Physical Attributes of Garlic (*Allium sativum* L.)

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ABSTRACT

Some physical attributes of two common types of Iranian garlic cloves (white and pink) were identified and compared. A machine vision system was used to determine three dimensions and both major and minor projected areas of garlic cloves at a moisture content of 42.4% w. b. The geometric mean diameter and sphericity were calculated, as well as the unit mass and volume of cloves were measured. In the moisture range from 34.9 to 56.7% w.b., the unit density, bulk density and porosity for both types were measured. Results showed that the unit density, bulk density and porosity of cloves were affected significantly by moisture content (p<0.01). The type of garlic had a highly significant effect on the unit density and porosity (P<0.01), and a significant effect on the bulk density (P<0.05). The relationship between volume and dimensions of cloves was established using regression analysis. The effect of moisture content on physical properties of cloves was also expressed by appropriate equations.

Keywords: Garlic, Machine vision, Physical attributes.

INTRODUCTION

Garlic (*Allium sativum L.*) has been cultivated since ancient times all over the world especially in Asia. Garlic has medicinal properties and it is an important ingredient in the leading cuisines around the world. Garlic as a spice is utilized in both fresh and dehydrated state in the food industry. It is dehydrated into different products such as flakes, slices, and powders (Ahmad, 1996).

Garlic does not produce seeds, so it must be propagated vegetatively with garlic cloves as the most common planting material. The yield quality of garlic is affected by planting methods and clove rates and sizes (Nourai, 1994; Matlob and Khalel, 1986). Lack of basic engineering properties of this planting material is a problem identified in the development of new methods of sowing the garlic crop, development of new equipment for processing and control strategies for crop storage. A number of researchers have worked on the physical properties of garlic (Madamba *et al.,* 1993, 1995, 1997; Pezzutti and Crapiste, 1997; Park *et al.,* 1981; Bhatt *et al.,* 1998; Sharma and Prasad, 2002).

Madamba *et al.,* (1993) measured the length, width, and thickness of garlic slices by using vernier caliper. Song and Litchfield, (1991) measured the length and width of seed grains by using a computer imaging system while using a caliper to measure the third dimension. Tabil *et al.,* (1999) used an image analysis program to determine the size and shape characteristics of some specialty crops such as chickpeas, lentils and peas including the length of the longest and shortest axes, cross section area, perimeter

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of the object, circularity and roundness of each seed. Olaoye, (2000) used an overhead projector to project the image of the nut samples on a plain cardboard sheet to characterize the shape.

Sizes of materials usually play a significant role under approximately the same operating conditions (Gupta and Das, 1997), as shown by Marjana (1996) who investigated the effects of the size of cloves on the yield of garlic.Gupta and Das (1997) reported a correlation among various dimensions of sunflower seeds. The influence of moisture content on several physical properties was reported by some researchers (Madamba *et al.,* 1994; Joshi *et al.,* 1993).

Information on the physical attributes of garlic cloves is not available in the literature. The objective of this study was to determine the physical attributes of garlic cloves including their dimensions, unit density, bulk density, porosity. Models were developed to express the relationship between volume and dimension as well as determining the moisture-dependent physical attributes of garlic cloves in the moisture range of 34.9 to 56.7 % w.b.

MATERIALS AND METHODS

Sample Preparation

Garlic bulbs (white and pink) were obtained locally in the region of Marvdasht, Fars province Iran. Freshly harvested garlic bulbs were randomly collected from different farms. Similar with local practice, the bulbs were dried by spreading them in a thin-layer inside a darkroom with open windows near the farms for 15 days. Samples were stored in a cabinet at 5°C. The sample bulbs were randomly selected from the bulk sample and their outer covering manually removed and cracked before the experiments.

The moisture content of the cloves was determined by following the ASAE S352.2 standard method (ASAE, 1999). Each sample weighing about 10 g, was placed in a

convection oven set at 130°c for 50 minutes. The desired sample moisture levels were prepared. Samples with lower moisture content were dried by placing in a oven at 60°c and spread in a thin layer. The sample cloves with higher moisture contents were prepared by adding distilled water. Before beginning the experiments the required quantity of the samples was placed in room temperature for 12 hours (Visvanathan *et al.,* 1996).

