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Short Communication

Frictional Coefficient under Banana Skin

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We measured the frictional coefficient under banana skin on floor material. Force transducer with six degrees of freedom was set under a flat panel of linoleum. Both frictional force and vertical force were simultaneously measured during a shoe sole was pushed and rubbed by a foot motion on the panel with banana skin. Measured frictional coefficient was about 0.07. This was much lower than the value on common materials and similar one on well lubricated surfaces. By the microscopic observation, it was estimated that polysaccharide follicular gel played the dominant role in lubricating effect of banana skin after the crush and the change to homogeneous sol.

Keywords: banana skin, frictional coefficient, follicular gel lubrication, biotribology

1. Introduction

Shortly after banana was imported to North America in the mid-nineteenth century, it became common sense that banana skin is slippery and sometimes causes accidental slip [1]. Then, banana skin has been often referred as a slipping tool by literatures. Under this situation, anyone could not doubt the lubricating ability of banana skin and dare not measure the friction. The simple question how much value frictional coefficient under banana skin has not been answered, yet. There must be some academic interest in this question.

Frictional coefficient is defined as a ratio of frictional force to vertical force and can be representative of lubricating conditions. Frictional force of solid is, however, not a characteristic of material itself because it is changed with different factors containing mechanical conditions, properties of lubricant, and material of opposite surface. Therefore, we must measure the specific friction under the specific circumferential conditions that simulate the actual conditions.

In the present study, we prepared an experimental setup, which can duplicate the actual situation of a slipping accident, to measure frictional coefficient under banana skin. Friction under banana skin was measured on a flat panel of common floor material during the sliding motion of a shoe sole. Force transducer with six degrees of freedom was set under the flat panel and used for the detection of two-directional horizontal forces and a vertical force. The frictional force was calculated as the resultant force of the horizontal forces. As the result, measured frictional coefficient was about 0.07. This value was compared with that under banana skin with some different conditions, that on different material, or that under other fruit peel.

Additionally, by the microscopic observation, it was found that gel was spilled out when follicles of banana skin was crushed by the trample under foot. It was estimated that polysaccharide follicular gel played the dominant role in lubricating effect of banana skin after the crush and the change to homogeneous sol.

2. Materials and method.

Banana skin, which is the epicarp of a fruit banana, was prepared from a giant Cavendish banana (*Musa* spp. Fig. 1). After peeling, banana skin was put on a linoleum plate as the softer side lower. A force transducer with multi degrees of freedom (IFS-100M40A, JR3, CA) was fixed under the linoleum plate. The directions of the detected forces f_x and f_y were set horizontal, as shown in Fig. 2. The direction of the force f_z was set vertical. The maximum ranges of this transducer were 200 N at f_x, 200 N at f_y and 400 N at f_z. The minimum resolution of the force for each direction was 0.012 N, 0.012 N or 0.024 N, respectively. This

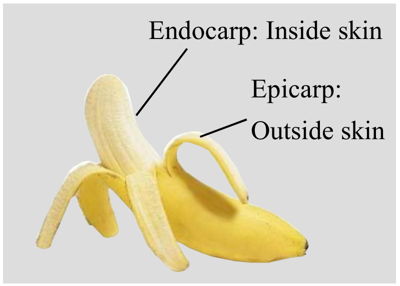

Fig. 1 Cavendish banana, *Musa* spp

layout enabled a simultaneous measurement of both frictional force and vertical force on the linoleum plate. The force data were acquired in a personal computer after digitization at the rate of one hundred per second.

Fig. 2 Experimental set up with the coordinate of the detected forces

Banana skin was rubbed with the forward sliding motion of a shoe sole immediately after the touch on banana skin. Vertical force during the test was generated by the pushing of the operator through his foot. The frictional coefficient μ was calculated by the ratio between the resultant force of horizontal forces and vertical force during the rubbing motion, as the following equation.

$$\mu = \frac{\sqrt{f_x^2 + f_y^2}}{|f_z|} \tag{1}$$

The detected vertical force during the measurement largely changed, as shown in Fig. 3, because the detection continued before the touch of the shoe sole and after the detachment. Therefore, the data were set aside when vertical force f_z lowered 60 N while the contact seemed insufficient. The calculated frictional coefficient, which data were approximately stable during the vertical force exceeded 60 N, as shown in Fig. 3, was saved as the result of a single measurement. Measurements on each specimen were repeated five times. Further measurements were repeated under some other different conditions of banana skin, including reverse side of skin, dried skin, or on another floor

