*The Canadian society for engineering in agricultural, food, and biological systems*

CSAE SCGR

*La société canadienne de génie agroalimentaire et biologique*

**Paper No. 03-330**

# Terminal velocity and frictional properties of garlic (*Allium sativum L.*)

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**Written for presentation at the**
**CSAE/SCGR 2003 Meeting**
**Montréal, Québec**
**July 6 - 9, 2003**

## Abstract

The frictional properties and terminal velocity of two common types of garlic cloves (white and pink) in Iran were determined. The static friction against three surfaces (galvanized steel, Plexiglas and rubber), emptying and filling angles of repose and terminal velocity of cloves were measured at a moisture range from 34.9 to 56.7% wet basis.

Analysis variance (ANOVA) showed that, the coefficient of friction, angle of repose and terminal velocity for both types of garlic cloves were affected significantly by moisture content ($P<0.01$). Relationship between the physical properties and moisture content were expressed by linear equations.

The maximum and minimum values of coefficient of friction were 74% for white garlic against rubber at moisture content of 55.67% (w.b.) and 26% for pink garlic against galvanized steel at 35.26%(w.b.), respectively. The maximum value of filling angle of repose was $43.5^{O}$ for white cloves at 55.67% (w.b.), and minimum corresponding value was $36.1^{O}$ for pink garlic cloves at 35.26% (w.b.). The white garlic cloves had minimum value of terminal velocity 9.82 m/min at 34.9% (w.b.), and maximum corresponding value was 16.66 m/min at 56.7% (w.b.) for pink cloves.

**Keywords:** garlic, coefficient of friction, angle of repose, terminal velocity

## 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 of the most exotic cuisine 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 seed, so it must be propagated vegetatively with garlic cloves as the most common planting material. Yield, yield components, and quality of garlic are affected by planting methods and cloves rates and sizes (Nourai 1994; Matlob and Khalel 1986; Marijana 1996).

Lack of basic engineering properties of this planting material is an identified problem 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, 1994, 1997; Pezzutti and Crapiste 1997; Park et al. 1981; Bhatt et al. 1998; Sharma and Prasad 2002).

Different techniques can be used for measuring physical properties. Previously, some researchers (Mohsenin 1986; Zhang et al. Kushwaha 1994) investigated the reasons of variation in the coefficient of friction values of biological materials. The experimental results showed that sliding surface, moisture content, velocity, normal pressure, temperature, humidity and operating technique affected friction values. Therefore, specific conditions should be considered while determining the coefficient of friction values of agricultural products. Zhang et al. (1994) used a Wykeham Farrace shear box apparatus to determine grain friction of wheat. Chandrasekar and Viswanathan (1999); Olajide and Ade-Omowaye (1999) used an inclined surfaces to measure coefficient of friction of material. Schaper and Yaeger (1992) used an instron to measure the frictional force between material and surfaces. A rotary disk was used to measure static and dynamic coefficient of frictions of chickpea seeds (Konak et al. 2002).

Carman (1996) and Konak et al. (2002) used the free fall method to determine the terminal velocity of seeds while Joshi et al. (1993) and, Singh and Goswami (1996) determined the terminal velocity values of pumpkin and cumin seed, respectively, by using a wind column.

The objective of this study was to determine and evaluate some physical properties of two types of garlic cloves (white and pink) including coefficient of friction against various surfaces, emptying and filling angle of repose and terminal velocity. Models were developed to express the relationship between moisture content and dependent physical properties of garlic cloves in the moisture range of 34.9 to 56.7 % w.b.

## Materials and Methods

### *Materials*

Garlic bulbs (White and Pink) were obtained locally in the region of Marvdasht, Fars, Iran. Freshly harvested garlic bulbs were randomly collected from different farms. Similar with local practice, the bulbs were dried by spreading in a thin-layer inside a darkroom with open windows near the farms for 15 d. Samples were stored in cool room at 5$^{o}$C

The sample bulbs were randomly selected from the bulk sample and the outer covering was manually peeled and cracked before experiments.

The moisture content of cloves was determined by following ASAE S352.2 (ASAE 1999). Each sample weighing about 10 g, were placed in a convection oven set at 130$^{o}$C for 50 min. The samples were then cooled in a dessicator, weighed and the moisture content was calculated and expressed in percent wet basis (w.b.).

