J ISSAAS Vol. 28, No. 2: 81–91 (2022)

PHYSICO-CHEMICAL CHANGES IN GARLIC *(Allium sativum L.)* AFTER PROLONGED STORAGE AT AMBIENT CONDITIONS IN THE PHILIPPINES

Leonisa A. Artes*, Matilde V. Maunahan, Jennelyn M. Resorez and Perlita A. Nuevo
Postharvest Horticulture Training and Research Center, College of Agriculture and Food Science,
University of the Philippines Los Banos, College, Laguna
*Corresponding author: laartes@up.edu.ph

(Received: January 25, 2022; Accepted: November 7, 2022)

ABSTRACT

Garlic bulbs from Batanes, Ilocos Norte, Nueva Vizcaya and Occidental Mindoro in the Philippines were collected to determine their physico–chemical characteristics including changes in pungency levels over time. Samples were taken during the harvest season (February–March, 2019) and stored for 6 - 8 months at ambient conditions (~30^0C). The following were evaluated: bulb size and weight, total soluble solids (TSS), and pungency in terms of pyruvate content. Garlic bulbs from major production areas in the Philippines would pass the premium ASEAN size standards (> 3.5cm), although actual size classification varies by production area. TSS values averaged 35°Brix but slightly declined after 6 – 8 months. Bulbs from Ilocos Norte and Nueva Vizcaya were initially more pungent, with higher pyruvate content (1.39 – 1.48 umol/g fresh weight (FW)) than those from Mindoro (1.13 umol/g FW) and Batanes (1.01 umol/g FW). After about 6 - 8 months, pyruvate level generally increased by 0.07 – 0.25 umol/g in most samples, except those from Batanes. Correlation between bulb size and pyruvate content showed that bigger bulbs had higher pyruvate content, except those from Occidental Mindoro. TSS values of Philippine garlics were comparable with those reported by other countries; but its pyruvate content was very low.

Key words: bulb size, bulb weight, weight loss, TSS level, pyruvate content

INTRODUCTION

Garlic is a popular spice in the Philippines and throughout the world. It is an ingredient in many food preparations, as well as in food supplements and herbal medicinal products (Petropoulos et al. 2017; 2018; Batiha et al. 2020). Hence, it is important that garlic is available the whole year round. However, being a bulb crop, garlic can be grown only during the dry months of the year. In developed countries, it is usually cold stored and thus it is available throughout the year. Such is not usually done in the Philippines, however, due to high cost of refrigeration. In garlic and other allium vegetables, total solids or dry weight (DW) is considered a quality trait positively associated with flavor intensity, length of postharvest life, and suitability for dehydration (Sance et al. 2008; Gelleta et al. 2013). An evaluation of a germplasm collection in Greece showed 26 - 42% DW of its garlic varieties (Avgeri et al. 2020). Those with > 40% DW had the longest shelf life; while those with low DW had short postharvest life, some of which had purple skin color.

Perception of garlic flavour is closely associated with its pungency level. The main bioactive compounds in garlic are saponins, flavonoids, organic acids, and various organosulfur compounds **(**Petropoulos et al. 2017). The latter are present in intact bulbs as peptides and sulfoxides (*i.e.* alliin). Alliin is synthesized in the leaves and translocated to the bulb in vesicles within the cytoplasm of mesophyll cells in cloves (Lawson 1996); while the enzyme allinase is said to be localized in the vacuoles of the bundle sheath cells, surrounding the phloem vessels (Ellimore and Feldberg 1994). Due to this difference in subcellular localization, allinase and alliin cannot interact until there is mechanical damage to the bulb, such as crushing (Yamazaki et al. 2002). In a way, this separation of the enzyme and its substrate contributes very well to the preservation of the bulb's pungency, as long as the bulb is intact.

When the bulb is crushed, alliin is metabolized to allicin by the enzyme allinase, producing ammonia and pyruvic acid (Yamaguchi and Kumagai 2019; Abe et al. 2020**)**. Hence, pyruvic acid is used as an indirect measure of pungency (Natale and Camargo 2005). It is reported to constitute up to 61% of total organic acids in garlic (Petropoulos et al. 2017). Those with high pyruvate content (plus organosulfur compounds) have the most intense flavor (Avgeri et al. 2020). Organo-sulphur compounds are responsible for the flavour and pungency of garlic. Of these, thiosulfinate**s** are the most abundant constituent (Barboza et al. 2020), and allicin is the predominant thiosulfinate (Block 2020). Pyruvate level is an estimator of total thiosulfinate content of garlic as they are positively correlated (Wall and Corgan 1992).

A local maturity study on garlic reported that when harvested 90 days after planting, it resulted in high weight loss, faster softening, and low TSS and pyruvate content, because the bulbs were still considered immature (Nuevo 1996). Hence, these bulbs were recommended to be harvested at least 105 days after planting. Bulbs were also found to be more pungent than its corresponding scapes, which are used in some food preparations (Gonzales et al. 2012).

Allicin content of garlic increased when bulbs were stored in low temperature (4 - 10^0C, and 60 - 90% RH) for 120 days (Sukkaew and Tira-umphon 2012). Maximum allicin level (36.5 mM/g DW) was found in bulbs stored at 4 - 6^0C, 80 - 90% RH after 60 days. The activity of allinase, the enzyme responsible for converting alliin to allicin yielding pyruvate, decreased at low temperature storage (-1.5^0C); while ambient storage (22^0C) maintained higher allinase activity up to six months after harvest (Ludlow et al. 2021). Similarly, onions stored for eight months at ambient conditions showed high allinase activity (Hanum et al. 1995). Pyruvate levels ranged from 3.69 to 72.47 umol/g fresh weight (FW) basis among 34 Greek genotypes (Avgeri et al. 2020). Pyruvate content was found to be strongly correlated with organosulfur compounds that had the most intense flavor among the Greek samples. The total phenolic content (12 - 82 mg GA /100g FW) was also found to be strongly and positively correlated with garlic's antioxidant capacity. Argentina, the second garlic exporter in the world, has garlic with 64 - 97 umol/g Pyruvic acid among its cultivars (Natale and Camargo 2005).