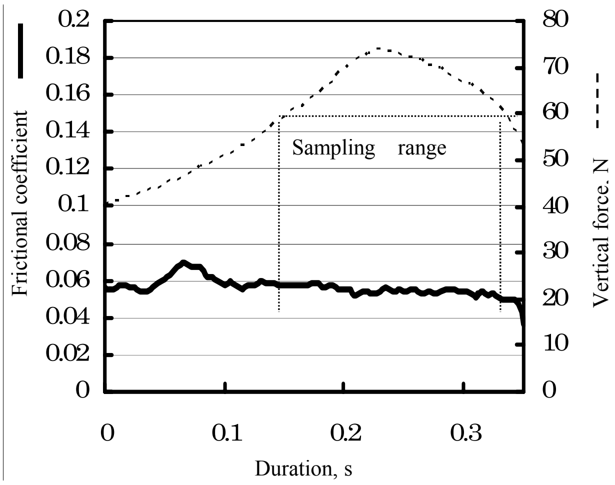

Fig. 3 Vertical force with calculated frictional coefficient during rubbing motion of banana skin on a linoleum plate

material. Additionally, friction under tangerine skin, citron skin and apple peel were also measured to be compared with banana skin. These fruit skins were microscopically observed for the speculation of lubricating mechanism in banana skin. A reflection microscope (KH-7700, HIROX Co. Ltd., Japan) was used for the observation.

3. Results

As the results of twelve specimens, five times per each and total 60 times measurements, the frictional coefficient under banana skin was mean 0.066 SD 0.028, as shown in Fig. 4, which can be approximated 0.07. This value was much lower than that under a direct shoe sole, which was mean 0.412 SD 0.019. Friction was lowered one sixth by lubrication effect of banana skin.

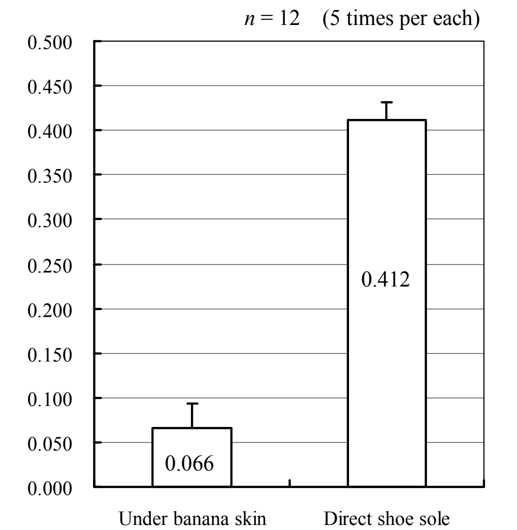

Fig. 4 Frictional coefficient under banana skin measured on a linoleum plate
(Error bar is the standard deviation.)

The averaged vertical force was 84.6 N SD 12.6 N during the friction under banana skin was measured. Frictional coefficient under banana skin was not significantly related with the average value of vertical force at each measurement, as shown in Fig. 5. The lubricating effect of banana skin was similar on wooden plate (Table 1) because the frictional coefficient was about 0.08 on a wooden plate, which is similar to that on a linoleum plate.

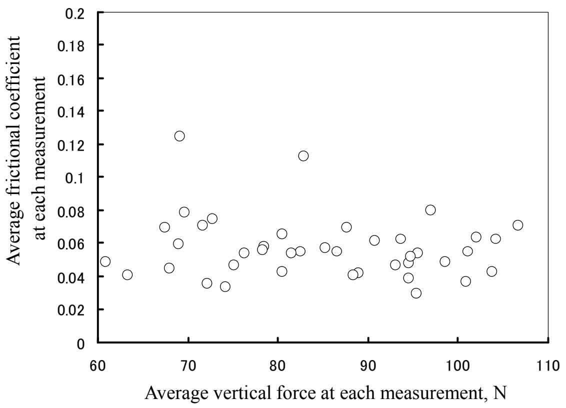

Fig. 5 Correlation chart of vertical force and frictional coefficient measured under banana skin on a linoleum plate

Table 1 Frictional coefficient under fruit skin or peel Each five times measurements

Additive	Base plate	Frictional coefficient Mean	±SD
Banana skin			
Fresh epicarp*	Linoleum	0.066	±0.028
Fresh epicarp	Wood	0.083	±0.028
Reverse epicarp	Linoleum	0.123	±0.028
Dry epicarp	Linoleum	0.329	±0.046
Apple peel			
Thickness 2 mm	Linoleum	0.125	±0.034
Thickness 3 mm	Linoleum	0.105	±0.044
Citron skin	Linoleum	0.198	±0.040
Tangerine skin	Linoleum	0.225	±0.040