Determination of Dimensions, Mass and Volume

Seventy-five cloves of each type were randomly selected from the bulk of the samples with their initial moisture and packed in labeled bags individually for easy identification. Size and shape characteristics were determined by using a computer imaging system. The sample cloves were placed on the black backplate under the camera individually and the image was acquired and the images analyzed using a Sony DXC-151A CCD color video camera (Sony Corporation, Japan), light stand, Matrox Meteor RGB capture card, Pentium III 700 PC, and Matrox Inspector Software version 2.1 (Matrox electronic systems, Quebec, Canada). In order to increase the accuracy of measuring the size and shape, significant contrast between the samples and background was required that was obtained by using the black sheet under samples as background and adjusting the lights, camera height, brightness, zoom and focus. Each clove was individually placed on a black sheet in its natural position with its length parallel to the y-coordinate and its image was taken. Then it was rotated 90 degrees to its major axis to take a second image. An 80-mm needle and a 10-mm square rubber with a 5 mm thickness was used to keep and rotate each clove on its major axis. The features of both images of each clove including area, perimeter, feret x and feret y (the dimensions of the minimum bounding box of the clove in the horizontal and vertical axes, respectively) were saved in Excel Workbook format for

further analysis. The average of feret y in both images of each clove was reported as the major dimension (mm). The longer and shorter of feret x in both images were reported as intermediate and minor dimensions (mm) of cloves, respectively.

The bulk clove sample was classified into three categories-namely small, medium and large-based on the unit mass of the cloves. The distribution of cloves by number and size for each category of unit mass was determined.

The geometric mean diameter (D_p) of the cloves was calculated by using the following relationship (Mohsenin, 1986):

$$D_p = (LWT)^{1/3} \qquad (1$$

where L, W and T are the length, width and thickness in mm, respectively. The sphericity (ϕ) of the cloves was calculated using the following equation (Mohsenin, 1986):

$$\Phi = \frac{(LWT)^{1/3}}{L} \qquad (2$$

The volume of each clove was measured using the gas comparison multipycnometer (Quanta Chrome Corporation, Boynton Beach FL, U.S.A). The pycnometer had cell cups of a volume of 6, 18, and 150 cm^3. Some of the sample cloves were larger than the smallest cell and partially occupied the large cell, so a more accurate calibration of the system was needed. The system was calibrated as follows. Actual and measured volumes of different unit sizes were compared by using the known volume of steel spheres. The average diameter of each sphere was measured by a digital caliper (resolution of 0.01 mm), to calculate its actual volume. Combinations of spheres were placed in different cell cups for volume determination by the gas pycnometer. The measurement was repeated three times. The data was analyzed to find the relationship between actual and measured volumes by using different cells for different unit sizes. To obtain the mass, each clove was weighed using an electronic weighing balance (Qhaus scale corp. G 160D, W. Germany) reading to 0.0001 g.

Physical Properties of Cloves

The bulk and unit densities as well as porosity of the various garlic cloves at different moisture contents were determined. Bulk density, ρ_b, was calculated from the mass and volume of the circular container with a known volume that was filled by the sample cloves. The cloves were dropped from a hopper into the container at a height of 200 mm and excess cloves were removed by passing a wooden stick across the top surface using 5 zigzag motions (Madamba *et al.*, 1993).

Unit density, ρ_p is defined as the ratio of the mass of the bulk of cloves to its volume (Joshi *et al.,* 1993). The average value of the densities was taken from three replications for each moisture content of each type of garlic.

The porosity, ε of bulk cloves expressed in a percentage was calculated from the bulk and unit densities by using the following relationship (Jha, 1999):

$$\varepsilon = \frac{\rho_p - \rho_b}{\rho_p} \times 100 \qquad (3$$

where ρ_b and ρ_p are the bulk density and the unit density.

Data Processing and Analysis

All the tests were conducted on two various garlic cloves commonly grown in Iran (white and pink). SAS PROC MEANS, FREQ and CORR were used to determine the maximum, minimum, mean, standard error, frequency distribution, and correlation of dimensions of cloves. The relationship between the volume and dimensions of cloves was established using regression analysis and the relationship between the physical properties of cloves and levels of moisture content was determined.