Aside from being an important ingredient in various food preparations, garlic has also many medicinal benefits. Its alliin and alliicin content can prevent and treat illnesses such as cancer (Nicastro et al. 2016), cardiovascular diseases (Banerjee and Maulik 2002), high blood pressure (Ried and Fakler 2014), diabetes (Ashral et al. 2005), Alzheimer's disease and dementia (Ray et al. 2011), as well as colds and infections (Josling 2001). Such medicinal benefits are attributed mainly to garlic's organosulfur and phenolic contents which are responsible for its flavor and pungency (Amagase et al. 2001; Rahman and Lowe 2006), of which thiosulfinates are the most abundant constituent (Block 2010). Its pyruvate content has been found to correlate positively with thiosulfinates, flavor intensity (Wall and Corgan 1992), and antioxidant activity (Soto et al. 2016; Beretta et al. 2017). Garlic has antimicrobial properties also (i. e. antifungal, antiparasitic, antiviral and antibacterial) due to its allicin content (Ankiri and Mirelman 1999; Harris et al. 2001).

In the Philippines, garlic can only be grown during the dry months of the year and also in limited areas of the country where there are distinct dry and wet seasons. Most popular of these areas is the Ilocos region in northern Philippines, where it is dry and hot during the summer season. After harvest, garlic is simply stored commercially at ambient temperatures. Hence, its price increases much toward the end of the year when it is off-season already.

Locally, there is no known study yet on the comparison of postharvest characteristics of garlic grown from various areas in the country. Hence, this study was conducted to document the size and weight of garlic, and the drying practices from key production areas in the country; to determine the TSS and pyruvate levels of garlic taken from key growing areas in the country; and to measure the pyruvate changes after prolonged storage under ambient condition.

MATERIALS AND METHODS

Garlic was collected during the harvest season (February–March 2019) from the following production areas of the country: Itbayat, Batanes; Pasuquin, Ilocos Norte; Bambang, Nueva Vizcaya and Lubang Island, Occidental Mindoro (Table 1). Bunched samples of various sizes of garlic, based on bulb diameter classified as extra large, large, medium, small, and extra small were collected from each area. These were further dried at ambient condition in the laboratory of the Postharvest Horticulture Training and Research Center, UP Los Banos for a month before analyses were done. The laboratory has an open window, with a temperature of 29 - 33^0C and 75 - 85% RH throughout storage. The diameter and weight of 10 individual bulbs for each size category were taken.

Table 1. Sources of garlic that were stored and analyzed for pungency, 2019.

Source	**Harvest Month**	**Initial Analyses**	**Final Analyses**	**Storage Period**
Batanes	February	April	November	7 months
Ilocos Norte	March	May	November	6 months
Nueva Vizcaya	March	May	November	6 months
Occidental Mindoro	February	April	December	8 months

The TSS content of the bulb was determined using a refractometer (Atago PR-1, Japan): 10 gm of garlic pulp was homogenized with 100 ml distilled water and filtered using cotton prior to placing the filtrate drop on the refractometer. The reading was multiplied with dilution factor and expressed in ^{0}Brix. Ten garlic bulbs from each size served as replicates.

Pungency was determined according to Schwimmer and Weston (1961) with some modifications (Gonzalez et al. 2012). Garlic cloves were peeled, weighed and blended in cold water. The sample was then filtered using cotton. One ml of the filtrate was mixed with 1 ml water and 1ml of 0.125% DNPH with 2N HCl. The tube content was mixed using a vortex mixer for 2 minutes, and then incubated at 37C water bath for 10 min. Afterwards, 5ml of 0.6N NaOH was added to the tube and the content was mixed again in a vortex mixer. It was left with cover against light for 10 min at room temperature for further reaction. Absorbance of the sample was measured using UV Vis spectrophotometer (Hitachi UH 5300, Japan) at 420 nm wavelength. A standard curve of pyruvic acid at various concentrations was prepared. Pyruvate levels of the bulbs were measured initially and after about 6 – 8 months at ambient conditions (29 - 33C). Analyses were done using 10 garlic bulbs of each size serving as replicates.

Data were analysed using SAS system (version 9). Means were compared using least significant difference (LSD) or Tukey's test (HSD) at 5% level of significance.

RESULTS AND DISCUSSION

Garlic size and weight. The size classification of the bulbs is variable by area. Actual measurement of bulb diameter differed in terms of extra small, small, medium, large and extra large bulbs (Fig.1). Only Batanes did not have the extra small (x-small) size bulbs, while only Ilocos Norte had the extra-large (x-large), the size of which (4.2 cm in diameter) however, was even smaller than the large bulbs of Nueva Vizcaya (4.5 cm) and of Occidental Mindoro (4.4 cm). Nevertheless, based on ASEAN standard for garlic size (https://www.asean.org/wp-content/), all sources had samples that would pass the ASEAN standard size 1 for garlic (Table 2). Hence, based on size, Philippine garlics can be marketed in the ASEAN countries.

