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Fruit ripeness and temperature affect friction coefficient of McLemore and Gala apples

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A b s t r a c t. The objective of this study was to determine the influence of apple flesh temperature and ripeness on the static and dynamic coefficients of friction. Two apple cultivars with two different degrees of ripeness were hand picked from trees in a commercial orchard and placed in the environments with temperatures of either 6, 12, 18, 24 or 30°C. Friction tests were performed on whole apples against masonite, rubber, plastic and cardboard paper surfaces. Temperature and apple ripeness had a significant effect on the static and dynamic coefficients of friction for both cultivars. More ripe apples had higher friction coefficients than less ripe apples.

K e y w o r d s: friction, measurement, ripeness, temperature, apple

INTRODUCTION

Friction of products against machine parts can cause mechanical damage to fruit and vegetables, particularly during harvesting and handling. Coefficient of friction is an important parameter in the optimum design of harvesting and handling equipment. Two important factors affecting the handling behaviour of fresh fruit and their quality are fruit ripeness and temperature. Hyde and Ingle (1968) found that bruise size increased with increasing maturity and decreased with increasing storage time. Saltveit (1984) reported that bruise susceptibility increased with increasing fruit temperature, but Schoorl and Holt (1978) found the opposite effect. Bajema *et al.* (1998) found that lower temperature and higher strain rate reduced failure properties of potato tuber tissue. Bourne (1982) stated that firmness of most fruit and vegetables showed a decrease with an increasing temperature over the range from 0 to 45°C. Puchalski and Brusewitz (1996) showed that the effect of the measurement date on the friction coefficient was significant with a tendency to decrease with time for watermelon.

The objective of this work was to determine the influence of fruit ripeness and temperature on the static and dynamic coefficients of friction of apples against different sliding surfaces.

MATERIALS AND METHODS

Two apple cultivars, Gala and McLemore were tested. Their characteristics was presented in Table 1. They were grown in a commercial orchard in the eastern Oklahoma and harvested on 24th July (McLemore) and 15th August (Gala). The apples were hand picked at two different stages of ripeness, i.e., McLemore - as unripe and ripe fruit indging by their firmness and colour and Gala - from sides of the tree more and less exposed to the sunlight referred to as south and north parts of the tree. Fruit were sorted by mass and size to obtain more uniform groups.

The fruit were put into plastic bags (to retain moisture) and stored in the chambers with temperatures at either 6, 12, 18 or 30°C. Additional fruit were left in the room at 24°C. The apples were tested just after harvest (for both cultivars) and on three test dates within 20 days of storage (first - before storage, second after 10 days and last at the end of storage of Gala fruit).

Fruit firmness was measured with an Effegi fruit pressure tester using a 11.1 mm diameter tip.

The device of Puchalski and Brusewitz (1996) was used to measure friction coefficients against various sliding surfaces (Fig. 1). The main components of the device were:
- a stationary sample holder,

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T a b l e 1. Apple characteristics (n=240)

Factor	Weight (g)		Dimension (mm) Min		Dimension (mm) Max		Moisture content (%)		Firmness (N)	
	M.	S.D.	M.	S.D.	M.	S.D.	M.	S.D.	M.	S.D.
					McLemore					
Unripe	151.4	17.3	72.1	2.8	74.0	3.2	86.2	1.7	71.3	3.6
Ripe	155.6	13.2	73.1	2.3	74.9	2.4	86.1	1.3	37.9	5.7
					Gala					
North	160.1	13.4	70.7	2.3	72.7	2.4	82.7	1.0	77.0	13
South	145.3	9.4	69.2	5.7	70.5	2.2	82.5	1.3	73.5	11

