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A comparison of the nutrient composition and statistical profile in red pepper fruits (*Capsicum annuum* L.) based on genetic and environmental factors

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Abstract

Red peppers are a remarkable source of nutrients in the human diet. However, comprehensive studies have not reported on the effects of genotype, cultivation region, and year on pepper fruit characteristics. To address this, 12 commercial pepper varieties were grown at two locations in South Korea, during 2016 and 2017, representing four environments, and concentrations of proximate, minerals, amino acids, fatty acids, capsaicinoids, and free sugars in pepper pericarps were determined. Variation in most nutrients was observed among the 12 varieties grown within each location in each year, indicating a significant genotype effect. Statistical analysis of combined data showed significant differences among varieties, locations, and years for the measured components. The % variability analysis demonstrated that environment (location and year) and genotype-environment interaction contributed more to the nutritional contents than genotype alone. Particularly, variation in many amino acids, capsaicinoids, free sugars, and myristic acid was attributed to location. Year effect was significant for palmitoleic acid, ash, tryptophan, copper, linolenic acid, crude fiber, and tyrosine. Insoluble dietary fiber, soluble dietary fiber, sodium, sulfate, linoleic acid, and alanine were primarily varied by genotype-environment interaction. Palmitic acid was the trait the most highly affected by genotype. Cultivation and the genotype-environment interaction have a major role in determining the composition of 12 pepper varieties across four environments. The data from this study could explain the natural variation in the compositional data of peppers by genotypes and environments.

Keywords: Red pepper, Nutrition, Genotype, Environment, *Capsicum annuum*

Introduction

Capsicum annuum L. belongs to the Solanaceae family along with other crops such as tomatoes, eggplants and potatoes. Their fruits are known as peppers or chilies. Peppers are one of the oldest domesticated crops in the western hemisphere. Peppers are the most widely grown spices in the world and are one of major ingredients in most global cuisines. Economically, peppers are a high

value crop in many countries. The top 10 pepper producing countries produced 30.7 and 3.85 million tons of green and dry pepper, respectively, in 2017, and production has dramatically increased over the past decades (Food and Agriculture Organization of the United Nations). The wide variability and genetic diversity of peppers allows the development of new varieties for use in the industry and market [1]. Recently, the genome sequence of *C. annuum* provided more advanced associations between genomic studies and important traits [2, 3].

Peppers are excellent source of essential vitamins, minerals, and nutrients and, thus, have great importance

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for human health. Peppers are also rich in a number of phytochemicals such as carotenoids, capsaicinoids, flavonoids, ascorbic acid, and tocopherols. These compounds are known to prevent inflammatory diseases associated with oxidative damages to maintain optimum health. Different pepper varieties show variation in the nutritional composition and level of metabolites [4–6]. Wahyuni et al. [6] showed great variations in the composition of phytonutrients of 32 capsicum accessions. The amount of proximates, minerals, fatty acids, and amino acids were found to vary significantly among different varieties [4, 7]. Comparative analysis of metabolite compositions have been conducted in a diverse collection of peppers for genetic improvement of metabolic traits, especially health related-compounds [6, 8, 9].

Even within the same variety, nutritional composition of peppers varies depending on developmental stages, growing regions, and agricultural practices [10–14]. Pérez-López et al. [14] showed that levels of ascorbic acid, total carotenoid, phenolic, and mineral were affected by the fruit maturation and types of agricultural practice. Capsaicinoid contents were significantly different among cultivars, environments, and by cultivar-environment interaction [15, 16]. The quantity of capsaicinoid was affected more by the genotype than the cultivation region [15, 16]. However, free sugar quantity was more affected by the cultivation region than by the genotype [16]. Comparative metabolite studies in pepper fruits and crop grains by multisite cultivation have suggested that selection of appropriate cultivars and growing regions enables increased metabolites in plants [17–19]. Although numerous studies of metabolite composition in pepper fruits have reported, they have mainly focused on determining the concentrations of carotenoids, capsaicinoids, vitamins, and phenolic compounds. In contrast, information is limited for other nutritional compositions such as proximates, minerals, amino acids, and fatty acid profiles in pepper varieties [20]. Furthermore, few studies about genotypic and environmental effects on those compounds in pepper fruits are available. Therefore, it is important to identify genotypes and environmental factors that influence the levels of these nutritional compounds in pepper in order to generate baseline information and to select appropriate cultivars and growing regions.

In this study, 12 commercial varieties of pepper were grown at two places in South Korea, Imsil (IS) and Yeongyang (YY), during 2 consecutive years. IS and YY are the representative areas for pepper production localized in the western and eastern region of South Korea, respectively. We analyzed and quantified proximates, minerals, fatty acid profiles, amino acids, capsaicinoids, and free sugars. Statistical methods were performed to determine

the relative roles of genotype, environment, and genotype–environment interactions, accounting for the variability in nutrient composition of pepper fruits. This study could explain natural variation in the compositional data of pepper by genotype and environment.

Materials and methods

Plant materials, fruit collection, and sample preparation

Twelve pepper cultivars were cultivated at two sites, Imsil (IS) and Youngyang (YY), in South Korea in 2016 and 2017. At each location, 12 cultivars were planted in May and fruits were harvested in October. All cultivars were planted in two blocks with a strip-plot design. Pepper fruits were collected randomly from each block and pooled together and then oven dried at 55 °C for 30 h. After the stalks, seeds, and placenta were removed from the whole fruits, pericarps were ground with a laboratory mill (Retsch planetary mono mill, PM100) and stored at –70 °C until the compositional analysis was performed. All of experiments were conducted in triplicate by collecting three samples from pooled powered samples. Weather data such as temperature, relative humidity, wind speed, and total rainfall were recorded (Additional file 1: Table S1 and Figure S1).

Compositional analysis

Proximates

Moisture was measured by gravimetric measurement using hot-air oven at 105 °C. Crude fat was analyzed using Soxhlet extraction method [21] while crude protein amount was calculated from total nitrogen content using Kjeldahl method [22]. Ash content was determined by incinerating the sample in a furnace at 600 °C for 22 h to constant weight [23]. Carbohydrates were calculated by 100% minus sum of % protein, % lipid, and % ash. Crude fiber content was determined according to AOAC method 962.09 [24]. Insoluble dietary fiber (IDF) and soluble dietary fiber (SDF) contents were determined by enzymatic–gravimetric methods using amylase, protease, and amyloglucosidase according to the MFDS Food Code 2.1.4.3 [25].

Minerals

Calcium, magnesium, phosphorus, potassium, sulfate, copper, iron, manganese, sodium, and zinc were determined using inductively coupled plasma optical emission spectrometry (Inegra XL; GBC Co., Melbourne, Australia) according to the MFDS Food Code [26].

Fatty acids profile

Individual fatty acids were determined according to the AOCS method Ce 1–62 [27] using a Shimadzu GC-2010

gas chromatograph (Shimadzu, Japan) and expressed as % of total fatty acids.

Amino acids profile

Amino acids were analyzed directly after protein hydrolysis using an automatic amino acid analyzer with hydrochloric acid [28]. The sulfur-containing amino acids (cysteine and methionine) were oxidized using performic acid before hydrolysis with 6N hydrochloric acid. The contents of individual amino acids were expressed as % of total protein.

Capsaicinoids analysis

The capsaicinoid extraction was carried out as described by Jeon and Lee [29] with slight modifications; 1.0 ± 0.05 g of red pepper powder sample was extracted with methanol at 70 °C using water bath for 5 h. The extract liquid was filtered (Whatman No. 2, Whatman International Ltd., Maidstone, UK) and filled with methanol to 100 mL. Before analyzing for HPLC, samples were filtered with a 0.45 μ m nylon membrane. Capsaicinoids were analyzed using Agilent-1100 HPLC equipped with autosampler and UV-FID detector. Luna C18(2) 100 A column (5 μ m, 4.6 \times 250 mm, Phenomenex Inc., Torrance, CA, USA) was used and compounds were detected by FID ($E\lambda = 280$ nm, $Em\lambda = 320$ nm).

Free sugars analysis

Sugar contents (fructose and glucose) of red pepper powder were analyzed with a simultaneous quantitative method with HPLC-RI according to Won et al. [30]. A ZORBAX carbohydrate column (4.6 mm ID \times 250 mm, 5 μ m) was used for analysis. The analysis conditions were as follows: mobile phase of 75% acetonitrile, column temperature of 35 °C, sample injection amount of 10 μ L and flow rate of 1 mL/min. Standard solutions were isolated without an interfering peak within 30 min, and the calibration curves of standards were confirmed excellent linearity from 0.10 to 1.00% with $R^2 \geq 0.999$.