*12 specimens

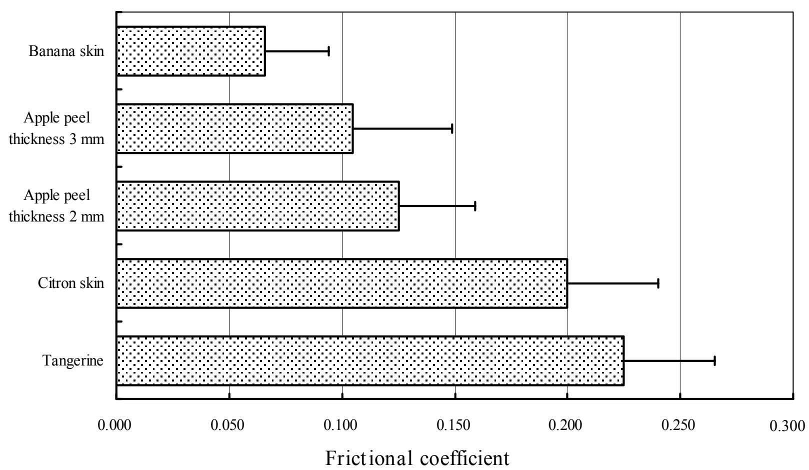

Fig. 6 Frictional coefficient under different fruit skin measured on a linoleum plate (Average and the standard deviation, error bar, of each five times measurements)

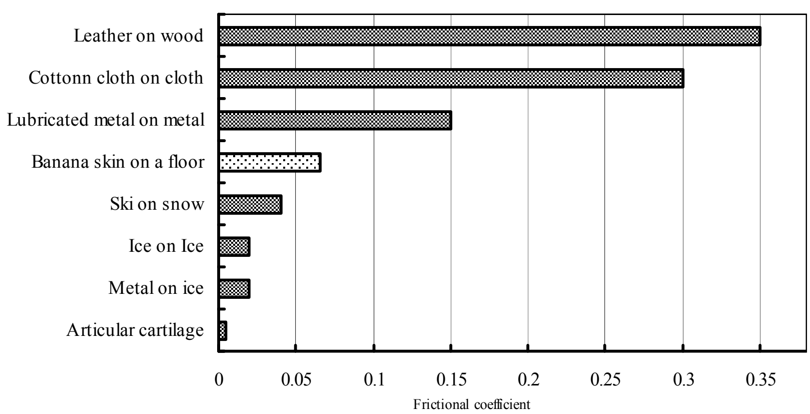

Fig. 7 Frictional coefficient of general materials [2,3]

Furthermore, frictional coefficients were mean 0.123 SD 0.028 under reverse side of banana skin, mean 0.329 SD 0.046 under perfectly dried banana skin, mean 0.225 SD 0.04 under tangerine skin, mean 0.200 SD 0.04 under citron skin, mean 0.125 SD 0.034 under apple peel of thickness 2 mm, and mean 0.105 SD 0.044 under apple peel of thickness 3 mm, respectively (Fig. 6, Table 1).

4. Discussion

Banana skin dramatically decreased the friction under shoe sole as one-fifth. Frictional coefficient under banana skin 0.07 was much smaller than that of general materials rubbing, which values generally exceed 0.1 (Fig. 7) [2]. The frictional coefficient under 0.1 belongs that of well lubricated surfaces, such as a ski on snow, ice on ice or articular cartilage [2,3]. From this comparison, the lubricating ability of banana skin can be proved excellent.

Lowering friction on a floor increases the risk of slip and fall. Frictional force must be larger than traction force of a front foot at the heel strike when we walk in safety, as shown in Fig. 8. The safety condition can be easily shown as the following equation from the frictional coefficient μ, force from the foot F [N], angle between the leg axis and vertical line θ [rad] [4].

$$\mu F \cos\theta > F \sin\theta \qquad \mu > \tan\theta \tag{2}$$

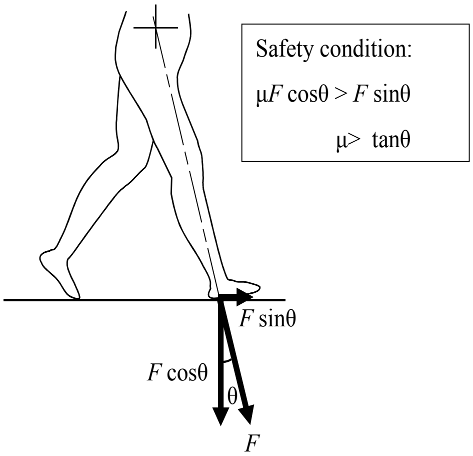

Fig. 8 Safety condition estimated by gait dynamics

Then, to prevent the slip of a foot, the angle θ is limited under the friction angle. If the frictional coefficient is 0.066 the friction angle is 3.8 degree. When we step on banana skin by the usual angle of 15 degree, the sudden change in friction must make us slip and fall. By an epidemiological research [4], the risk of fall exceeds 90% if the frictional coefficient is lower than 0.1. These findings are identical to the common knowledge of slip and fall on banana skin.

