Development of Post-harvest Bulk Handling System of Onions（I）: Characteristics of Friction and Airflow Resistance

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Development of Post–harvest Bulk Handling System of Onions (I) – Characteristics of Friction and Airflow Resistance

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Onion is one of the major vegetables and is also the number one crop from the perspective of storage amount in South Korea. However, the postharvest processing for onions has been accomplished mainly with net package, causing high cost and low efficiency. Thus, development of a continuous and integrated processing system is required to ensure buyer satisfaction and marketing success. The objective was to determine frictional properties and airflow resistance of onion, which are very important to understand the behavior of onions in developing its bulk handling system. Frictional properties of onions, friction coefficient and rolling resistance, were determined by the method of inclined surface. Those values were investigated on three different surfaces (rubber, plywood, and galvanized steel) for four size grades (extra–large, large, medium, small). The airflow resistance, or static pressure drop, was measured with different mixing rate of onion sizes, and equations were developed for prediction of pressure drop in bulk state. The static–friction coefficient ranged from 0.35 to 0.46 for all experiment condition. The highest value was obtained on the plywood surface (0.46±0.06) followed by the rubber (0.41±0.03) and galvanized steel surface (0.35±0.03). This friction coefficient decreased with the onion bulb size. The static–rolling resistance ranged from 8.4° to 17.6° for all sizes, and, unlike the friction coefficient, increased with the onion bulb size. The highest values of rolling angles were obtained on the rubber surface (15.43±4.78) followed by the plywood (13.77±3.77) and galvanized steel surface (10.84±4.26). The airflow resistance increased as the onion size decreased, and a low porosity produced a higher pressure drop in all mixing rate of onion size. The pressure drop in stacked onion was also proportional to the superficial air velocity. Equation developed for prediction of pressure drop with superficial air velocity (SV) and stacking depth (SD) (r^2=0.99) was better than one with stacking depth (SD) (r^2=0.95) only. These results are invaluable to design post–harvest bulk handling system of onions.

Key words: onion, bulk handling, airflow resistance, static–friction coefficient

INTRODUCTION

Recently, onion production and acreage in South Korea are constantly increasing by the changes in dietary patterns and diversification of consumption. Storage onions account for about 50% of the entire storage agricultural commodities by volume, resulting in the number one crop in the nation from a storage amount perspective.

The post–harvest practices for onions in Korea, i.e., carrying, handling, stacking, and storage, have been accomplished mainly based upon net package, such as 20 kgf–net bags. However, a net package–based handling system can cause a decreased efficiency in the handling operation and an increased risk of compression damage. Furthermore, it is very difficult to remove the bulbs decayed during storage, because onion bags were packed in the bulk pallet. With reducing labor pool and increasing wages due to rapid population ageing in Korean rural society, it is urgently required to develop a more efficient post–harvest system that could replace the current 20 kgf–net–package–based handling system.

In order to develop a large–scale and better–efficient postharvest handling system, all processing (harvesting, carrying, curing, grading, and packaging) should be integrated and carefully organized as well. In addition, it is highly recommended to use standard size box pallets.

Friction characteristics between onion bulb and its direct contact surface, and the airflow resistance (static pressure drop) characteristics among stacked onion bulbs in bulk state should be evaluated to prevent the physical damage of onions during the postharvest handling process. These characteristics are also needed to optimize the operating condition of its post–harvest bulk handling system.

Therefore, in order to obtain the necessary data for designing an onion post–harvest bulk handling system, we determined and analyzed the friction coefficient and rolling resistance between the working surface (plywood, rubber, or galvanized steel plate) and onion bulbs. The airflow resistance was also analyzed and modeled in various size distribution of onions.

EXPERIMENTAL DESIGN AND METHODS

Experimental Materials

Onions (*Allium cepa*) used in the study is intermediate turbo cultivar, which is account for more than 70 percent of onion acreage. They were harvested in the late May 2008 and were stored at 5℃ for 5 months. Before the tests, samples were washed using brush and sorted

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Table 1. Geometric properties of the onions used in this study

| Grades[1]	Extra–large (EL)	Large (L)	Medium (M)	Small (S)
Gemmetric mean diameter (D_{gm}) (mm)[2]	92.3 (3.1)	81.3 (2.4)	73.1 (2.7)	55.4 (4.7)
Volume (m³)[3]	4.1364×10^{-4} (0.4099×10^{-4})	2.8240×10^{-4} (0.2554×10^{-4})	2.0546×10^{-4} (0.2286×10^{-4})	0.8372×10^{-4} (0.1296×10^{-4})
Mass (g)	374.3 (32.5)	262.3 (20.4)	182.8 (18.3)	81.2 (9.7)
True density (kg/m³)	904.9 (28.7)	928.8 (29.1)	889.7 (28.9)	974.2 (34.4)
D_e/D_p	1.04 (0.12)	1.03 (0.10)	0.99 (0.08)	0.97 (0.10)
phericity (%)[4]	1.02 (0.08)	1.02 (0.07)	0.99 (0.06)	0.98 (0.08)