Statistical analyses

Statistical analysis of the data was carried out with SAS Enterprise Guide 7.0. To identify differences among pepper varieties within each location per year and across four environments, the significance probability (p -value) was calculated by one-way analysis of variance (ANOVA). The mean discrimination was performed applying Bonferroni corrected t -tests, and statistically significant differences were determined at the probability level of $p \leq 0.05$. The difference in components between two locations or between 2 cultivation years was calculated by paired t -test. Pearson's correlation analysis was conducted with SAS Enterprise Guide 7.0. Hierarchical

cluster analysis (HCA) and heat mapping were conducted in the MultiExperiment Viewer, version 4.0. The heat map visualization of all the correlation coefficients with Pearson's correlation analysis was performed for correlations between analytes.

Results and discussion

Crop composition is significantly affected by genetics and environmental conditions including rainfall, temperature, soil types, and the interactions between these two factors [19, 31]. To investigate variations in nutritional composition among 12 pepper cultivars, we analyzed data within each location per year to exclude the influence of the environment. This enabled us to assume the variance for components was attributed to genotypes. Statistical analysis demonstrated that most components showed significant variation among 12 pepper cultivars, indicating a clear genotypic effect (Additional file 1: Figures S2–S6). The nutritional composition of the 12 pepper cultivars across four environments are presented in Tables 1, 2, 3, 4 and 5 as the mean and ranges. Further, the nutritional compounds across the 12 cultivars were compared by location and year, respectively, in order to determine the effect of the environment on composition (Tables 1, 2, 3, 4 and 5). The random effect of individual varieties, location, year, and the mix of these factors on the nutritional variation was described using the linear mixed model in R statistics (Fig. 1). The variation in nutritional components is apportioned between the effects of variety, year, location, interaction of location:variety:year (hereafter referred to as the $G \times E$ interaction) and that which cannot be explained by these factors (termed the residual). Then, correlations between the nutrient compositions were determined by the Pearson's correlation and presented by HCA (Fig. 2).

Eight proximate compositions

Moisture, protein, crude fat, carbohydrate, ash, and crude fiber, including SDF and IDF, were measured and/or calculated for the 12 varieties obtained from IS and YY cultivated during 2016 and 2017. When these compounds were compared among all cultivars within location by year, all of cultivars showed high variance among all varieties except ash (all conditions), protein from cultivars obtained from YY in 2016, and crude fiber from cultivars obtained from YY in 2017 (Additional file 1: Figure S2). Table 1 shows combined proximates data obtained from the four environments. Carbohydrates were the major component (~60%), followed by IDF (~22%), and crude fiber (~19%). Crude protein and crude fat were present in similar levels (~13%). Ash was present at ~9%. SDF was present at the lowest amount (~2%). Variation in proximate contents was observed

Table 1 Eight proximate compositions in the pericarps of 12 capsicum varieties grown across four environments by variety, location, and year

	Components (%)							
	Moisture	Protein	Crude fat	Ash	Crude fiber	SDF	IDF	Carbohydrate
Varieties								
BST	10.3 ^{ab} (8.3–13.3)	13.9 ^{ab} (11.9–16.8)	12.8 ^a (10.4–14.2)	9.8 ^a (5.9–13.1)	19.8 ^a (14.6–24.4)	1.7 ^{ab} (1.2–2.7)	24.1 ^{ab} (21.4–28.1)	63.4 ^a (58.8–67.9)
MCB	11.5 ^{ab} (9.6–14.6)	13.1 ^{ab} (11.7–14.7)	12.6 ^a (10.6–14.8)	9.6 ^a (6.6–14.4)	20.6 ^a (14.7–25.2)	1.8 ^{ab} (1.0–3.0)	22.8 ^{abc} (20.1–28.6)	64.7 ^a (59.3–68.4)
HBC	8.7 ^a (6.04–12.4)	12.2 ^{ab} (11.4–13.6)	13.1 ^a (11.7–14.4)	10.0 ^a (5.9–13.6)	20.5 ^a (18.3–22.3)	1.8 ^{ab} (0.3–2.9)	22.5 ^{abc} (19.2–25.9)	64.7 ^a (60.6–69.4)
GCH	9.9 ^{ab} (7.6–13.2)	13.5 ^{ab} (10.9–15.3)	13.8 ^a (10.8–16.2)	11.0 ^a (6.6–17.1)	21.5 ^a (18.2–26.0)	2.7 ^a (1.6–4.3)	22.9 ^{abc} (18.7–29.6)	61.7 ^a (57.1–65.1)
JSN	9.6 ^{ab} (6.6–13.5)	13.0 ^{ab} (10.7–15.1)	13.6 ^a (12.6–14.7)	11.1 ^a (6.4–13.6)	21.4 ^a (13.0–26.5)	2.2 ^{ab} (1.2–3.4)	22.1 ^{abc} (18.6–26.0)	62.3 ^a (55.7–67.6)
AJB	10.6 ^{ab} (8.2–14.1)	11.9 ^a (10.3–14.9)	12.3 ^a (9.4–14.6)	10.2 ^a (6.3–13.0)	19.1 ^a (14.2–22.7)	2.2 ^{ab} (1.4–3.4)	21.8 ^{abc} (18.3–25.9)	65.6 ^a (61.9–70.2)
PJDG	13.2 ^b (9.1–19.2)	13.4 ^{ab} (11.5–14.6)	13.8 ^a (11.4–16.5)	10.0 ^a (6.4–14.7)	19.3 ^a (14.2–23.6)	1.2 ^b (0.3–2.1)	23.3 ^{abc} (19.0–28.4)	62.8 ^a (57.8–66.4)
PMBI	10.8 ^{ab} (8.3–13.9)	12.9 ^{ab} (11.5–14.6)	12.4 ^a (9.9–13.7)	9.9 ^a (6.2–13.2)	18.7 ^a (13.9–24.2)	2.1 ^{ab} (1.5–3.4)	20.1 ^{bc} (17.2–24.1)	64.8 ^a (59.2–68.7)
PSUL	11.0 ^{ab} (8.6–13.7)	13.3 ^{ab} (11.3–16.9)	13.3 ^a (9.6–15.4)	9.9 ^a (6.7–13.8)	18.2 ^a (13.6–24.5)	2.6 ^a (1.7–3.7)	20.8 ^{abc} (18.8–23.4)	63.4 ^a (55.5–71.7)
PKST	10.0 ^{ab} (7.5–13.9)	13.6 ^{ab} (11.0–16.8)	13.6 ^a (10.2–15.8)	10.4 ^a (6.5–17.3)	19.0 ^a (13.5–24.2)	2.0 ^{ab} (1.1–4.0)	20.6 ^{bc} (17.0–23.1)	62.4 ^a (56.9–67.0)
MM	10.5 ^{ab} (7.8–14.7)	12.8 ^{ab} (11.5–15.8)	12.5 ^a (10.7–13.9)	10.0 ^a (6.2–13.3)	20.2 ^a (16.7–23.2)	1.2 ^b (0.3–2.1)	19.3 ^c (16.9–23.3)	64.7 ^a (60.0–67.8)
PEVR	12.0 ^{ab} (9.1–16.7)	14.0 ^b (11.5–18.5)	13.2 ^a (10.8–16.4)	11.1 ^a (7.3–15.3)	21.1 ^a (16.6–25.0)	1.7 ^{ab} (0.3–2.7)	24.8 ^a (20.9–30.5)	61.8 ^a (54.2–66.3)
p-value	**	*	NS	NS	NS	***	***	NS
Location								
IM	11.2 (6.04–15.5)	10.1 (6.04–19.2)	13.2 (9.42–16.2)	9.5 (5.90–17.3)	19.7 (13.0–26.5)	1.9 (0.34–4.08)	21.7 (17.4–29.6)	65.1 (56.8–71.7)
YY	10.1 (9.36–19.2)	12.2 (10.3–14.6)	13.0 (10.2–16.6)	11.0 (6.83–15.5)	20.2 (14.3–24.9)	1.9 (0.28–4.28)	22.4 (16.9–30.5)	61.9 (54.2–67.0)
p-value	*	***	NS	**	NS	NS	NS	***
Year								
2016	12.5 (9.36–19.2)	13.7 (11.4–18.5)	13.9 (11.5–16.5)	8.1 (5.90–12.9)	22.3 (18.9–26.5)	2.1 (0.28–4.28)	21.1 (16.9–28.4)	64.3 (55.4–69.4)
2017	8.8 (6.04–14.6)	12.6 (10.3–15.1)	12.3 (9.42–16.4)	12.4 (6.56–17.3)	17.5 (13.0–24.9)	1.7 (0.99–3.11)	23.0 (16.9–30.5)	62.8 (54.2–71.7)
p-value	***	***	***	***	***	**	***	**