Model coefficients were determined using the SAS routines, REG for linear models and NLIN for non-linear models (SAS, 2001). The analysis of variance (ANOVA) and comparison of means were performed

using PROC ANOVA. The coefficient of multiple determination (R^2) and the mean square error (MSE) of models and the variation of predicted values with respect to measured values as well as the distribution of the residuals with respect to the estimated coefficients were used to evaluate the models for fit to the experimental data.

RESULTS AND DISCUSSION

Dimensions and Size Distribution of Garlic Cloves

Table 1 shows the size distribution of both the white and pink garlic clove samples at a 42.4% moisture content (w.b.). About 36% and 38.67% of the white and pink cloves, respectively, had a mass ranging from 3-5 g, whereas 28% and 37.33% of the white and pink cloves, respectively, had a mass less than 3 g, (small). The larger (mass greater than 5 g) white and pink cloves were 36% and 24% of cloves, respectively.

The mean values of 75 measurements for the major, intermediate and minor dimensions as well as the major and minor projected areas of white cloves were found to be 31.71 mm, 19.91 mm, 15.41 mm, and 473.83 mm^2, 377.88 mm^2, respectively. The corresponding values for pink cloves were 30.56 mm, 18.72 mm, 15.15 mm, 427.59 mm^2 and 352.76 mm^2, respectively.

The unit mass and volume of white cloves were found to be 4.28 g and 4410 mm^3, respectively. The values for pink cloves were 3.68 g and 3809 mm^3, respectively.

Table 2 shows the Pearson correlation coefficients of cloves at a moisture content of 42.4% (w.b.). These values indicate a high correlation among all the parameters of both cloves. For both types, the major dimension of the cloves were also closely related to the

Table 1. Size and distribution of white and pink garlic cloves at 42.4% moisture content (w. b.).

| Type | Physical attributes | Size category [a] | | | |
		Total	Small	Medium	Large
White					
	Percent of sample				
	By number	100	28	36	36
	By mass	100	12.5	34.98	52.52
	Average dimensions				
	Major (a), mm	31.71±0.46	27.41 ± 0.97	32.38 ± 0.41	34.40 ± 0.29
	Intermediate (b), mm	19.91±0.47	14.50 ± 0.49	20.63 ± 0.41	23.39 ± 0.30
	Minor (c), mm	15.41±0.45	11.06 ± 0.39	15.39 ± 0.46	18.81 ± 0.54
	Major projected area (A_1), mm^2	473.8±16.1	303.3 ± 19.2	485.6 ± 14.8	594.6 ± 13.1
	Minor projected area (A_2), mm^2	377.9±14.6	227 ± 13.4	377.4 ± 10.8	495.7 ± 15.8
	Unit mass (M), g	4.28±0.22	1.19 ± 0.15	4.16 ± 0.11	6.25 ± 0.21
	Unit volume (V), mm^3	4401±213	2122 ± 212	4387 ± 129	6188 ± 260
Pink					
	Percentage of sample				
	By number	100	37.33	38.67	24
	By mass	100	19.07	40.99	39.94
	Average dimensions				
	Major (a), mm	30.56±0.54	26.10 ± 0.74	31.89 ± 0.35	35.39 ± 0.59
	Intermediate (b), mm	18.72±0.46	14.73 ± 0.50	20.16 ± 0.37	22.62 ± 0.54
	Minor (c), mm	15.15±0.41	12.24 ± 0.45	15.39 ± 0.33	19.29 ± 0.68
	Major projected area (A_1), mm^2	427.6±16.6	281.3 ± 14.4	470.8 ± 13.2	585.4 ± 20.8
	Minor projected area (A_2), mm^2	352.8±14.15	241±12.8	364.7± 8.43	507.4 ± 21.8
	Unit mass (M), g	3.68±0.21	1.88 ± 0.12	3.90± 0.11	6.13 ± 0.26
	Unit volume (V), mm^3	3809±199	2114±132	4101±151	5974±260

[a] Small <3g; Meduium 3-5g; Large>5g.

intermediate dimension. The geometric mean diameter and sphericity of cloves were calculated. Table 3 shows these values for both white and pink cloves.

