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Measurement of Physical Properties of Korean Garlic for Grade Standard

J. H. Hong, H. K. Koh

Abstract: Garlic is one of the major seasoning vegetables in Korea and consumed mostly in a form of peeled cloves. Conventional Korean standards for garlic grading consist of four classes according to the size of bulb and its shape. Sorting and grading of garlic are manually done but could be in the process of automated mechanization using machine vision system in the near future. The proportion of mass of cloves in a garlic bulb to the volume of the bulb (g/ml) was determined to find out the best way of representing both the quantity and quality of cloves in each bulb. Garlic bulb was assumed as an ellipsoid and its major and minor axis and its height were measured to calculate its volume. The mass proportions and density of a garlic bulb and cloves were measured for four domestic varieties of garlic to propose it as a standard for Korean garlic grading machine.

Keywords: Garlic, Grading, Size, Sorting, Standard

Introduction

Garlic is one of the major seasoning vegetables along with red peppers and onions in Korea. Consumption per man of these vegetables was 12.4, 6.6, and 2.4 kg of onions, garlic, and red peppers, respectively, in 1997. The yield of garlic in 1999 was 483,778 tons produced in 42,416 ha. Garlic is usually harvested by hand pulling using a folk or a tractor drawn blade to loosen the soil under the bulbs. And a mechanized system is about to be used to loosen the soil under the bulbs, lift the bulbs, remove the tops, and separate the dirt and trash from the bulbs. Garlic is usually sorted and graded at field by hand and braided in 50 units after curing and drying.

The garlic in braid is trimmed, roots are removed and tops are clipped to 2 cm or further processed into peeled cloves by wholesaler, local distributors, or workers at farmer's market or local supermarket. This untrimmed garlic caused waste problem in cities with the trimmed tops and roots, bulb and clove wrappers, and dirt, which are about two thirds of total mass of untrimmed garlic. In order to minimize the waste problems and the cost of transportation and handling, trimming at field is encouraged and trimmed garlic is packed in plastic knitted bags. At the present time, garlic is graded by hand according to its size and quality factor such as consistency of clove size, shape of bulb, moisture content, color, and number of immature cloves. This whole process can be mechanized to achieve the best price at the market by value added techniques of minimizing the labor intensity and quantifying the quality of garlic. This would save labor cost for grading and then be able to cope with the price competition with cheap Chinese imports. Consistency of grading could be achieved as physical properties are once determined which can represent the quality of garlic such as size of bulb and size and number of sound cloves inside.

Producers of garlic have four grades for sorting and standards for grades of garlic from National Agricultural Products Quality Management Service (NAQS) of Korea. The grading at field is mainly based on the size and shape of bulbs rather than the physical properties that can represent the quantity and quality such as mass, size, or number of sound cloves inside. The garlic is graded into four classes, extra large, large, medium, and small according to the size standards of NAQS. However, the size grading at field is using the largest measured diameter of garlic bulb for convenience' sake and better price, while the average value of the largest and smallest diameter of a garlic bulb could represent its size better.

Sorting and grading of garlic are manually done but

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could be in the process of automated mechanization. And the automated process leads to the need for development of a way to quantify the quality of each bulb. The quality of bulb depends on the conditions of cloves inside a bulb wrapping. The overall objective of this study is to investigate possible means to quantify the quality of garlic bulb that can be used in the mechanized sorting and grading system. Detailed laboratory and field studies were conducted to meet the following objectives:

1) Measure the shape and color characteristics of garlic bulb of two typical groups of subspecies of garlic in Korea, one for cold winter area and the other for mild winter area.

2) Determine the mass proportions and densities of cloves in a bulb as the ratio of total mass of cloves inside a bulb to the volume of the bulb that is assumed as an ellipsoid.

3) Develop a regression model to predict the bulb mean diameter with the bulb weight.

Materials and Methods

Korean garlic is genetically softnecks (Allium sativum sativum) and possesses characteristics of both softneck and stiffneck garlic. They feature a single circle or layer of cloves arranged around the woody remnants of the scape, false flower stalk, which is a typical characteristic of stiffnecks (Allium sativum ophioscorodon). And the number of cloves per bulb is commonly six to ten. There are two groups or subspecies of garlic in Korea: One for cold winter area and another for mild winter area. The garlics for cold winter region have a set of distinct characteristics that distinguish them from mild winter region group. Within each group, they have similar characteristics such as the size and shape of bulbs and cloves.

