1   Impacts of hot air and vacuum drying on the quality attributes of kiwifruit slices.

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23

24 **Abstract**

25 Hot air and vacuum drying were performed to investigate changes in the
26 moisture content, hardness, L-ascorbic acid content, antioxidant activity, and
27 surface color of kiwifruit samples over the course of the drying process at
28 temperatures of 50, 60, and 70°C and a vacuum drying pressure of 3.00 kPa. The
29 residual ratio of AsA and the antioxidant activity in the dried kiwifruit samples
30 was 0.75-0.99 and 4.3-5.5, respectively. The L-ascorbic acid changes in the
31 kiwifruit samples during the hot air drying process followed first order reaction
32 kinetics. Changes in the sample hardness and antioxidant activity were represented
33 by zero-order reaction kinetics. The sample surface color changes after drying
34 were also measured, and the total color change (ΔE) of the samples at all
35 temperatures and for each drying process was greater than 12. The sample color
36 changes (Δa^*) after vacuum drying at each temperature level were significantly (P
37 < 0.01) lower than those associated with hot air drying.

38

39 **Keywords**

40 Kiwifruit, hot air drying, vacuum drying, hardness, L-ascorbic acid, antioxidant
41 activity

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44   **1. Introduction**

45   Kiwifruit (*Actinidia deliciosa*) originated in China and was later improved
46   and cultivated in New Zealand. This fruit contains a significant amount of
47   L-ascorbic acid and has a limited shelf life after the fruit is fully ripened. In Japan,
48   the kiwifruit crop yield and shipped quantity in 2011 were 26,100 t and 21,900 t,
49   respectively (MAFF, 2013). These data show that approximately 16 % of the
50   kiwifruit were discarded as “food loss”. Drying operations may not only help
51   reduce this food loss but also renew interest in high-quality dried products.

52   Drying is a process in which water is removed to halt or slow down the
53   growth of spoilage microorganisms and the occurrence of chemical reactions.
54   Dehydration plays an important role in extending the shelf life of fleshy
55   agricultural products. In addition to preservation, drying is used to reduce the cost
56   or difficulty of packaging, handling, storage, and transport by converting raw food
57   into a dry solid. This action reduces the weight and sometimes the volume of a
58   food (Barbosa-Cánovas and Vega-Mercado, 1996). Hot air drying is a simple,
59   common method for drying vegetables and fruits (Leonid et al., 2006; Ogura,
60   1993). Numerous investigators have examined the hot air drying characteristics in
61   fruits and vegetables with a high moisture content, such as tomatoes (Orikasa et al.,
62   2005), apples (Sjoholm and Gekas, 1995), garden beets, carrots (Pabis and Jaros,
63   2002), and sweet potatoes (Orikasa et al., 2010). The disadvantages of hot air
64   drying include its low energy efficiency and lengthy drying time during the falling
65   rate period. Hot air also causes substantial color and nutrient degradation (Drouzas

66 et al., 1999; Leonid et al., 2006; Maskan, 2000). Vacuum drying is a process in
67 which moist material is dried under sub-atmospheric pressure (Arevalo-Pinedo and
68 Murr, 2006). Vacuum drying has some distinctive characteristics compared with
69 conventional atmospheric drying. For example, oxidization is prevented because
70 the sample has no contact with air during the drying process. Therefore, the
71 sensory and nutritive qualities of foodstuffs are effectively maintained as a result
72 of the comparatively short drying time and low drying temperature (Wu et al.,
73 2007).

74   Chen et al. (2001) and Orikasa et al. (2008) designed a mathematical model
75 to describe the moisture content changes during the hot air drying of sliced
76 kiwifruit. Orikasa et al. (2012) also reported the vacuum drying characteristics and
77 kiwifruit shrinkage. However, few quality change investigations in kiwifruit
78 during hot air drying and vacuum drying have been reported. These characteristics
79 may help us establish an optimal drying condition for a more nutritious and
80 high-quality dried product.

81   In this paper, changes in sliced kiwifruit sample hardness, L-ascorbic acid,
82 antioxidant activity, and surface color during hot air and vacuum drying were
83 investigated by reaction rate theory. The objectives of this study were as follows:
84 (1) obtain quantitative measurements of the quality changes of kiwifruit sample
85 during hot air and vacuum drying, (2) model changes in the hardness, L-ascorbic
86 acid, and antioxidant activity using reaction rate kinetics, and (3) discuss the
87 different quality changes in kiwifruit samples between hot air and vacuum drying.

