

Research Article

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Comparison of important quality components of red-flesh kiwifruit (*Actinidia chinensis*) in different locations

<https://doi.org/10.1515/opag-2022-0283>

received October 17, 2023; accepted March 21, 2024

Abstract: Important quality components of red-fleshed kiwifruit which was grown in three different regions in North of Iran were investigated in this research. Fruits produced in the region with higher altitude and cool summer temperatures showed higher ascorbic acid content (AAC), total phenolic content, and antioxidant activity than the two other regions both at harvest time and storage. It was observed that the 1,1-diphenyl-2-picrylhydrazyl was positively correlated with the AAC ($r = 0.98$), total phenolic content ($r = 0.94$), and the ferric reducing antioxidant power was positively correlated with the AAC ($r = 0.98$), TPC ($r = 0.93$). Fruits harvested in region 2 with cool environments, presented dark red flesh color with the highest values of anthocyanin content at harvest (2.78 mg CGE/100 g), with a gradually increasing trend during storage to reach 3.47 mg CGE/100 g at the end of storage. Total anthocyanin content correlated positively with soluble solids content (SSC; $r = 0.82$), total Soluble sugars (TSS; $r = 0.94$), pH ($r = 0.94$), SSC/titratable acidity (TA; $r = 0.83$) and negatively with TA ($r = -0.77$). Fruits grown in region 2

received the highest SCC and TSS scores after sensory test evaluations made by the panelists. During storage fruits firmness and total acidity of kiwifruit decreased while SSC, TSS, and anthocyanin content increased. Additionally, antioxidant compounds and taste-related quality of kiwifruit had a positive relationship with the product region. Results showed that the growing region and storage duration considerably influenced the antioxidant compounds and nutritional quality of red flesh kiwifruit.

Keywords: nutritional quality, flesh color, product region, total phenolic, antioxidant capacity

1 Introduction

Kiwifruit, the edible berry of vertical woody vines in the genus *Actinidia*, has a high nutritional value and is a good source of vitamins A, C, E and K, folate, carbohydrates, sugars, minerals, amino acids, proteins, carotenoids, and fatty acids such as linoleic acid [1]. The genus *Actinidia* is distributed worldwide due to its high nutritional potential, high levels of ascorbic acid, excellent organoleptic qualities, and adaptability to temperate and subtropical climates [2]

There is a diversity of flesh color in kiwifruit cultivars. Traditionally, kiwifruit have either green or yellow flesh color, or colors in between. In recent years, new kiwifruit cultivars with red flesh color have been selected in China [3] and New Zealand [4]. These cultivars are characterized by red coloration in the inner pericarp region of the fruit, surrounding the central core. Red-fleshed kiwifruit has drawn broad attention for its novelty and high quality. The fruit has an attractive color pattern of yellow or green in the outer pericarp, red in the inner pericarp, and white in the central core. Moreover, the red-fleshed kiwifruit usually has good taste, with high soluble solids content (SSC) and sweetness, and low acidity. These new cultivars have become available either as selections from wild populations or from specific breeding programs [3]. The most important red-

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fleshed cultivars including “Hongyang”, “Donghong,” “Hongshi,” and “Qihong” are mainly cultivated in China, New Zealand, the United States, Greece, Italy, Chile, France, Japan, and Korea [4]

The cultivation of red-fleshed kiwifruit is considerably increased in Iran due to its high commercial value and nutritional quality. In recent years, consumer preference for red-fleshed kiwifruit has increased due to its novelty, attractive color, overall liking score, sweetness, and rich content of phenolic and flavonoid compounds compared to green- and yellow-fleshed kiwifruit. Consequently, many growers have turned to cultivate red-fleshed cultivars to increase their profits and at the same time and improve consumer nutrition [5]. The main red-fleshed kiwifruit that recent years introduced to Iranian kiwifruit growers is known as “Khoni,” which has a deep red color around the core.

It is well known that the chemical composition of kiwifruit can change due to a large number of factors. In red-fleshed kiwifruit, the intensity of the red color can be quite variable from inconsiderable to an intense deep red color. Several factors have been found to affect the red color expression nutritional value of kiwifruit, such as altitude, plant age, and use of CPPU [1-(2-chloro-4-pyridyl)-3-phenylurea] [3]. Previous studies showed that fruit compositions such as proteins, vitamins, sugars, acids, elements as well as aroma compounds are influenced by special geographical climate conditions of producing area, which are responsible for the quality difference in agricultural products from different regions [6,7]. Climatic conditions, including light and average temperature, have a great influence on the chemical composition of horticultural crops. For all fruits, postharvest performance is dependent on both the physiological state of the fruit at harvest and the postharvest management applied. The physiological changes are influenced by a complex interaction of developmental, hormonal, and environmental influences [8]. The differences in the content and number of bioactive compounds in the fruits depend on a sum of elements such as genotype, environmental conditions, maturity, as well as geographical location [9]. Several studies have focused on the effects of geographic origin and environmental conditions on the nutrient and phytochemical contents of fruits [6–10]. Henwood *et al.* [10] indicated that the variation between orchards and regions was larger than within orchards but no clear regional patterns existed. The regional effect cannot be explained by variation in altitude or by regional temperatures alone: in two cases, red-fleshed kiwifruit color intensity was significantly different between two orchards found in the same region with very similar altitudes. Thus, orchard practices and microclimate differences between orchards are likely to be important.

Kiwifruit is widely accepted as a functional food, and most consumers are interested in knowing more about the

quantity variations of bioactive components across diverse batches of kiwifruit available in the market. Therefore, the current study aimed to collect data on the possible relation between the geographic location of red-fleshed kiwifruit orchards on the functional and nutritional values of kiwifruit. This study also noted the specific geographic conditions that contribute positively to the quality of kiwifruits which grown in the north of Iran. This information could be valuable for growers and stakeholders to make a good decision about site selection before planting to optimize the nutritional content and organoleptic features of red-fleshed kiwifruits.

2 Materials and methods

2.1 Materials

2.1.1 The trial site and climatic characteristic

The red-fleshed kiwifruit was obtained from commercial vineyards in three different production regions of Talesh (west Guilan, latitude 37° 47' N, longitude 48° 56' E, altitude 6 m), Langarud (east Guilan, latitude 37° 8' N, longitude 50° 3' E, and altitude 121 m) and Rasht (center Guilan, latitude 37° 11' N, longitude 49° 38' E, and altitude 27 m). The average monthly temperature, rainfall, and relative humidity values of these three growing locations for the season 2022 are presented in Figure 1. In general, the average monthly temperature in Rasht was reported to be higher than in Talesh and Langarud. The weather tends to be colder in Langarud during September and October which coincides with the kiwifruit harvest season. The mean monthly rainfall is higher in Rasht than in other regions. Also, all regions are characterized by high relative humidity, especially in winter.