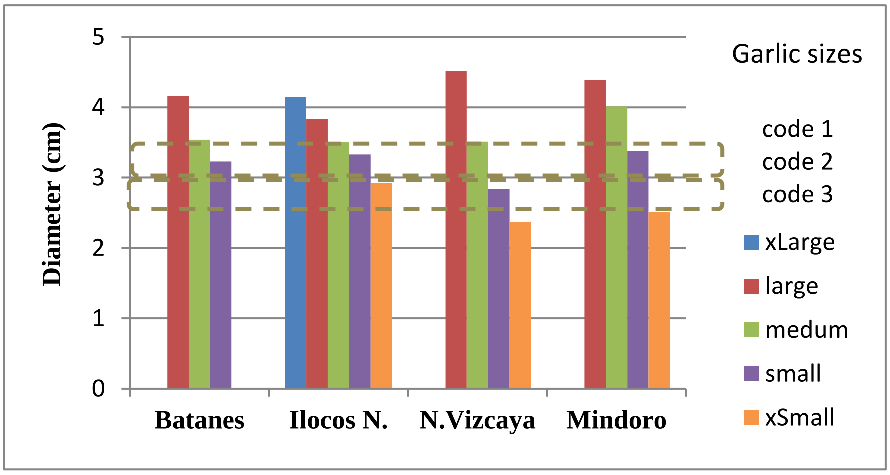

Fig. 1. Size classification of garlic according to source area compared with ASEAN standard codes 1-3. Each bar is the average of 10 bulbs. (Ilocos N.= Ilocos Norte; N.Vizcaya = Nueva Vizcaya; Mindoro = Occidental Mindoro).

Table 2. ASEAN Standard for garlic[1]

Code	Bulb diameter (cm)
1	> 3.5
2	3.0 < 3.5
3	2.5 < 3.0
4	1.5 < 2.5
5	< 1.5

[1]Based on ASEAN Standards 13.2009.

Garlic from Ilocos Norte, Nueva Vizcaya, and Occidental Mindoro had similar weights (8 - 24 g) across various size categories (Fig. 2). Bulbs from Ilocos Norte and Nueva Vizcaya used the same variety (Ilocos white), but those from Ilocos Norte had more categories having extra large and extra small sizes. Those from Batanes had the lowest bulb weight (<15 g).

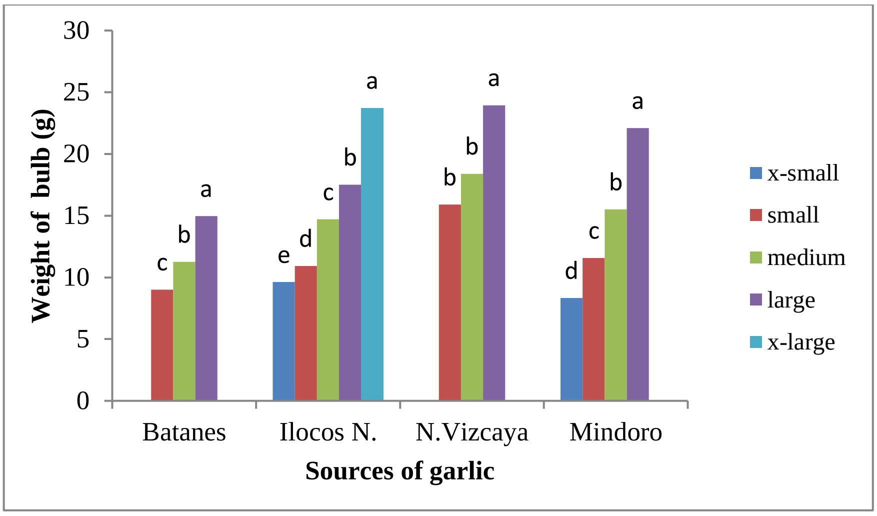

Fig. 2. Bulb weight (g) of garlic according to size classification in each production area. Each bar is the average weight of 10 bulbs. Mean comparison within each area is by LSD, 5%. (Ilocos N.= Ilocos Norte; N.Vizcaya = Nueva Vizcaya; Mindoro = Occidental Mindoro).

The bulbs from most areas were pure white (i.e. Ilocos Norte, Nueva Vizcaya and Occidental Mindoro), but those from Batanes had a slight red tinge in its skin. This coloring indicates that the Batanes variety likely belonged to cluster 2 or 3 of garlic like in Argentine cultivars, while the white variety belongs to cluster 1 (Barboza et al. 2020).

A very high regression coefficient (R^2) was obtained from all sources of garlic with respect to bulb weight at each size classification (Table 3). This means that farmers from each source of garlic were able to segregate well the bulbs even if based only on diameter estimation

Table 3. Correlation coefficient between garlic size and weight

Source of garlic	Linear equation	R^2
Batanes	2.98x + 2.81	0.98
Ilocos Norte	3.48x + 4.86	0.95
Nueva Vizcaya	4.02x + 7.34	0.95
Occidental .Mindoro	4.52x + 3.07	0.97

Drying and weight loss. In general, garlic farmers dried their harvest in bundles for about two weeks in their own areas (Table 4). Newly harvested garlic bulbs were laid flat on the ground for sun-drying and/or hung under the shade to air-dry. In case of Batanes, however, bulb samples were dried for one week only. Based on average monthly weight loss during storage, the samples from Batanes had the highest weight loss (Batanes Red: 4%; Batanes White: 12%). Samples from other places that were sun-dried or air-dried for two weeks had minimal weight loss (1-2%) in the next months. Hence, a minimum of two weeks drying under Philippines's ambient condition is necessary before storing garlic to have minimal weight loss later.