88

89 **2. Materials and Methods**

90 **2.1 Materials**

91   Kiwifruits (Hayward, *Actinidia deliciosa*; New Zealand) were purchased
92 from a local market and stored in a refrigerator at approximately 5°C prior to the
93 experiment. The initial moisture content of the kiwifruit was measured by using
94 film with diatomite (Japan Food Research Laboratories, 1973). This method can
95 dry completely high moisture content sample by using a diatomite as dehydrate
96 additive, which prevent hardening of the sample surface and accelerate moving
97 moisture in the dried sample (Tsutsumi, 1996). The kiwifruit was mashed up in a
98 juice mixer, and the slurry was dried with dehydrated diatomite at 70°C and at
99 ambient atmospheric pressure. The weight was measured when the sample reached
100 an equilibrium moisture content at which its weight reading remained the same for
101 1 h, and this number was converted to a dry basis moisture content (kg water/kg
102 dry matter [d.b. decimal]). The initial moisture content was estimated to be
103 4.91 ± 1.296 (d.b. decimal) (number of replication = 15). The fruits were cut into
104 approximately 10 mm slices (approximately 20 g) and then used for the drying
105 tests.

106

107 **2.2 Hot air drying**

108   The hot air drying experiments were conducted at temperatures of 50, 60,
109 and 70°C in a hot air drying chamber (WFO-400, EYELA, Japan) with a volume

110 of 400 L. The air velocity during drying was 0.3 m s^{-1} . Four samples were dried
111 during each experiment. Each sample was weighed with a digital balance at 2.0 h
112 intervals and dried from 4.91 to 0.20 (d.b. decimal). The temperature at the center
113 of each kiwifruit sample was measured using 0.3 mm diameter T-type
114 thermocouples that were inserted into the center of the sample and attached
115 vertically along the sample surface. The experiments were replicated two times at
116 each temperature, and the mean value was used in the analyses.

117

118 **2.3 Vacuum drying**

119 Figure 1 shows a schematic diagram of the vacuum drying apparatus used in
120 this test. It consisted of a vacuum pump, a vacuum control unit, a cold trap, a dryer
121 (which was also used as a temperature controller), and a desiccator. The desiccator,
122 which functioned as a vacuum drying chamber, was placed inside the dryer
123 (WFO-400, EYELA, Japan) to maintain the desired drying temperature. The
124 vacuum pressure in the desiccator was maintained at 3.00 kPa by a vacuum pump
125 (TSW-300, SATO SHINKU, Japan), a cold trap (UT-50, EYELA, Japan), and a
126 vacuum control unit (NVC-2100, EYELA, Japan). The vacuum pressure level was
127 determined from the literature (Bazyma et al., 2006; Cui et al., 2004). The vacuum
128 drying chamber was preheated for 12 h before the start of each test to obtain a
129 stable drying temperature. Sample drying tests were performed at temperatures of
130 50, 60, and 70°C, and the moisture content was reduced from 4.91 to 0.20 (d.b.
131 decimal). Four samples were dried during each experiment. The drying tests were

132 repeated two times at each predetermined temperature, and the mean value was
133 used for the analyses.

134

135 **2.4 Hardness**

136 Penetration tests were performed to evaluate changes in the sample hardness
137 during the drying process. The tests were performed using a food hardness meter
138 (RE2-3305S, YAMADEN, Japan) with a 20 N load cell and a 3 mm diameter
139 flat-ended cylindrical probe. The deformation speed was 2 mm/s. The moving
140 distance of the probe was 2 mm. The average maximum load at four different edge
141 spots on the surface of the samples was defined as the hardness of the samples in
142 this study. The hardness at six to eight moisture content levels was measured
143 during drying at each temperature. The hardening ratio x_h was defined by the
144 following equation (1) ($x_h > 0$ indicates hardening, $x_h < 0$ indicates softening):

$$145 \quad x_h = \frac{y_0 - y}{y_0 - y_e} \quad (1)$$

146 where y_0 is the initial hardness of the sample [N], y is the measured hardness
147 during drying [N], and y_e is the equilibrium hardness of the sample [N]. The
148 equilibrium hardness y_e during hot air and vacuum drying represented the
149 maximum actual hardness values, which were 6.98 N and 5.95 N, respectively.