*Sample Preparation*

The desired sample moisture levels were prepared. The samples were dried by spreading them in thin layer in convection oven set at 50$^{o}$C. The desired moisture content was obtained by controlling the sample mass during drying.

The sample cloves with higher moisture contents were prepared by adding calculated amounts of distilled water.The samples were thoroughly mixed and then sealing in separate polyethylene bags and kept at 5$^{o}$C in a refrigerator for 7 d to allow the moisture to distribute uniformly throughout the sample.

Before beginning the experiments the required quantity of the samples were placed in room temperature for 12 h (Visvanathan et al. 1996).

*Static Coefficient* of *Friction*

The static coefficient of friction was determined for various garlic cloves samples against three surfaces namely galvanized steel, plexiglass and rubber. A galvanized box with neither base nor lid and with dimensions 150×100×40 mm was placed on the test surface and filled with the sample while the test surface sit on adjustable tilting plate (Fig.1).

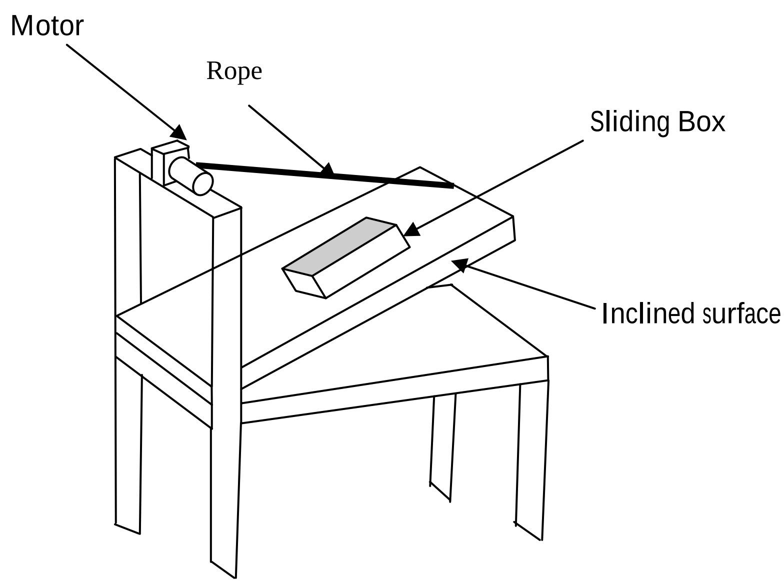


**Fig. 1. Schematic diagram of the measuring static coefficient of friction**

The box was raised slightly so as not to touch the surface. The tilting plate was inclined gradually with a cable that was pulled up by a rotating pulley. A DC electric motor was used to rotate the pulley smoothly until the box just started to slide down and the coefficient of static friction (μ) was calculated from the following equation:

$$\mu = \tan^{-1}\left(\frac{H}{L}\right) \qquad (1)$$

where H and L are values of rise and length of tilt plate respectively, mm. The experiment was replicated three times at three levels of moisture content.

*Angle of Repose*

To determine the emptying or dynamic angle of repose, a plexiglass box with 430 mm long, 200 mm wide, and 430 mm high was used. A removable front panel with 50 mm high and 200 mm wide was used to flow out the material. The box was filled using a 50-mm square opening hopper located 120 mm above the center of the top of the box. The cloves were leveled and then the front panel was quickly removed and the cloves were allowed to flow. The emptying angle of repose was calculated from the measurement of the maximum depth of the free surface of the sample and length of the box.

The filling angle of repose was measured in a plexiglass box with 1220 mm long, 100 mm wide and 760 mm high. To fill the box a 53-mm square opening hopper located midway along the box length and 800 mm above the bottom of the box. The differences in height of the samples pile were measured in two locations. The filling angle of repose was calculated from the base length and height of cloves in box. Both emptying and filling angle of repose measurement were repeated three times.

*Terminal Velocity*

The terminal velocities of garlic clove samples were measured by using an air column (Tabak and Wolf 1998). The clove samples were grouped respected to weight in three levels (small, medium and large). Five medium cloves of each group were randomly selected from various types of cloves and tested. For each experiment the selected cloves were dropped from the top of a 75-mm diameter, 1m long plexiglass tube (Fig.2). The air was blown upwards in the tube while its velocity was adjusted by using an inverter–type motor speed control until the major fraction of the sample remained suspended in the air stream. Air velocity was measured by using a cross pitot-tube and reported as terminal velocity. Three replications were taken for each sample. This procedure was done at three levels of moisture content of the clove samples.