Unit Volume

The relationship between unit volume and dimensions of cloves for both types of garlic were established using the following regression analyses:

jor and minor dimensions of white and pink garlic cloves at 42.4% moisture content (w.b.) was close but the corresponding values for intermediate dimensions of white garlic cloves were larger than pink garlic cloves. The same results can be observed from Equations 7 and 8.

Unit Density

Type and moisture level had a significant effect ($P<0.01$) on the unit density of garlic cloves as revealed by a one-way analysis of

Table 2. Correlation of white and pink garlic cloves dimensions, volume and mass at 42.4% moisture content (w. b.).

| Type		$A_2(mm^2)$	$A_1(mm^2)$	a(mm)	b(mm)	c(mm)	V(mm³)
White	$A_1(mm^2)$	0.8024**	1				
	a (mm)	0.7701**	0.9007**	1			
	b (mm)	0.8108**	0.9719**	0.8305**	1		
	c (mm)	0.9680**	0.6763**	0.6172**	0.7122**	1	
	V (mm³)	0.9230**	0.9192**	0.8187**	0.9232**	0.8473**	1
	M (g)	0.9411**	0.9164**	0.8089**	0.9157**	0.8756**	0.9793**
Pink	$A_1(mm^2)$	0.8497**	1				
	A (mm)	0.8776**	0.9177**	1			
	B (mm)	0.7966**	0.9633**	0.8533**	1		
	c (mm)	0.9641**	0.7303**	0.7524**	0.6933**	1	
	V (mm³)	0.9308**	0.9020**	0.8768**	0.8571**	0.8577**	1
	M (g)	0.9367**	0.9209**	0.8762**	0.8785**	0.8601**	0.9692**

**Significant at 1% level.

$$\text{Ln} (V_W) = -0.73 + 1.2 \, \text{Ln} (a) +$$
$$1.16 \, \text{Ln} (b) + 0.62 \, \text{Ln} (c)$$
$$(R^2 = 0.96) \tag{4}$$
$$\text{Ln}(V_p) = -0.36 + 1.4 \, \text{Ln} (a) +$$
$$0.67 \, \text{Ln} (b) + 0.61 \, \text{Ln} (c)$$
$$(R^2 = 0.93) \tag{5}$$

where (V_w) and (V_p) are the unit volume of white and pink cloves (mm³) and a, b , and c are the major, intermediate and minor dimensions (mm), respectively. Mohsenin (1986) reported the same model for corn with various coefficients. As Table 2 shows the correlation between volume and the ma-

variance. The Duncan multiple range test indicated that, at each moisture level, the mean unit density for both types of cloves was significantly different ($P<0.01$).

The unit density of the white and pink garlic clove samples were found to decrease from 1142 to 1106 and 1184 to 1108 kg/m³, respectively, when the moisture content increased from about 34.9 to 56.7 %w.b. (Figure 1). The relationship between unit density and moisture content for both types of cloves is shown as:
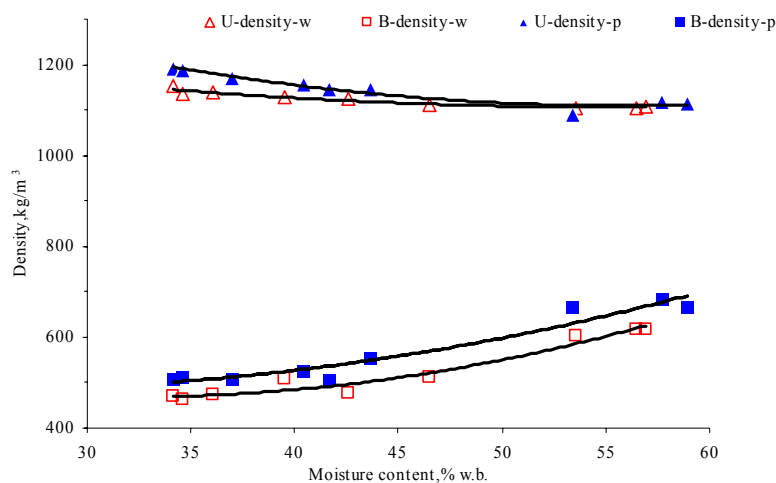
Figure 1. Effect of moisture content on unit and bulk densities of white and pink garlic cloves.