150

151 **2.5 L-ascorbic acid (AsA)**

152 The AsA content [mg/100 g fresh weight] was determined by using a

153 reflectometer (RQ-flex-plus, Merck, Japan) as described by Orikasa et al. (2008).
154 A 5 g portion of the sample was placed in a beaker, and approximately 100 mL of
155 1 % metaphosphoric acid solution was added. The mixture was homogenized for 1
156 min and then centrifuged at 8000 rpm for 10 min. The supernatant solution was
157 used to analyze the ascorbic acid concentration. The total quantity of AsA [mg] in
158 the test sample was calculated by multiplying the measured content [mg/100 g
159 fresh weight] by the initial sample weight [g]. There were distinct differences in
160 the total AsA quantities between the samples. Therefore, the AsA content changes
161 were evaluated by using the residual AsA content ratio, which was defined as the
162 value obtained by dividing the total quantity of AsA in the dried sample by that of
163 the initial sample before drying. The measurements of each sample at each
164 temperature were repeated four to twelve times.

165

166 **2.6 Antioxidant activity**

167 The antioxidant activity of each sample was determined as described by
168 Suda (2000). The diluted sample was pipetted into 0.95 mL of
169 2,2-diphenyl-1-picrylhydrazyl (DPPH) solution to initiate the reaction. The
170 absorbance was measured after 20 min at 520 nm by using a spectrophotometer
171 (V-630, JASCO, Japan). The antioxidant activity was estimated by using the slope
172 of a Trolox standard, which was described in μg Trolox equivalent (TE) per 1 g of
173 dry sample weight (μg Trolox equivalent/ g-DW). Changes in the antioxidant
174 activity were evaluated by using the ratio of antioxidant activity x_a , which was

175 defined as the value obtained by dividing the antioxidant activity in the dried
176 sample by that of the initial sample before drying. The measurements of each
177 sample at each temperature were repeated four times.

178

179 **2.7 Color**

180 The sample surface color was measured with a chroma meter (CR-13,
181 KONICA MINOLTA, Japan) at four different edge spots on the surface of each
182 sample before and after the drying treatment. The mean values of the measured
183 data are described as the color values in this study. The color values were
184 expressed as L^* (whiteness/darkness), a^* (redness/greenness), and b^*
185 (yellowness/blueness). The surface color change, which is referred to as the total
186 color difference (ΔE), was calculated according to the following equation:

$$187 \quad \Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (2)$$

188 The measurements were repeated four to eight times at each temperature.

189

190 **3. Results and Discussion**

191 **3.1 Moisture content**

192 Figure 2 shows the kiwifruit moisture content changes during hot air and
193 vacuum drying. The moisture content decreased as the drying time elapsed, which
194 resulted in a gentle downward curve. As shown here, the changes in the moisture
195 content during each drying treatment were considered to be within the first falling
196 rate drying period. The moisture content during the first falling rate period was

197 given by the following exponential model (equation (3)):

198
$$\frac{M - M_e}{M_0 - M_e} = \exp(-k_{d1}t) \quad (3)$$

199 where M_0 is the initial moisture content (d.b. decimal), M_e is the equilibrium
200 moisture content (d.b. decimal), k_{d1} is the drying rate constant of the first falling
201 rate drying period [h^{-1}], and t is the drying time [h]. The equilibrium moisture
202 content M_e of the samples during drying was measured at 0.05 (d.b. decimal). The
203 equilibrium moisture contents of the samples were considered stable when the
204 weight changes were less than 0.01 g/day. Parameter k_{d1} of the samples during
205 drying was determined by the linear least squares method using the moisture
206 content results for kiwifruit samples treated with hot air drying. Table 1 shows
207 the calculated values for parameter k_{d1} . The calculated moisture content was
208 represented as a solid line in Fig. 2. The measured results agreed well with the
209 calculated results (RMSE= 0.019-0.194). This finding showed that the hot air
210 drying process of the kiwifruit samples from the initial moisture content until
211 approximately 0.2 (d.b. decimal) was explained by the exponential model. In the
212 vacuum drying process, the results occurring only from the initial moisture
213 content to approximately 1.8 (d.b. decimal) concurred with the calculated results
214 (RMSE= 0.019-0.146). The actual values from an approximate moisture content
215 of 1.8 (d.b. decimal) to the final stage of drying did not share any calculated
216 values with equation (3). Therefore, changes in the moisture content below 1.8
217 (d.b. decimal) must be analyzed using other equations. Page's model has

