted in duplicate (or triplicate, if necessary) from the sample using a mixture of acetone and hexane (1:1 v:v). The hexane layer was evaporated under vacuum (25 °C, 150 mbar) and the residue was dissolved in 2-propanol. The aliquots were analysed using an HPLC with a diode array detector SPD-M10Avp (Shimadzu, Kyoto, Japan) [3]. For quantification of β-carotene, *trans*-β-apo-8′-carotenal (Fluka, Buchs SG, Switzerland) was used as an internal standard. β-Carotene contents were calculated based on the dry weight (d.w.). The moisture content of dried products was determined by Karl-Fischer titration [21]. To assess the vitamin A value, retinol equivalents (RE) were calculated according to FAO/WHO [22], with 1 μg of β-carotene equal to 0.167 RE. For each quality parameter, the respective means and standard deviations were calculated, using Microsoft® Office Excel 2003 and its previous version.

Sensory analyses of dried products

By analogy with our previous study [7], the sensory evaluation of colour, aroma, taste, texture and total acceptance of dried fruits was performed using a 9-point hedonic scale (1 = dislike extremely to 9 = like extremely) by 13 trained German panellists. However, dried mango slices cv. 'Kaew' were evaluated by eight trained panellists. For each sensory parameter, respective medians and the median absolute deviations (*MAD*) were calculated, using Microsoft® Office Excel 2003 and its previous version. From the attribute scores assigned by each taster i, sensory quality scores QS_i were calculated according to Eq. (1), where OCS_i, $OAMS_i$, $OTAS_i$, $OTXS_i$, and $OACS_i$ were the scores that taster i had attributed to overall colour, overall aroma, overall taste, overall texture, and overall acceptance, respectively. For each product variant, the sensory results were finally summarised by the quality score QS, defined as the median of QS_i.

$$QS_i = (4OCS_i + 4OAMS_i + 4OTAS_i + 2OTXS_i + 3.5OACS_i)/17.5 \quad (1)$$

The influence of fruit ripeness on the quality of dried mango slices was deduced from the sensory scores and β-carotene contents of the dried products for each cultivar.

Statistical analyses

The effects of the ripening parameters, that is, ripening times, ripening temperatures and methods, on each of the chemical and physical quality attributes of the fresh and dried fruits were assessed for each cultivar 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.

Sensory results were analysed for each cultivar by means of the SPSS software, applying the non-parametric test for more than two related samples (k related samples). Multiple comparisons based on Friedman rank sums were applied to test the differences among ripening parameters, including method, temperature and time of postharvest ripening [23, 24].

To identify interactions among the various quality parameters of fresh and dried fruits, bivariate correlations between all these parameters were calculated with the SPSS software and expressed by Pearson's correlation coefficients r, with one and two asterisks indicating significance levels of $P \leq 0.05$ (r^*) and 0.01 (r^{**}). Additionally, linear regression based on the method of least squares was calculated for selected pairs of parameters, using the RGP function and the F-statistic functions of Microsoft® Office Excel 2003 and its previous version.

Results and discussion

Ripening behaviour

Physical and chemical properties at eating ripeness of the fresh fruits of three cultivars harvested in 2002 were shown

Table 1 Eating quality of fresh mangoes when full ripeness has just been reached

Cv./ripening conditions	*TSS*[a] [°Brix]	*TSS/TA*[a]	Firmness[a] [N]	C^* (flesh)[a]	H° (flesh)[a]	*RPI*[a]
ND/24 °C, 3 days	16.9 ± 0.2	20.9 ± 1.1	30.7 ± 7.6	32.2 ± 1.1	76.5 ± 4.1	5.0 ± 0.3
ND/33 °C, 2 days	17.4 ± 0.4	21.2 ± 2.1	29.7 ± 5.2	32.3 ± 0.3	74.2 ± 1.3	4.9 ± 0.1
KA/24 °C, 3 days	17.2 ± 1.9	20.8 ± 6.5	64.6 ± 20.0	30.6 ± 2.5	69.2 ± 3.9	5.7 ± 0.7
KA/33 °C, 2 days	16.7 ± 1.0	18.5 ± 1.3	57.2 ± 12.9	32.1 ± 0.6	66.1 ± 1.6	5.7 ± 0.3
CA/24 °C, 4 days	24.0 ± 0.5	75.3 ± 6.8	31.7 ± 9.8	33.8 ± 0.8	69.6 ± 1.4	3.7 ± 0.3
CA/33 °C, 3 days	20.2 ± 1.3	64.9 ± 8.2	24.3 ± 9.0	34.6 ± 1.0	66.4 ± 1.2	3.6 ± 0.5

[a]Mean ± standard deviation of values originating from the three different ripening methods (control, CaC_2, CEPA) in crop year 2002.