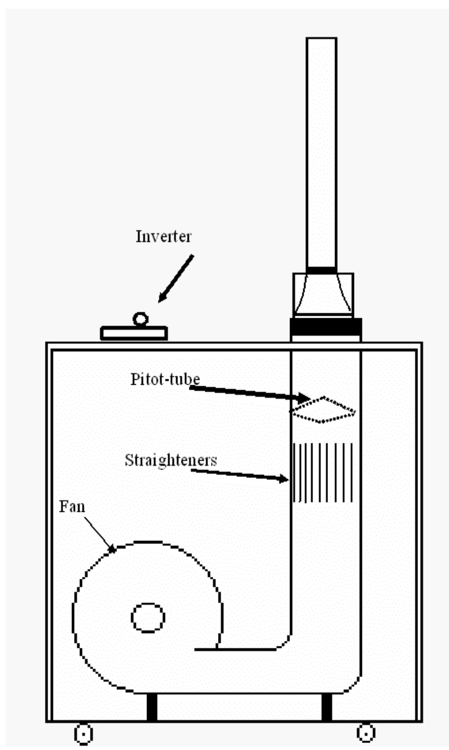


**Fig. 2. Schematic diagram of air column used for measurement of terminal velocity.**

*Data processing and analysis*

All tests were conducted on two various garlic cloves (white and pink) at three levels of moisture content and repeated three times. The analysis of variance (ANOVA) and comparison of means were performed using PROC ANOVA in SAS program (SAS, 2001). Relationship between physical properties of cloves and levels of moisture content was determined. Model coefficients were determined by using the SAS routines, REG for linear models and NLIN for non-linear models. 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.

## Result and Discussion

*Static Coefficient of Friction*

Relationship between values of static coefficient of friction ($\mu_s$) against various surfaces (galvanized steel, plexiglass, and rubber) and moisture content (M) for various types of garlic clove samples are shown in Table 1.

**Table1: Relationship between physical properties and moisture content of various garlic cloves†.**

| Physical property | White garlic clove | | Pink garlic clove | |
|---|---|---|---|---|
| | Model | $R^2$ | Model | $R^2$ |
| **Coefficient of friction** | | | | |
| Galvanized steel | $\mu_s$=0.021M-0.48 | 1.000 | $\mu_s$=0.021M-0.45 | 0.994 |
| Plexiglass | $\mu_s$=0.018M-0.32 | 0.979 | $\mu_s$=0.016M-0.232 | 0.928 |
| Rubber | $\mu_s$=0.014M-0.052 | 0.929 | $\mu_s$=0.018M-0.29 | 0.981 |
| **Angle of repose** | | | | |
| Emptying | $Y_e$=0.305M-26.63 | 0.997 | $Y_e$=0.127M-32.64 | 0.998 |
| Filling | $Y_f$=0.317M-25.68 | 0.954 | $Y_f$=0.124M-32.02 | 0.935 |
| **Terminal velocity*** | $V_w$=0.09M+8.14 | 0.983 | $V_p$=0.14M+6.75 | 0.987 |

†The levels of moisture content are 34.93-55.67 and 35.26-56.68 percent (wet basis).

* Terminal velocity of medium size cloves.

Figure 3 shows that static coefficients of friction for various type of garlic against various surfaces increased with moisture content. The same result was reported by Konak et al. (2002) and, Singh and Goswami (1996).