218 produced good fits to describe the drying of many foods and agricultural products
 219 (Doymaz, 2007; Kashaninejad et al., 2007; Sacilik and Unal, 2005). This model
 220 is expressed as follows:

$$221 \quad \frac{M - M_e}{M_0 - M_e} = \exp(-k_{d2}t^N) \quad (4)$$

222 where k_{d2} is the drying rate constant of the second falling rate drying period
 223 [h^{-1}] and N is a constant. Page's model was used to describe the behavior of
 224 kiwifruit slices during vacuum drying from an approximate moisture content of
 225 1.8 (d.b. decimal) to the final stage of drying. From a moisture content of
 226 approximately 1.8 (d.b. decimal) until the final drying stage, Page's model was
 227 used to describe the changes in the kiwifruit moisture content during vacuum
 228 drying. The k_{d2} and N parameters in equation (4) were determined by a nonlinear
 229 least squares method (Deming method) using the existing moisture content data.
 230 The calculated values of k_{d2} and N in equation (4) are shown in Table 1. The
 231 dashed curves in Figure 2 represent the results calculated from equation (4). The
 232 measured data agreed with the calculated values ($\text{RMSE}=0.017\text{-}0.039$), which
 233 supported the use of Page's model to characterize the drying process of kiwifruit
 234 slices from a moisture content of approximately 1.8 (d.b. decimal) until the final
 235 stage of drying. These results clearly indicated that the changes in the moisture
 236 content from approximately 1.8 (d.b. decimal) to the final drying stage by
 237 vacuum drying can be explained by combining an exponential model and Page's
 238 model.

As shown in Table 1, the calculated parameter k_{d1} during hot air treatment was higher than that of vacuum drying, which may be due to the difference in the sample body temperatures between each drying method. Figure 3 shows changes in the center temperature of the sample during the drying process (drying temperature of 50°C). As shown, the center temperature of the sample during hot air drying gradually increased. However, this trend was not observed during vacuum drying. The same tendency was observed under other temperature conditions (at drying temperatures of 60 and 70°C). The factor that causes these changes is thought to be related to a smaller sensible heat during vacuum drying than during hot air drying. The average temperature of each drying temperature range was calculated from the center temperature data. Table 2 shows the average temperature of each sample. The average center temperatures of the samples during hot air drying were higher than the temperatures during vacuum drying. The temperature difference was clearly caused by a smaller k_{d1} drying constant during the vacuum drying process.

3.2 Hardness

Figure 4 shows the changes in the hardening ratio for the kiwifruit samples during hot air and vacuum drying. The hardness of the sample increased gradually following a slight decrease in hardness after drying began. The sample hardened after 10 h of hot air drying at 50°C, 8 h of vacuum drying at 50°C, and 6 h under the other conditions. The changes in sample hardness during the hardening period

261 were analyzed mathematically by reaction rate theory (Hosaka, 1972). Figure 5
 262 shows the changes in the hardening ratio during the hardening period. When
 263 plotting x_h on a vertical axis against time t (the start point of the hardening period
 264 was considered to be $t=0$ in this figure) on the horizontal axis, the hardening ratio
 265 was increased as the drying time elapsed. Some studies (Okazaki et al., 1997;
 266 Kasai et al., 1994) have postulated that changes in fruit and vegetable hardness
 267 during the heating process could be analyzed by a first-order reaction equation. An
 268 equation and parameters determined by the reaction rate theory would be useful in
 269 an engineering calculation to determine an optimal drying condition (temperature
 270 and drying time) for evaluating the hardness of dried kiwifruit samples. Therefore,
 271 the empirical hardening ratio during drying was applied to the first-order reaction
 272 rate equation (equation (5)).

273 Thus, the following first-order reaction rate equation (4) was assumed:

$$274 \quad \frac{dx}{dt} = k_h (1 - x_h) \quad (5)$$

275 where k_h is the hardening constant [h^{-1}]. Equation (5) is integrated under the
 276 initial condition of $x_h = 0$ to $t = 0$; thus, equation (6) is given as follows:

$$277 \quad \ln(1 - x_h) = -k_h t \quad (6)$$

278 where t is time [h]. The parameter k_h is then determined by the least squares
 279 method using the measured results for kiwifruit sample hardness. Table 3 shows
 280 the calculated values for parameter k_h . The hardening constant k_h becomes larger
 281 during each drying process as the drying temperature rises. The calculated

282 hardness was represented as a line in Fig. 5. The measured results agree with the
283 calculated results (RMSE= 0.059-0.177), and the hardening ratio can be explained
284 by using the first-order reaction equation.