Garlics from Indonesia stored at room temperature (29 - 31^{0}C) for four months showed also similar weight loss (1.0 - 6.0%), while those kept at 5^{0}C had relatively higher weight loss (0.5 - 8.0%) toward the end of storage (Nurmalia et al. 2019).

In the Philippines, garlic is marketed based on bulb size, not weight, which is practiced as well in other ASEAN countries. However, since garlic is a fresh produce, weight loss is expected. Table 5 shows the weight loss of garlic samples from various production areas within six months. In general, garlic incurred 8 - 25% weight loss after six months. For Batanes, both varieties had minimal weight loss in the first four months, but from fifth month onwards, Batanes Red incurred a very high weight loss (37%), possibly due to disease that was manifested later.

Table 4. Drying practices of garlic farmers by production area.

Production area	Variety	Drying duration in the area	Storage method	Monthly rate of weight loss[1]
Itbayat, Batanes	Batanes white Batanes red	1 week air drying	Detopped, packed in net bags, piled	3.84 b 11.67 a
Pasuquin, Ilocos Norte	IIocos white	2 weeks sun drying	Bundled, piled	2.12 bc
Barat, Bambang, Nueva Vizcaya	IIocos white	1 week sun drying +1week air drying	Braided, hung	0.94 c
San Leonardo, Bambang, Nueva Vizcaya	IIocos white	4-5days sun drying + 1 week air drying	Bundled, piled	1.32 c
Tangal, Lubang, Occidental Mindoro	'Mindoro var.'	2 weeks sun drying	Bundled, hung	1.04 c
Tagbac, Lubang, Occidental Mindoro	'Mindoro var.'	2 weeks sun drying	Bundled, hung	1.05 c

[1]Weight loss in the last 3 months of storage. Comparison of means by HSD, 5%.

Table 5. Weight loss (%) of garlic during storage at ambient room (29 - 33^{0}C)[1].

Source	Color /Size	Length of Storage (months)		
		2	4	6
Batanes	Red	0.7a	5 a	37 a
	White	0.4 a	3 a	13 b
	Ave.	**0.5**	**4.0**	**25.0**
Ilocos Norte	x-Large	1.8 a	4 a	9 a
	Large	1.5 b	3 b	9 ab
	Medium	1.4 bc	3 b	8 ab
	Small	1.2 cd	2 c	7 c
	x-Small	1.2 d	2 c	8 b
	Ave.	**1.42**	**2.8**	**8.2**
Occidental Mindoro	Large	18 b	20 b	22 b
	Medium	18 b	20 b	22 b
	Small	20 b	21 b	24 b
	x-Small	26 a	27 a	29 a
	Ave.	**20.5**	**22.0**	**24.2**

[1]Each value is the average of 10 bulbs. Comparison of means within columns per area is by LSD, 5%.

For the first four months, the average weight loss of the various sizes of garlic from Batanes and Ilocos Norte was low (0.5-2.8%); whereas those from Occidental Mindoro were very high (18 - 26%). After six months, both Batanes Red and those from Occidental Mindoro exhibited a high weight loss (37%, 24%); whereas those from Ilocos Norte incurred only 8%. This may be due to immaturity of the Mindoro bulbs, where the peel or outer skin is not well developed, or the bulbs were not properly dried yet by the time garlic samples were set up. Weight loss of garlic was found to be lower after 120 days under ambient conditions (3 - 4%) than under low temperature storage ranging from 4 to 10^{0}C (4 - 11%) (Nurmalia et al. 2019; Sukkaew and Tira-umphon 2012). Moreover, moisture content of garlic was reported to remain constant (59 - 68%) during storage for 12 months, both at 22^{0}C and at -1.5^{0}C (Ludlow et al. 2021).

Total soluble solids (TSS). Initial TSS levels of garlic ranged from 28 to 39 ^{0}Brix. Samples from Mindoro had the highest initial TSS levels (37.6 ^{0}Brix), followed by Batanes (35.2 ^{0}Brix), Nueva Vizcaya (34.1 ^{0}Brix) and Ilocos Norte (31.8 ^{0}Brix). After 6 – 8 months of storage (final), the TSS levels in all samples slightly decreased (Fig. 3). Those of garlic from Occidental Mindoro decreased the most (6 ^{0}Brix); those from Batanes had the lowest decrease (1 ^{0}Brix). The TSS decrease was due to garlic's continuous respiration as it uses energy for its cellular maintenance.

The pattern of changes in TSS values with respect to bulb sizes was not consistent for all sources of garlic (Table 6). Initially, TSS values decreased as bulb size increased except for samples from Occidental Mindoro. However, only garlic from Ilocos Norte and Nueva Vizcaya showed the same pattern, after 6 - 8 months in storage. Those from Batanes and Occidental Mindoro have increasing TSS values with increase in bulb size. Hence, bulb size of garlic seems not a factor of TSS level in this case. Possibly, more samples must be taken to verify such correlation.