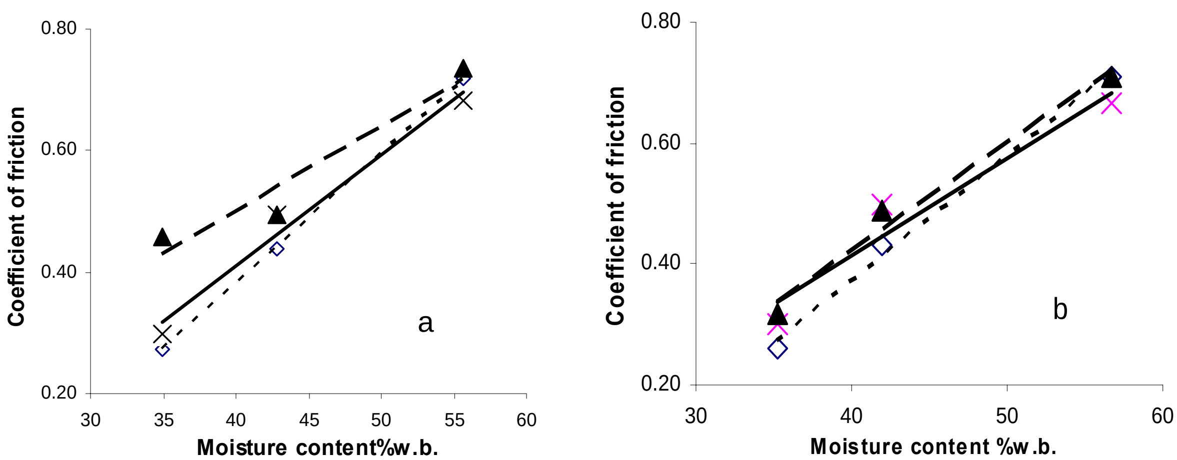


**Fig. 3. Effect of moisture content on static coefficient of friction against various surfaces a) white clove b) pink clove. Rubber (▲), plexiglass(×) and galvanized steel(◊).**

Comparison of means indicated significant difference (P<0.05) between the mean values of coefficient of friction at different moisture contents and various surfaces (Tables 2 and 3). As Table 4 shows the effect of various clove samples on coefficient of friction were not significant (p<0.05).

**Table 2. The multiple Duncan's comparison of means for physical properties at various moisture contents.**

| Moisture content (w.b.) | Coefficient of friction (%) | Angle of repose (degree) | Terminal velocity (m/min) |
|---|---|---|---|
| **35.1** | 30[c] | 36.7[c] | 11.24[c] |
| **42.4** | 47[b] | 38.9[b] | 11.73[b] |
| **56.2** | 70[a] | 41.32[a] | 14.00[a] |

Comparison of means at significant level of 0.5%

**Table 3. The multiple Duncan's comparison of means for physical properties at different conditions.**

| Conditions | Coefficient of friction (%) | Angle of repose (degree) | Terminal velocity (m/min) |
|---|---|---|---|
| **Galvanized steel** | 47[c] | n/a | n/a |
| **Plexiglass** | 49[b] | n/a | n/a |
| **Rubber** | 51[a] | n/a | n/a |
| **Emptying** | n/a | 39.24[a] | n/a |
| **Filling** | n/a | 38.66[a] | n/a |
| **Small** | n/a | n/a | 10.46[c] |
| **Medium** | n/a | n/a | 12.56[b] |
| **Large** | n/a | n/a | 13.94[a] |

Comparison of means at significant level of 0.5%

**Table 4. The multiple Duncan's comparison of means for physical properties at various type of galic.**

| Type | Coefficient of friction (%) | Angle of repose (degree) | Terminal velocity (m/min) |
|---|---|---|---|
| **White** | 50[a] | 40.0[a] | 12.21[b] |
| **Pink** | 49[a] | 37.9[b] | 12.44[a] |

Comparison of means at significant level of 0.5%

*Angle of Repose*

The values of emptying and filling angles of repose for various types of garlic clove samples ($Y_e$ and $Y_f$ for emptying and filling angle of repose, respectively) increased with moisture content (fig. 4). As figure 4 shows the curve of emptying method for both type of garlic samples are above than curve of filling angle of repose. The most researchers reported the same result (White and Jayas 2001; Tabil et al. 1999; Moysey and Hitz 1985). The effect of moisture content on angles of repose of clove samples were expressed by linear equation for filling and emptying angles of repose (Table 1). Comparison of means revealed significant difference (P<0.05) between the mean values of angles of repose at different moisture contents for various types of garlic (Tables 2 and 4). The emptying and filling angles of repose had no difference for both garlic (P<0.05), (Table 3).

*Terminal Velocity*

Table 5 shows the values of terminal velocity at different moisture levels for various garlic samples, which were randomly selected from different category sizes of bulk samples.