M. - mean, S.D. - standard deviation.

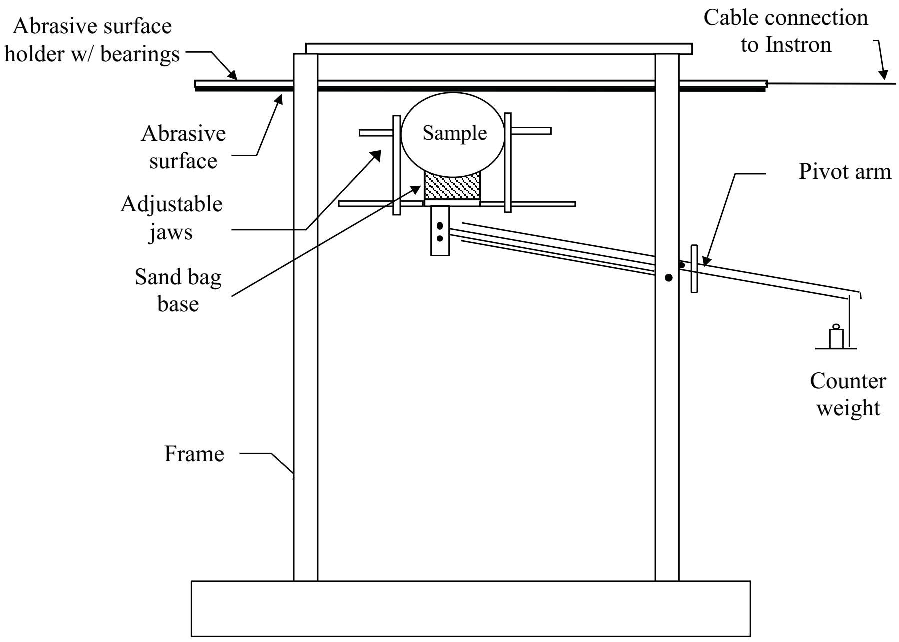

Fig. 1. The device for testing friction.

- a horizontally moving friction surface connected to the Instron's crosshead,
- a data acquisition system including a personal computer to measure the frictional force.

The sample holder has two independently adjustable jaws that rigidly hold the sample and also applies the required normal force with a pivoting arm and a counter weight. A rigid, flat friction surface of 0.1 m wide and 0.6 m long was bolted to the underside of a pulling plate supported by a precision rail and linear bearing to minimise friction. The pulling force was supplied by the Instron's crosshead with a non-stretching 1.0-mm diameter steel cable.

Testing was done at a constant normal force of 17 N and a sliding speed of 4.17 mm s^{-1} over a travelling distance of 40 mm against masonite and plastic surfaces. Static and dynamic coefficients of friction were calculated on the basis of the peak static force and an average dynamic force (Puchalski and Brusewitz, 1996). Data on the individual factors were subjected to the analysis of variance (ANOVA) and the means were separated by the Duncan's multiple range test.

RESULTS AND DISCUSSION

Effect of fruit temperature

An analysis of variance (ANOVA) showed a significant effect (at $p < 0.01$) of fruit temperature on the static and dynamic coefficients of friction for both cultivars. Generally, the static coefficient of friction decreased with an increase in fruit temperature from 6 to 24°C, except on plastic for the McLemore (Fig. 2). These decreases in the static coefficient of friction were 14 to 26% of the initial value. An increase in fruit temperature from 6 to 24°C probably caused smoothing of the fruit surface; hence, a decrease in the coefficient of friction. Roy *et al.* (1994), using scanning electron microscopy, revealed such smoothing of apple surface with no deep cracks with heat treatment.

Figure 2 shows also the effect of fruit temperature on the dynamic coefficient of friction related to the cultivar, and sliding surface. The dynamic coefficient of friction decreased as the temperature was rising from 12 to 24°C on both surfaces for the unripe Gala fruit. However, for the ripe McLemore, this tendency was opposite. For the plastic very smooth surface, changes in the dynamic coefficient of friction were strongly affected by cultivar differences at a temperature below 18°C. It means that probably the physical and chemical processes involved during contact with this surface changed behaviour of the samples.