Two cultivars of each mild and cold areas were chosen as sample garlic: Namhae and Muan from mild area in Kyungnam and Jeonnam Province, respectively, and Uisung and Sosan from cold area in Kyungbuk and Chungnam province, respectively. 50 bulbs of each three grades of garlic were purchased at each producing area. Sample garlics were harvested in May, 1999 at Namhae and Muan and in June, 1999 at Uisung and Sosan. Due to the storage and other conditions, there were some rotten and dried cloves inside the sample bulbs.

Garlic bulb was assumed as ellipsoid with semi-axes a, b, and c as shown in Fig. 1 and its semi-axis 2c represents the height of the bulb and 2b and 2a represent the diameters of major axis and minor axis of the model bulb, respectively. 20 bulbs of each cultivar were sampled randomly. These semi-axes a, b, and c were measured to determine the volume of each bulb and characteristics of shape and size.

Besides the physical properties of garlic such as shape and size of the bulb, mass proportion of each component to the total mass of the bulb was measured. It was divided into four parts: peeled cloves, bulb wrappers, stalk - woody remnants of the scape, and roots where bulb wrappers include covering material of bulb other than peeled cloves, stalk, and roots. Mass proportions of each component to the mass of bulb were determined as the soundness of the bulb. Along with the mass proportions of each component, density of a bulb and cloves were determined as secondary means to determine the bulb quality. Density of cloves in a bulb was defined as the ratio of total mass of cloves in a bulb to the volume of the bulb that was assumed as an ellipsoid.

Moisture content of garlic was measured for four components; stalk, peeled cloves, bulb wrappers, and

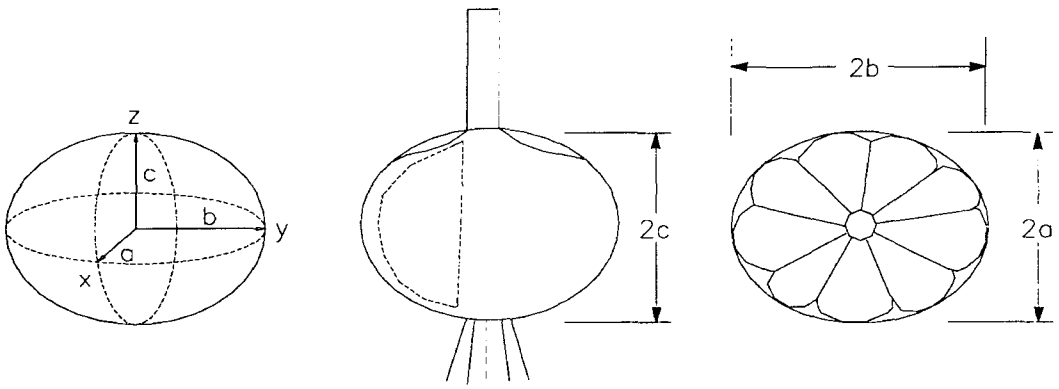

Fig. 1 Model garlic bulb of an ellipsoid with semi-axes a, b, and c.

bulb. Tops of the samples were clipped to 2 cm and roots were trimmed to its bottom. Soil was gently brushed from the bulb wrapper and roots. The trimmed garlic was then divided into stalk, peeled cloves, and bulb wrappers. Moisture content of each components of sample garlic was determined by convection oven method and each components of garlic was dried in a convection oven at 100℃ for 24 hours. Moisture content of bulb was determined from stalk, peeled cloves, and bulb wrappers, which were taken as bulb components. Moisture content of a bulb was determined from the total mass of each component before and after drying.

To develop a machine vision system for garlic grading and sorting, the proportion of mass of peeled cloves in a garlic bulb to the volume of the bulb (g/ml) was determined to find out the best way of representing both the quantity and quality of cloves in each garlic bulb. Garlic bulb was assumed as an ellipsoid and its semi-axes of a, b, and c were measured to determine the characteristics of its size and shape, and calculate its volume. The mass proportions were measured for four domestic varieties of garlic to propose it as a standard for Korean garlic grading machine. The mass proportion of peeled garlic was defined as the ratio of total mass of peeled garlic inside a bulb to the volume of the bulb that was calculated as the volume of ellipsoid.