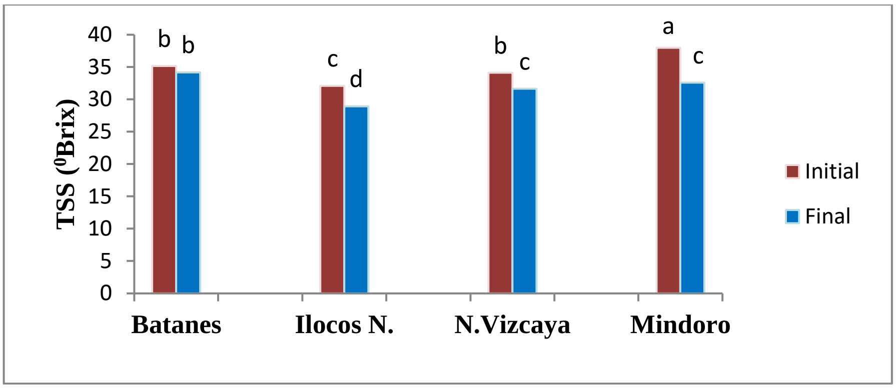

Fig. 3. Changes in TSS content of garlic after 6 - 8 months storage at ambient conditions. Each bar represents the average of 30 garlic samples. Mean comparison is by LSD, 5%. (Ilocos N.= Ilocos Norte; N.Vizcaya = Nueva Vizcaya; Mindoro = Occidental Mindoro).

Table 6. Correlation between garlic sizes and TSS values from each production source over 6 - 8 months at ambient conditions[1].

	Initial		Final	
Garlic source	**Linear equation**	**R^2**	**Linear equation**	**R^2**
Batanes	-0.25x + 35.92	0.03	0.5x + 32.77	0.99
Ilocos Norte	-0.51x + 33.33	0.54	-0.26x + 29.66	0.73
Nueva Vizcaya	-0.98x + 37.04	0.9998	-0.75x + 33.88	0.70
Occidental Mindoro	0.73x + 35.8	0.92	1.445x + 28.3	0.95

[1]Each value represents the average of 30-50 garlic bulbs of various sizes (x-large, large, medium, small, x-small)

In the present study, after six to eight months of ambient storage, most of the garlic samples that were stored, were still of marketable quality. The TSS values obtained here (28 - 39 ^{0}Brix, raw data not shown) were higher than garlic samples from Spain (25 - 29 ^{0}Brix) (Pardo et al. 2007), but slightly lower than some samples (32-40 ^{0}Brix) from Greece (Petropoulos et al. 2018). TSS level of garlic from another Greek study (26 - 42%) indicated long shelf life (Avgeri et al. 2020). In comparison, the TSS levels of some tropical fruits at the edible ripe stage are usually lower than that of garlic: banana (20 - 24 ^{0}Brix), mango (17 - 19 ^{0}Brix), citrus fruits (8 - 9 ^{0}Brix) and papaya (9 ^{0}Brix) (Agillon et al. 1987; Lado et al. 2014; Khandaker et al. 2018).

Pyruvate content. The initial pyruvate levels (Table 7) were highest in samples from Ilocos Norte (123 ug/g FW or 1.39 umol/g FW) and Nueva Vizcaya (130 ug/g FW or 1.48 umol/g FW), and lowest in samples from Batanes (89 ug/g FW or 1.01 umol/g FW). Values obtained were comparable with local samples analysed before (Nuevo 1996); but were much lower than samples from Greece (0.95 – 1.91 g/100 g FW) (Petropoulos et al. 2018).

After 6 - 8 months of storage at ambient conditions (Fig. 4), most samples had an increase in pyruvate content (6 - 22 ug/g FW or 0.02 - 0.49 umol/g FW), except those from Batanes which showed a slight decline (8 ug/g FW or 0.09 umol/g FW). Those from both Batanes and Nueva Vizcaya samples did not change much after six months. Ilocos Norte and Nueva Vizcaya samples, which are actually of same variety (Ilocos white), had the highest pyruvate content. It is possible that samples from Occidental Mindoro were not properly dried before its collection. Hence, the big difference in pyruvate content over time due to changes in bulb weight, on which pyruvate computation is based.

Storage of local garlic at ambient conditions is comparable with other countries, where garlic or onion is usually stored at low temperature (-1.5 ^{0}C) to have an extended shelf life for 6 - 8 months (Hanum et al. 1995; Ludlow et al. 2021).

Table 7. Pyruvate content of different sizes of garlic from various areas in the Philippines.[1]

Source	Size	Pyruvate content			
		ug/g FW		umol/g FW	
		Initial	Final	Initial	Final
Batanes	Small	78 ns	72 b	0.88	0.82
	Medium	91	79 b	1.03	0.90
	Large	98	93 a	1.11	1.06
	Ave.	**89.0**	**81.0**	**1.01**	**0.93**
	c.v.	40	9.8	0.12	0.12
Ilocos Norte	x-Small	115 d	122 b	1.31	1.39
	Small	125 c	142 a	1.42	1.61
	Medium	128 bc	134 ab	1.45	1.52
	Large	134 ab	139 a	1.52	1.58
	x-Large	138 a	142 a	1.57	1.61
	Ave.	**122.7**	**135.9**	**1.39**	**1.54**
	c.v.	7.7	11.8	0.10	0.09
Nueva Vizcaya	Small	128 ns	134 b	1.45	1.52
	Medium	130	132 b	1.48	1.50
	Large	133	144 a	1.51	1.64
	Ave.	**130.3**	**136.5**	**1.48**	**1.55**
	c.v.	11.3	6.7	0.03	0.08
Occidental Mindoro	x-Small	97 ab	140 a	1.10	1.59
	Small	98 ab	126 ab	1.11	1.43
	Medium	91 b	125 ab	1.03	1.42
	Large	108 a	114 b	1.23	1.29
	Ave.	**99.3**	**121.7**	**1.13**	**1.38**
	c.v.	13.8	13.6	0.08	0.12

[1]Each value is the average of 10 bulbs. Mean comparison within each area and period is by LSD, 5%.