Data are the mean and range (parentheses), expressed as % dry weight

NS not significant

*p < 0.05; **p < 0.01; ***p < 0.001. The means in the same column followed by the same letter(s) are not significantly different at (p < 0.05) by least significant difference

among pepper varieties in previous studies [4, 32]. Statistical significance was observed in moisture, protein, SDF, and IDF among all varieties across four environments, indicating a genetic contribution to the variation in these compounds. The location effect across 12 pepper varieties was significant for moisture, protein, ash, and carbohydrates. All compounds across all 12 pepper varieties were influenced by cultivation year. The results

of % variability for proximate from R statistics (Fig. 1) showed that the quantity of ash, crude fiber, moisture, and crude fat were significantly affected by year, the effects of which account for 69.0, 66.3, 59.8, and 41.8%, respectively, of the total variation. The level of SDF (79.1%) and IDF (69.7%) were primarily determined by the G × E interactions. The amount of protein showed the highest variability due to location (50.7%).

Table 2 Ten mineral contents in the pericarps of 12 capsicum varieties grown across four environments by variety, location and year

	Components									
	Calcium	Magnesium	Phosphorus	Potassium	Sulfate	Copper	Iron	Manganese	Sodium	Zinc
Varieties										
BST	106.2 ^{ab} (90–121)	158.8 ^a (130–207)	289.9 ^a (268–323)	3525 ^a (2576–5015)	259.4 ^a (230–311)	0.9 ^a (0.43–2.4)	6.2 ^{ab} (4.6–8.1)	0.9 ^a (0.74–1.15)	32.5 ^{ab} (23.1–43.0)	1.9 ^a (1.6–3.0)
MCB	96.5 ^b (73–127)	154.5 ^a (96–230)	270.2 ^a (237–305)	3777 ^a (2129–6400)	241.2 ^{abc} (213–712)	0.9 ^a (0.4–2.2)	5.9 ^{ab} (4.2–8.9)	0.9 ^a (0.79–1.2)	35.8 ^a (20.2–47.8)	1.9 ^a (1.5–2.4)
HBC	92.8 ^b (71.8–111)	149.8 ^a (125–179)	289.6 ^a (232–412)	2878 ^a (2059–3670)	233.0 ^{abc} (198–290)	1.0 ^a (0.33–2.0)	5.0 ^b (4.1–6.3)	0.8 ^a (0.52–1.2)	22.6 ^{cd} (12.2–32.3)	2.3 ^a (1.5–3.8)
GCH	92.2 ^b (63.6–112)	144.4 ^a (123–175)	296.5 ^a (277–328)	3478 ^a (2786–4806)	221.4 ^{abcd} (154–306)	1.2 ^a (0.51–4.04)	5.8 ^{ab} (4.49–8.35)	0.9 ^a (0.71–1.1)	28.7 ^{abc} (18.6–43.3)	1.8 ^a (1.34–2.27)
JSN	105.9 ^{ab} (75.3–103)	146.9 ^a (103–189)	269.6 ^a (229–318)	3638 ^a (2652–4470)	208.8 ^{bcd} (165–269)	1.0 ^a (0.38–1.83)	5.8 ^{ab} (4.4–7.3)	1.0 ^a (0.67–1.28)	22.9 ^{cd} (16.1–32.9)	1.9 ^a (1.48–2.5)
AJB	98.8 ^b (57.8–132)	140.1 ^a (109–167)	261.4 ^a (209–313)	3822 ^a (2021–4022)	182.7 ^d (143–224)	1.2 ^a (0.53–3.92)	6.0 ^{ab} (4.4–8.6)	0.9 ^a (0.32–1.74)	28.9 ^{abc} (20.2–43.7)	1.9 ^a (1.29–2.97)
PJDG	108.7 ^{ab} (94–127)	148.7 ^a (133–167)	280.7 ^a (252–304)	3800 ^a (3024–5394)	198.6 ^{cd} (168–231)	1.0 ^a (0.52–1.67)	6.7 ^{ab} (4.54–10.0)	0.9 ^a (0.74–1.1)	25.3 ^{bcd} (15.7–34.1)	2.2 ^a (1.51–2.88)
PMBI	115.8 ^{ab} (80.7–135)	148.9 ^a (121–179)	266.8 ^a (219–301)	3418 ^a (2353–4481)	201.1 ^{cd} (161–236)	1.6 ^a (0.55–5.5)	7.0 ^{ab} (5.5–10.3)	0.9 ^a (0.7–1.46)	27.0 ^{abcd} (15.9–41)	1.9 ^a (1.22–2.45)
PSUL	131.0 ^a (104–164)	162.4 ^a (133–192)	280.1 ^a (244–327)	3504 ^a (2660–4630)	228.4 ^{abcd} (208–263)	1.1 ^a (0.69–2.04)	7.7 ^a (4.91–10.7)	1.1 ^a (0.74–1.62)	24.0 ^{bcd} (17.6–35.8)	2.2 ^a (1.53–3.17)
PKST	124.4 ^a (107–151)	145.5 ^a (127–175)	278.9 ^a (232–313)	3203 ^a (2437–4586)	205.0 ^{bcd} (97.4–282)	1.1 ^a (0.66–1.78)	5.8 ^{ab} (4.68–8.2)	1.0 ^a (0.56–1.32)	19.3 ^d (14.0–15.6)	2.0 ^a (1.54–2.37)
MM	110.8 ^{ab} (18.4–146)	146.8 ^a (122–194)	263.9 ^a (222–304)	3360 ^a (2496–5069)	214.8 ^{abcd} (161–257)	1.2 ^a (0.58–3.67)	6.6 ^{ab} (4.0–9.38)	0.9 ^a (0.51–1.31)	21.5 ^{cd} (1.32–32.4)	1.8 ^a (1.2–2.3)
PEVR	126.3 ^a (100–154)	160.9 ^a (136–205)	297.2 ^a (250–377)	3647 ^a (2709–5564)	252.0 ^{ab} (210–287)	1.1 ^a (0.53–2.37)	7.6 ^a (4.59–10.4)	1.0 ^a (0.7–1.21)	23.3 ^{bcd} (13.7–34.8)	2.2 ^a (1.5–4.57)
p-value	***	NS	*	NS	***	NS	***	NS	***	NS
Location										
IM	114.4 (74.3–164)	137.9 (109–230)	292.2 (229–412)	2821 (2021–3939)	208.9 (97.4–283)	1.0 (0.33–5.53)	6.1 (4.08–10.7)	1.0 (0.69–1.74)	26.9 (16.2–47.8)	2.1 (1.35–3.85)
YY	103.8 (57.8–152)	163.4 (96.2–160)	265.3 (210–377)	4125 (2656–6400)	232.2 (143–311)	1.2 (0.52–4.05)	6.6 (4.0–10.3)	0.9 (0.32–1.46)	25.1 (12.3–47.7)	1.9 (1.20–4.57)
p-value	**	***	***	***	***	NS	NS	***	NS	*
Year										
2016	101.5 (57.8–164)	140.7 (96.2–189)	272.0 (210–377)	3160 (2021–4171)	215.8 (97.4–311)	0.9 (0.33–5.53)	6.5 (4.0–10.7)	1.0 (0.32–1.74)	25.5 (13.7–47.7)	1.9 (1.20–3.17)
2017	116.7 (82.8–151)	160.6 (125–230)	285.4 (227–412)	3785 (2320–6400)	225.3 (175–272)	1.4 (0.61–4.05)	6.2 (4.48–8.91)	0.9 (0.52–1.32)	26.4 (12.3–47.8)	2.1 (1.75–3.70)
p-value	***	***	*	***	NS	***	NS	NS	NS	NS

Data are the mean and range (parentheses), expressed as mg/100 g dry weight

NS not significant

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. The means in the same column followed by the same letter(s) are not significantly different at ($p < 0.05$) by least significant difference