2.1.2 Plant material

The red-fleshed kiwifruit (*Actinidia chinensis* cv. Khoni) from commercial vineyards harvested from the uniform vines with the same irrigation regime, pruning, and fertilization. Pollination was performed during anthesis in late April to early May 2022 when flower buds open completely. The date on which 5% of flowers opened in the canopy was recorded in Rasht (April 17), Talesh (April 20), and Langarud (April 27). According to the previous study by Choi *et al.* [11], red “Hongyang” kiwifruit cultivars were harvested at 160 days after full bloom (DAFB), and stored for up to 4 months without affecting major quality indices during storage. However, overall sensory quality evaluation showed that kiwifruits harvested at

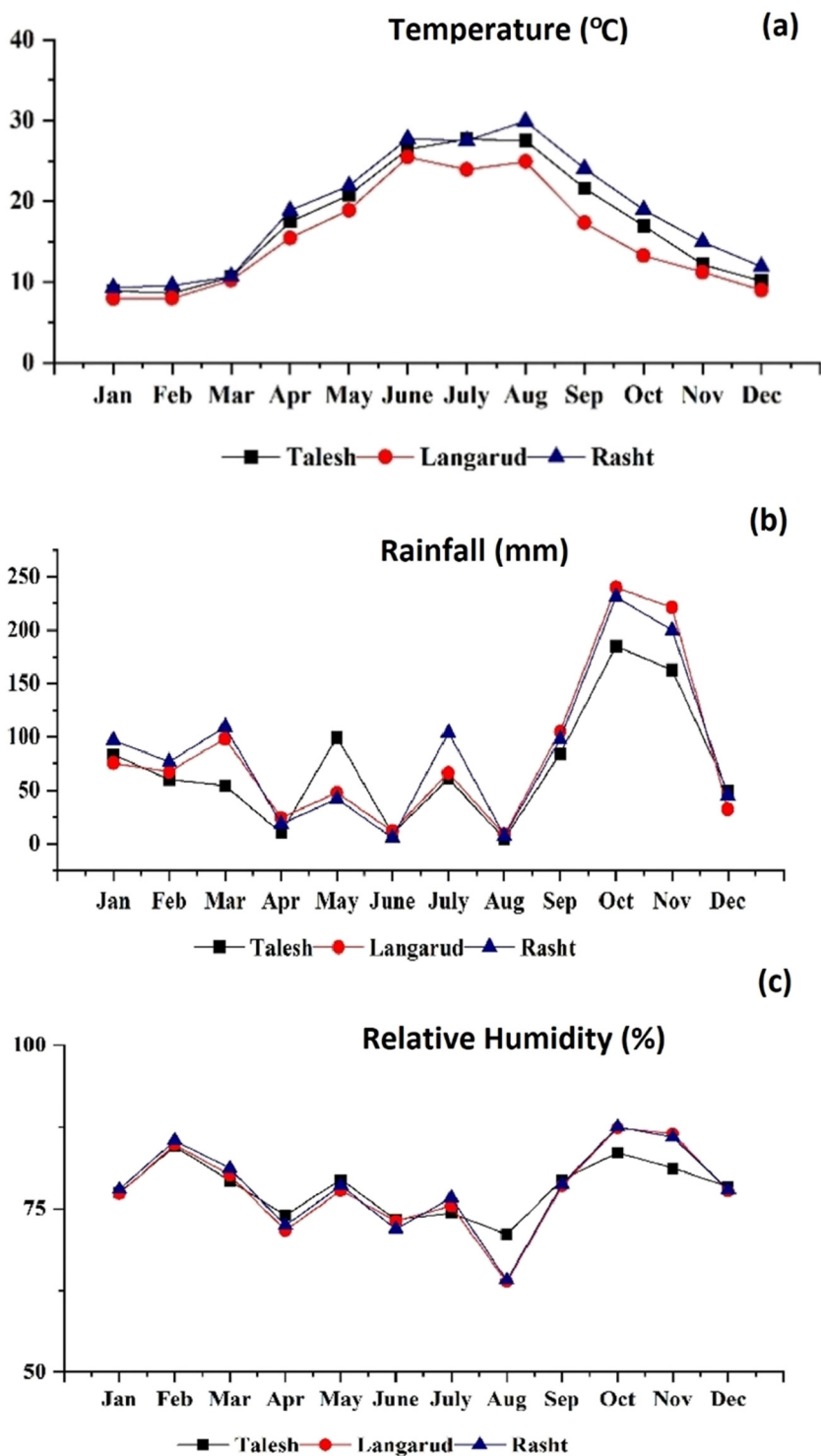


Figure 1: Climatic data of the three studied regions: (a) temperature, (b) rainfall, and (c) relative humidity (Iran Meteorological Organization).

160 DAFB attained good eating quality after 3 months of storage in red kiwi cultivars [11]. Pre-experiment data showed that the optimum harvest time for red flesh kiwifruits in the north of Iran was when fruits were harvested after 170 DAFB. Therefore, 90 red-fleshed kiwifruits were randomly harvested after 170

DAFB from different commercial vineyards in October 2022. Immediately, fruits were transported to the postharvest laboratory at the university of Guilan, Iran. Fruits were uniform in size (average weight of 75–80 g), and free of physical injuries, sunburn, blemishes, bruises, and pathogen and insect attacks.

2.2 Methods

2.2.1 Experiment design

The experiment was designed as a split-plot design structure with three replicates. Then, 90 red-fleshed kiwifruits were randomly selected from commercial vineyards located in each region, packed in corrugated fiberboard boxes, and stored at 0.5°C with 90–95% relative humidity for a duration of 2 months. The weight loss, flesh firmness, SSC, total soluble sugars (TSS), titratable acidity (TA), pH, ascorbic acid Content (AAC), total phenolic content (TPC), total antioxidant capacity as 1,1-diphenyl-2-picrylhydrazyl (DPPH) and ferric reducing antioxidant power (FRAP) and total anthocyanin content (TAC) of fruits were measured at harvest time and every 15 days during storage.

2.2.2 Determination of physical attributes

A total of five kiwifruits in each replicate were randomly selected and weighed at the beginning of the experiment, and at 15-day intervals during the storage period. Weight loss was calculated as follows:

$$\text{Weight loss (\%)} = [(W_0 - W_1)/W_0] \times 100,$$

where W_0 is the initial weight and W_1 is the weight measured during storage [12], and fruit firmness was measured using a penetrometer (Model FT 011, USA) with an 8 mm probe. Measurements were taken at the equator of the fruit, and the results were expressed in kg/cm^2 .

2.2.3 Determination of SSC, TA, pH, and TSS

The SSC of kiwifruit juice was measured by a digital refractometer (Euromex RD 635, Holland) for five fruits from each location at 15-day intervals over the storage period at 22°C and expressed as % Brix [13]. In order to determine the TA of each fruit, diluted kiwifruit juice (1 mL fruit juice added to 19 mL distilled water) was titrated against NaOH, 0.1 N using phenolphthalein as a pH indicator, and expressed as Citric acid percentage [13]. Also, the Brix-acid ratio (SSC/TA) was determined simply by dividing SSC by TA [14]. The pH values of fruit juices were measured using a digital pH meter (Hanna HI 8519, Italy) at 25°C [15]. The TSS was measured based on the improved anthrone colorimetric method. For this purpose, 5 mL distilled water was added to 1 g ground kiwifruit from the frozen sample and bathed in a water bath at 100°C for 20 min. Samples

were centrifuged at 4,000 rpm for 5 min. The supernatant was transferred to a 1,000 mL volumetric flask, and the previous step was repeated. About 1 mL of the obtained solution was brought to a final volume of 25 mL, and finally, 1 mL of the prepared extract was added to 0.5 mL anthrone ethyl acetate and 5 mL sulfuric acid. The solution was fully oscillated and placed in a boiling water bath (100°C, 10 min). After cooling the samples, a spectrophotometer (PG Instruments T80 +, Leicester, UK) was used to measure absorbance at 620 nm in three replicates. Glucose was used to achieve the calibration curve [16].