in Table 1. The criterion, specifying eating ripeness, was the ripening time elapsed with linear increase of *TSS*, until its final level was approximately reached and a concurrent, disproportionately high increase in sugar/acid ratio set in due to ongoing acid degradation. The mean of the three ripening methods was given, since the method did not significantly influence *TSS*, *TA* and *TSS/TA* [7]. By analogy with [18], the ripening index as a function of fruit firmness (F) and sugar/acid ratio (*TSS/TA*) was expressed according to Eq. (2).

$$RPI = \ln(100\, F\, TSS^{-1}\, TA) \quad (2)$$

Ripening time, required to reach eating ripeness, differed at the two ripening temperatures. However, *RPI* at eating ripeness was similar in each cultivar (Table 1). Consistent with previous reports [18], *RPI* linearly decreased during ripening at both temperatures with coefficients of determination (R^2) ≥ 0.94 (Fig. 1). The relationship between *RPI* and ripening time of our preliminary work [7] in mango season 2001, with ripening at 25 ± 2 °C and 50–70% RH, is also illustrated in Fig. 1. Accelerated postharvest ripening at elevated temperatures was reflected by the more pronounced reduction of *RPI*, especially in cvs. 'Nam Dokmai' and 'Chok Anan'. Temperature also significantly affected the rate of ripening of mango cv. 'Kensington' [25]. Fruits ripened faster at 30 °C compared to those ripened at 22 and 13 °C. Reduction of acidity (*TA*) was slower in the fruits ripened at low temperature, while *TSS* was not influenced by the temperature.

Due to the different temperatures, two times (2 and 3 days), and three methods of postharvest ripening, fruit ripeness at processing varied in the range of *RPI* levels from 3.0 to 5.8, 3.9 to 6.3, and 4.6 to 6.6 for cvs. 'Chok Anan', 'Nam Dokmai', and 'Kaew', respectively (Table 2). As shown by the previous ripening experiments carried out at 25 °C [7], ripeness of the fruits, which were subjected to drying in year 2001, was primarily modulated by ripening for 2, 3, and 4 days, rather than by the three methods. With 3.3–5.8 for cvs. 'Nam Dokmai' and 'Chok Anan', respective *RPI* ranges were similar to those presented in Table 2, but an extended range of 3.8–6.8 was considered for cv. 'Kaew'.

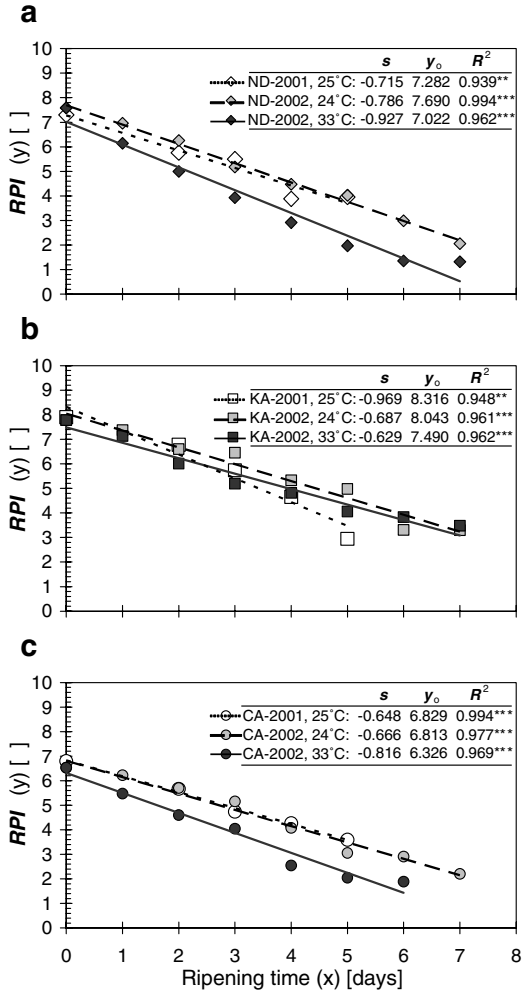

Fig. 1 Changes of the ripening index (*RPI*) as observed for three Thai mango cultivars, harvested in years 2001 and 2002, during postharvest ripening at different temperatures (24, 25, and 33 °C) without application of any ripening accelerator (controls). **a** cv. 'Nam Dokmai' (ND); **b** cv. 'Kaew' (KA); **c** cv. 'Chok Anan' (CA). Linear regressions of the type $y = sx + y_o$ between *RPI* (y) and ripening time (x) with coefficients of determination (R^2) that were significant at $P \leq 0.001$ (R^{2***}) or 0.01 (R^{2**})

β-Carotene contents and colour of dried products

All-trans-β-carotene contents and colour values of dried mango slices and the *RPI* of the fresh fruits, ripened at various

Table 2 Colour and β-carotene contents of dried mango slices from fruits harvested in year 2002