HSI color characteristics (Hue, Saturation, Intensity) of garlic bulb wrappers were measured using a machine vision system for each grades and varieties. HSI characteristics were measured to find a difference between grades and varieties of bulb wrappers on which machine vision system captures its image. The machine vision system consisted with RGB color CCD camera (GC-305, LG Honeywell, Korea) and color image processing board (MV-Pro, Flashbus, USA), Image-Pro Plus 3 (Media Cybernetics, USA) for image analysis, and IBM PC(Pentium III 300MHz). The RGB signals of the bulb wrappers from the image board was converted into HSI coordinate using the following equations (1).

Table 1 Moisture content (w.b. %) of garlic

Cultivars	Grade	Stalk	Cloves**	Wrapper	Bulb
Kyongnam Namhae (mild area)	Extra large	10.8*	55.4*	12.5*	50.5
	(Std. dev.)	(2.36)*	(6.07)*	(3.47)*	(6.23)
	Large	11.1	43.8	13.6	40.0
	(Std. dev.)	(1.91)	(13.43)	(3.10)	(11.97)
	Medium	10.6	52.3	14.1	49.3
	(Std. dev.)	(2.77)	(7.35)	(5.46)	(11.13)
Jeonnam Muan (mild area)	Extra large	9.6	60.5	12.5	55.6
	(Std. dev.)	(1.96)	(5.58)	(5.37)	(5.53)
	Large	10.1	61.3	11.6	54.7
	(Std. dev.)	(2.42)	(3.71)	(3.36)	(4.45)
	Medium	9.9	58.5	12.6	54.1
	(Std. dev.)	(2.56)	(10.68)	(6.28)	(6.37)
Kyoungbuk Uisung (cold area)	Extra Large	12.1	55.2	14.0	51.1
	(Std. dev.)	(2.49)	(8.09)	(3.27)	(7.98)
	Large	13.0	54.7	15.4	50.9
	(Std. dev.)	(3.59)	(6.34)	(4.38)	(6.06)
	Medium	11.8	43.6	16.5	37.1
	(Std. dev.)	(3.78)	(10.23)	(9.98)	(9.67)
Chungnam Sosan (cold area)	Extra large	10.3	55.8	15.0	49.4
	(Std. dev.)	(1.91)	(6.16)	(3.94)	(8.52)
	Large	13.3	44.6	13.2	43.0
	(Std. dev.)	(5.43)	(10.59)	(2.52)	(8.68)
	Medium	11.9	60.4	13.9	52.0
	(Std. dev.)	(4.11)	(6.48)	(4.56)	(11.71)

* Average and its standard deviation of 20 samples.

** Peeled cloves.

$$\begin{bmatrix} I \\ V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} \frac{\sqrt{3}}{3} & \frac{\sqrt{3}}{3} & \frac{\sqrt{3}}{3} \\ 0 & \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ \frac{2}{\sqrt{6}} & -\frac{1}{\sqrt{6}} & -\frac{1}{\sqrt{6}} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (1 - 1)$$

$$H = \tan^{-1}\left(\frac{V_2}{V_1}\right) \quad (1 - 2)$$

$$S = \sqrt{V_1^2 + V_2^2} \quad (1 - 3)$$

where I is Intensity, H is Hue, and S is Saturation, respectively.

Results and Discussion

Moisture content (w.b.%) is in close relation with the mass proportion of cloves to the rest of components such as bulb wrappers and scape or stalk. Moisture content of cloves was ranged 43.6 to 61.3 %, scapes 9.6 to 13.3%, and bulb wrappers 11.6 to 16.5%, bulb 37.1 to 55.6 %, respectively, as shown in Table 1. From the moisture content measurement, garlic was dried properly. Bulb wrappers showed higher moisture content than that of stalk and it is because of the lost of some broken flaky wrappers and was taken as the moisture removed from the wrappers during measurement of its mass measurement.

Among samples there were rotten and dried cloves inside the bulb since it was sampled randomly. Moisture contents of cloves showed large variation in values of standard deviations, which were three to four times as larger than those of stalk. This is from the variations of clove conditions such as rotten and dried while stalk showed small variations. From the moisture contents of each components of garlic, cloves would determine the mass of bulb since other components has less variation in mass and moisture content. The mass proportion of peeled cloves to bulb may lead to the possible mean to represent the quality of cloves inside the bulb.