2.2.4 Determination of AAC

The AAC was determined by following the method stated by Oliveira *et al.* [17] with little modification. A 5 g sample was weighed, and the volume was made up to 100 mL with 3% metaphosphoric acid and filtered. An aliquot of 10 mL was taken in a titration flask and titrated against 2, 6-dichlorophenol indophenol until light pink color appeared and the result was expressed by mg ascorbic acid/100 g FW.

2.2.5 Determination of TPC, TAC and antioxidant activity

For preparing extracts to measure TPC, TAC, and antioxidant capacity, 5 grams of the homogenate for fruits harvested from each cultivation region with 5 replications on 15-day intervals during the storage (skin removed) was mixed with 20 mL of ethanol: acetone (7:3) solution and ultrasonicated for 15 min and centrifuged at 4°C 8,000 rpm for 10 min to obtain the supernatant. The supernatant was used as a base extract to measure TPC, TAC, and antioxidant capacity. The TPC was determined by the Folin–Ciocalteu colorimetric method. For each sample, 25 μL of the extract was added into 125 μL diluted Folin–Ciocalteu solution and 100 μL of 7.5% sodium carbonate solution, then mixed, and placed in the dark for 1 h. The absorbance of solutions was measured at 760 nm using a Power Wave HT microplate spectrophotometer. The results were expressed as mg gallic acid (GAE)/100 g FW [18]. The differential pH method was applied to the measurement of existing TAC. According to the method, the pH value of 0.5 mL of extract was added to 2.5 mL of 0.025 M potassium chloride (KCl) buffer (pH = 1) and 2.5 mL of 0.4 M sodium acetate ($\text{C}_2\text{H}_3\text{NaO}_2 \cdot 3\text{H}_2\text{O}$) buffer (pH = 4.5). Then, the absorption of total anthocyanin from each sample in both pH values was determined at 520 nm and 700 nm by UV/Vis spectrophotometer. TAC was calculated as mg cyanidin-3-glucoside equivalents (CGE)/100 g FW using equation (1) [19].

$$\text{TAC}(\text{mg/L}) = \frac{A \times \text{MW} \times 103 \times \text{Dilution factor}}{\varepsilon \times l}, \quad (1)$$

where ε is the molar extinction coefficient of cyanidin-3-glucoside (26900 L/mol/cm), l is spectrophotometer cell length (1 cm), and MW is the molecular weight of cyanidin-3-glucoside (449.2 g/mol). The A value was calculated using equation (2).

$$A = (A_{520 \text{ nm}} - A_{700 \text{ nm}}) \text{pH}1.0 - (A_{520 \text{ nm}} - A_{700 \text{ nm}}) \text{pH}4.5, \quad (2)$$

Antioxidant activity was measured by two different methods; DPPH and FRAP [4,19]. For the DPPH assay, 250 μL of the supernatant was mixed with 4 mL of DPPH solution. After 30 min of reaction, the absorbance was measured at 517 nm. Regarding the FRAP assay, 0.25 mL of extract and 8 mL of TPTZ (Tripyridyltriazine) solution were allowed to react for 10 min in a 37°C water bath, and absorption was read at 593 nm. The results of the DPPH test were expressed as a percentage, and the FRAP test as μmol ascorbic acid/g FW.

2.2.6 Sensory evaluation

At the end of storage, 30 fruits from each site were stored for 7 additional days at 25°C to be examined for sensory evaluation. For sensory analysis, a panel of eight women and 10 men aged 28–60 years were randomly selected from

professors, students, producers, exporters, and members of the Kiwifruit Association of Iran. Considered attributes for sensory evaluation were based on Nunes-Damaceno et al. [20], including hairiness, external aroma intensity, firmness (endpoints: an anti-stress ball and a tennis ball), internal aroma intensity, flesh color (endpoints: Pantone colors 085 to 032°C), flavor intensity, sweetness (endpoints: 7.2 and 24.0 g/L saccharose solutions), tartness (endpoints: 0.38 and 1.40 g/L citric acid solutions), juiciness (midpoint: a Granny Smith apple), fibrosity (endpoints: canned peach and canned pineapple), and astringency (endpoints: 0.25 and 0.40 g/L tannic acid solutions). Questionnaires were prepared based on a seven-point scale and given a score of 1–7 from very negative to very positive.

2.2.7 Statistical analysis

Statistical analyses were performed using one-way analysis of variance (ANOVA), to determine the significance of differences between region and storage time at $p < 0.05$ using SAS statistical software (SAS/STAT® 9.4; SAS Institute Inc., Cary, NC, USA). The Pearson correlation test was used to correlate the collected parameters. All figures were drawn using the 2022 edition of Origin Pro software (OriginLab Corporation, USA).

Table 1: Variation of fruit firmness and taste related compounds in red kiwifruit according to region and storage time

Location	Storage (days)	Firmness (kg/cm ²)	SSC (°Brix)	TSS (%)	TA (%)	pH	SSC/TA
Talesh	0	7.50 ± 0.10b	10.12 ± 0.37h	7.21 ± 0.72h	1.41 ± 0.02c	3.63 ± 0.03h	7.14 ± 0.24k
	15	6.26 ± 0.21d	12.47 ± 0.27f	8.42 ± 0.62fg	1.12 ± 0.04f	3.69 ± 0.02e–g	11.08 ± 0.61h
	30	4.60 ± 0.10g	14.18 ± 0.45e	8.96 ± 0.59d–f	0.91 ± 0.02h	3.72 ± 0.01ef	15.58 ± 0.17f
	45	3.46 ± 0.15h	17.27 ± 0.54c	9.85 ± 0.30cd	0.86 ± 0.04i	3.77 ± 0.04cd	20.10 ± 0.75d
	60	1.96 ± 0.21j	18.30 ± 0.26b	10.12 ± 0.35c	0.72 ± 0.02k	3.82 ± 0.04ab	25.19 ± 0.64b
Langarud	0	6.96 ± 0.25c	11.66 ± 0.25g	9.46 ± 0.45c–e	1.35 ± 0.02d	3.69 ± 0.02e–g	8.62 ± 0.23j
	15	5.83 ± 0.31e	12.90 ± 0.56f	9.78 ± 0.20cd	1.23 ± 0.01e	3.72 ± 0.02ef	10.48 ± 0.43hi
	30	5.36 ± 0.21f	15.40 ± 0.36d	11.40 ± 0.81b	0.90 ± 0.02h	3.78 ± 0.02bc	16.99 ± 0.66e
	45	3.43 ± 0.12h	18.73 ± 0.40b	12.19 ± 0.70b	0.77 ± 0.02j	3.81 ± 0.02a–c	24.22 ± 0.17c
	60	2.10 ± 0.17j	19.97 ± 0.45a	13.33 ± 0.95a	0.61 ± 0.01l	3.85 ± 0.03a	32.37 ± 0.48a
Rasht	0	8.66 ± 0.21a	8.83 ± 0.45i	6.85 ± 0.47h	1.57 ± 0.04a	3.60 ± 0.03h	5.60 ± 0.43l
	15	7.70 ± 0.17b	11.13 ± 0.67g	8.24 ± 0.66g	1.47 ± 0.01b	3.63 ± 0.03h	7.53 ± 0.39k
	30	5.60 ± 0.10ef	12.43 ± 0.42f	8.74 ± 0.57e–g	1.22 ± 0.01e	3.65 ± 0.04gh	10.19 ± 0.41i
	45	3.66 ± 0.15h	14.53 ± 0.55e	8.70 ± 0.39e–g	1.02 ± 0.03g	3.68 ± 0.04fg	14.26 ± 0.93g
	60	2.87 ± 0.21i	17.13 ± 0.31c	9.27 ± 0.12c–f	0.82 ± 0.02i	3.73 ± 0.04de	20.73 ± 0.65d
Significance levels (p)							
Storage (B)		**	**	*	**	*	**
Region (A)		**	**	**	**	**	**
$A \times B$		**	**	*	**	n.s	**