Effect of ripeness of McLemore

Figure 3 shows the effect of ripeness on the static and dynamic coefficients of friction at various fruit temperatures and sliding surfaces. Generally, ripe fruit (with a firmness of 37.9 N) exhibit higher coefficients of friction than unripe ones (firmness, 71.3 N) at all fruit temperatures, except at 30°C on plastic for both coefficients. Probably, as apples ripen, there is a change in the fruit surface wax, which affects the materials in contact during the friction test. It was observed by Roy *et al.* (1994) for apple and Corey *et al.* (1988) for watermelon. A significant difference of 5-32% in coefficient of friction between ripe and unripe fruit was evident at 6 and 12°C (for both coefficients) on plastic and 6 and 18°C (for the static and dynamic coefficients, respectively) on masonite. The biggest differences of up to 40% in the dynamic coefficient of friction between ripe and unripe fruit were noted at 30°C on masonite.

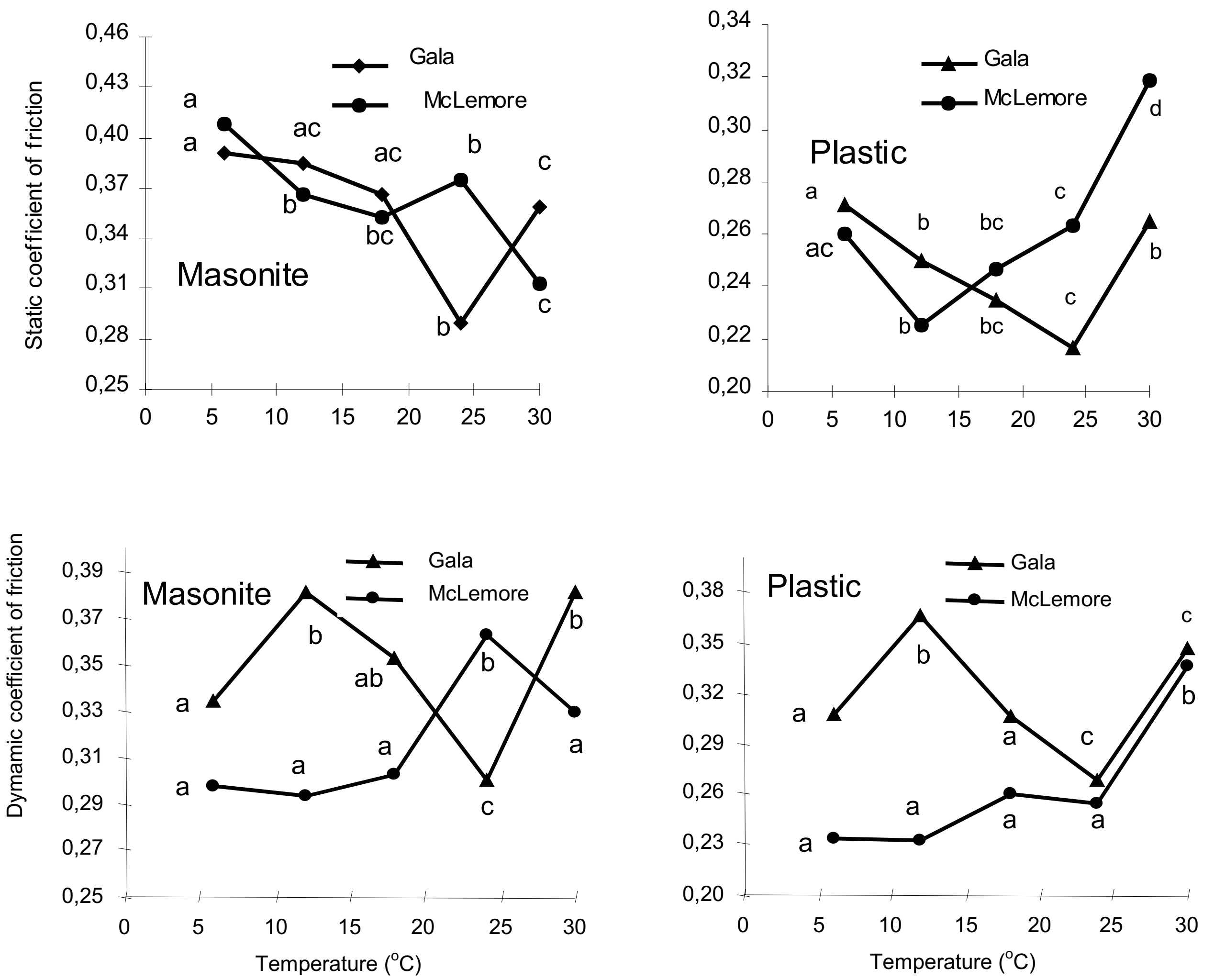

Fig. 2. Effect of fruit temperature on the static and dynamic coefficients of friction against masonite and plastic surfaces for both cultivars. Different letters represent a significant difference in the mean values, within the curve, by the Duncan's multiple range test at the 5% level.