Ripening temperature: 24 ± 2 °C						Ripening temperature: 33 ± 2 °C					
RPI	L^*	H°	C^*	$c_{at\beta}$	*RT/M*	*RPI*	L^*	H°	C^*	$c_{at\beta}$	*RT/M*
'Nam Dokmai'											
6.26 a	67.25 bc	86.72 ab	38.63 c	9.99 b	2/A	4.99 a	67.10 b	84.84 ab	41.77 bc	11.06 cd	2/A
6.13 ab	74.35 a	88.15 a	42.03 ab	8.14 e	2/C	4.97 a	69.26 a	86.17 a	43.89 b	9.11 d	2/C
5.27 bc	67.70 bc	85.56 b	41.12 b	8.94 bcd	2/B	4.84 ab	69.39 a	86.21 a	43.37 bc	10.36 d	2/B
5.18 c	69.05 b	85.54 b	42.56 ab	8.66 cd	3/A	4.18 bc	63.04 c	82.45 bc	40.62 c	13.85 ab	3/C
5.10 c	70.65 ab	85.05 b	43.47 a	9.64 bc	3/C	3.94 c	64.47 c	80.95 c	40.95 c	15.47 a	3/B
4.61 c	62.54 c	81.64 c	37.08 c	12.18 a	3/B	3.93 c	70.34 a	84.50 ab	47.03 a	12.96 bc	3/A
'Kaew'											
6.60 a	61.40 de	83.00 c	36.65 d	23.38 b	2/A	6.01 a	63.60 b	82.14 a	44.22 c	28.85 d	2/A
6.52 a	69.04 a	86.60 a	43.64 b	18.42 b	2/C	5.70 ab	67.81 a	82.25 a	49.84 a	39.04 bc	2/C
6.45 a	60.61 e	79.31 e	39.72 c	34.08 a	3/A	5.45 ab	62.49 b	81.16 b	41.57 d	42.92 b	2/B
6.18 a	63.81 c	84.18 b	42.80 b	22.03 b	2/B	5.20 bc	59.37 c	75.41 d	39.27 e	54.31 a	3/C
5.61 b	66.16 b	81.62 d	45.19 a	34.80 a	3/C	5.19 bc	67.77 a	82.41 a	47.12 b	30.90 d	3/A
5.17 b	63.39 cd	80.05 e	40.44 c	34.05 a	3/B	4.55 c	61.72 bc	79.90 c	41.34 d	32.96 cd	3/B
'Chok Anan'											
5.76 a	65.25 a	83.16 ab	39.22 a	12.44 d	2/C	4.76 a	63.14 a	81.12 a	43.34 a	17.43 bc	2/C
5.70 a	63.05 b	83.96 a	33.27 b	11.61 d	2/A	4.60 ab	61.10 a	80.71 a	38.22 b	15.99 c	2/A
5.16 b	59.56 c	80.37 bc	37.90 a	17.60 b	3/A	4.05abc	58.00 b	75.07 c	35.36 c	22.52 a	3/A
5.04 b	62.56 b	80.67 bc	38.97 a	16.69 bc	2/B	3.69bcd	58.29 b	78.12 b	35.51 c	21.69 a	3/C
4.45 c	58.70 c	78.99 c	34.73 b	14.19 cd	3/C	3.13 cd	58.86 b	78.40 b	34.06 c	15.08 c	2/B
3.81 d	58.30 c	78.37 c	33.68 b	21.62 a	3/B	3.00 d	56.75 b	76.14 c	34.07 c	20.27 ab	3/B

$c_{at\beta}$, *all-trans*-β-carotene contents in mg kg^{-1} (dry weight); *RT*, ripening time in days; *M*, postharvest treatment; A, control (no treatment); B, treatment with CaC_2; C, treatment with CEPA. a, b, c, d, e: on the basis of least significant difference tests (LSD), different letters within a column of each attribute indicate significant differences of the means obtained per cultivar and ripening temperature, at a level of significance of $P \leq 0.05$.

conditions, are presented in Table 2 for all three cultivars. In most cases, cultivars, ripening temperature and time showed a marked effect on the *all-trans*-β-carotene contents when compared to the ripening method. An impact of the latter was only measurable with respect to the *all-trans*-β-carotene content in 'Kaew' products when fruits were ripened at 33 °C. In this case, CaC_2 and CEPA enhanced the β-carotene contents at the applied concentrations (Table 2). Higher carotenoid contents of fresh pulp of mango cv. 'Rataul' was detected, when CaC_2 and Ethrel® (CEPA) were applied, than in pulp of the control [17].