Note : ( ) standard devitation
1) standard grade for agricultural products (NAQS, 2008) :
EL; $D_e \geqq 90$, L; $90 > De \geqq 80$, M; $80 > D_e \geqq 60$), S; $D_e < 60$)
2) $D_{gm} = (D_e D_p T)^{1/3} = (D_e^2 D_p)^{1/3}$ for $D_e = T$
3) $V = (\pi/6)(D_{gm})^3$
4) $S = D_{gm}/L = D_{gm}/D_p$ for $D_p = L$
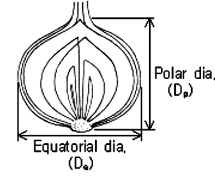
into 4 grades (extra–large, large, medium and small) using the shape sorter by the Korean Grading Standard of Agricultural Products (NAQS, 2008).

Table 1 shows the geometric characteristics for onions in each group.

EXPERIMENTAL DEVICE AND METHODS

Friction Characteristic Test

Experimental apparatus for measuring friction characteristics, such as friction coefficient and rolling resistance is shown in Fig. 1. It consists of a variable–speed motor and a controller to control the rotational speed of the working surface, and an inclinometer to measure the angle of the rotational plate.

① rotating plate
② working surface
③ digital protractor
④ VS moter
⑤ controller
⑥ acryl cylindrical tube

Fig. 1. Test equipment for friction and rolling resistance of onion bulbs.

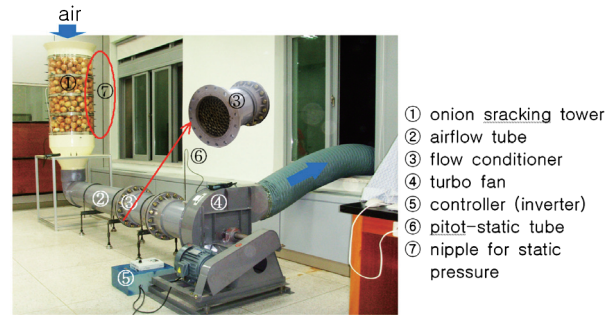**Table 2.** Property of working surface in the test equipment

Plywood		Rubber	Galvanized steel
to wood grain	count to wood grain		
3.98 (±1.27)	15.33 (±1.36)	1.20 (±0.43)	0.62 (±0.03)

Note : ( ) standard devitation, arithmetic average roughness height (R_a) (KS B0161)

Prior to the measurement of the friction coefficients, normal pressure intensity was determined by filling the thin acrylic cylinder (34 cm diameter) with onion bulbs. Table 2 shows the roughness of the working surfaces which contacts with onion bulbs directly.

Airflow Resistance Test

Experimental apparatus for the measurement of airflow resistance of stacked onion bulbs is shown in Fig. 2. It consists of a stacking tower of onion bulbs, an airflow tube installed a flow conditioner inside, a centrifugal (turbo) fan, and a measuring device.

① onion sracking tower
② airflow tube
③ flow conditioner
④ turbo fan
⑤ controller (inverter)
⑥ pitot–static tube
⑦ nipple for static pressure

Fig. 2. Test equipment for airflow resistance of onion bulbs.

Digital Micromanometer (KIMO MP202, 0~1 kPa, Resolution 1 Pa) was used to measure the static pressure difference. Pitot–static tube and digital manometer were used to calculate the air flow rate. An electronic inverter was used to control the operating speed of motor. The bundle–type flow conditioner, composed of a hundred–twenty pipes (2.54 cm diameter, 50 cm length, and 0.1 cm thickness) was installed near the pitot–static tube to measure an air velocity accurately by stabilizing an air flow in the pipe. For measuring the static pressure difference, four nipples (0.6 cm diameter) were installed vertically from the bottom to the top (90 cm height) at a 30 cm interval, and its measurement in different heights was replicated at four times.