Ten mineral compositions

Pepper fruits contain many essential minerals. Most minerals showed variation among the 12 pepper varieties produced at the same location by year (Additional file 1: Figure S3). Only magnesium of YY 2016, sulfate of IS 2017, copper of IS 2016 and YY 2016, iron of YY 2017, and zinc of YY 2017 did not show variance among the 12 varieties (Additional file 1: Figure S3). Mineral content is provided in Table 2. Potassium is the most abundant

mineral, followed by phosphorus, sulfate, magnesium and calcium. Calcium, phosphorus, sulfate, iron, and sodium showed significant difference, while others were not varied among varieties across the four environments. The levels of each mineral across four environments showed a high variation, indicating these compounds are strongly influenced by environmental factors. Previous studies have shown that amounts of minerals in peppers depend on the ripening stage, agricultural practices,

Table 3 Ten fatty acid compositions in the pericarps of 12 capsicum varieties grown across four environments by variety, location, and year

	Components									
	Lauric	Myristic	Palmitic	Palmitoleic	Stearic	Oleic	linoleic	Linolenic	Arachidic	Behenic
Varieties										
BST	1.53 ^a (0.83–2.69)	3.99 ^a (2.35–6.55)	19.1 ^{bc} (18.5–19.6)	1.4 ^b (0.79–2.04)	4.3 ^{ab} (3.58–4.79)	11.3 ^a (9.04–15.1)	40.7 ^{abc} (34.8–43.7)	15.8 ^{ab} (12.1–19.9)	0.78 ^a (0.62–0.92)	0.49 ^a (0.43–0.59)
MCB	1.71 ^a (0.81–2.29)	4.67 ^a (2.31–6.11)	18.6 ^{bcd} (17.4–20.2)	1.2 ^{ab} (0.58–1.93)	4.3 ^{ab} (3.76–4.96)	11.9 ^a (10.1–15.3)	39.2 ^{abc} (35.4–43.8)	16.7 ^{ab} (11.7–19.4)	0.71 ^{ab} (0.63–0.82)	0.43 ^a (0.00–0.60)
HBC	1.82 ^a (1.23–2.52)	5.06 ^a (3.88–6.41)	20.8 ^a (20.1–21.5)	1.3 ^{ab} (0.83–1.76)	3.2 ^c (2.56–3.69)	10.3 ^a (8.10–12.6)	39.2 ^{abc} (37.1–41.7)	16.5 ^{ab} (14.0–19.1)	0.56 ^c (0.49–0.61)	0.46 ^a (0.39–0.61)
GCH	1.83 ^a (0.79–2.90)	4.81 ^a (2.30–6.65)	18.9 ^{bcd} (17.9–19.9)	1.4 ^{ab} (0.95–1.97)	4.6 ^a (3.54–5.47)	9.8 ^a (7.05–14.9)	38.2 ^{bc} (31.8–43.1)	18.4 ^{ab} (12.4–23.7)	0.80 ^a (0.64–0.97)	0.51 ^a (0.00–0.62)
JSN	1.84 ^a (0.94–2.71)	4.79 ^a (2.73–6.31)	19.7 ^{ab} (19.5–20.0)	1.4 ^{ab} (0.68–1.99)	4.1 ^{ab} (3.54–4.94)	11.2 ^a (8.75–15.2)	36.6 ^c (31.3–43.5)	18.4 ^{ab} (12.1–22.4)	0.72 ^{ab} (0.62–0.85)	0.54 ^a (0.44–0.72)
AJB	1.69 ^a (1.15–2.67)	4.13 ^a (3.22–5.79)	17.5 ^{de} (16.6–19.7)	1.0 ^{ab} (0.64–1.35)	3.7 ^c (3.27–4.30)	12.2 ^a (9.61–14.5)	43.7 ^a (40.3–46.7)	14.2 ^b (12.5–17.7)	0.65 ^{bc} (0.57–0.72)	0.49 ^a (0.40–0.58)
PJDG	2.02 ^a (0.81–3.43)	5.09 ^a (2.43–7.67)	17.6 ^{cde} (16.6–19.7)	1.0 ^{ab} (0.81–1.29)	4.4 ^a (3.65–4.82)	9.5 ^a (6.76–14.5)	40.2 ^{abc} (33.8–43.9)	18.1 ^{ab} (12.4–23.0)	0.76 ^a (0.65–0.89)	0.55 ^a (0.00–0.72)
PMBI	1.94 ^a (0.93–3.04)	5.05 ^a (2.77–7.59)	17.5 ^{cde} (16.4–19.3)	1.4 ^{ab} (0.83–2.09)	4.1 ^{ab} (3.81–4.60)	9.41 ^a (5.54–14.1)	42.9 ^a (37.3–48.0)	15.9 ^{ab} (13.0–19.3)	0.72 ^{ab} (0.67–0.80)	0.44 ^a (0.00–0.66)
PSUL	2.10 ^a (0.93–3.17)	5.17 ^a (2.99–7.11)	17.4 ^{de} (15.8–20.1)	1.1 ^a (0.79–1.65)	4.6 ^a (3.80–5.75)	8.58 ^a (3.40–15.6)	39.2 ^{abc} (34.3–44.3)	19.7 ^a (12.0–24.4)	0.77 ^a (0.66–0.96)	0.50 ^a (0.00–0.68)
PKST	1.58 ^a (0.67–2.63)	4.17 ^a (2.70–6.35)	18.1 ^{bcd} (16.5–19.9)	1.4 ^{ab} (0.74–2.18)	4.2 ^{ab} (3.84–4.95)	12.3 ^a (6.48–21.4)	40.1 ^{abc} (37.6–43.2)	16.2 ^{ab} (10.2–23.7)	0.74 ^{ab} (0.61–0.84)	0.53 ^a (0.41–0.63)
MM	2.01 ^a (0.75–3.72)	4.86 ^a (2.17–8.60)	18.1 ^{bcd} (16.7–19.7)	1.2 ^{ab} (0.67–1.73)	4.3 ^{ab} (3.65–4.79)	9.01 ^a (2.67–14.9)	42.1 ^{ab} (33.8–45.4)	16.7 ^{ab} (12.3–21.3)	0.72 ^{ab} (0.63–0.85)	0.42 ^a (0.00–0.59)
PEVR	1.73 ^a (0.84–2.83)	4.57 ^a (2.51–7.02)	16.3 ^e (14.3–19.5)	1.0 ^{ab} (0.71–1.50)	4.4 ^a (3.71–5.16)	8.76 ^a (5.62–14.8)	41.9 ^{ab} (36.1–44.1)	19.2 ^{ab} (12.2–24.0)	0.73 ^{ab} (0.63–0.80)	0.56 ^a (0.48–0.67)
p-value	NS	NS	***	*	***	*	***	**	***	NS
Location										
IM	1.4 (0.75–3.36)	3.9 (2.17–7.85)	18.7 (14.8–21.0)	1.3 (0.58–2.09)	3.9 (2.56–4.82)	11.4 (2.67–15.7)	42.5 (36.9–48.0)	15.1 (11.7–21.0)	0.5 (0.0–0.66)	0.7 (0.49–0.92)
YY	2.2 (0.67–3.72)	5.5 (2.70–8.60)	17.9 (14.3–21.5)	1.2 (0.64–2.18)	4.5 (2.96–5.75)	9.3 (3.40–21.4)	38.1 (31.3–45.5)	19.2 (10.2–24.4)	0.5 (0.0–0.72)	0.7 (0.53–0.97)
p-value	***	***	**	NS	***	***	***	***	*	NS
Year										
2016	1.9 (0.67–3.36)	4.9 (2.70–7.85)	17.7 (14.3–21.0)	1.5 (0.97–2.18)	4.3 (2.56–5.75)	9.1 (2.67–21.4)	40.8 (32.4–48.0)	17.8 (10.2–24.2)	0.5 (0.39–0.72)	0.8 (0.49–0.97)
2017	1.8 (0.75–3.72)	4.5 (2.17–8.60)	18.9 (15.7–21.5)	0.9 (0.58–1.39)	4.1 (2.96–5.26)	11.6 (5.62–15.7)	39.8 (31.3–45.5)	16.5 (11.7–24.4)	0.4 (0.0–0.66)	0.8 (0.49–0.97)
p-value	NS	NS	***	***	**	***	NS	*	***	***

Data are the mean and range (parenthesis), expressed as % dry weight

NS not significant

*p < 0.05; **p < 0.01; ***p < 0.001. The means in the same column followed by the same letter(s) are not significantly different at (p < 0.05) by least significant difference

genotype, and environments [4, 9, 14, 33]. Consistently, significant variance in mineral compounds was found by location, except potassium, iron, and sodium in this study. The levels of calcium, magnesium, phosphorus, potassium, and copper varied significantly between 2016 and 2017. The results of % variability for minerals (Fig. 1) showed that five minerals exhibited high percentages of variance by the G × E interaction: this interaction accounts for 79.1%, 63.7%, 55.4%, 55.2%, and 47.9%

in the content of sodium, sulfate, potassium, phosphorus, and zinc, respectively. The level of copper (66.5%) was primarily determined by year. The range of natural variation in calcium and manganese were associated with variety (22.9%), year (19.9%), and G × E interaction (28.2%). Magnesium was mainly affected by location (42.8%) and then by year (25.8%). It is worth noting that calcium, manganese, phosphorus, and sulfate were traits explained by genotype.