At the same ripening condition, dried mangoes cv. 'Kaew' had approximately 2- and 3-fold higher *all-trans*-β-carotene contents than those of cvs. 'Chok Anan' and 'Nam Dokmai', respectively. By analogy, a higher *all-trans*-β-carotene content of fresh pulp of cv. 'Kaew' was observed relative to those of the other two cultivars [11]. In general, dried mangoes from the fruits ripened at 33 °C were richer in *all-trans*-β-carotene than those after ripening of the fruit at 24 °C, as shown, regardless of the cultivar, by the comparison of samples that were treated with the same ripening accelerator and subjected to drying after the same ripening time. Similarly, the development of total carotenoids in fresh pulp of mango cv. 'Kensington', ripened at 13 °C, was less than in that of fruits, ripened at 22 and 30 °C, and resulted in lower sensory scores for pulp colour quality [25]. This effect of ripening temperature is in line with the observation by Thomas [12], who noticed that mangoes cv. 'Alphonso', stored at low temperature and subsequently ripened at ambient temperature, failed to synthesise as much carotenoids as those fruits that were continuously stored at room temperature. In this study, regardless of sensory results, a maximum *all-trans*-β-carotene content amounting to 54.3 mg kg^{-1} of the edible part on a dry weight base, equivalent to 9052 RE kg^{-1}, was observed in dried 'Kaew' slices, when the fruits were ripened for 3 days after application of CEPA.

Pearson correlation was performed to explore linear correlation between *RPI* of fresh fruits and L^*, C^*, a^*, H° values, and *all-trans*-β-carotene contents of dried products from each cultivar ripened at 24 and 33 °C. The hue angles (H°) and *all-trans*-β-carotene contents were found to have a significant, linear negative correlation at $P \leq 0.05$ for products of 'Nam Dokmai' and 'Kaew' fruits ripened at 24 °C ($r = -0.864^*$ and -0.924^*) and 33 °C ($r = -0.955^{**}$ and -0.812^*). Thus, an increase in H° could indicate a reduction of the *all-trans*-β-carotene content (Table 2), similarly to the situation in fresh mango fruits [18]. For cv. 'Chok Anan', even though no significant differences were detected, the relationship between these two parameters also trended to be linear. When the fruits of this cultivar were ripened at 33 °C, the Cartesian hue coordinate a^* of the products significantly correlated with their *all-trans*-β-carotene contents

($r = 0.819^{*}$). Among the other fruits ripened under such conditions, significant correlations between a^* and *all-trans*-β-carotene contents were also identified for the dried fruits of cvs. 'Nam Dokmai' ($r = 0.978^{**}$) and 'Kaew' ($r = 0.831^{*}$), in case of the latter variety also for products from the fruits ripened at the lower temperature of 24 °C ($r = 0.975^{**}$). Vasquez-Caicedo et al. [18, 26] reported good correlation of the mesocarp a^*-values and *all-trans*-β-carotene contents for fresh mangoes, consistent with increasing redness that is indicated by rising positive a^*-values. Thus, the a^*-value was suggested to be a suitable indicator for predicting β-carotene contents in fresh fruit pulp and also in dried slices, provided that the product colour is not additionally influenced by browning due to different drying conditions [27]. A relationship between the a^*-value of the product and *RPI* was only found for cv. 'Nam Dokmai' ($r = -0.933^{**}$ and -0.843^{*} within the groups ripened at 24 and 33 °C, respectively). β-Carotene content and C^* of products did not correlate.

Exponential development with proceeding ripening, expressed by a descending postharvest ripening index equivalent to the *RPI* of this study, was reported for the hue angle and *all-trans*-β-carotene levels of fresh mangoes for all nine Thai cultivars studied [18]. In the present study, the *RPI* range resulted from different ripening conditions rather than the course of a single ripening process and carotenogenesis was only one factor that could influence colour and carotenoid levels of the products, beside the drying process. Nevertheless, regression analysis was similarly used to explore potential interactions of the respective attributes of fresh and dried fruits. For cv. 'Nam Dokmai', much higher linear correlation, irrespective of ripening conditions, was observed between *RPI* and the hue angle ratio of dried and fresh mangoes ($H^{\circ}_{d}/H^{\circ}_{f}$) than for cv. 'Kaew' and 'Chok Anan', with coefficients of determination (R^2) of 0.89, 0.66 and 0.53, respectively (Fig. 2b). Better R^2 was achieved, when the same ripening methods were applied to mature-green mangoes that were subjected to drying after ripening for 2–4 days at 25 °C, as confirmed by our previous data of mangoes originating from season 2001 [7], with R^2 of 0.83, 0.80 and 0.67 for cvs. 'Nam Dokmai', 'Kaew' and 'Chok Anan', respectively (Fig. 2a). Increasing $H^{\circ}_{d}/H^{\circ}_{f}$ ratios with proceeding ripeness indicated a relative rise of H°_{d} and, thus, higher susceptibility of riper fruits to colour changes during drying in the form of a shift towards yellow hues.