n.s, *, ** indicate non-significant and significant differences at $p < 0.05$ and 0.01, respectively. Means with different letters within the same column are significantly different ($p < 0.01$). Different letters, for each method, indicate significant differences among regions and storage times at $p < 0.01$.

3 Results

The results of ANOVA are summarized in Tables 1 and 2. As the results showed, the storage time, growing region, and the interaction between storage and region had significant effects on firmness, SSC, TA, SSC/TA, ascorbic acid, DPPH, and FRAP ($p < 0.01$). Interaction effect of region $\times$ storage on fruit weight loss and TAC are shown in Figures 2 and 5, respectively. However, no significant difference was found in the interaction between storage and region on the pH and TPC.

3.1 Fruit weight loss

The fruit weight loss increased progressively over 2 months of storage depending on growing locations (Figure 2). The values were significantly higher in Langarud than in Talesh and Rasht (Figure 2). The lower weight loss was found in the Rasht region in the center of Guilan province (Figure 2).

3.2 Fruit firmness

The fruit firmness at harvest time varied significantly according to geographical origin. The fruits grown in Rasht (center from Guilan) were firmer (8.66 kg/cm^2) than those from Talesh and Langarud. Furthermore, fruit firmness decreased at low-

temperature storage. The rate of softening in fruit harvested from Rasht was faster than those of Langarud and Talesh (Table 1). According to the results of simple correlation analysis (Figure 3), a negative correlation was observed between weight loss percentage and flesh firmness ($r = -0.90$).

3.3 SSC and TSS

The SSC is an important criterion in fruit taste and quality. It revealed a significant variation from one region to another (Table 1). Its content increased dramatically over storage time. The fruits from Langarud were characterized by the highest SSC (19.97% Brix), while the lowest SSC (17.3% Brix) was recorded in kiwifruit produced in Rasht. The results also showed a positive correlation between both weight loss and SSC ($r = 0.90$) and weight loss and TSS ($r = 0.84$; Figure 3).

The TSS varied significantly according to geographical origin. Kiwifruit produced in Langarud (9.46%) showed the highest TSS than two other regions at harvest time, while the lowest value (9.27%) was recorded in kiwifruit from Rasht (Table 1). With increased storage time, the TSS value of the samples of all regions increased and fruits harvested from Langarud (13.33%) showed the highest TSS after 60 days of storage (Table 1).

Table 2: Variation of fruit antioxidant compounds in red kiwifruit according to region and storage time

Location	Storage (days)	AAC (mg/100 g)	TPC (mg GAE/100 g)	DPPH (%)	FRAP ($\mu\text{mol/g}$)
Talesh	0	$87.91 \pm 1.14\text{de}$	$98.78 \pm 1.63\text{cd}$	$70.22 \pm 1.53\text{cd}$	$10.12 \pm 0.09\text{cd}$
	15	$84.42 \pm 1.47\text{f}$	$96.97 \pm 0.68\text{ed}$	$67.39 \pm 1.84\text{e-f}$	$9.67 \pm 0.12\text{de}$
	30	$80.21 \pm 1.36\text{g}$	$94.52 \pm 1.30\text{f}$	$66.14 \pm 1.57\text{f}$	$9.19 \pm 0.33\text{ef}$
	45	$77.32 \pm 1.42\text{h}$	$90.68 \pm 1.79\text{g}$	$61.49 \pm 1.53\text{gh}$	$8.78 \pm 0.75\text{fg}$
	60	$73.49 \pm 1.18\text{h}$	$86.54 \pm 1.17\text{h}$	$60.12 \pm 1.49\text{hi}$	$7.32 \pm 0.15\text{ij}$
Langrud	0	$97.59 \pm 1.88\text{a}$	$111.52 \pm 0.73\text{a}$	$77.26 \pm 1.45\text{a}$	$11.62 \pm 0.46\text{a}$
	15	$95.14 \pm 1.13\text{b}$	$109.67 \pm 1.71\text{a}$	$73.60 \pm 1.23\text{b}$	$10.85 \pm 0.28\text{b}$
	30	$92.98 \pm 1.17\text{c}$	$105.83 \pm 0.77\text{b}$	$70.66 \pm 1.61\text{c}$	$10.60 \pm 0.13\text{bc}$
	45	$89.11 \pm 1.01\text{d}$	$104.28 \pm 1.57\text{b}$	$69.65 \pm 1.09\text{c-e}$	$9.84 \pm 0.26\text{d}$
	60	$86.39 \pm 1.08\text{ef}$	$100.52 \pm 1.59\text{c}$	$67.96 \pm 1.37\text{d-f}$	$9.75 \pm 0.49\text{de}$
Rasht	0	$82.17 \pm 1.44\text{g}$	$97.3 \pm 0.80\text{d}$	$68.87 \pm 1.35\text{c-e}$	$9.20 \pm 0.16\text{ef}$
	15	$76.66 \pm 1.14\text{h}$	$94.98 \pm 1.23\text{ef}$	$63.10 \pm 0.79\text{g}$	$8.22 \pm 0.15\text{gh}$
	30	$73.51 \pm 0.90\text{i}$	$93.85 \pm 1.85\text{f}$	$59.17 \pm 1.72\text{i}$	$7.74 \pm 0.44\text{hi}$
	45	$67.33 \pm 1.74\text{j}$	$89.33 \pm 1.28\text{g}$	$56.54 \pm 1.45\text{j}$	$6.96 \pm 0.34\text{j}$
	60	$64.40 \pm 1.15\text{k}$	$83.48 \pm 1.58\text{i}$	$52.55 \pm 1.14\text{k}$	$6.88 \pm 0.33\text{j}$
Significance levels (p)					
Storage (B)		*	*	*	**
Region (A)		**	**	**	**
$A \times B$		**	n.s	**	*

n.s, *, ** indicate non-significant and significant differences at $p < 0.05$ and 0.01 , respectively. Means with different letters within the same column are significantly different ($p < 0.01$). Different letters, for each method, indicate significant differences among regions and storage time at $p < 0.01$.