HSI color characteristics (Hue, Saturation, Intensity) of garlic bulbs were measured using a machine vision system for each grade and variety. The HSI values

Table 2 HIS(Hue, Saturation, Intensity) values and projection area of garlic bulb

Cultivars	Grade	Hue	Saturation	Intensity	Area, mm^2
Kyongnam Namhae (mild area)	Extra large	22*	33*	321*	1350*
	(Std. dev.)	(0.7)*	(3.3)*	(13.8)*	(222.7)*
	Large	22	35	305	1134
	(Std. dev.)	(1.5)	(5.2)	(16.8)	(171.7)
	Medium	22	32	314	842
	(Std. dev.)	(1.1)	(3.6)	(14.4)	(143.5)
Jeonnam Muan (mild area)	Extra large	23	34	311	1293
	(Std. dev.)	(1.2)	(3.6)	(15.8)	(184.2)
	Large	23	38	304	991
	(Std. dev.)	(1.0)	(4.7)	(23.2)	(139.7)
	Medium	22	38	300	778
	(Std. dev.)	(1.8)	(4.4)	(20.0)	(134.8)
Kyoungbuk Uisung (cold area)	Extra large	21	33	316	1045
	(Std. dev.)	(1.9)	(3.7)	(11.1)	(269.6)
	Large	21	31	322	737
	(Std. dev.)	(1.4)	(2.7)	(10.4)	(140.5)
	Medium	20	28	321	507
	(Std. dev.)	(2.1)	(2.5)	(24.0)	(79.6)
Chungnam Sosan (cold area)	Extra large	22	38	310	1408
	(Std. dev.)	(0.9)	(4.2)	(10.7)	(402.7)
	Large	22	36	304	1058
	(Std. dev.)	(1.1)	(4.3)	(16.1)	(311.5)
	Medium	22	42	288	547
	(Std. dev.)	(2.1)	(5.4)	(21.8)	(59.9)

* Average and its standard deviation of 20 samples.

were measured for four varieties of garlic of 20 bulbs and shown in Table 2. However, the HSI values were not significantly different between varieties and grades since the bulb wrappers of each varieties and grades were very similar. Therefore, HIS characteristics would not indicate the clove conditions inside the bulb.

The size and shape characteristics of garlic were measured for four cultivars sold in three grades at the Karak Farmer's Market in Seoul: each two for cold and mild area. The diameters of major and minor axes and height of sample garlic were measured with digital calipers as defined in Fig. 1. The digital caliper has a resolution of 0.01mm accuracy of measurement. 20 bulbs of each cultivar were randomly sampled at the Farmer's Market.

At the Farmer's Market, only upper three grades were sold. Cultivars of cold area were Uisung and Sosan produced at Kyongbuk and Chungnam, respectively and Kohung and Namhae from mild area Jeonnam and Kyongnam, respectively. Cultivar of Muan from Jeonnam was not available at that time for the measurement. Garlic at the Farmer's Market were sorted at field into four graded according to the standards for grades of garlic from National Agricultural Products Quality Management Service (NAQS) of Korea which is shown in Table 5.

Measurements of shape characteristics of four cultivars at the Farmer's Market are shown in Table 3. From the measurements of Table 3 and standards for grades in Table 5, it was shown that grading at field was done with major diameter of bulb rather than mean diameter that can best represent the sizing. It might be for the convenience's sake.

Mass proportions of garlic were determined for each cultivars and grades and it is shown in Table 4. Mass proportions decreased, as grade was lower. This means