Table 4 Eighteen amino acid compositions in the pericarps of 12 capsicum varieties grown across four environments by variety, location, and year

Components		Alanine	Arginine	Aspartic acid	Cysteine	Glutamic acid	Glycine	Histidine	Isoleucine	Leucine	Lysine	Methionine
Varieties												
BST	3.3 ^a (2.67–4.24)	3.3 ^b (2.87–3.97)	3.1 ^a (2.93–3.41)	1.38 ^{bc} (1.36–2.0)	10.8 ^a (9.34–14.4)	3.14 ^{ab} (2.68–3.75)	1.10 ^a (1.01–1.22)	1.83 ^a (1.70–2.18)	3.52 ^a (2.98–4.53)	2.58 ^a (2.29–3.05)	0.67 ^a (0.56–0.92)	
MCB	3.3 ^a (2.87–3.97)	3.1 ^b (2.93–3.41)	19.0 ^a (15.7–23.5)	1.52 ^{abc} (1.36–2.0)	9.4 ^{abc} (8.05–11.5)	3.20 ^{ab} (2.68–3.75)	1.13 ^a (1.01–1.22)	1.93 ^a (1.70–2.18)	3.69 ^a (2.98–4.53)	2.69 ^a (2.29–3.05)	0.71 ^a (0.56–0.92)	
HBC	3.3 ^a (2.73–3.98)	2.7 ^b (2.49–2.92)	19.4 ^a (16.9–21.9)	1.71 ^a (1.50–1.97)	8.5 ^c (7.37–9.52)	3.43 ^a (3.12–3.82)	1.16 ^a (1.08–1.22)	1.94 ^a (1.71–2.32)	3.93 ^a (3.38–4.88)	2.55 ^a (2.32–2.71)	0.75 ^a (0.58–0.86)	
GCH	3.1 ^a (2.34–3.99)	2.9 ^b (2.41–3.43)	19.2 ^a (12.0–24.1)	1.60 ^{abc} (1.33–1.92)	9.8 ^{abc} (7.97–12.41)	3.24 ^{ab} (2.69–3.96)	1.10 ^a (0.90–1.27)	1.88 ^a (1.40–2.26)	3.62 ^a (2.75–4.34)	2.57 ^a (2.03–3.25)	0.70 ^a (0.58–0.87)	
JSN	3.8 ^a (3.04–4.58)	3.6 ^a (2.94–4.76)	23.0 ^a (18.1–32.2)	1.33 ^c (1.11–1.69)	10.2 ^a (9.05–12.7)	3.23 ^{ab} (2.77–3.81)	1.21 ^a (1.03–1.54)	1.97 ^a (1.70–2.28)	3.67 ^a (3.0–4.55)	2.69 ^a (2.24–3.36)	0.69 ^a (0.56–0.87)	
AJB	3.5 ^a (2.89–4.43)	2.9 ^b (2.38–3.95)	19.0 ^a (16.8–21.8)	1.62 ^{ab} (1.31–2.04)	10.5 ^a (8.59–14.0)	3.31 ^{ab} (2.68–3.91)	1.17 ^a (0.94–1.49)	2.03 ^a (1.72–2.50)	3.89 ^a (3.16–4.55)	2.61 ^a (1.98–3.62)	0.74 ^a (0.51–0.98)	
PJDG	3.8 ^a (3.07–4.69)	2.8 ^b (2.45–3.41)	19.1 ^a (16.6–22.6)	1.51 ^{abc} (1.30–2.12)	10.4 ^a (9.01–11.7)	2.91 ^b (2.42–3.23)	1.13 ^a (0.98–1.31)	1.83 ^a (1.72–2.02)	3.46 ^a (2.85–4.04)	2.56 ^a (2.07–3.18)	0.71 ^a (0.55–0.92)	
PMBI	3.3 ^a (2.74–4.0)	3.0 ^b (2.70–3.19)	18.8 ^a (16.0–23.2)	1.51 ^{abc} (1.32–1.81)	8.6 ^{bc} (7.01–11.2)	3.21 ^{ab} (2.71–3.69)	1.14 ^a (0.99–1.27)	1.82 ^a (1.56–2.16)	3.73 ^a (2.90–4.58)	2.60 ^a (2.11–3.07)	0.72 ^a (0.58–0.88)	
PSUL	3.4 ^a (2.78–3.88)	2.8 ^b (2.35–3.29)	20.1 ^a (15.4–25.2)	1.55 ^{abc} (1.25–1.98)	9.2 ^{abc} (7.98–10.4)	3.10 ^{ab} (2.46–3.41)	1.18 ^a (0.97–1.36)	1.86 ^a (1.48–2.27)	3.75 ^a (2.87–4.71)	2.73 ^a (2.08–3.33)	0.73 ^a (0.54–0.92)	
PKST	3.6 ^a (2.90–4.22)	2.7 ^b (2.79–3.53)	19.4 ^a (15.4–27.1)	1.53 ^{abc} (1.30–1.93)	10.1 ^{ab} (7.60–11.1)	3.03 ^{ab} (3.03–3.79)	1.10 ^a (0.95–1.38)	1.80 ^a (1.74–2.08)	3.52 ^a (3.27–4.47)	2.51 ^a (2.11–3.03)	0.70 ^a (0.55–0.89)	
MM	3.5 ^a (2.90–4.22)	3.0 ^b (2.79–3.53)	20.2 ^a (15.4–27.1)	1.56 ^{abc} (1.30–1.93)	9.2 ^{abc} (7.60–11.1)	3.38 ^a (3.03–3.79)	1.15 ^a (0.95–1.38)	1.94 ^a (1.74–2.08)	3.73 ^a (3.27–4.47)	2.66 ^a (2.11–3.03)	0.70 ^a (0.55–0.89)	
PEVR	3.6 ^a (2.86–4.76)	2.7 ^b (2.31–3.72)	19.3 ^a (15.1–23.2)	1.47 ^{abc} (1.18–1.83)	10.5 ^a (9.32–12.3)	3.06 ^{ab} (2.44–3.35)	1.11 ^a (0.91–1.23)	1.82 ^a (1.66–2.09)	3.61 ^a (2.96–4.28)	2.52 ^a (2.06–2.92)	0.70 ^a (0.54–0.87)	
p-value	NS	***	NS	**	***	**	NS	NS	NS	NS	NS	
Location												
IM	3.71 (2.83–4.76)	3.07 (2.55–4.76)	18.5 (15.1–32.2)	2.1 (1.26–2.12)	9.94 (7.59–14.0)	3.33 (2.80–3.96)	1.19 (1.02–1.54)	2.01 (1.70–2.50)	4.10 (3.45–4.88)	2.82 (2.36–3.62)	0.80 (0.63–0.98)	
YY	3.22 (2.34–4.69)	2.80 (2.31–3.72)	20.9 (12.0–28.4)	1.5 (1.11–1.83)	9.56 (7.0–14.4)	3.04 (2.42–3.89)	1.09 (0.88–1.38)	1.77 (1.40–2.09)	3.25 (2.75–3.99)	2.38 (1.93–3.03)	0.62 (0.51–0.78)	
p-value	***	***	***	***	NS	***	***	***	***	***	***	
Year												
2016	3.55 (2.52–4.76)	2.76 (2.31–3.25)	19.4 (17.4–22.7)	1.43 (1.11–1.77)	16.35 (7.59–12.4)	3.20 (2.44–3.75)	1.07 (0.88–1.22)	1.90 (1.48–2.32)	3.88 (2.87–4.88)	2.41 (1.93–2.84)	0.66 (0.51–0.86)	
2017	3.37 (2.34–4.69)	3.12 (2.41–4.76)	20.0 (12.0–32.2)	1.61 (1.22–2.12)	16.92 (7.01–14.4)	3.18 (2.42–3.96)	1.21 (0.90–1.54)	1.88 (1.40–2.50)	3.47 (2.75–4.55)	2.80 (2.27–3.62)	0.76 (0.60–0.98)	
p-value	NS	***	NS	***	*	NS	***	NS	***	***	***	