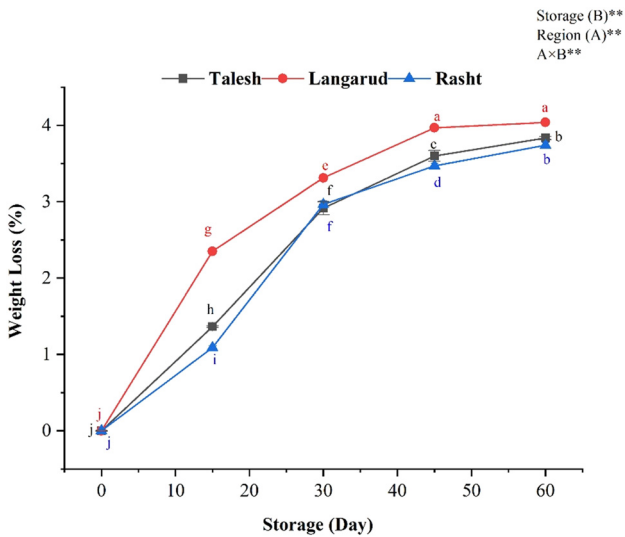


Figure 2: Variation of weight loss percentage in red kiwifruit. According to different lowercase letters show significant differences ($p < 0.01$) among treatments for each sampling date. *The results are expressed as mean $\pm$ standard deviation and the (n) number of replicates in each experimental parameter determined.

3.4 TA and pH

The fruit TA is a taste-related attribute. The geographical origin had a significant effect on the fruit TA. The highest

TA (1.57%) was found in fruits harvested from the Rasht region. However, the lowest value was observed in fruits produced in Langarud (Table 1). The results also showed that the TA percentage declined over storage time independence on growing location. In this study, with increasing SSC and TSS, the amount of TA decreased simultaneously in fruits harvested from all three regions during cold storage (Table 1). According to the results of this study, TA correlates positively with flesh firmness ($r = 0.95$) and negatively with weight loss percentage ($r = -0.91$), pH ($r = -0.92$), SSC ($r = -0.97$), and TSS ($r = -0.79$; Figure 3).

Fruit juice pH is another parameter that is significantly affected by growing location. The highest and lowest pH levels were observed in fruits harvested from Langarud and Rasht, respectively (Table 1). During storage, the fruit pH of all fruits harvested from all three locations increased. No significant difference was observed either between different storage times or interaction between harvest location and storage period (Table 1). This value correlates negatively with TA ($r = -0.92$; Figure 3).

3.5 Maturity index

The growing location had a significant effect on the SSC to TA ratio (maturity index). The SSC/TA value ranged

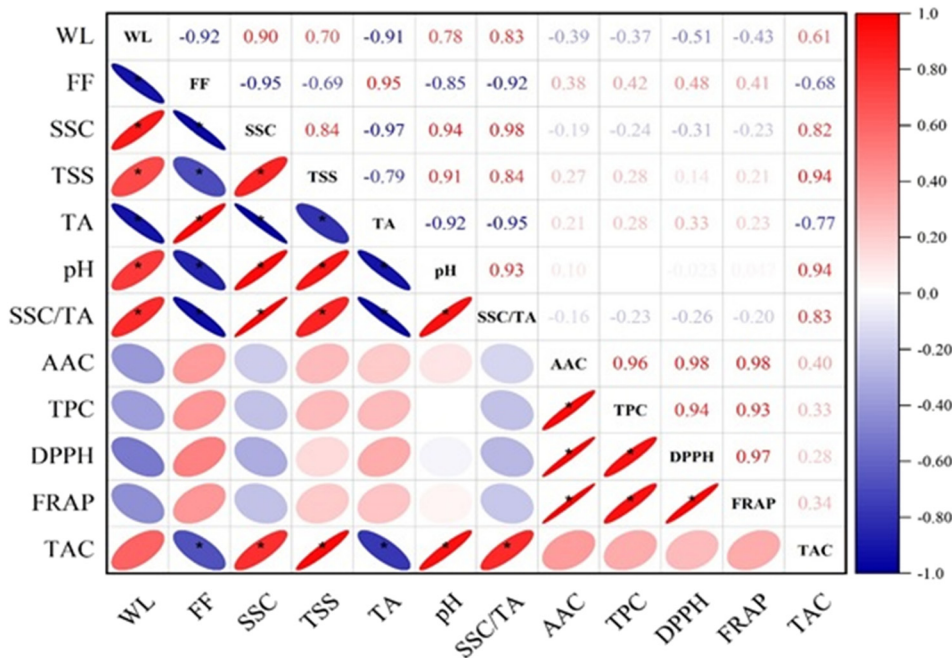


Figure 3: Correlation heat map ($*p < 0.01$); WL, weight loss percentage; FF, flesh firmness; SSC, soluble solids content; TSS, total soluble sugars; TA, titratable acidity; SSC/TA, soluble solids content ratio to titratable acidity; pH: acidity; AAC, ascorbic acid content; TPC, total phenol content; DPPH, antioxidant capacity; FRAP, antioxidant capacity; TAC, total anthocyanin content.

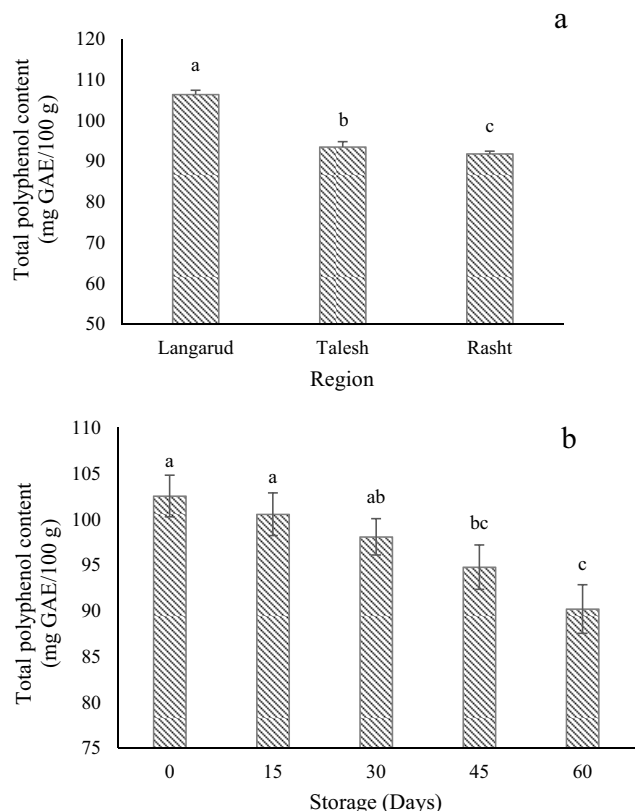


Figure 4: Variation of TPC according to (a) regions and (b) storage time. Different letters, for each determination, indicate significant differences among regions at $p < 0.01$ level. *The results are expressed as mean $\pm$ standard deviation and the (n) number of replicates in each experimental parameter determined.

between 5.60 and 8.62 at harvest, where the samples from the Langarud region had the highest content. This difference was also observed after 60 days of cold storage. Fruits harvested from Rasht and Talesh had an SSC/TA value of 20.73 and 25.19, respectively; this amount in Langarud was 32.37. According to the results of simple correlation analysis (Figure 3), a negative correlation was observed between SSC/TA and both flesh firmness ($r = -0.92$) and TA ($r = -0.95$), while a positive correlation was observed between SSC/TA and weight loss percentage ($r = 0.83$), SSC ($r = 0.98$), TSS ($r = 0.84$), and pH ($r = 0.93$).