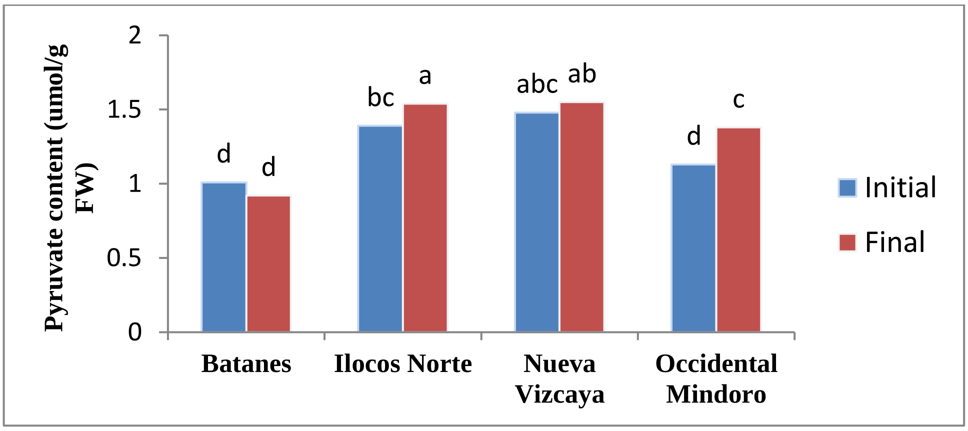

Fig. 4. Changes in pyruvate content of garlic from various areas over time. Only small, medium and large bulbs were considered in getting the average (n=30). Comparison is by LSD test at 5%.

Samples from Ilocos Norte (northwest Philippines) and Nueva Vizcaya (northeast Philippines), which planted the Ilocos white variety, showed almost the same pyruvate content levels, both initially and after storage. These areas are on opposite sides of the northern Philippines archipelago and have different topography and climate. Likewise, Petropoulos (2018) reported that in Greece, various garlic genotypes from the same or different regions showed similarities in terms of chemical composition and morphology. A study of garlic from America also showed that pyruvate levels after storage in normal air (33.9 umol/g) or under controlled atmospheres (35.4 umol/g), were almost similar after six months (Cantwell et al. 2003a).

Sizes of garlic from Batanes, Ilocos Norte and Nueva Vizcaya were found initially correlated with its pyruvate levels (Table 8). Pyruvate content increased with increase in bulb size consistently, except those from Occidental Mindoro. After 6 - 8 months of storage (final), garlic from the same three areas still showed positive correlations between size and pyruvate content, although lower values were shown in Ilocos Norte and Nueva Vizcaya samples

($R^2 = 0.5, 0.6$). Possibly, pyruvate content of garlic later becomes stable, or garlic had minimal changes in weight loss after prolonged storage.

Whereas samples from Batanes consistently showed nearly the same pyruvate levels (89, 81 ug/g FW or 1.01, 0.93 umol/g FW) with respect to storage time; only garlic from Occidental Mindoro had decreasing pyruvate content with increase in bulb size after 6 - 8 months of storage. Hence, the effect of bulb size on pyruvate content is conclusive only for garlic samples from Batanes, Ilocos Norte and Nueva Vizcaya, which are all located in northern Philippines.

Both Ilocos Norte and Occidental Mindoro have Type I climate, while Nueva Vizcaya has Type III. Batanes which is located in the northernmost part of the country has also dry months before July (~Type I). During the growing season of garlic which only takes about 110 days to mature, all areas are dry between January to May (https://discover the Philippines.com/Climate of the Philippines/).

Table 8. Correlation between size of garlic and pyruvate content from each production source over 6 - 8 months at ambient condition[1].

Source of garlic	Initial		Final	
	Linear equation	**R^2**	**Linear equation**	**R^2**
Batanes	10.0x + 59	0.9709	10.0x + 51	0.9709
Ilocos Norte	5.5x + 111.5	0.9634	3.88x + 124	0.507
Nueva Vizcaya	2.5x + 122.8	0.9868	5.0x + 121.5	0.5714
Occidental. Mindoro	2.6x + 92.4	0.2165	7.9 x + 146	-0.9158

[1]Each equation considered 30-50 bulbs of garlic taken from each area.

The pyruvate levels obtained from local garlic (1.01 – 1.55 umol/g FW) were way below than those reported in Argentina, which were about 60 - 97 umol/g FW (Natale and Camargo 2005), as well as those of the Greek genotypes (4 - 73 umol/g FW) (Avgeri et al. 2020). Hence, Philippine garlics were less pungent than most cultivars from other countries, in terms of pyruvate content. However, local garlics may also be stored up to eight months under ambient conditions, resulting in slight increase in its pyruvate content.

Great diversity in organic acid content (i.e. pyruvic acid) was observed between genotypes regardless of the growing area, indicating that other than genotypes, other factors may affect its chemical composition; as well as the assays used (Petropoulos 2018). It was also reported in Argentinian garlics that significant differences in pyruvic acid content was observed between different cultivars grown in the same area; as well as between the same cultivar grown in different areas (Soto et al. 2010). Preharvest practices such as sulfur fertilizer application may have significant effect on pyruvic acid content as well (Poldma et al. 2011).

CONCLUSION

This evaluation of garlic from major production areas in the Philippines shows that all sources are producing sizes that pass the ASEAN standard for garlic. There is a need, however, to realign the local size classifications with the ASEAN standard in order to be able to export. The shelf life extension of garlic through drying and ambient storage practices of local growers in the Philippines is at par with that of low temperature storage in other countries. However, in terms of pyruvate levels, the quality of local garlic under ambient conditions is inferior to garlics from Argentina and Greece, which are stored under low temperature. Although production sources and/or varieties yielded some differences, pungency levels of garlic from the Philippines did not dramatically decline even after 6 – 8 months under ambient conditions (29 - 33^{0}C).