Table 4 (continued)

Components		Phenylalanine	Proline	Serine	Threonine	Tryptophan	Tyrosine	Valine
Varieties								
BST	2.6 ^a (2.25–2.85)	4.8 ^{bc} (3.65–5.39)	3.7 ^a (3.12–4.32)	3.0 ^b (2.66–3.28)	0.49 ^a (0.37–0.56)	1.4 ^b (0.95–1.85)	2.9 ^b (2.55–3.23)	
MCB	2.6 ^a (2.25–2.85)	4.8 ^{abc} (3.65–5.39)	3.7 ^a (3.12–4.32)	3.0 ^b (2.66–3.28)	0.47 ^a (0.37–0.56)	1.4 ^a (0.95–1.85)	2.9 ^a (2.55–3.23)	
HBC	2.7 ^a (2.49–3.11)	5.7 ^a (4.10–8.11)	3.4 ^a (2.96–3.79)	2.9 ^a (2.64–3.13)	0.50 ^a (0.42–0.56)	1.5 ^a (1.19–1.74)	2.9 ^a (2.65–3.35)	
GCH	2.5 ^a (2.10–2.92)	4.2 ^{abc} (2.69–5.35)	3.3 ^a (2.72–3.94)	2.9 ^b (2.43–3.43)	0.45 ^a (0.38–0.55)	1.4 ^b (1.00–1.83)	2.7 ^b (2.26–3.36)	
JSN	2.5 ^a (2.18–3.03)	5.2 ^{abc} (3.11–8.43)	3.7 ^a (3.09–4.35)	3.2 ^a (2.57–4.21)	0.50 ^a (0.40–0.66)	1.4 ^a (0.96–1.87)	3.0 ^a (2.55–3.52)	
AJB	2.7 ^a (2.07–3.24)	5.3 ^{abc} (4.05–6.05)	3.7 ^a (3.03–4.53)	3.1 ^a (2.48–3.89)	0.52 ^a (0.40–0.67)	1.5 ^a (0.96–1.93)	3.0 ^a (2.46–3.87)	
PJDG	2.4 ^b (2.12–2.85)	4.1 ^{bc} (2.42–5.85)	3.7 ^a (3.09–4.25)	3.0 ^b (2.45–3.39)	0.50 ^a (0.40–0.61)	1.3 ^b (0.89–1.75)	2.8 ^b (2.60–3.22)	
PMBI	2.6 ^a (2.28–2.87)	4.8 ^{abc} (2.97–6.07)	3.6 ^a (3.04–4.32)	2.9 ^a (2.37–3.31)	0.48 ^a (0.38–0.57)	1.4 ^a (1.00–1.70)	2.7 ^a (2.33–3.26)	
PSUL	2.7 ^a (2.18–3.14)	4.6 ^{abc} (3.21–5.74)	3.8 ^a (3.32–4.46)	3.1 ^a (2.47–3.45)	0.51 ^a (0.40–0.60)	1.4 ^a (0.95–1.89)	2.9 ^a (2.19–3.36)	
PKST	2.5 ^a (2.14–2.85)	4.5 ^{abc} (3.95–7.86)	3.5 ^a (3.40–4.34)	2.9 ^b (2.55–3.66)	0.49 ^a (0.38–0.63)	1.3 ^b (0.94–1.73)	2.7 ^a (2.42–3.20)	
MM	2.6 ^a (2.14–2.85)	5.6 ^{ab} (3.95–7.86)	3.8 ^a (3.40–4.34)	3.0 ^b (2.55–3.66)	0.48 ^a (0.38–0.63)	1.4 ^a (0.94–1.73)	2.9 ^a (2.42–3.20)	
PEVR	2.5 ^a (2.04–2.86)	3.8 ^c (2.97–5.79)	3.6 ^a (3.10–4.15)	2.9 ^b (2.48–3.08)	0.47 ^a (0.36–0.59)	1.4 ^a (0.94–1.78)	2.8 ^a (2.28–2.97)	
p-value	*	***	**	NS	NS	NS	NS	
Location								
IM	2.77 (2.38–3.24)	4.57 (2.42–8.43)	3.94 (3.33–4.53)	3.15 (2.82–4.21)	0.51 (0.40–0.67)	1.51 (1.0–1.93)	3.22 (2.68–3.87)	
YY	2.37 (1.91–2.93)	4.88 (3.02–8.11)	3.25 (2.72–4.23)	2.83 (2.22–3.66)	0.46 (0.36–0.63)	1.27 (0.81–1.83)	3.07 (2.11–3.10)	
p-value	***	NS	***	***	***	***	***	
Year								
2016	2.50 (1.91–3.14)	4.23 (2.42–8.11)	3.19 (2.72–4.46)	2.79 (2.22–3.28)	1.18 (0.36–0.56)	1.18 (0.81–1.74)	2.77 (2.11–3.35)	
2017	2.64 (2.10–3.24)	1.23 (3.02–8.43)	3.61 (2.81–4.53)	3.19 (2.43–4.21)	1.61 (0.40–0.67)	1.61 (1.25–1.93)	2.92 (2.27–3.87)	
p-value	**	***	NS	NS	***	***	**	

Data are the mean and range (parenthesis), expressed as % of protein

NS not significant

*p < 0.05; **p < 0.01; ***p < 0.001. The means in the same column followed by the same letter(s) are not significantly different at (p < 0.05) by least significant difference

Ten fatty acid compositions

Lipids and fatty acids compose a small portion of the edible part of peppers. However, they play important roles in the structure of the pepper, which is expected, considering several bioactives, vitamins, and carotenoids are liposoluble. Fatty acid composition is observed differentially in different pepper fruit components [14]. Linoleic acid is very highly concentrated in the seed while linoleic, linolenic, and palmitic acids are the major fatty acids in the pericarp [34]. In our study, only pericarp tissue was used for analysis. Most fatty acid compositions showed variation among 12 pepper varieties produced at same location per year. Only linoleic acid of YY 2016 and behenic acid of IS 2017 and YY 2017 did not show significant variance among 12 varieties (Additional file 1: Figure S4). Table 3 shows the percentage composition of fatty acids of pepper pericarp. The results showed that linoleic acid is the major compound, followed by palmitic, linolenic, oleic, myristic, and steric acids. Lauric, palmitoleic, arachidic, and behenic acids were present in traces. Most fatty acids were significantly different among varieties across the four environments, with the exception of lauric, myristic, and behenic acids. The location effect was significant for all the fatty acids except palmitoleic and behenic acids. All the fatty acids, with exception of lauric, myristic and linoleic acids, varied significantly by year.

The genotypic effect on fatty acid composition of capsicum has previously been reported [4]. A few studies of environmental and the $G \times E$ interaction effects on fatty acid composition of pepper are available. In our study, further statistical analysis suggested that genotype and the $G \times E$ interaction primarily determined levels of all fatty acids measured. The results of % variability for fatty acids (Fig. 1) showed that palmitoleic and linolenic acids were highly affected by year, accounting for 72.2% and 66.5% of the variation, respectively. Myristic and lauric acids were affected by location, the effect of which accounts for 51.3% and 35.6% of the variation, respectively. Myristic and lauric acids were influenced by $G \times E$ interactions, accounting for 31.7% and 25.8% of the variation, respectively. Linoleic (63.7%) and oleic (52.2%) acids were also highly affected by $G \times E$ interaction. Arachidic acid was mainly affected by $G \times E$ interaction (55.4%) but also showed a location effect (24.9%). Palmitic, stearic, and behenic acids were affected by genotypes, location, year, and $G \times E$ interactions in similar proportions. Notably, palmitic, stearic, behenic, and oleic acids were one of top ranked traits influenced by genotype.