Consistent with a linearised exponential development of *all-trans*-β-carotene, moderate linear correlations between *RPI* and the logarithm of the *all-trans*-β-carotene contents of fresh pulp and dried mango slices, regardless of the ripening conditions, were exclusively observed for cv. 'Nam Dokmai' and 'Chok Anan' harvested in 2001 (Fig. 3a and b), when the observed *RPI* range was extended by the additional inclusion of drying after 4 days of ripening at 25 °C rather than by an

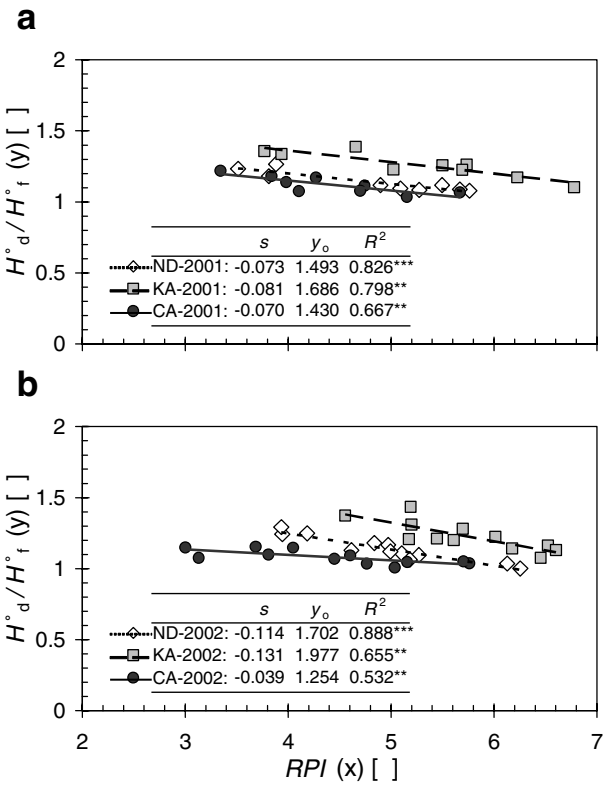

Fig. 2 Linear relationships between *RPI* and the hue angle ratio of dried and fresh mango slices ($H^{\circ}_{d}/H^{\circ}_{f}$) of three mango cultivars on the basis of **a** nine product variants in year 2001 and **b** 12 in year 2002 per cultivar, irrespective of time, temperature, and method of postharvest ripening. Linear regressions of the type $y = sx + y_o$ between $H^{\circ}_{d}/H^{\circ}_{f}$ (y) and *RPI* (x) with coefficients of determination (R^2) that were significant at $P \leq 0.001$ (R^{2***}) or 0.01 (R^{2**}). ND, 'Nam Dokmai'; KA, 'Kaew'; CA, 'Chok Anan'

increase in the ripening temperature as performed in 2002. Lower R^2 were indicated in the same cultivars originating from season 2002 (Fig. 3c). In accordance with these relationships, cultivar-specific maximum *all-trans*-β-carotene contents of 13–16 and 20–23 mg kg^{-1} usually characterised the products of 'Nam Dokmai' and 'Chok Anan' fruits with low *RPI* levels between 3 and 4 (Table 2). Conversely, fruits cv. 'Kaew' of *RPI* levels above 6 generally yielded products inferior in β-carotene, while the overall influence of fruit ripeness on the *all-trans*-β-carotene contents of the dried products was diminishing in the case of this cultivar.

Sensory evaluation of dried mango slices

As regards overall acceptance scores, significant sensory differences ($P \leq 0.05$) among the products, obtained after ripening at various conditions, were not observed for each cultivar. The greatest differences in overall acceptance occurred among the products of cv. 'Kaew' (Fig. 4a). The relationships among sensory attributes of the dried products and the *RPI* of the fresh fruits are shown in Fig. 4 for each of