What needs attention is the control of postharvest diseases during prolonged storage, beginning from its field production. Future work may also focus on evaluation of garlic from other production areas in the country.

Moreover, other active components of the local garlic varieties like alliin, allicin, phenolic content, thiosulfinates and antioxidant activity, and their antimicrobial properties need to be established so that their potential for medicinal use can be harnessed.

ACKNOWLEDGMENT

The authors wish to thank the Bureau of Plant Industry of the Department of Agriculture, Philippines, for funding the said research, which is part of the project “Extending the Storability and Maintaining Quality of Garlic Bulbs (Postharvest handling)”.

REFERENCES CITED

Abe K, Y. Hori, and T. Myoda. 2020. Volatile compounds of fresh and processed garlic (Review). Exp. Ther. Med 19:1585-15593.

Agillon, A.B. L.A. Artes and M.C.C. Lizada. 1987. Some physico-chemical and physiological changes in ‘Lakatan’ and ‘Latundan’ bananas subjected to modified atmosphere storage. ASEAN Food J. 3: 117-123

Amagase H., B.I. Petesch, H. Matsuura, S. Kasuga, and Y. Itakura. 2001. Intake of garlic and its bioactive components. J.Nutr. 131: 955s-962s.

Ankiri, S. and D. Mirelman. 1999. Antimicrobial properties of allicin from garlic. Microbes and Infection 2:125-129.

ASEAN Standards 13:2009. ASEAN Standard for garlic. https://www.asean.org/wp-content/uploads/images/archive/AMAF%2031%20asean%standard %20garlic.pdf

Ashral, R., K.A. Amir, A.R. Shaikh and T. Ahmed. 2005. Effects of garlic on dyslipidemia in patients with type 2 diabetes mellitus. J. Ayub. Med. Coll. Abbottabad 17(3):60-64. https://pubmed.ncbi.nlm.nih.gov/16320801/

Avgeri, J, K. Zeliou, S.A. Petropoulos, P.J. Bebeli, V. Papasotiropoulus and F.N. Lamari. 2020. Variability in bulb organosulfur compounds, sugars, phenolics and pyruvate among Greek garlic genotypes: association with antioxidant properties. Antioxidants 9:967. www.mdpi.com/journal/antioxidants

Banerjee, S.K. and S.K. Maulik.. 2002. Effect of garlic on cardiovascular disorders: a review. Nutr. J. 1:4. https://ncbi/nlm.nih.gov/pmc/articles/PMC139960/.

Barboza K, M.C. Salinas, C.V.Acuna, F. Bannoud, V. Beretta, S.G. Lampasona, J.L. Burba, C. R. Galmarini, and P.F. Cavagnaro. 2020. Assessment of genetic diversity and population structure in a garlic germplasm collection varying in bulb content of pyruvate, phenolics and solids. Scientia Hort. 261:108900

Batiha, G.E.S., A.M. Beshishy, L.G. Wasef, Y.H.A. Elewa, A.A. Al-Sagan, M.E.A. El-Hack, A.E. Taha, Y.M. Abd-Elhakim, and H.P. Devkota. 2020. Chemical constituents and pharmacological activities of garlic: A review. Nutrition 12: 872.

Beretta, H.V., F. Bannoud, M.. Insani, M. Berti, P. Hirschegger, C.R. Galmarini and P.F. Cavagnaro. 2017. Relationship between bioactive compounds content and the antiplatelet and antioxidant activities of six allium vegetables species. Food Technol. Biotechnol. 55:266-275.

Block, E. 2010. Garlic and other alliums: the lore and the science. RSC Publishing. Cambridge, UK.

Cantwell, M.I., G. Hong, J. Kang, and X. Nie. 2003a. Controlled atmospheres retard sprout growth, affect compositional changes and maintain visual quality attributes of garlic. Acta Hort. 600:791-794.

Cantwell, M.I., J. Kang and G. Hong. 2003b. Heat treatments control sprouting and rooting of garlic gloves. Postharvest Biol. Tech. 30:57-65.

Ellimore G.S. and R.S. Feldberg. 1994. Alliin lyase localization in bundle sheaths of the garlic clove. Amer. J.Bot.81:89-94.

Gelleta, D.S., K. Woldetsadik, R. Nigussie-Dechassa, G. Tabor and J. J. Sharma. 2013. Postharvest quality and shelf life of garlic bulbs as influenced by storage season, soil type, and different compound fertilizer. J. Posth. Technol. 1:69-83.

Gonzalez, R.E., M.M. Sance, V.C. Soto and C.R. Galmarini. 2012. Garlic scape, an alternative food with human health benefits. Acta Hort. 969:233-237.

Hanum, T., N.K. Sinha, and J.N. Cash.1995. Characteristics of gamma-glutamyl transpeptidase and allinase of onion and their effects on the enhancement of pyruvate formation in onion macerates. J.Food Biochem. 19(1): 51-65.

Harris J.C., S..L Cottrell, S. Plummers, and D. Lloyd. 2001. Antimicrobial properties of Allium sativum (garlic). Applied Microb. and Biotechn. 57: 282-286.

https://discoverthephilippines.com/ClimateofthePhilippines. October 15**, 2022**.

Josling. P. 2001. Preventing the common cod with a garlic supplement: a double-blind, placebo–controlled survey. Clinical trial. Adv. Ther. 14(4): 189-193. https://pubmed.ncbi.nlm.nih.gov/ 11697022/.