3.6 TPC

No significant difference was found between the interaction effect of growing locations and storage period (Table 2). Therefore, the simple effects of different storage periods and cultivation regions were investigated separately. According to Figure 4a, the highest TPC at harvest time (106.36 mg GAE/100 g) was observed in kiwifruit grown in Langarud, while the fruits from

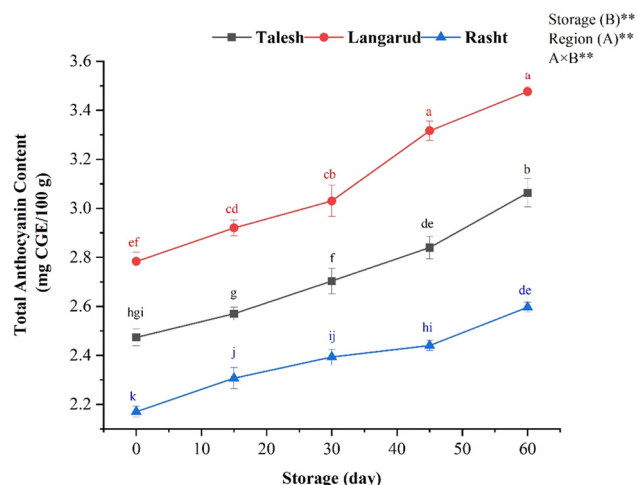


Figure 5: The change of TAC of red kiwifruit in relation growing location and storage times. Different lowercase letters show significant differences ($p < 0.01$) among treatments for each sampling date. *The results are expressed as mean $\pm$ standard deviation and the (n) number of replicates in each experimental parameter determined.

Rasht (center of Guilan) showed the lowest TPC (91.79 mg GAE/100 g). As shown in Figure 4b, TPC decreased significantly during low-temperature storage. The highest TPC (102.53 mg GAE/100 g) was observed at harvest time (0 days), while the fruits at the end of storage (60 days) showed the lowest TPC (90.18 mg GAE/100 g).

3.7 AAC

The AAC changed significantly among regions (Table 2). The AAC was higher in red flesh kiwifruit from the Langarud region (97.59 mg/100 g fresh weight) than that recorded in the Talesh and Rasht regions. The lowest AAC was observed at harvest time in Rasht (64.60 mg/100 g FW). The AAC in kiwifruit from Talesh and Rasht regions was proved statistically similar despite the extreme difference in average temperature, rainfall, and relative humidity during fruit development. Furthermore, AAC decreased over 60 storages without considering growing regions.

3.8 TAC

Anthocyanins are water-soluble pigments responsible for the blue, purple, and red colors of many fruits. The growing location had a significant effect on TAC (Figure 5). The TAC ranged between 2.78 and 3.47 mg CGE/100 g, among which the fruits harvested from Langarud regions had the highest content. The TAC value correlated positively with SSC ($r = 0.82$), TSS ($r = 0.94$), pH ($r = 0.94$), and SSC/TA ($r = 0.83$), and

negatively with TA ($r = -0.77$). The TAC measure increased during cold storage in red flesh kiwifruit.

3.9 Antioxidant activity

Antioxidants are important bioactive compounds due to their high health benefits. The antioxidant activity evaluated by DPPH and FRAP assays was found significantly different among regions (Table 2). The DPPH scavenging activity was higher in red kiwifruit from Langarud (77.26%), while the fruits grown in Rasht had the lowest DPPH scavenging activity (66.21%). Regarding the FRAP assay, the fruits produced in Langarud exhibited the highest activity (11.96 μmol ascorbic acid/g). On the other hand, the lowest FRAP (9.20 μmol ascorbic acid/g) was observed in fruits from Rasht. During 2 months of storage, the antioxidant activity of fruits significantly decreased independently in growing locations (Table 2). DPPH correlated positively with AAC ($r = 0.98$), TPC ($r = 0.94$), and FRAP with AAC ($r = 0.98$), and TPC ($r = 0.93$).

3.10 Sensory evaluations

In this study, in addition to evaluating some physicochemical characteristics through laboratory methods, attention

was also paid to sensory and taste aspects of kiwifruit by consumers with different taste preferences. As shown in Figure 6, fruits harvested from Langarud with higher SSC (11.73°Bx) than the other two sites showed a higher liking score by consumers in terms of external appearance, flesh color, juiciness, internal aroma intensity, sweetness, and overall liking. Furthermore, tartness, firmness, fibrosity (texture), and astringency of fruits harvested from Rasht with SSC of 9.13°Bx were the highest. In conclusion, fruit harvested from Langarud, which had the highest soluble solids and sugar contents, were sensorially sweeter and juicier than others and were judged more palatable by consumers.

4 Discussion

The average water content of kiwifruit at harvesting time is reported to be approximately 80 to 90% of the fresh weight [21]. Kiwifruit is sensitive to shrinkage due to water loss and this phenomenon is reported to be the most important factor in shortening storage life and increasing waste of kiwifruit. Maturity stage, concentration of minerals, and fruit size are all considered important variables affecting the weight loss rate in kiwifruit [22]. Reducing fruit water loss during storage and ripening helps maintain fruit quality and guarantees a longer storage life [21]. In this study, the

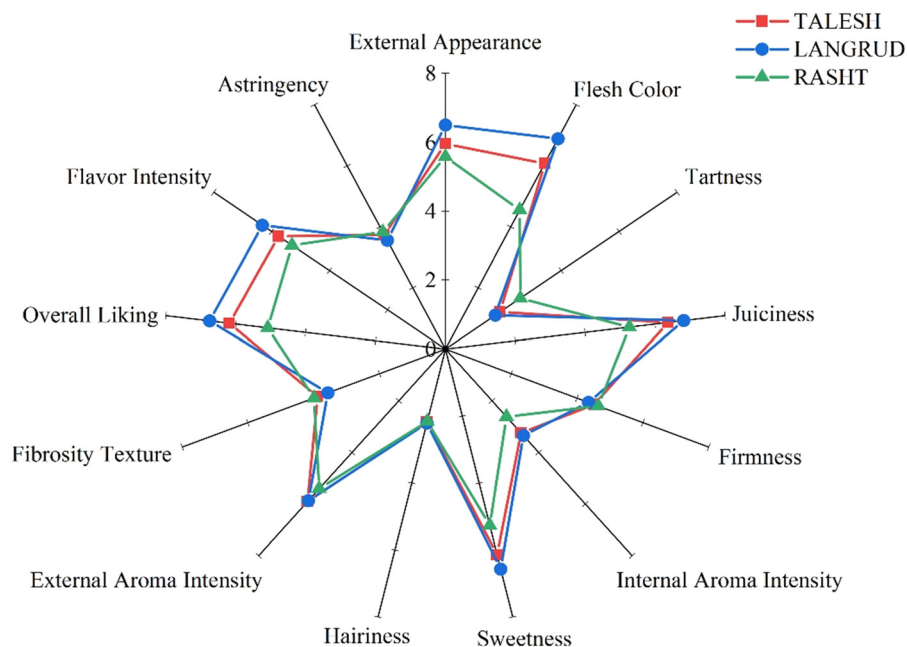


Figure 6: Sensory profiles of red-fleshed kiwifruit harvested from Rasht (▲), Talesh (■), and Langarud (●). For each variable, the possible range of values was 0–7.