285 Kasai et al. (1994) reported that the heating process caused fruit and
286 vegetables to soften and harden simultaneously; the hardening occurs
287 overwhelmingly at 50-70°C, above which the rapid initial hardening is followed
288 by a gradual softening. The hardening and softening of vegetables are caused by
289 denaturation of the middle lamella. Bartolome and Hoff (1972) reported that
290 hardening was caused by the demethylation of cell wall pectin by pectin
291 methylesterase (PME), which was activated at temperatures above 50°C, and the
292 subsequent formation of a bridge bond between the free carboxyl groups and Ca
293 ions. The main factor that causes vegetable softening during cooking is thought to
294 be the decomposition of pectin by β -elimination because of the decrease in cell
295 membrane function caused by heating (Fuchigami, 1986). Fuchigami (1986) also
296 reported that drying caused decreased esterification and that the decomposition of
297 pectin by the β -elimination reaction was inhibited. Based on these studies, sample
298 transpiration during the drying process can be considered to cause cell membrane
299 damage. PME was activated by the decreasing cell membrane function, and
300 softening was also inhibited by the decreased esterification during drying. Thus,
301 sample hardening was comparatively accelerated more than softening.

302

303 **3.3 AsA content**

304 AsA is a water soluble vitamin that is widely used as an indicator of food
305 quality changes during fruit and vegetable processing (Negi and Roy, 2000; Alibas
306 *et al.*, 2007; Chuah *et al.*, 2008; Karina and Guillermo, 2008; Orikasa *et al.*, 2008).
307 Figure 6 shows the residual ratio of AsA in a kiwifruit sample after drying. The
308 residual ratio of AsA in the kiwifruit samples during hot air drying and vacuum
309 drying was 0.75-0.88 and 0.90-0.99, respectively. The residual ratio of L-ascorbic
310 acid after vacuum drying is higher than that after hot air drying at all tested
311 temperatures. The AsA in fruits and vegetables was decomposed by an enzyme or
312 by non-enzyme oxidation, and the decomposition of AsA was accelerated more at
313 higher temperatures (Miura and Araki, 1988). The enzymatic decomposition of
314 AsA was caused by ascorbic oxidase, and the non-enzymatic decomposition was
315 caused by oxygen in the atmosphere. During the vacuum drying process (3.00 kPa),
316 a small amount of atmospheric oxygen might inhibit the non-enzymatic
317 decomposition of AsA in the sample. Vacuum drying could be a more desirable
318 drying method for protecting the AsA in the kiwifruit sample. Because the AsA
319 content was maintained at a high level during vacuum drying, only the
320 decomposition of AsA during the hot air drying process is discussed in the
321 following theoretical analysis.

322 Figure 7 shows the changes in the residual ratio of the L-ascorbic acid
323 content during hot air drying. The results showed that the AsA content decreased
324 as the drying proceeded over time, that is, as the moisture content decreased.
325 Hosaka (1972) proposed that L-ascorbic acid decomposition was a first-order

326 reaction. An equation and parameters determined by the reaction rate theory would
 327 be useful in an indicator for decomposition of AsA in the kiwifruit sample during
 328 drying process. Therefore, the empirical residual ratio during drying was applied
 329 to the first-order reaction rate equation (equation (7)):

$$330 \quad \frac{dx}{dt} = k_L(1 - x_L) \quad (7)$$

331 where k_L is the coefficient of the AsA decomposition rate [h^{-1}] and x_L is the
 332 residual ratio of L-ascorbic acid, which decreases after t h [decimal] (that is, $1 - x_L$
 333 is the residual ratio of the L-ascorbic acid content after drying [decimal]).
 334 Equation (7) is integrated under the initial condition of $x_L = 0$ to $t = 0$; thus,
 335 equation (8) is given as follows:

$$336 \quad \ln \frac{1}{1 - x_L} = k_L t \quad (8)$$

337 A least squares method was applied to equation (8) with an empirical
 338 residual ratio. Table 3 shows the values for coefficient k_L at each drying
 339 temperature. Figure 6 shows that the residual AsA ratio decreased linearly with
 340 increases in the drying time and temperature. The actual results agreed with the
 341 calculated results (RMSE= 0.023-0.038). This finding demonstrated that the
 342 changes in the kiwifruit sample AsA levels during hot air drying were explained by
 343 first-order reaction kinetics. These experimental results could contribute to the
 344 production of dried kiwifruit with high AsA contents.