$$\rho_{p(w)} = 13607 - 9.1 M_c + 0.1 M_c^2$$
$(R^2 = 0.93)$ \hfill (6

$$\rho_{p(p)} = 1667.8 - 20 M_c + 0.18 M_c^2$$
$(R^2 = 0.94)$ \hfill (7

$\rho_{p(w)}$ and $\rho_{p(p)}$ represent the unit density of white and pink garlic cloves (kg/m³), respectively and M_c is the percentage of moisture content (w. b.). Madamba *et al.* (1994) proposed the second degree polynomial model to predict the apparent density of garlic cloves (cv. Early California) as follows:

$$\rho_{ap} = 1267.2 + 2.6 M_c - 0.1 M_c^2$$
$(R^2 = 0.93)$ \hfill (8

where $\rho_{(ap)}$ is the apparent density kg/m³. As shown in Equations 6 to 8, the difference in coefficients may be due to the garlic variety.

Bulk Density

In this study, significant differences (P<0.01) in bulk density were found between the two types and moisture levels of cloves. The mean bulk density for both types of cloves were significantly different (P<0.05).

The bulk density for white and pink garlic cloves was found to increase from 468.8 to 612.8, and 510.2 to 672 kg/m³, respectively, while the moisture level increased from about 34.9 to 56.7 % w.b. (Figure 1). The second degree polynomial model was found to predict bulk density values for both types of garlic, shown as:

$$\rho_{b(w)} = 725.8 - 16.1 M_c + 0.25 M_c^2$$
$(R^2 = 0.96)$ \hfill (9)

$$\rho_{p(b)} = 591.8 - 8.61 M_c + 0.17 M_c^2$$
$(R^2 = 0.94)$ \hfill (10)

where $\rho_{b(w)}$ and $\rho_{b(p)}$ are the bulk density of white and pink garlic cloves (kg/mm³), respectively. Some researchers such as (Joshi *et al.* 1993) expressed the bulk density of pumpkin seeds as a function of moisture content using the second degree polynomial model. Modamba *et al.* (1993) proposed the linear model for bulk density of garlic slices as a function of moisture content and slice thickness.

Porosity

The relationship between porosity and

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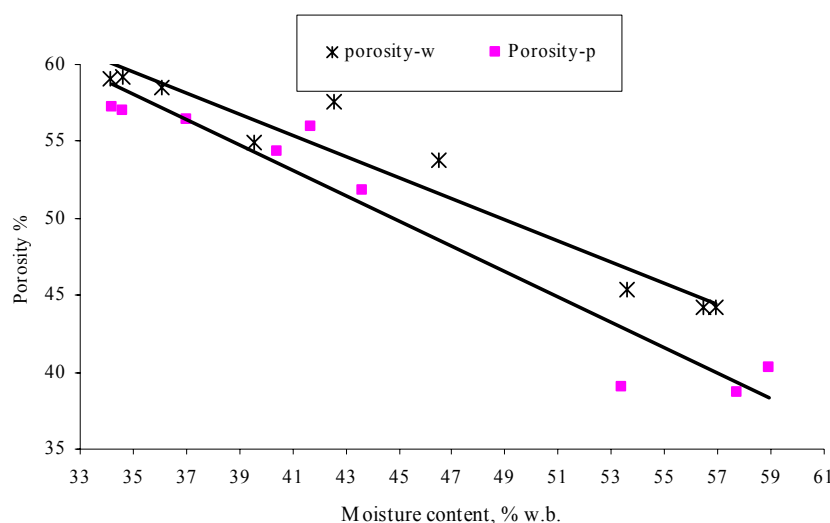
Figure 2. Effect of moisture content on porosity of white and pink garlic clove.

moisture content of both cloves is given in Figure 2. The porosity decreased from 59 to 45% and 57 to 39% for white and pink garlic cloves, respectively, when the moisture content increased from about 34.9 to 56.7% w.b. The results revealed a high significant effect of both moisture content and garlic type on the porosity (P<0.01). The variation in porosity with respect to moisture can be expressed by the following equations:

$$\varepsilon_W = 83.49 - 0.68 M_c \quad (R^2 = 0.94) \qquad (11$$

$$\varepsilon_p = 86.9 - 0.82 M_c \quad (R^2 = 0.93) \qquad (12$$

where ε_w and ε_p are the porosity of white and pink garlic cloves (%) respectively.