geographical conditions in which fruits are produced could be an important factor that affected fruit weight loss and postharvest performance of kiwifruits. A negative correlation was found between weight loss and flesh firmness ($r = -0.90$; Figure 6). Fruit water loss in the postharvest phase depends on several factors related to production, harvest, postharvest handling, storage, and marketing [23]. Kiwifruits harvested from Langarod showed higher water loss and lower firmness than two other sites over 60 days' storage.

Firmness is a key parameter that reflects fruit quality and influences consumer acceptability. Also, the rate of firmness decrease during cold storage is effective on storage life and market supply [24]. Results of this study are consistent with the findings of Tavarini *et al.* [24], and Chiamonti and Barboni [25] which reported a decreasing fruit firmness and increasing SSC in Hayward kiwifruit during cold storage. Previous reports showed that fruits harvested with high SSC had a longer shelf life and maintained better firmness over storage time [26]. The SSC includes compounds in water-soluble sugar, acids, vitamins, and some minerals. It is also considered one of the important indicators for evaluating fruit and vegetable quality [27]. Previous studies also showed that SSC increased during storage in kiwifruit due to the breakdown of starches and increased activity of sucrose phosphate synthase enzyme [24,25]. Amodio *et al.* [28] reported that SSC increase during storage is not only related to an increase in sugar levels but also related to other soluble solids such as soluble pectin and phenolic compounds. By examining the relationship between SSC and postharvest quality, it is pointed out that fruits harvested with high sugar levels had a longer shelf life [24]. The dominant sugars in kiwifruit include glucose and fructose, and when the fruit is ripe and ready to eat, there is also a small amount of sucrose present in fruits. Total sugars and the proportion of these sugars vary not only as a function of maturity but also according to the type of kiwifruit, e.g., species, genotype, cultivar, etc. [29]. Barboni *et al.* [30] reported that kiwifruit flavors are associated with the balance between the most prominent sugars (glucose, fructose, and sucrose) and non-volatile organic acids.

A previous study showed that the TA content decreased in kiwifruit during 42 days of cold storage from 1.26% to less than 1% [31]. The conversion of organic acids into sugars and their derivatives or their use in respiration processes may be the reason for the acidity decrease during prolonged cold storage [14]. Results of this study suggest that the fruits retain their firmness during the cold storage and have more TA at the time of harvest, which is consistent with the findings of Harker and Hallett [32]. The metabolism of total acids during the ripening process reduces the total acidity and increases fruit juice pH. According to Fisk [31], as the TA of fruits

continuously decreased from 1.26% to less than 1% after 42 days of storage, and the pH continuously increased from 3.61 to 3.75.

The low temperature and high rainfall average could be responsible for the increase in the maturity index of kiwifruit samples from Langarud. During storage, SSC/TA in fruits increased as a result of TA decrease and SSC increase [26]. Although Rossiter *et al.* [33] reported that the flavor quality of kiwifruit increased with increasing Brix value and was not affected by acidity, Harker *et al.* [34] found that overall consumer preference for kiwifruit was primarily influenced by sugar–acid balance and secondarily by firmness and volatile content. Sensory preference for fruits is often better described by the SSC/TA ratio compared to sugar or acid content alone [35].

The polyphenolic profile is greatly dependent on environmental conditions. Light, radiation, temperature, as well as water and nutritional status, are the most influential factors of which phenolic synthesis [36]. Our results revealed that lower temperatures especially in September and October (17.32 and 13.24°C, respectively) and higher precipitations in September and October (104.91 and 239.7 mm, respectively) resulted in higher phenol content in kiwifruit from Langarud (east from Guilan). These findings support those reported by Mditshwa *et al.* [37] who found that a cool climate induces higher TPC in pomegranate juice. Furthermore, the results revealed that the TPC of fruits decreased over 60 days of storage independently of growing location. The main phenolic compounds in kiwifruit include phenolic acids, flavonols, flavanols, and anthocyanins [4]. The composition of phenolic compounds in kiwifruit also depends on variety [38], genotype [39], accumulation sites inside the fruit [27], and stage of maturity [40]. Among these factors, different cultivars and genotypes of kiwifruit can be significantly different from each other in both the type of phenolic compounds and the TPC [38–40]. A previous study also confirmed that TPC in kiwifruit decreases with prolonged cold storage [41]. However, Tavarini *et al.* [24] reported that the TPC in kiwifruits with delayed harvest and higher SSC was higher at the end of 6 months of storage. Most studies have been conducted on green or yellow-fleshed kiwifruit cultivars, and there is little information on the phenolic compounds found in red-fleshed kiwifruit cultivars.

AAC is a key factor for quality evaluation in many fruits [39]. Esti *et al.* [42] observed that the AAC of kiwifruit depends on genotypes, ripeness, storage, and the analysis method used to measure it. In previous reports, genotype was one of the key factors determining kiwifruit AAC [18,24,29]. In addition to genotype, factors such as region and cultivation conditions, use of fertilizers, maturity stage at harvest, harvesting time, and ripening can cause variation

in kiwifruit AAC [43]. During storage, fruits face post-harvest stress in which ascorbate peroxidase enzymes reduce oxidative metabolism by consuming ascorbic acid as an electron donor [28]. Kiwifruit ascorbic acid decrease at the end of storage was also reported by Tavarini et al. [44] and Amodio et al. [28].

The TAC measure increased during cold storage in red flesh kiwifruit. This is in agreement with previous findings showed that the TAC increased as kiwifruit ripened and was exposed to prolonged low temperatures [45,46]. The low temperature and high rainfall average could be responsible for the increase of TAC in kiwifruit from Langarud. As Figure 7 shows, there is a deep difference in inner pericarp color intensity between fruits harvested from Rasht, Langarud, and Talesh. Fruits produced in Langarud, with an average temperature in September and October (17.32 and 13.24°C, respectively) and an altitude of 121 meters above sea level, had the highest anthocyanin concentration at the time of harvest, as well as during and at the end of storage. The importance of orchard location and planting site is unsurprising, given previous reports emphasizing variation between orchards [47,48]. The red color of current commercial cultivars, both in New Zealand and in China, is often reported to be heterogeneous or paler than expected. This variation, which often occurs between orchards and different planting sites, has also been observed between the vines themselves [47–49]. However, environmental conditions have been found to play an important role in determining anthocyanin concentrations in many types of plants, including red-fleshed kiwifruit. The relationship between temperature and anthocyanin concentration has been demonstrated in a wide variety of plants. High temperatures in apples [50], grapes [51], and sweet potatoes [52] decrease the anthocyanin concentration, while low temperatures cause it to increase. Similar relationships between

temperature and anthocyanin content have been discovered in red-fleshed kiwifruit. In several studies in China, fruits harvested from higher altitudes with lower summer temperatures had a more intense flesh color [47,48]. Higher temperatures, particularly temperatures above 35°C, are associated with anthocyanin degradation or inhibited anthocyanin expression. The variation between orchards in previous studies is thought to be related to variation in altitude and temperature.