345

346 **3.4 Antioxidant activity**

347 As described above, the ratio of antioxidant activity was obtained by
348 dividing the antioxidant activity in the sample after drying by the activity found
349 before drying. Figure 8 shows the antioxidant activity ratio of the kiwifruit
350 samples after drying. The antioxidant activity in the samples during hot air drying
351 and vacuum drying was 4.5-5.5 and 4.3-5.2, respectively. As shown, the ratio of
352 the sample antioxidant activity after drying is approximately five times larger than
353 that of the initial sample. The heat energy during drying has the ability to break
354 down the molecular structures of the covalent complex and release some
355 antioxidant compounds, such as flavonoids, carotene, lycopene, tannin, ascorbate,
356 flavoprotein, and polyphenol polymers (Niwa et al., 1988). Siriamornpun et al.
357 (2012) noted that the increased antioxidant activity of many thermally processed
358 fruits and vegetables could be explained by the increased amount of these
359 components or other phytochemicals released from the matrix by thermal
360 processing. The results from our study indicated a similar trend (Niwa et al., 1988;
361 Siriamornpun et al. 2012).

362 An equation and parameters determined by a reaction rate theory would be
363 useful in an indicator for changes in antioxidant activity of the kiwifruit sample
364 during drying. Therefore, the empirically increasing ratio of the antioxidant
365 activity during drying was applied to the reaction rate equation to model changes
366 in the kiwifruit antioxidant activity during drying. When plotting x_a on a vertical
367 axis and time t on a horizontal axis, the ratio of the antioxidant activity increased
368 linearly as drying advanced with the initial conditions of $t=0$ and $x_a=1.0$. Therefore,

369 the following zero-order reaction rate equation (9) was assumed:

370
$$x_a = k_a t + 1.0 \quad (9)$$

371 where k_a is the antioxidant activity constant [h^{-1}], t is the drying time [h],
372 and x_a is the ratio of the antioxidant activity. Parameter k_a of equation (9) was
373 determined by a linear least squares method using the measured ratio of the
374 antioxidant activity. Table 4 shows the coefficient k_a for each drying temperature.
375 Figure 9 shows the changes in the antioxidant activity ratios during hot air and
376 vacuum drying. These results agreed with the calculated results (RMSE=
377 0.290-1.018), and the ratio of antioxidant activity can be explained using equation
378 9.

379

380 **3.5 Color**

381 The total color change (ΔE) in the kiwifruit samples was determined by
382 using surface color values (L^* , a^* , b^*) to evaluate the color change during drying.
383 A larger ΔE value represents a larger color change from the fresh kiwifruit
384 reference color. Table 6 shows the color parameters for fresh and dried kiwifruit
385 during drying. The total color change (ΔE) of the samples at all temperatures and
386 for each drying process was greater than 12, for which the sensory evaluation level
387 was described as “very much” (Kato et al., 1987). The color change (Δa^*) of the
388 samples after vacuum drying at each temperature level was significantly ($P < 0.01$)
389 lower than that after hot air drying. The sample color changes (Δa^*) could be
390 attributed to a non-enzymatic browning reaction (= Maillard reaction), which was

391 inhibited by a lower temperature (Honma et al., 2011). The sample temperature
392 during vacuum drying was lower than that of hot air drying. The color change
393 (Δa^*) by Maillard reaction was believed to be considerably inhibited during
394 vacuum drying.

395

396 **4. Conclusions**

397 Kiwifruit slices were dried in hot air and under a vacuum at three different
398 temperatures (50, 60, and 70°C), and the physical and chemical properties
399 (moisture content, hardening, L-ascorbic acid decomposition, and antioxidant
400 activity) of the slices were evaluated during the drying processes. The conclusions
401 are summarized as follows:

- 402 1. Changes in the kiwifruit moisture content during hot air drying were predicted
403 by an exponential drying model. Changes in the moisture content during
404 vacuum drying can be explained by using a combination of an exponential
405 model and Page's model.
- 406 2. The residual ratio of AsA in the kiwifruit samples during hot air drying and
407 vacuum drying was 0.75-0.88 and 0.90-0.99, respectively. The antioxidant
408 activity in the samples during hot air drying and vacuum drying was 4.5-5.5
409 and 4.3-5.2, respectively. Changes in the sample hardness, L-ascorbic acid,
410 and antioxidant activity during drying were analyzed by reaction rate theory,
411 and the calculated results concurred with the actual data.
- 412 3. The total color change (ΔE) of the samples at all temperatures and for each

drying process was greater than 12. The sample color changes (Δa^*) after vacuum drying at each temperature level were significantly ($P < 0.01$) lower than those after hot air drying.