Table 3 Measurements of shape characteristics of garlic at Farmer's Market

Cultivars	Grade	Bulb diameter, mm			
		Major-axis (2b)**	Minor-axis (2a)**	Height (2c)**	Mean (a + b)**
Kyoungbuk Uisung (cold area)	Extra large	52.9*	49.7	42.6	51.3
	(Std. dev.)	(3.87)*	(4.08)	(4.14)	(3.84)
	Large	45.8	42.5	38.0	44.1
	(Std. dev.)	(4.06)	(3.66)	(3.82)	(3.73)
	Medium	41.3	37.9	33.5	39.6
	(Std. dev.)	(3.62)	(3.75)	(2.56)	(3.41)
Chungnam Sosan (cold area)	Extra large	50.3	46.9	41.3	48.6
	(Std. dev.)	(2.63)	(2.04)	(2.25)	(2.22)
	Large	44.3	41.5	37.0	42.9
	(Std. dev.)	(2.13)	(2.61)	(2.04)	(2.27)
	Medium	41.5	37.8	35.0	39.6
	(Std. dev.)	(2.41)	(3.48)	(1.59)	(2.68)
Jeonnam Kohung (mild area)	Extra large	48.8	45.5	31.0	47.1
	(Std. dev.)	(3.87)	(4.08)	(2.13)	(3.89)
	Large	n/a	n/a	n/a	n/a
	Medium	n/a	n/a	n/a	n/a
Kyongnam Namhae (mild area)	Extra large	51.7	46.6	31.9	49.1
	(Std. dev.)	(3.02)	(3.21)	(2.53)	(2.87)
	Large	n/a	n/a	n/a	n/a
	Medium	n/a	n/a	n/a	n/a

* Average and its standard deviation of 20 samples.

** a, b, c are dimensions of semi-axes of ellipsoid as defined in Fig. 1.

Table 4 Size and mass proportions of garlic

Cultivars	Grade	Bulb diameter (mm)			Mass (g)		Mass ratio (%)
		Major	Minor	Height	Bulb (B)	Cloves (C)	(C / B)
Kyongnam Namhae (mild area)	Extra large (Std. dev.).	54.5* (4.12)*	50.5 (3.97)	33.1 (2.74)	31.3 (6.47)	29.6 (6.29)	94.4 (1.21)
	Large (Std. dev.)	47.3 (3.70)	42.7 (3.43)	31.1 (7.08)	20.6 (5.40)	19.3 (5.20)	93.4 (1.60)
	Medium (Std. dev.)	39.1 (3.34)	35.1 (3.47)	28.1 (2.24)	12.2 (3.45)	11.3 (3.35)	91.9 (2.33)
Jeonnam Muan (mild area)	Extra large (Std. dev.).	50.7 (3.76)	45.9 (3.51)	31.2 (1.75)	23.5 (3.44)	21.6 (3.22)	91.7 (1.74)
	Large (Std. dev.)	43.5 (2.97)	38.5 (2.89)	28.5 (2.06)	15.4 (3.09)	13.9 (2.94)	90.2 (2.74)
	Medium (Std. dev.)	37.8 (2.98)	34.4 (3.40)	26.2 (2.26)	10.6 (2.14)	9.3 (1.98)	87.8 (2.90)
Kyoungbuk Uisung (cold area)	Extra large (Std. dev.)	43.9 (4.40)	40.4 (4.33)	30.7 (3.38)	21.6 (6.43)	19.1 (6.03)	87.8 (2.84)
	Large (Std. dev.)	39.7 (3.46)	36.5 (4.10)	25.7 (2.14)	12.6 (3.16)	11.1 (2.83)	88.0 (2.17)
	Medium (Std. dev.)	30.7 (2.06)	27.3 (2.78)	21.9 (2.06)	7.3 (1.64)	5.9 (1.43)	80.5 (3.20)
Chungnam Sosan (cold area)	Extra large (Std. dev.).	52.8 (2.48)	47.8 (2.07)	32.6 (2.49)	23.0 (3.32)	19.5 (3.03)	84.8 (3.52)
	Large (Std. dev.)	47.3 (2.48)	43.4 (2.07)	28.1 (2.07)	17.3 (3.13)	14.2 (2.82)	81.6 (3.73)
	Medium (Std. dev.)	34.0 (4.49)	31.7 (1.72)	22.6 (1.26)	8.6 (1.38)	7.2 (1.21)	84.2 (1.92)

* Average and its standard deviation of 30 samples.

the other parts other than cloves is not proportional to the bulb size, especially the stalk. This mass proportions would not represent the conditions of the peeled cloves inside the bulb since this data was taken form the sample garlic among which has damaged cloves. There should be a grading standard, which can quantify the degree of damage of peeled cloves in a bulb. With this standard, the mass proportions could be better arranged to represent the conditions of the peeled cloves inside each bulb. Therefore, further measurement need to be made to make use of mass ratio (%) as an indication of rotten or dry cloves if the mass ratio measured was lower than the averages for sound cloves of a specific cultivar and grade.