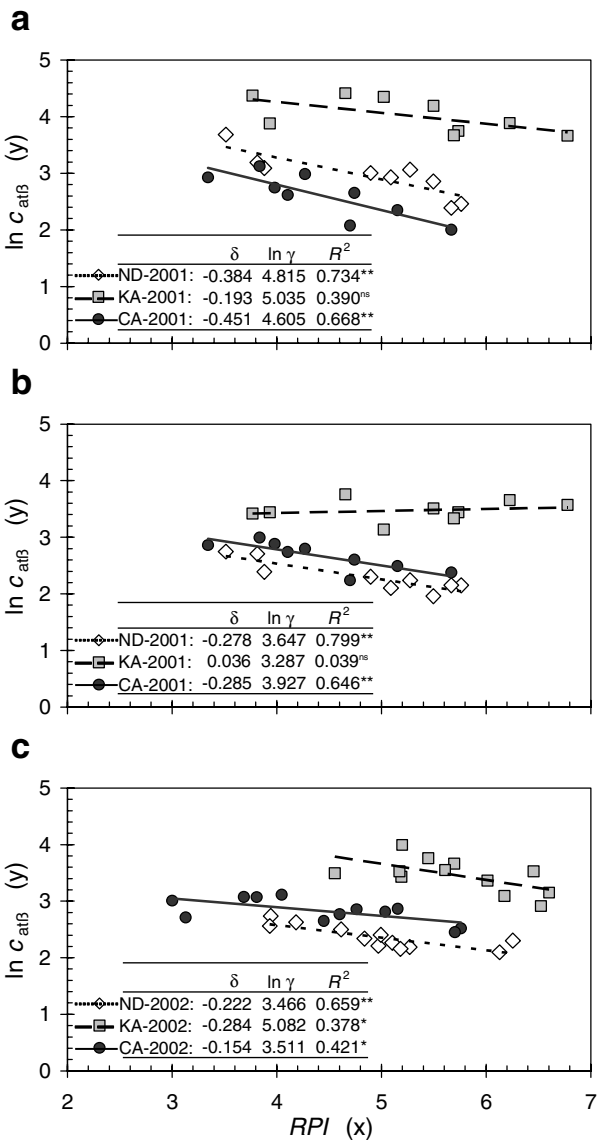

Fig. 3 Linearised exponential relationships between *RPI* and the *all-trans-β*-carotene contents ($c_{at\beta}$) of fresh and dried mangoes from seasons 2001 and 2002 on the basis of 9 and 12 observations per cultivar in 2001 and 2002, respectively, irrespective of time, temperature, and method of postharvest ripening. **a** Pulp of fresh fruits of year 2001; **b** dried fruit slices of year 2001; **c** dried fruit slices of year 2002 (*all-trans-β*-carotene levels as logarithm of the absolute values in mg kg^{-1} d.w.). Linear regressions of the type $y = \delta x + \ln \gamma$ between ln $c_{at\beta}$ (y) and *RPI* (x) with coefficients of determination (R^2) that were either not significant (ns) or significant at $P \leq 0.01$ (R^{2**}) or 0.05 (R^{2*}). ND, 'Nam Dokmai'; KA, 'Kaew'; CA, 'Chok Anan'

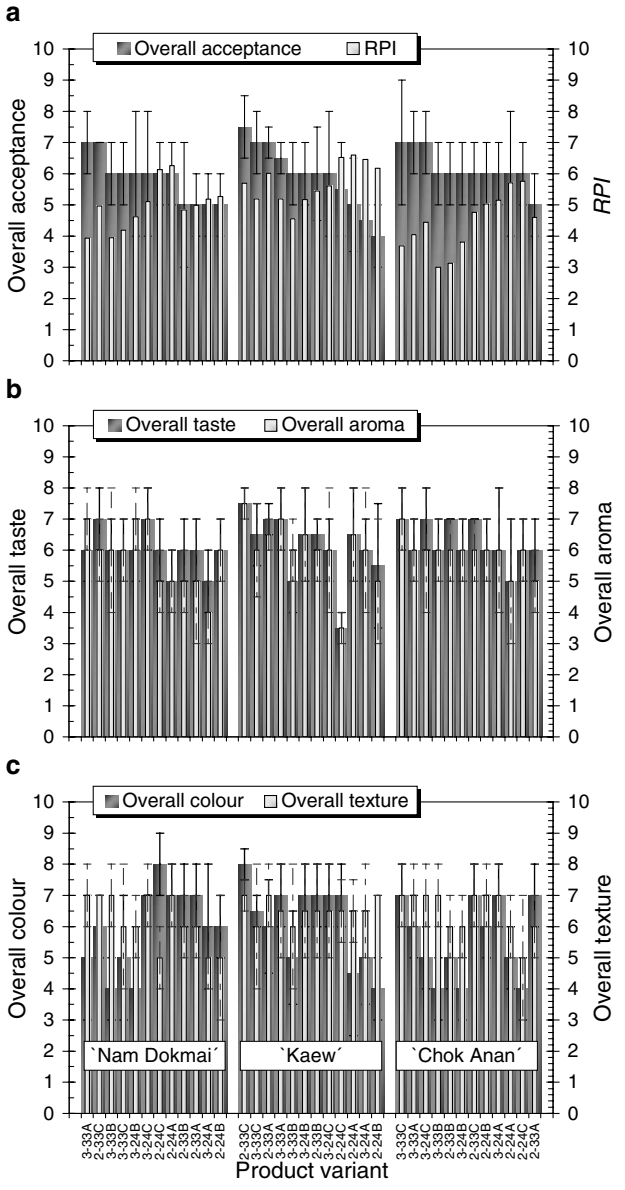

Fig. 4 Sensory attribute scores of dried mango slices and respective *RPI* of fresh fruits ripened at various conditions in harvest year 2002. **a** Fruit ripeness (*RPI*) and overall acceptance scores (*OACS*) of the products; **b** corresponding product scores for overall aroma (*OAMS*) and taste (*OTAS*); and **c** respective product scores for overall colour (*OCS*) and texture (*OTXS*). Product variants were sorted per cultivar according to declining overall acceptance, followed by decreasing ripeness (increasing *RPI*). Error bars of sensory scores: median absolute deviations (*MAD*). Coding of product variants of the type "[*RT*] – [*T*][*M*]", based on the time (*RT* in days), temperature (*T* in °C) and method (M = A, B, C) of postharvest ripening. A, control (no treatment); B, treatment with CaC_2; C, treatment with CEPA