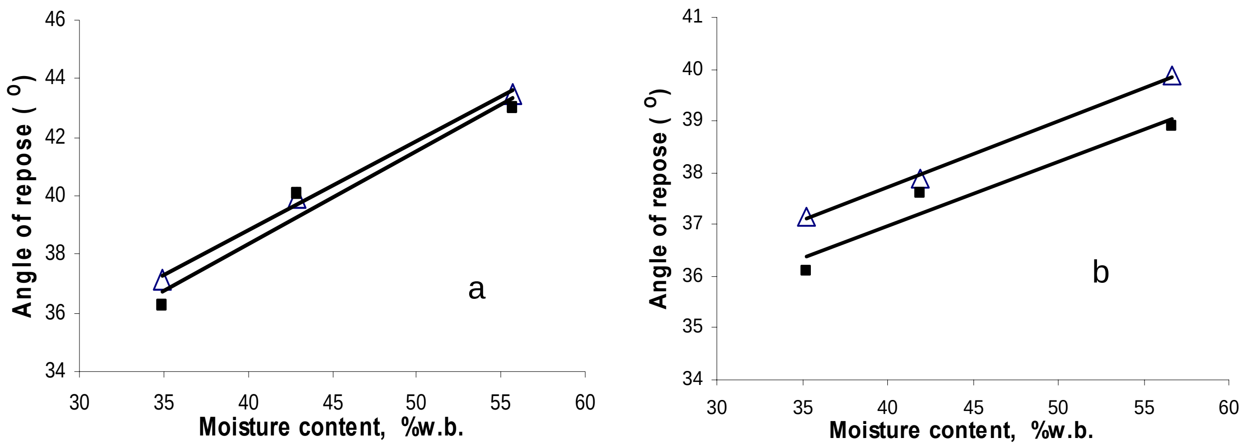


**Fig. 3. Effect of moisture content on angle of repose a) white clove b) pink clove. Emptying angle of repose (Δ), and filling angle of repose (■).**

The relationship between terminal velocity and moisture content for medium size of both white and pink cloves were expressed by linear equations at levels of moisture content 34.93-55.67 and 35.26-56.68 percent of wet basis for white and pink cloves, respectively (Table 1).

**Table 5. Values of terminal velocity of various category sizes of garlic cloves.**

| Type | Moisture content, %w.b. | Terminal velocity (m/s) | | |
|---|---|---|---|---|
| | | Small* | Medium* | Large* |
| **White** | | | | |
| | 34.93 | 9.83±0.01 | 11.32±0.24 | 12.53±0.06 |
| | 42.9 | 10.35±0.02 | 11.80±0.20 | 12.99±0.07 |
| | 55.67 | 11.02±0.23 | 13.62±0.16 | 16.40±0.08 |
| **Pink** | | | | |
| | 35.26 | 10.04±0.12 | 11.43±0.16 | 12.32±0.04 |
| | 41.9 | 10.48±0.11 | 12.00±0.16 | 12.76±0.02 |
| | 56.68 | 11.07±0.28 | 15.20±0.27 | 16.66±0.15 |

*Small<3 g, medium 3-5 g, large >5 g.

Comparison of means indicated significant difference ($P<0.05$) between the mean values of terminal velocity at different moisture contents and various garlic samples (Tables 2 and 4). As Table 3 shows the effect of various sizes of clove samples on terminal velocity were significant ($p<0.05$).

## CONCLUSIONS

1. The moisture content of white and pink cloves of garlic affected the different physical properties measured.

2. The static coefficient of friction, emptying and filling angle of repose and terminal velocity of various types of garlic clove samples increased linearly with moisture content.

3. The mean values of angle of repose and terminal velocity of various type of garlic cloves had significant difference ($P<0.05$), but coefficient of friction for white and pink cloves had no significantly different ($P<0.05$).

3. The mean values of coefficient of friction against various surfaces, as well the mean values of terminal velocity of different cloves sizes had significant difference ($P<0.05$).

4. The maximum and minimum values of coefficient of friction were 74% for white garlic against rubber at moisture content of 55.67% (w.b.) and 26% for pink garlic against galvanized steel at 35.26%(w.b.), respectively.

5. The maximum value of filling angle of repose was $43.5^{O}$ for white cloves at 55.67% (w.b.), and minimum corresponding value was $36.1^{O}$ for pink garlic cloves at 35.26% (w.b.).

6. The white garlic cloves had minimum value of terminal velocity 9.82 m/min at 34.9% (w.b.), and maximum corresponding value was 16.66 m/min at 56.7% (w.b.) for pink cloves.

**Acknowledgement**

The authors would like to acknowledge the Department of Agricultural and Bioresource Engineering University of Saskatchewan for technical support; we also appreciate the help extended by Mr. Bill Crerar during the experimental work.

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