Density of the garlic bulb for each cultivar and grade was determined by dividing the mass of a bulb by the volume of the bulb and density of the cloves was determined by dividing the mass of cloves in a bulb by the volume of its bulb. For density determination, 30 bulbs were randomly sampled from each cultivar and grade. Table 6 shows the densities of bulbs and cloves which are mean values of 30 measurements. Both density of bulb and clove for Extra large and Large grades were close to each other for mild area but were not for cold area.

Regression analysis was done to find a measure to determine the size of garlic by just weighing its bulb with its top and roots cut. Regression equations of (2) to (7) were developed in this study. However, the R^2 values were not high enough to determine the size of garlic accurately, since there were variations of mass of garlic bulb from sample garlic that has damaged cloves inside. The accuracy of the prediction of the diameter with its mass could be improved by using samples with only sound cloves.

Physical properties of Korean garlic were measured

Table 5 Grade standards for garlic of NAQS

Cultivars	Bulb diameter (cm)			
	Extra Large	Large	Medium	Small
Cold area	5.0 and up	4.0 - 5.0	3.0 - 4.0	2.0 - 3.0
Mild area	5.5 and up	4.5 - 5.5	4.0 - 4.5	3.5 - 4.0

Table 6 Measurements of size and shape characteristics of garlic

Cultivars	Grade	Bulb volume (B) 10^{-3}kg	Cloves mass (C) 10^{-3}kg	Density, 10^{3}kg / m^3	
				Bulb	(C/B) Cloves**
Kyongnam Namhae (mild area)	Extra large (Std. dev.).	48.1* (9.26)*	29.6 (6.29)	0.66 (0.105)	0.62 (0.104)
	Large (Std. dev.)	33.2 (9.02)	19.3 (5.20)	0.66 (0.268)	0.62 (0.254)
	Medium (Std. dev.)	20.5 (4.37)	11.3 (3.35)	0.61 (0.161)	0.56 (0.155)
Jeonnam Muan (mild area)	Extra large (Std. dev.).	38.4 (6.84)	21.6 (3.22)	0.62 (0.077)	0.57 (0.077)
	Large (Std. dev.)	25.2 (4.65)	13.9 (2.94)	0.61 (0.097)	0.55 (0.092)
	Medium (Std. dev.)	18.0 (3.89)	9.3 (1.98)	0.60 (0.084)	0.52 (0.077)
Kyoungbuk Uisung (cold area)	Extra large (Std. dev.).	29.3 (9.18)	19.1 (6.03)	0.75 (0.113)	0.66 (0.111)
	Large (Std. dev.)	19.9 (5.20)	11.1 (2.83)	0.64 (0.073)	0.57 (0.072)
	Medium (Std. dev.)	9.8 (2.24)	5.9 (1.43)	0.76 (0.104)	0.61 (0.093)
Chungnam Sosan (cold area)	Extra large (Std. dev.).	43.4 (7.18)	19.5 (3.03)	0.54 (0.071)	0.46 (0.061)
	Large (Std. dev.)	30.3 (4.49)	14.2 (2.82)	0.57 (0.077)	0.47 (0.069)
	Medium (Std. dev.)	12.8 (2.31)	7.2 (1.21)	0.68 (0.115)	0.58 (0.096)

* Average and its standard deviation of 30 samples.

** Density of cloves was determined as the ratio of total mass of peeled cloves in a bulb to the volume of the bulb calculated as an ellipsoid.

for the typical cultivars for mild winter area; Namhae and Muan and cold winter area; Uisung and Susan. Their properties were represented by the regression equations as follows. Regression equation (2) can be used to estimate the garlic bulb diameter of cold area by weighing the bulb in general and equation (3) and (4) are for cultivars of Susan and Uisung, respectively.

$$Y = 1.0028X + 24.512,\ R^2 = 0.7988 \quad (2)$$

$$Y = 1.1242X + 24.501,\ R^2 = 0.8883 \quad (3)$$

$$Y = 0.8169X + 26.805,\ R^2 = 0.8277 \quad (4)$$

Regression equation (5) can be used to estimate the garlic bulb diameter of mild winter area by weighingthe bulb in general and equation (6) and (7) are for cultivars of Namhae and Muan, respectively.