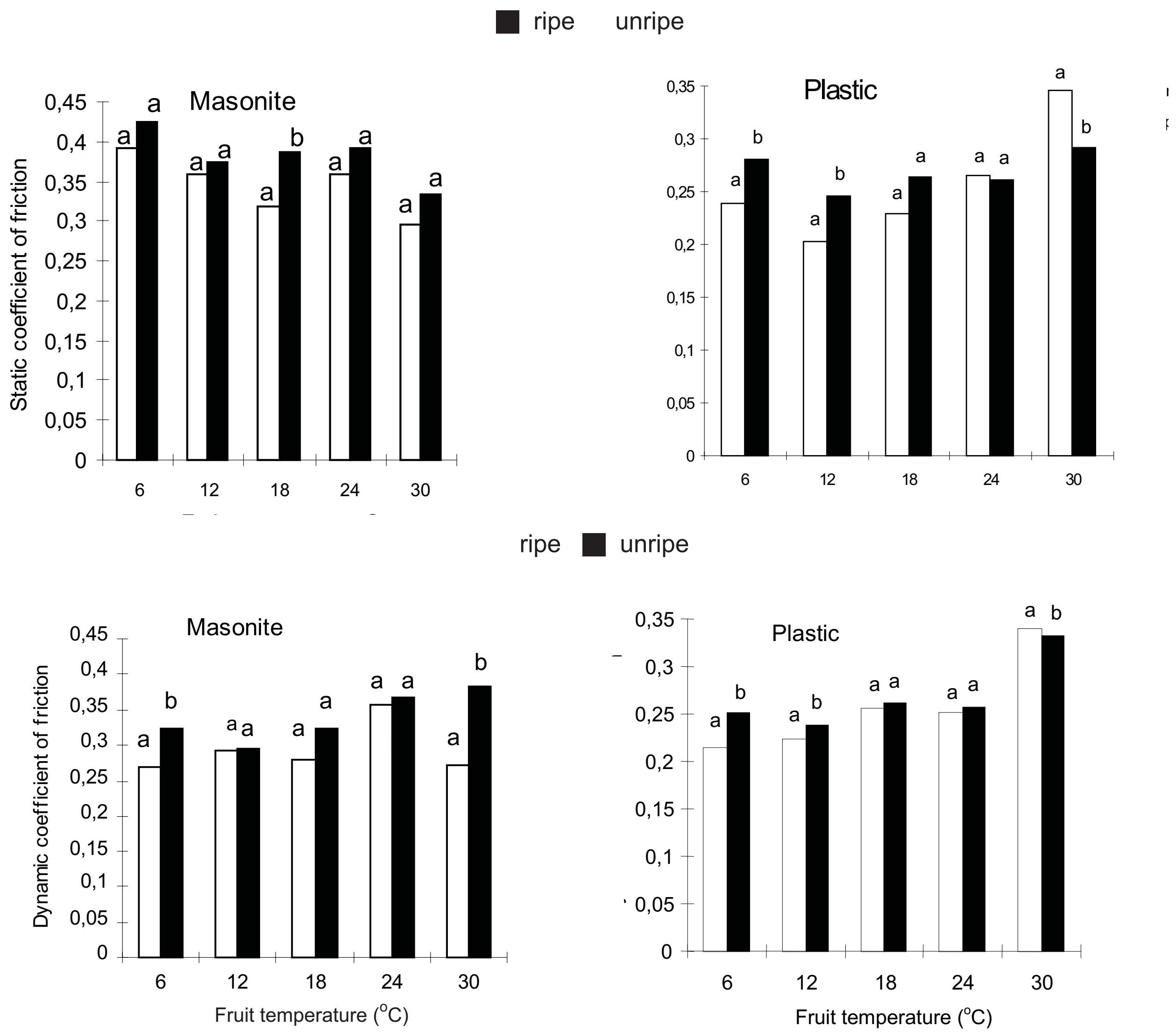

Fig. 3. Effect of ripeness on the static and dynamic coefficients of friction at various temperatures against masonite and plastic for McLemore. Different letters represent a significant difference in the mean values, within ripe and unripe, by the Duncan's multiple range test at the 5% level.

Effect of apple location on tree for Gala

Figure 4 presents the effect of apple location on the tree on the coefficient of friction for the fruit stored at 6 to 30°C. Generally, the static and dynamic friction coefficients of apples from the south side of trees were higher than those from the north side. Differences in the coefficients of friction between the samples taken from the south and north sides of trees were from 4.3 to 37% and were more evident at 12°C. Apples taken from the north side of trees had higher firmness (Table 1) and were less exposed to sunlight than those from the south side of trees.

Effect of storage days of Gala

Figure 5 shows the effect of storage length on the static and dynamic coefficients of friction against masonite and plastic surfaces. Static and dynamic coefficients of friction increased significantly with storage length, except for the static friction coefficient on plastic. It agrees with what has been found for the ripe and unripe McLemore fruit. The effect of storage time was more pronounced for the dynamic than for the static coefficient of friction. Linear relationships fit static and dynamic coefficients of friction versus storage days well (Table 2). However, for the static coefficient on the plastic surface, the second degree polynomials were necessary to get a good fit of the data.