Madamba *et al.* (1993) proposed a linear model as a function of moisture content and of garlic slice thickness also showed de-

creasing porosity with respect to the increasing moisture content of garlic slices.

CONCLUSION

The average major, intermediate and minor dimensions as well as the major and minor projected areas of white garlic cloves were 31.71 mm, 19.91 mm, 15.41 mm and 473.8 mm^2 and 377.9 mm^2, respectively; the corresponding values for pink garlic were 30.56 mm, 18.72 mm, 15.15 mm and 427.6 mm^2 and 352.8 mm^2, respectively. The values of average unit mass and volume were 1.19 g and 2122.4 mm^3, respectively, for white garlic cloves and 1.88 g and 214.4 mm^3, respectively, for pink garlic.

Table 3. Geometric mean diameter and sphericity of white and pink garlic cloves at 42.4% moisture content (w. b.).

Type	Geometric mean diameter (mm)		Sphericity	
	Range	Mean	Range	Mean
White	12.43 – 27.55	21.25 (3.74)	0.58 - 0.91	0.72 (0.08)
Pink	11.14 - 28.38	20.46 (3.77)	0.57 – 0.87	0.74 (0.07)

Each value is a mean of 75 measurements. The standard deviation is given in parentheses.

The mean values of geometric mean diameter and sphericity of white garlic cloves were 21.25 mm and 0.72, respectively, while corresponding values for pink garlic were 20.46 mm and 0.74, respectively.

The unit density, bulk density and porosity of cloves were found to be dependent on moisture content. The unit density and porosity decreased when the moisture content increased, while bulk density increased with increasing of moisture content. The type of garlic also significantly affected the above named physical properties.

ACKNOWLEDGMENTS

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خصوصیات فیزیکی سیر (*Allium sativum L.*)

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چکیده

بعضـی از مشخصـات وخصوصـیات فیزیکـی حبـه‌هـای سیـر بـومی در ایـران در دو نـوع سـفید و صـورتی تعیین و بـا یکـدیگر مقایسـه شـدند. از سیسـتم ماشـین بینـائی بـرای تعیین ابعـاد اصلـی، سطح تصویر شـده کمینـه و بیشـینه سیـرچه‌های آزمایشـی بـا محتـوای رطـوبتی 4/42٪ (بـر اسـاس وزن تـر) اسـتفاده گردیـد. قطر میـانگین هندسـی و کرویـت آنهـا محاسـبه و همچنیـن جـرم و حجم سیـرچه هـا انـدازه گیـری شـدند. برخـی از خصوصـیات فیزیکـی شـامل جـرم مخصـوص سیـرچه، جـرم مخصـوص تـوده وخلـل و فـرج هـر دو نـوع حبـه هـای سیـر در محـدوده رطـوبتی 9 /34٪ الـی 7/56٪ (بـر اسـاس وزن تـر) انـدازه گیـری شـدند. تجزیـه وتحلیـل واریـانس (ANOVA) داده هـا نشـان داد کـه محتـوای رطـوبتی سیـرچه هـا تـأثیر بسـیار معنـی داری (1.٪ > P) بـر مقـادیر جـرم مخصـوص سیـرچه هـا، جـرم مخصـوص تـوده و میـزان خلـل و فـرج آنهـا داشـت. در ایـن آزمـایش تفـاوت بسیار معنـی داری بیـن جـرم مخصـوص سیـرچه و خلـل و فـرج انـواع سیـرهای اسـتفاده شـده مشـاهده گردیـد (P<1.٪)، هـم چنین جـرم مخصـوص تـوده دو نـوع سیـرچه آزمایشـی تفـاوت معنـی داری داشـتند (5 .٪ > P). رابطـه بیـن حجـم وابعـاد سیـرچه‌هـا بـا اسـتفاده از روش رگرسـیون بدسـت آمدنـد. هـم چنین اثـر محتـوای رطـوبتی سیـرچه هـا بـر خـواص فیزیکـی آنهـا توسـط روابـط ریاضـی مناسبی کـه با اسـتفاده از آنالیز واریانس ارزیابی شـده بودند، بیان شدند.