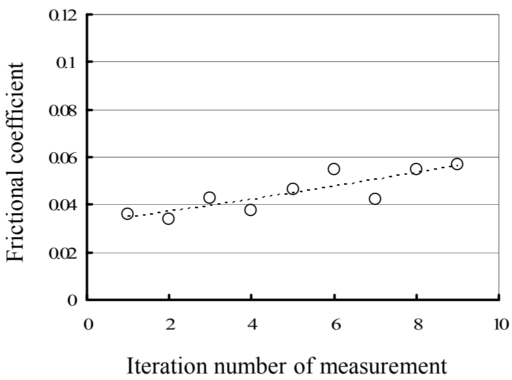

Fig. 9 Frictional coefficient measured at sequential experiments

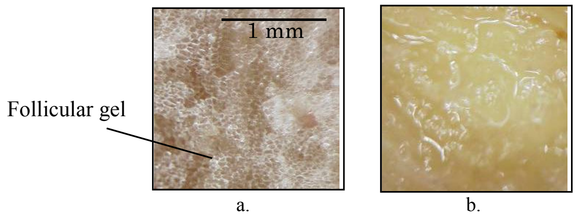

Fig.10 Microscopic image of banana skin
a. Fresh, b. After crush

Water content of banana skin, which was calculated with the weight loss of one month drying in air, was 85%. If water was lost by drying, the frictional coefficient increased to 0.329 (Table 1). On the other hand, friction under single banana skin increased with the measurement iteration, as shown in Fig. 9. From these findings, it can be supposed that the lubricating effect of banana skin is owed to constituent water and that the mechanism is like as the squeeze film lubrication. The surface roughness must be, however, sufficiently small to form lubricating fluid film. The surface roughness of the linoleum plate that we used here for floor material was measured *Rz* 47 μm. Wooden plate was *Rz* 23 μm. These values can be sufficiently small to prevent the rupture of fluid film for a second. On the other hand, the reason why reverse side of banana skin did not show lubricating effect can be estimated that the irregularity of the shoe sole, which is a few millimeters, broke fluid film at once.

When the banana skin was microscopically observed, a bunch of follicular gel, which size is about a few micro meters, was found inside skin, as shown in Fig. 10a. The constituent of this gel is presumed polysaccharide with some protein, which is common gel constituent in plant tissues. The shape of banana skin was maintained by the strength of follicle membrane under no load, like as a grease capsule. The thin cellulose membranes of these follicles were easily crushed when banana skin was compressed. Substance in follicles will exude and unite together to become homogeneous sol, as shown in Fig. 10b. In contrast, follicular gel was not rich in apple peel or citron skin, as shown in Fig. 11. This difference must be the reason why the friction under citron skin or apple peel was rather higher than that under banana skin (Fig. 6). Therefore, follicular gel must play the dominant role in lubricating effect of banana skin. This unique mechanism can be called follicular gel lubrication (Fig. 12).

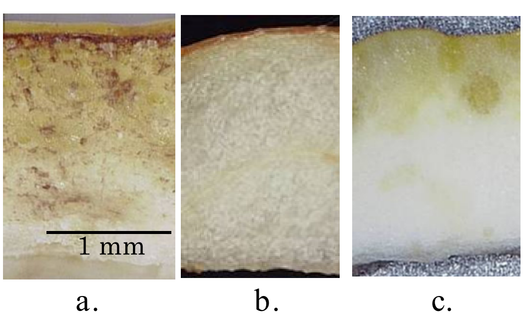

Fig.11 Cross section of fruit skin
a. Banana skin, b. Apple peel, c. Citron skin

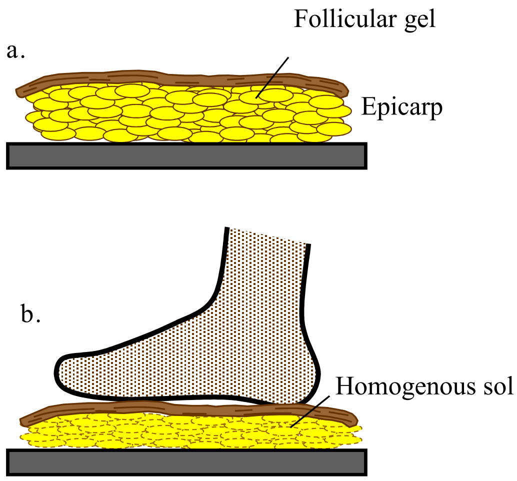

Fig.12 Follicular gel in banana skin

5. Conclusion

Frictional coefficient under banana skin on common floor material is about 0.07. It was estimated that polysaccharide follicular gel played the dominant role in lubricating effect of banana skin after the crush and the change to homogeneous sol.

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