Eighteen amino acid compositions

We analyzed 18 amino acids profiles in pepper pericarps and expressed as % composition to total protein. Most

Table 5 Contents of capsaicin, dihydrocapsaicin, fructose, and glucose in the pericarps of 12 capsicum varieties grown across four environments by variety, location, and year

	Component			
	Capsaicin	Dihydrocapsaicin	Fructose	Glucose
Varieties				
BST	40.0 ^a (2.37–104)	18.4 ^a (0.65–61.4)	15.7 ^a (13.0–21.7)	8.7 ^a (4.96–14.0)
MCB	37.4 ^a (2.85–142)	19.2 ^a (1.21–80.6)	15.2 ^a (11.6–22.1)	9.3 ^a (5.36–14.6)
HBC	24.8 ^a (8.63–41.0)	11.0 ^a (3.12–19.0)	14.9 ^a (12.4–17.0)	8.6 ^a (6.01–10.8)
GCH	22.8 ^a (3.17–44.0)	11.2 ^a (1.64–23.3)	15.0 ^a (12.7–19.0)	7.8 ^a (5.69–12.0)
JSN	20.8 ^a (0.02–98.0)	10.9 ^a (0.01–53.5)	15.9 ^a (12.2–22.0)	9.1 ^a (5.36–13.8)
AJB	12.9 ^a (0.38–55.2)	7.3 ^a (0.25–35.8)	18.8 ^a (17.1–21.4)	10.9 ^a (7.16–13.8)
PJDG	23.8 ^a (2.12–113)	13.9 ^a (1.36–65.4)	17.7 ^a (14.8–21.4)	10.7 ^a (8.13–13.5)
PMBI	31.0 ^a (1.51–102)	16.5 ^a (0.44–62.1)	17.6 ^a (15.0–21.5)	11.0 ^a (7.95–13.6)
PSUL	51.3 ^a (4.08–130)	28.9 ^a (1.84–76.0)	16.8 ^a (12.9–22.0)	10.2 ^a (6.37–14.6)
PKST	42.6 ^a (4.91–125)	23.7 ^a (2.38–70.9)	16.9 ^a (12.0–22.0)	9.7 ^a (5.24–14.2)
MM	23.2 ^a (2.32–88.4)	12.0 ^a (1.44–51.8)	16.6 ^a (14.2–20.3)	10.2 ^a (6.97–13.1)
PEVR	37.1 ^a (2.92–93.1)	23.1 ^a (1.66–55.6)	14.9 ^a (12.2–21.7)	8.7 ^a (5.40–14.1)
p-value	NS	NS	*	NS
Location				
IM	51.5 (1.71–142)	27.8 (0.06–80.6)	17.8 (12.3–22.1)	11.6 (5.7–14.6)
YY	33.7 (0.02–40.0)	20.7 (0.01–21.3)	14.9 (11.6–19.2)	7.5 (5.0–10.8)
p-value	***	***	***	***
Year				
2016	20.9 (0.02–73.0)	10.1 (0.01–46.3)	14.8 (11.6–19.9)	8.6 (5.0–12.8)
2017	40.4 (0.30–142)	22.6 (0.22–80.6)	17.9 (12.6–22.1)	10.5 (5.0–14.6)
p-value	***	***	***	***

Data are the mean and range (parentheses). Capsaicin and dihydrocapsaicin data are expressed as mg/100 g dry weight. Fructose and glucose data are expressed as g/100 g dry weight

NS not significant

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. The means in the same column followed by the same letter(s) are not significantly different at ($p < 0.05$) by least significant difference

amino acid compositions showed variation among 12 pepper varieties produced in same place by year (Additional file 1: Figure S5), with exception of alanine, aspartic acid, glycine, leucine, methionine, tyrosine, and valine

produced in YY 2016. This result suggests a genotypic effect on these compounds was not expressed in the YY 2016 environment (Additional file 1: Figure S5). Table 4 shows the percentage composition to total protein of 18 amino acids in 12 pepper varieties. The main amino acids were glutamic acid and aspartic acid, followed by proline, serine, leucine, alanine, arginine, valine. The contents of methionine, cysteine, tyrosine, tryptophan, isoleucine, and lysine were low. Significant differences were observed in arginine, cysteine, glutamic acid, glycine, phenylalanine, proline, and serine content among 12 varieties across four environments. The location effect was significant for all amino acid except glutamic acid and proline. All amino acids displayed significant difference by year, with the exception of alanine, aspartic acid, glycine, isoleucine, serine, and threonine. The results of % variability for amino acid (Fig. 1) showed that serine, leucine, methionine, valine, phenylalanine, isoleucine, cysteine, and lysine were highly affected by growing regions ranging from 74.6 to 45.7%. Tryptophan (67.6%), tyrosine (65.6%), histidine (43.2%), and threonine (42.5%) variation was mainly explained by the year effect. Alanine, proline, aspartic acid, glutamic acid, and glycine were affected by the $G \times E$ interaction ranging from 62 to 39.7%. The content of arginine varied by genotype, year, location, and the $G \times E$ interaction with similar proportions.

Capsaicinoid and free sugar compositions

Capsaicinoids are a group of alkaloids that contribute to pungency. Peppers are a popular food ingredient worldwide due to their heat characteristics. Capsaicin and dihydrocapsaicin are the major capsaicinoids, constituting approximately 90% of total capsaicinoids in pepper fruits [35]. Capsaicinoid content in fruit is influenced by several factors such as genotype, geographical location, fruit development, and environmental stresses [15, 17].

In our study, capsaicinoids were highly variable among 12 varieties grown in IS 2016, IS 2017, and YY 2016 (Additional file 1: Figure S6). The range of capsaicin and dihydrocapsaicin in an individual variety is very broad. In nearly all varieties, capsaicinoid content was higher in peppers produced from IS than YY both years (Additional file 1: Figure S6). The amount of capsaicinoid in the 12 varieties was dramatically higher in peppers produced from IS 2017 than those from IS 2016, while it was similar between YY 2016 and YY 2017 (Additional file 1: Figure S6). However, levels of capsaicin and dihydrocapsaicin were not significantly different among 12 varieties across four environments (Table 5). It is likely that the high increase in capsaicinoids varieties from IS 2017 has influenced the disappearance of variability among the varieties. For example, JSN, AJB, and PJDG showed lower capsaicinoid levels compared to other varieties in IS 2016 and YY 2016. However, their capsaicinoid contents were ~eightfold higher in peppers grown in IS 2017. In alignment with this observation, capsaicinoid content showed significant differences between sites and years, respectively (Table 5). Previous reports [15, 17, 36] showed that variations in capsaicinoids were the result of environmental differences including location, soil type, solar radiation, and precipitation. It was suggested that choosing the appropriate combination of environment and genotype is an important factor to produce suitable nutritional trait.

The concentration of free sugars is one of the components, along with organic acids, that determine fruit flavor attributed to sweetness in the red mature stage of pepper fruit [37]. Both fructose and glucose composition differed by year in varieties when plants were grown in the same place (Additional file 1: Figure S6). The level of fructose across all samples was higher than that of glucose (Table 5). Concentrations (mg/100 mg DW) of fructose and glucose in 12 pepper pericarps ranged from

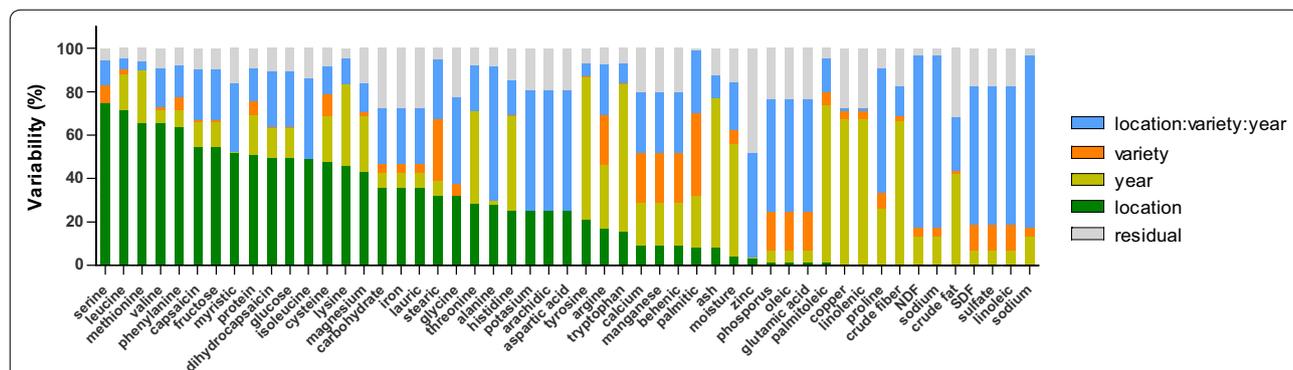


Fig. 1 Variability proportion affecting on natural variation in analytes. Variability of each analyte explained by the location effect was used to order analytes on the X-axis (from the highest to the lowest)