As mentioned above, vacuum drying was more suitable method than hot air drying for preventing L-ascorbic acid in kiwifruit sample. However, other parameters of quality change (hardness, antioxidant activity, and total color change) in the each dried samples were not significantly. Further research including organoleptic examination and drying test on other drying temperature range would be contribute to make high quality dried kiwifruit.

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Fig. 1
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Figure captions

Figure 1. Schematic diagram of the vacuum-drying apparatus.

Figure 2. Changes in the kiwifruit moisture content during hot air and vacuum drying.

Figure 3. Changes in the center temperature of the sample during the drying process (drying temperature: 50°C).

Figure 4. Changes in the hardening ratio of kiwifruit samples during hot air and vacuum drying.

Figure 5. Changes in the hardening ratio during the hardening period.

Figure 6. Residual AsA ratio in the kiwifruit samples after drying.

Each value represents the mean $\pm$ S.D. (n=4-12).

Figure 7. Changes in the residual ratio of the L-ascorbic acid content during hot air drying.

Figure 8. Antioxidant activity ratios in the kiwifruit samples after drying.

Each value represents the mean $\pm$ S.D. (n=4).

Figure 9. Changes in the antioxidant activity ratio during hot air and vacuum drying.

Table 1 Calculated parameters k_{d1} , k_{d2} and M_e of equation (3) and (4).

Drying temperature [°C]	Hot air drying		Vacuum drying		Vacuum drying		
	k_{d1} [h ⁻¹]	RMSE	k_{d1} [h ⁻¹]	RMSE	k_{d2} [h ⁻¹]	N	RMSE
50	0.236	0.194	0.126	0.084	0.013	2.096	0.017
60	0.305	0.105	0.186	0.146	0.057	1.649	0.039
70	0.376	0.145	0.219	0.019	0.079	1.715	0.022

Table 2 Average center temperature of the sample during drying

Drying temperature [°C]	Hot air drying	Vacuum drying
50	42.5	39.2
60	48.2	39.4
70	54.7	39.8

Table 3 Calculated parameters k_h of equation (6).

Drying temperature [°C]	Hot air drying		Vacuum drying	
	k_h [h ⁻¹]	RMSE	k_h [h ⁻¹]	RMSE
50	0.083	0.093	0.184	0.136
60	0.114	0.204	0.100	0.202
70	0.146	0.126	0.115	0.216

Table 4 Calculated parameters k_L .

Drying temperature [°C]	Hot air drying		Vacuum drying	
	k_L [h ⁻¹]	RMSE	k_L [h ⁻¹]	RMSE
50	0.012	0.024	0.004	0.022
60	0.022	0.038	0.002	0.034
70	0.023	0.023	-0.001	0.022

Table 5 Calculated parameters k_a .

Drying temperature [°C]	Hot air drying		Vacuum drying	
	k_a [h ⁻¹]	RMSE	k_a [h ⁻¹]	RMSE
50	0.238	1.018	0.120	0.328
60	0.351	0.450	0.236	0.290
70	0.391	0.569	0.351	0.785

Table 6 Color parameters of fresh and dried kiwifruit during drying

Parameters	Hot air drying			Vacuum drying		
	Drying temperature			Drying temperature		
	50°C	60°C	70°C	50°C	60°C	70°C
ΔL^*	11.7±7.243	5.60±5.126	7.85±7.686	10.7±1.348	8.23±2.965	13.7±3.158
Δa^*	7.83±0.921	7.63±0.881	8.93±0.650	3.40±1.465	3.38±1.441	4.38±1.784
Δb^*	9.70±5.431	6.18±4.636	8.33±9.608	6.88±1.597	6.68±3.037	7.63±3.200
ΔE	17.7±7.379	12.4±3.836	15.8±9.910	13.3±1.318	11.3±3.809	16.5±3.762

Each value represents the mean±S.D. (n=8).