Khandaker, M.M., F. Nor Amirah, A. Majrashi, M. H. Sajili, K. S. Mohd and N.Mat. 2018. Peel color, anthocyanin, TSS content and sensory evaluation of some common fruits: a comparative study. Australian J of Crop Science. 12(11): 1788-1795.

Lado, J., M.J. Rodrigo and L. Zacarias. 2014. Maturity indicators and citrus fruit quality. Stewart PH Review 2:2. www.stewartpostharvest.com (ISSN:1745-9656).

Lawson, L.D. 1996. The composition and chemistry of garlic gloves and processed garlic. In Koch H.P., and L.D. Lawson (eds). The science and therapeutic application of *Allium sativum L.* and related species. pp. 37-108. Williams and Wilkins, Maryland, USA.

Ludlow, RA, M. Pacenza, A Chiappetta, S.R. Christofides, G. Evans, M. Graz, G. Marti, H.J. Rogers, and C.T. Muller. 2021. Storage time and temperature affect volatile organic compound profile, allinase activity and postharvest quality of garlic. Posth. Biol. Techn. 177: 111533.

Natale, P.J. and A. Camargo. 2005. Characterization of Argentine garlic cv. by their pungency. Acta Hort. 688: 313-316.

Nicastro, H.L., S.A. Ross and J.A. Milner. 2016. Garlic and onions: their cancer prevention properties. Cancer Prev. Res. (Philia) 8(3): 181-189. https://Ncbi/nlm.nih.gov/pmc/articles/ PMC4366009/.

Nuevo, P.A. 1996. Morpho-anatomical features of garlic at different maturities in relation to postharvest behavior during ambient storage. Ph.D. Dissertation, University of the Philippines Los Banos. Los Banos, Laguna, Philippines.

Nurmalia, Y.A., Purwanto, Sobir, Sulassih, and N. Naibaho.2019. Effect of low temperature storage and period of storage on the quality of garlic seeds *(Allium sativum L*). IOP Conf. Series: Mat. Sci. and Eng. 557: 012088 doi:088/1757-899X/557/1/012088.

Pardo, J.E., J. Escribano, R. Gomez, and A. Alvarruiz. 2007. Physical-chemical and sensory quality evaluation of garlic cultivars. J. Food Quality 30:609-622.

Poldma,P., T. Tonutare, A. Viitak, A. Luik, U. Moor. 2011. Effects of selenium treatment on mineral nutrition, bulb size, and antioxidant properties of garlic (*Allium sativum L.*). J. Agric. Food Chem. 59:5498-5503. (Cross Ref. Pub. Med.)

Petropoulos, S, A. Fernandes, G.Ntasi, K.Petrotos, L. Barros, and I.C.F.R. Ferreira. 2018. Nutritional value, chemical characterization and bulb morphology of Greek garlic landraces. Molecules 23:319 doi:10. 3390/molecules 23020319.

Petropoulos, S. A., F. Di Gioai, and G. Natasi, 2017. Vegetable organosulfur compounds and their health effects. Curr. Pharm. Des. 23:1-26.

Rahman K. and G. M. Lowe 2006. Garlic and cardiovascular disease: A critical review. J.Nutri.136:736s-740s.

Ray, B., N.B. Chauhan, and D.K. Lahiri. 2011. Oxidative insults to neurons and synapse are prevented by aged garlic extract and S-allyl-Lcysteine treatment in the neuronal culture and APP-Tg mouse model. Neurochem. 117(3): 388-402. https://pubmed.ncbi.nlm.nih.gov/ 21166677/.

Ried, K. and P. Fakler. 2014. Potential of garlic in lowering high blood pressure: mechanism of action and clinical relevance. Integr. Blood Press. Control 7:71-82. https://Ncbi.nlm.nih.gov/pmc/articles/PMC4266250/.

Sance M.M., R.E. Gonzalez, V.C. Soto, and C.R. Galmarini.2008. Relationship between anti- platelet activity, dry matter content and flavour in onion cvs. J. Food Agric. and Env. 6:3-4: 41-46.

Schwimmer, S. and W.J. Weston .1961. Enzymatic development of pyruvic acid in onion as a measure of pungency. Agric. Food Chem. 9: 301-304.

Soto, V.C., R.E. Gonzales, M.M. Sance, and C.R. Galmarini. 2016. Organosulfur and phenolic content of garlic and onion and its relationship with antioxidant activity. Acta Hort. 1143: 277-290.

Soto, V.C., R. E. Gonzalez, M. M. Sance, J. Luis Barba, A. Beatriz Camargo. 2010. Genotype-environment interaction on the expression of allicin and pyruvic acid in garlic (*Allium sativum L.*) Rev. La. Fac. Ciencias Agrar. 42:15-22.

Sukkaew, P. and A. Tira-umphon, 2012. Effects of storage conditions on allicin content in garlic (*Allium sativum*). Acta Hort. 969: 209-212.

Wall, M.M. and J. N. Corgan. 1992. Relationship between pyruvate analysis and flavor perception for onion pungency determination. Hort.Sci. 27: 1029-1030.

Yamaguchi, Y. and H. Kumagai, 2019. Characteristics, biosynthesis decomposition, metabolism, and functions of garlic odour precursor, S-allyl csyteine sulfoxide (Review). Exp. Ther. Med.19:1528-1535.

Yamazaki M., M. Sugiyama, and K. Saito, 2002. Intercellular localization of cysteine synthase and allinase in bundle sheaths of Allium plants. Plant Biotechnol. 19(1): 7-10.