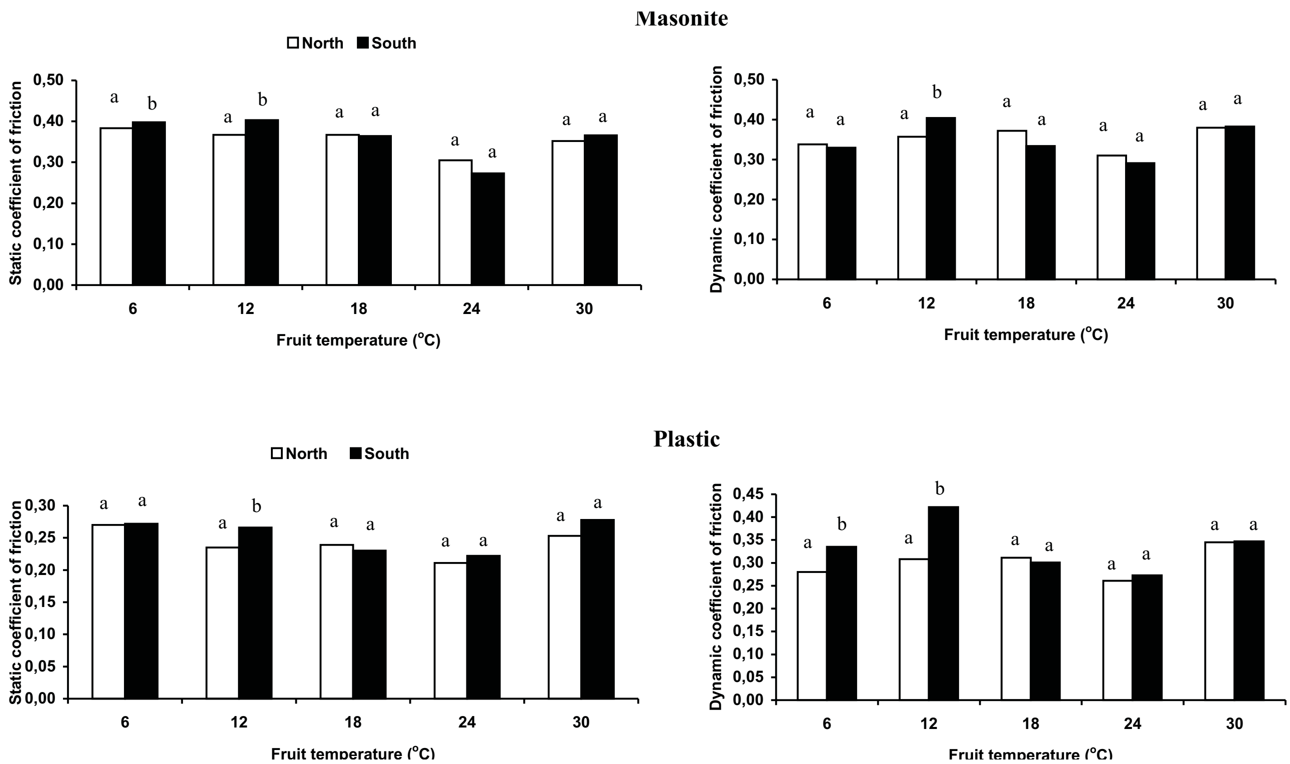

Fig. 4. Effect of apple location on tree on the static and dynamic coefficients of friction against masonite and plastic for Gala. Different letters represent a significant difference in the mean values, within North and South, by the Duncan's multiple range test at the 5 % level.

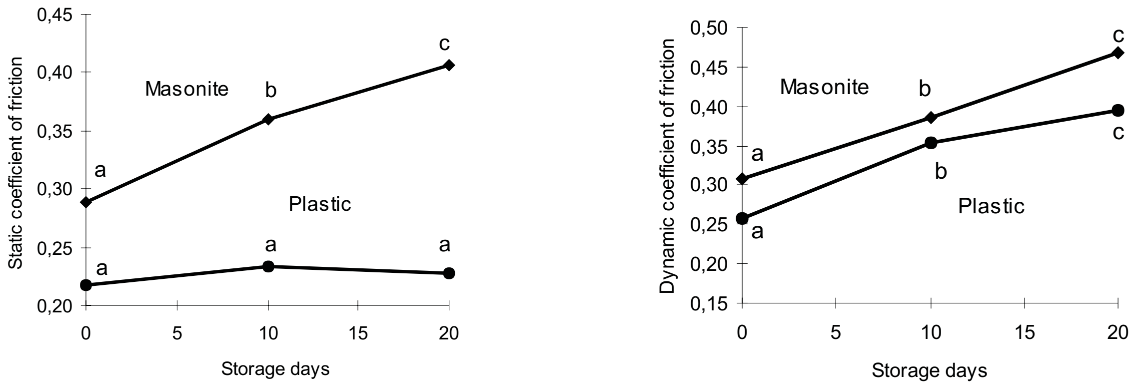

Fig. 5. Effect of storage days on the static and dynamic coefficients of friction on the masonite and plastic surfaces for Gala.

T a b l e 2. Relationship between coefficients of friction and storage time (x = days) for two sliding surfaces against Gala

Coefficient of friction	Sliding surface	Regression equation	R^2
Static	Masonite	$0.0059x + 0.29$	0.985
	Plastic	$-0.0001 x^2 + 0.03 x + 0.22$	1.000
Dynamic	Masonite	$0.0081x + 0.31$	1.000
	Plastic	$0.0069 x + 0.27$	0.945

CONCLUSIONS

1. Some factors, such as ripeness, temperature and apple location on the tree, had significant effects on both static and dynamic coefficients of friction.

2. Static and dynamic coefficients increased from 5 to 40% with fruit ripening, depending on the sliding surface and fruit temperature.

3. Static coefficient of friction significantly decreased with higher fruit temperature (from 6 to 24°C), except for plastic against McLemore.

4. Generally, the static and dynamic coefficients of friction of apples from the side of the tree which is more exposed to sunlight (south part of trees), were higher than those from the opposite side.

5. As apples of Gala were stored for 20 days after harvest, their dynamic friction coefficients increased as much as 53% on the masonite and plastic surfaces.

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