During 2 months of storage, the antioxidant activity of fruits decreased. In agreement with these findings, Tavarini et al. [24] reported that the antioxidant activity of kiwifruit was the highest at harvest time and thereafter decreased to the end of the 6th month. Kiwifruit has a high antioxidant capacity which is due to high levels of TPC and AAC. In addition, researchers have shown that during storage, the antioxidant capacity of fruits harvested with a Brix degree of 8 and above was higher than fruits harvested with a Brix degree of less than 8 [53]. Ferreyra et al. [54] showed that the reduction of antioxidant activity in strawberries during storage is due to ACC, flavonoids, and phenolic compounds deterioration. In general, products with a higher antioxidant activity show better resistance against different environmental stresses and also have better nutritional quality and storage properties [55]. In a study conducted in Italy, the geographical location of orchards did not significantly affect ascorbic acid or polyphenol contents [6]. In grapes and apples, antioxidant activity is measured by the content of polyphenols [56]. Therefore, based on previous reports, the correlation between bioactive components (TAC, AAC, TA, and TPC) and antioxidant activity in kiwifruit was evaluated to determine the main factors affecting antioxidant activity. In particular, ACC showed a higher correlation with antioxidant activity than other fruits such as grapes and apples, which is probably due to the high content of ascorbic acid in kiwifruit. In grapes

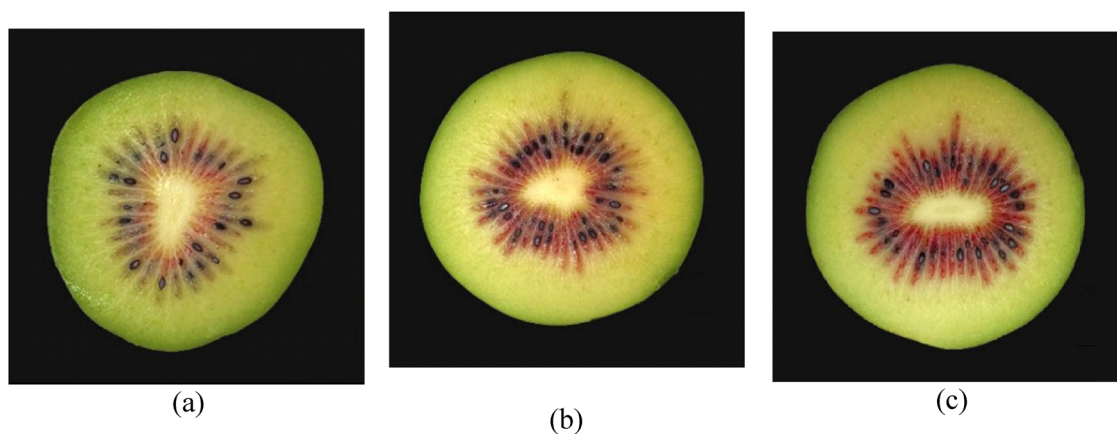


Figure 7: Comparison of inner pericarp color intensity in fruits from (a) Rasht, (b) Talash and (c) Langarud at harvest.

and its products (juice and wine), the TA index showed a high correlation (approximately 1) with antioxidant activity and was one of the main factors of antioxidant activity [57]. In another report, a correlation index of approximately 0.9268 was reported [58], but this high correlation was not observed in kiwifruit. This result may be because the content of TA in kiwifruit is very low as compared to other fruits such as grapes.

Morphometric, colorimetric, textural, and organoleptic characteristics due to genotypic variations, have a great effect on consumer preferences. Consumer preference or acceptability of novel kiwifruit cultivars will depend on sensory attributes [59]. Fruit harvested from Langarud which had the highest SSC and TSS, were sensorially sweeter and juicier than others and were judged more palatable by consumers. It is perhaps not surprising that DM or SSC only accounted for a small degree of the variability in flavor, while other factors including sugars, acids, and volatiles played a more prominent role. In addition, other factors such as cultivation practices, maturity, storage, and ripening conditions may also influence flavor [60]. Harker *et al.* [34] demonstrated that most consumers provided their highest satisfaction scores after tasting samples with the highest SSC. The maturity index (SSC/TA), which plays an important role in fruit taste, is highly dependent on cultivars, horticultural practices, and weather conditions [61]. This index was higher in fruits harvested from Langarud compared to Rasht and Talesh. Generally, fruits harvested with a higher SSC maintain their organoleptic characteristics better during cold storage. In order to improve sensory quality, we suggest higher SSC at harvest to meet consumer preferences.

5 Conclusion and recommendation

A significant regional effect was observed on the bioactive compounds and antioxidant activity of “Khoni” kiwifruit. Although cultivar type is the main factor affecting the nutritional quality of kiwifruit, environmental conditions can also significantly impact fruit characteristics, especially on nutritional and bioactive compounds. The results of this study show that the orchard location as a pre-harvesting factor, has an important effect on both the nutritional and functional values of kiwifruit. The characteristics such as flesh firmness, SSC, TSS, TA, antioxidant capacity, total phenols, ascorbic acid, and TAC, which are important indicators for evaluating the internal quality of kiwifruit, were significantly influenced by orchard location, altitude, and average temperature over growing season. During storage, the firmness and total acidity of kiwifruit decreased while SSC, TSS,

and anthocyanin content increased. These results will provide a better understanding of the effect of environmental conditions on physical properties and synthesis of bioactive compounds in order to obtain kiwifruits with better appearance and nutritional quality. According to these results, we also found that in red-fleshed kiwifruit cultivars, color development, stability, and intensity, along with storability are more dependent on maturity stage and environmental conditions (e.g., temperature, altitude, rainfall, relative humidity, etc.).

Acknowledgments: The authors appreciate University of Guilan for financial support.

Funding information: This research was funded by University of Guilan.

Author contributions: Methodology, M.A and M.Gh; data curation; M.A.; writing—original draft preparation, M.A, M.Gh, A.A.; Conceptualization, M.Gh; Investigation, M.Gh; resources, M.Gh; writing – review & editing, M.Gh, A.A.; supervision, M.Gh; project administration; M.Gh; investigation; A.A.; writing – review & editing; A.A.; software, M.H.M and AB; formal analysis, J.O. All authors have read and agreed to the published version of the manuscript.

Conflict of interest: The authors state no conflict of interest.

Data availability statement: The authors will make the results available if requested.

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