the three cultivars. The main attributes, influencing overall acceptance of dried mangoes cv. 'Nam Dokmai', were aroma and texture (Table 3), whereas textural differences among the products of the other two cultivars were hardly noticed (Fig. 4a and c). Greatest differences in the overall aroma were found among the samples of cv. 'Kaew', followed by those of cv. 'Nam Dokmai' (Fig. 4b). It was also cv. 'Kaew' that yielded the products with the greatest variation in taste (Fig. 4b). As exemplarily shown for cv. 'Nam Dokmai' by the Pearson's correlation coefficient in Table 3, the scores of overall aroma correlated with those of overall taste (Fig. 4b). Among all sensory attributes evaluated, rating of colour varied at most among the product variants, but also among

tasters and did usually not influence overall acceptance, except for the worst product variant obtained from cv.

Table 3 Pearson correlations between sensory attributes of dried mango slices cv. 'Nam Dokmai' and *RPI* of the fresh fruits[a]

	Overall colour	Overall taste	Overall aroma	Overall texture	Overall acceptance	*RPI*
Overall colour	1					
Overall taste	ns	1				
Overall aroma	ns	0.6*	1			
Overall texture	ns	ns	ns	1		
Overall acceptance	ns	ns	0.6*	0.7*	1	
RPI	0.8**	ns	ns	ns	ns	1

ns: not significant.

[a]Sample size: 12 fruit lots of harvest season 2002 with different ripeness at processing as a result of different postharvest ripening conditions and times.

*Significance of correlation at the level of 0.01.

**Significance of correlation at the level of 0.05.

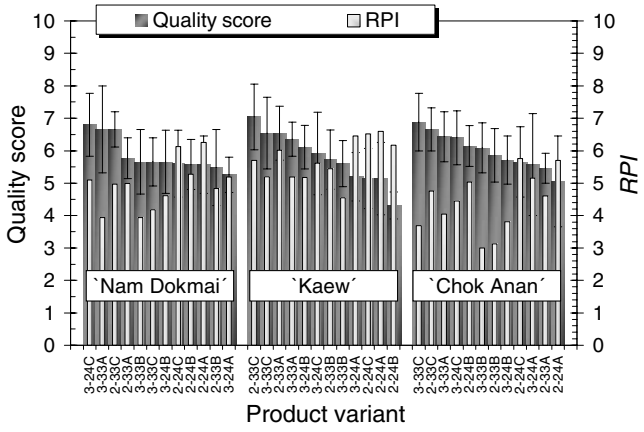

Fig. 5 Median quality scores (*QS*) of dried mango slices, as defined by Eq. (1), and respective *RPI* of fresh fruits ripened at various conditions in harvest year 2002. Product variants were sorted per cultivar according to declining *QS*, followed by decreasing ripeness (increasing *RPI*). Error bars of *QS*: median absolute deviations (*MAD*). Coding of product variants as described in Fig. 4

'Kaew' (Fig. 4a and c). As shown by Pearson correlations, *RPI* linearly correlated with overall colour at $P \leq 0.01$ for products of cv. 'Nam Dokmai' (Table 3), whereas the known influence of fruit ripeness on mesocarp colour [11] was obviously completely masked by that of the drying process in case of the other two cultivars. Since the five sensory attributes were mostly independent of each other, with the exceptions described above, a summarising sensory quality score (*QS*) was additionally calculated according to Eq. (1), weighting each attribute according to the respective overall range of scores that was achieved in this sensory experiment, irrespective of the cultivar. Significant differences in *QS* occurred between the best and the worst products from cv. 'Kaew' (Fig. 5), similar to the differences in overall acceptance.

Considering the cultivar with the greatest differences in overall acceptance, cv. 'Kaew', high acceptance scores were only gained by the products of fruits ripened at 33 °C (Fig. 4a), whereas most of the products from fruits ripened at 24 °C were inferior, due to deficiencies in colour or aroma/taste. Considerably low overall colour, acceptance and quality scores were acquired at $RPI > 6$ (Fig. 4a and c and Fig. 5).