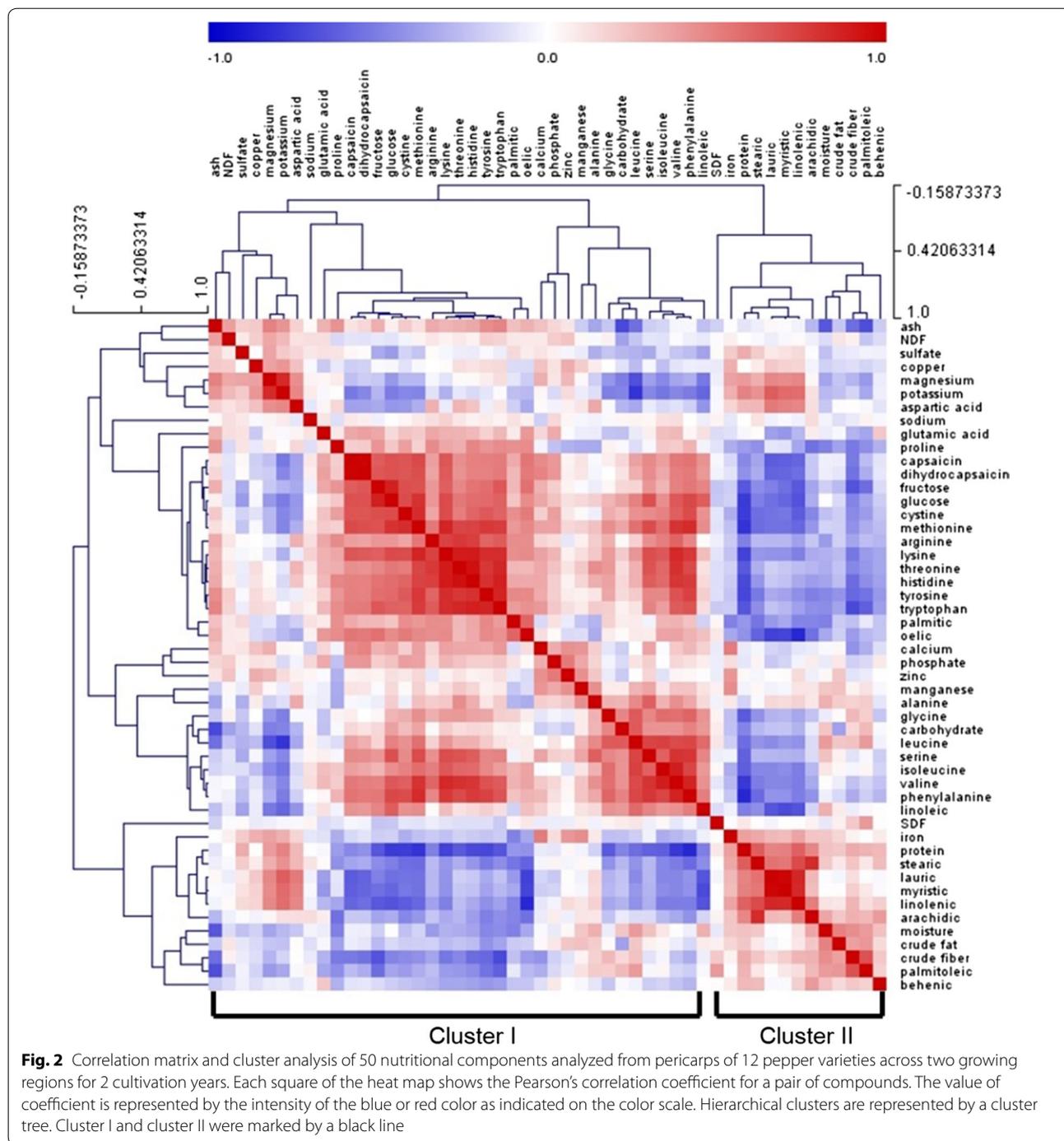


Fig. 2 Correlation matrix and cluster analysis of 50 nutritional components analyzed from pericarps of 12 pepper varieties across two growing regions for 2 cultivation years. Each square of the heat map shows the Pearson's correlation coefficient for a pair of compounds. The value of coefficient is represented by the intensity of the blue or red color as indicated on the color scale. Hierarchical clusters are represented by a cluster tree. Cluster I and cluster II were marked by a cluster line

11.6 to 22.1 and 5.0 to 14.6, respectively. Jarret et al. [5] showed the great diversity of free sugars within the *C. chinense* gene pool. Further, free sugar quantity was affected by pepper cultivars, fruit maturation, cultivation region, and year in Korea [10, 16, 38]. The contents of fructose and glucose across varieties were higher in

peppers produced from IS than those of YY and both compounds significantly varied by year (Table 5). The results of % variability for capsaicinoids and free sugars from R statistics (Fig. 1) showed that they were affected significantly by location, G × E interaction, and year. The location effect for capsaicin, dihydrocapsaicin, fructose,

and glucose explained 54.6%, 49.2%, 54.6%, and 49.2% of variability, respectively. The genotype effects for these compounds were very small portion, ranging from 1.3 to 0.7%.

Correlation of analytes measured from 12 varieties across four environments

Correlation between the concentrations of various metabolites provides information regarding metabolic associations. To examine detailed relationships between the 50 nutritional components in pepper, we calculated the Pearson's correlation matrix between nutritional components and applied HCA on the datasets (Fig. 2). The HCA results showed two clusters: cluster I consisted of ash, IDF, carbohydrates, minerals (except iron), amino acids, capsaicinoids, free sugars, oleic, and linoleic acids. Cluster II consisted of SDF, iron, protein, crude fat, crude fiber, and other fatty acids. These results showed that analytes in the same or related biosynthetic pathways were generally closely clustered. For example, capsaicin and dihydrocapsaicin showed a strong positive correlation ($r=0.989$, $p<0.0001$). Likewise, significant positive relationships were observed between fructose and glucose ($r=0.875$, $p<0.0001$). In addition, most amino acids were positively correlated among each other. The Pearson correlation coefficients among leucine, isoleucine, and valine, which are branched amino acids, were higher than 0.7 ($p<0.0001$). In regard to fatty acids, palmitic acid was positively correlated with oleic acid ($r=0.6048$, $p<0.0001$), while it showed negative correlation with other fatty acid. Similar results have been reported in maize and rice [39, 40]. Correlations between 18-carbon fatty acids were either significantly positive at $p<0.01$ (stearic and linolenic, oleic and linoleic) or significantly negative at $p<0.01$ (stearic and oleic, stearic and linoleic, oleic and linolenic, linoleic and linolenic).

Supplementary information

Supplementary information accompanies this paper at <https://doi.org/10.1186/s13765-019-0456-y>.

Additional file 1: Table S1. Monthly mean temperature and rainfall data. **Figure S1.** Mean temperature and total rainfall during the periods of May–October in Imsil (IS) and Youngyang (YY) in the years 2016 and 2017. **Figure S2.** Scatter plots of moisture, protein, ash, crude fiber, SDF, IDF, and carbohydrate contents of 12 pepper varieties grown in Imsil (IS) and Youngyang (YY) in 2016 and 2017. **Figure S3.** Scatter plots of mineral contents of 12 pepper varieties grown in Imsil (IS) and Youngyang (YY) in 2016 and 2017. **Figure S4.** Scatter plots of fatty acid compositions of 12 pepper varieties grown in Imsil (IS) and Youngyang (YY) in 2016 and 2017. **Figure S5.** Scatter plots of amino acid compositions of 12 pepper varieties grown in Imsil (IS) and Youngyang (YY) in 2016 and 2017. **Figure S6.** Scatter plots of capsaicin, dihydrocapsaicin, fructose, and glucose contents of 12 pepper varieties grown in Imsil (IS) and Youngyang (YY) in 2016 and 2017.

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Authors' contributions

EHK conducted the analysis of nutritional composition in peppers and prepared the whole manuscripts. SWO reviewed and edited the manuscript including statistical analysis. SYL, SYP, SGL, and DYB provided technical assistance to EHK and SWO and helped with the data collection. THR and SKL assisted the revision of the manuscript and helped the process of this research project. HJK supervised the whole work. OHK and MK cultivated the peppers in the fields and contributed to the plant materials. All authors read and approved the final manuscript.

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Availability of data and materials

All data generated or analyzed during this study are included in this published article and its additional information files.

Competing interests

The authors declare that they have no competing interests.

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