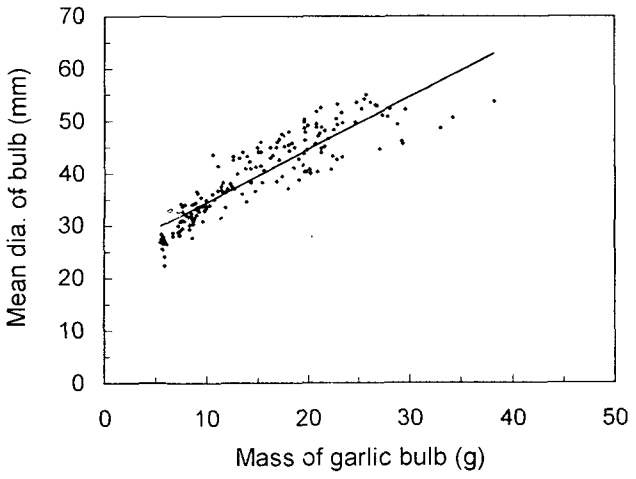

Fig. 2 Regression analysis of mean diameter on the mass of garlic bulb produced in cold area, Uisung and Susan.

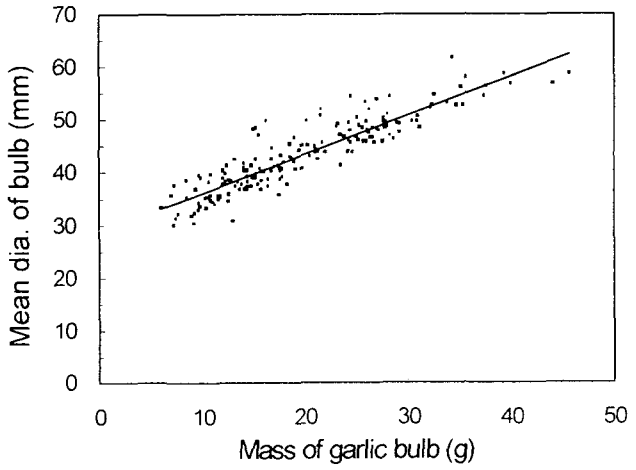

Fig. 3 Regression analysis of mean diameter on the mass of garlic bulb produced in mild area, Namhae and Muan.

$$Y = 0.7515X + 30.674,\ R^2 = 0.8010 \quad (5)$$

$$Y = 0.6791X + 30.330,\ R^2 = 0.7925 \quad (6)$$

$$Y = 0.8398X + 26.645,\ R^2 = 0.8717 \quad (7)$$

Where Y is the mean diameter (mm) of garlic bulb and X is mass (g) of the bulb.

Conclusion

The grading at field and market was based on the size of major diameter of bulb rather than mean diameter that can best represent the size of garlic bulb and mass of cloves inside. The shape characteristics for each grades and cultivars could be better represented if mean value of bulb diameter was used for grading.

The HIS values is not a proper mean to estimate the clove conditions inside the bulb and varieties of garlic.

Density and mass proportions of cloves of four cultivars and three grades of garlic were measured and the clove to bulb mass ratio of garlic from warm area was higher than that from cold area. Since there were damaged cloves in the sample garlic, further measurement is required to investigate the relationship between these values and the conditions of cloves inside such as rotten, dried, or immature cloves as well as sound ones. The Density and mass proportions of bulb and cloves could be better represented if it is graded by mean value of the major and minor diameter rather than the major diameter method as the grading system at field in all measurements in this study. The values of density and mass proportions of garlic with sound cloves can be used to differentiate it from the one in bad condition. These values could be used in automated sorting and grading process using these values to find out the quality of cloves inside garlic bulb by measuring its size and volume with a machine vision system and weighing bulbs with a load cell.

Regression models were developed to predict mean diameter of bulb with the bulb mass for garlic from mild and cold area. However, the R^2 values for these models were not high enough to predict its mean diameter from bulb mass, which is due to the damaged cloves in the sample bulbs. The R^2 values would be improved when sample garlic bulbs are used with all sound cloves.

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