Despite significant differences in colour scores (Fig. 4c), the main attribute influencing the overall acceptance of cv. 'Chok Anan' products was overall aroma (Fig. 4aand b), even though the differences among these products were minor in terms of both attributes. The products of this cultivar always gained similar sensory acceptance, irrespective of the processed raw material (Fig 4a). Maneepun and Yunchalad [28] reported that mixing mango pulp cv. 'Chok Anan' with other less acceptable cultivars such as cvs. 'Rad' and 'Pimsen' improved the consumers' preference of mango nectar.

Apart from the colour scores of 'Nam Dokmai' products, no significant correlations occurred between the sensory attributes of the products and fruit ripeness (*RPI*). However, in addition to the mentioned upper *RPI* threshold of > 6 that was ascribed to 'Kaew' products of inferior sensory acceptance, 'Nam Dokmai' and 'Chok Anan' fruits with *RPI* levels between 3 and 4 generated products of good sensory acceptance.

No correlations were detected between overall acceptance scores and *all-trans*-β-carotene contents as well as measured colour values (H°, L^* and C^*) of the products from all cultivars. Some negative correlation ($r = -0.77$) was found between overall colour scores and *all-trans*-β-carotene contents of products from cv. 'Nam Dokmai'. Similarly, relationships between overall colour and measured colour values

(H°) were only found for the products of this cultivar ($r = 0.83^{*}$).

Conclusion: appropriate fruit ripeness and ripening conditions for producing dried mango slices

Both good sensory acceptance and cultivar-specific maximum *all-trans*-β-carotene contents of 13–16 and 20–23 mg kg^{-1} usually characterised the products of 'Nam Dokmai' and 'Chok Anan' fruits with *RPI* levels between 3 and 4 (Table 2, Fig. 4a). Conversely, fruits cv. 'Kaew' of *RPI* levels above 6 generally yielded products inferior in sensory acceptance and β-carotene contents. Fruit ripening at subtropical ambient temperature (33 °C) increased *all-trans*-β-carotene contents and overall acceptance scores of the dried fruits. For superior product qualities, as regards sensory acceptance in combination with high *all-trans*-β-carotene levels, the longer ripening time of 3 days was usually needed. In case of cvs. 'Nam Dokmai' and 'Chok Anan', the additional benefit of the ripening accelerators, CaC_2 (method B) and CEPA (method C), was minor relative to natural ripening (control method A) (Fig. 4a and Table 2). However, the product, derived from 'Kaew' fruits, ripened for 3 days at 33 °C after application of CEPA, showed by far the highest *all-trans*-β-carotene content with 54.31 mg kg^{-1} of the edible portion (d.w.), which was equivalent to 9052 RE kg^{-1} (d.w.). Relative to the product from fruits after natural ripening under the same conditions, *all-trans*-β-carotene amounted to the 1.76-fold level (Table 2). However, both product variants were derived from 'Kaew' fruits of the same ripeness ($RPI = 5.2$) and revealed insignificant differences in sensory acceptance (Fig. 4a). A disadvantage of the application of ethephon (CEPA) is the application in aqueous solution, enhancing the spread of diseases [29]. Moreover, supplementary steps are needed for handling and also for wastewater treatment, leading to an increase in production costs. Furthermore, the impact of the ripening methods on the β-carotene contents of the dried products was limited to 'Kaew' fruits ripened at 33 °C (Table 2, [7]). On the whole, the presented findings indicated that the application of the ripening accelerators was not necessary with respect to the quality of the dried products.

The estimated mean requirement and safe level of intake for vitamin A for adults are 270 and 500 RE per day, respectively, for females as well as 300 and 600 RE per day for males [22]. Hence, according to the present study, 100 g of sulphite-free dried mango slices from fruits of cvs. 'Kaew' and 'Chok Anan' of superior product quality provided sufficient amounts of pro-vitamin A for adults, with *all-trans*-β-carotene contents of 29–54 and 20–23 mg kg^{-1} and vitamin A values of 4830–9000 and 3330–3830 RE kg^{-1}. Additionally, the price of mature-green mangoes of cvs. 'Kaew' and 'Chok Anan' is usually lower than that of cv. 'Nam Dokmai'. As a result, the former two cultivars are particularly suggested for mango drying. Selection of the optimum ripening condition, maturity, and cultivar was shown to be crucial for the quality of dried mango slices, thereby meeting the challenge of providing high-quality products in terms of lacking sulphite residues and high nutritive value to both domestic and international markets. *RPI* proved to be a useful tool in the control of postharvest ripening and the specification of the raw material for drying.

Acknowledgements This study was performed as a supplement to the Special Research Program (SFB 564) 'Research for Sustainable Land Use and Rural Development in Mountainous Regions of Southeast Asia' (Uplands Program). The authors are grateful to DaimlerChrysler AG and the Deutsche Forschungsgemeinschaft (DFG) for financial support, to the Royal Chitralada Projects, Thailand, for providing the conventional dryer, and to Silpakorn University for supporting laboratory facilities.

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