The most critical factor in designing a system for

static pressure drop measurement is to minimize the static pressure drop in each element. Considering pressure drop at the equipment and samples, we carefully selected a fan. Pressure loss in the experimental apparatus was induced from both friction loss at the wall of straight pipe and local pressure drop at the reducer, elbow, and flow conditioner, where an air direction can be changed abruptly (Shin, 1998). The total static pressure drop in its apparatus itself was estimated as an approximately 190.5 Pa by calculation. The static pressure drop in the stacked onion bulbs was expected less than 1,000 Pa (Yun *et al.*, 1995; Kim *et al.*, 1996). Therefore, we selected a centrifugal (turbo) fan (air pressure: 1,717 Pa, air flow: 67 CMM (m³/min)) enough to overcome the maximum static pressure drop of 1,190.5 Pa.

An air flow rate was estimated by measuring the average air velocity through the flow conditioner. This air flow rate can be used to calculate the superficial air velocity at stacked area by onion bulbs (Eq. (1)) (Yun *et al.*, 1995; Kim *et al.*, 1996).

superficial air velocity [CMM/m²]

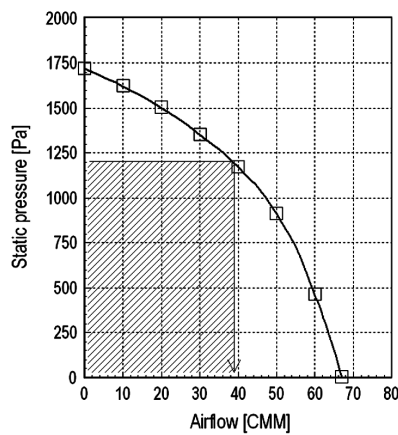$$= \frac{air\ flow\ rate\ through\ stacked\ area}{cross\text{–}sectional\ area\ of\ stacked\ area} \quad (1)$$

RESULTS AND CONSIDERATIONS

Friction Characteristics

The static–friction coefficient, the ratio of the static–friction force and the normal force, is calculated by measuring the tangential value of slope when the object on an adjusted tilted plate starts to slide (ASAE D251.1; Kim *et al.*, 2006; Mohsenin, 1986).

Generally, the static–friction coefficient of agricultural products can be affected by moisture contents, surface pressure, sliding velocity, contact surface temperature and roughness (Kim *et al.*, 2006). Therefore, we set the surface pressure, the size of onion bulbs, and the roughness of the working surface as the variables in calculating static–friction coefficient of onions.

Table 3 shows the static–friction coefficient of onions each condition: working surface, sizes of onion bulbs, and surface pressure. More qualitatively, the static–friction coefficient of onion according to both working surface and onion size is shown in Fig. 4.

The static–friction coefficient of onion was the largest on the plywood, followed by the rubber and the galvanized steel, in all size grades (Fig. 4). These results are in agreement with ones at Egyptian onions (Bahnasawy *et al.*, 2004), dried pomegranate seeds (Kingsly *et al.*, 2006), and bambara groundnut (Baryeh, 2001). However, Topuz *et al.* (2005) reported that the static–friction coefficient of oranges on rubber surface was larger than those of plywood and galvanized steel, which were not significantly different at the P–value of 1% and 0.1% between them.
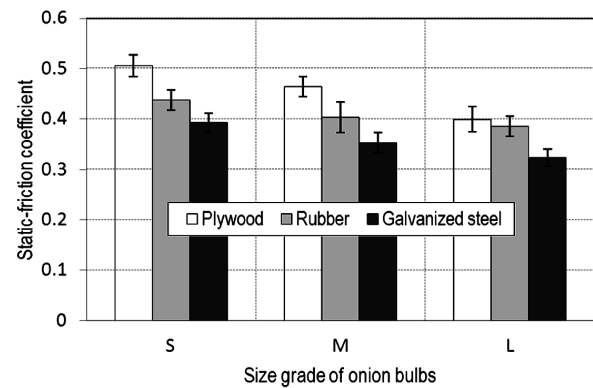

Fig. 3. Performance curve of a centrifugal fan (1717 Pa, 67 CMM).

Fig. 4. Static–friction coefficient according to the working surface and the size of onion bulbs.

Table 3. Friction characteristics and ANOVA results of onions

Items	Surface materials			Size grade			Normal pressure		
	Plywood	rubber	galvanized steel	S	M	L	0.58 kPa	0.98 kPa	1.50 kPa
Static–friction coefficient	0.4561 (±0.0567)[a]	0.4095 (±0.0333)[b]	0.3563 (±0.0344)[c]	0.4459 (±0.0512)[a]	0.4067 (±0.0516)[b]	0.3693 (±0.0484)[c]	0.4267 (±0.0591)[a]	0.3970 (±0.0594)[bc]	0.3982 (±0.0550)[bc]
Static–rolling resistance	13.17 (±3.77)[a]	15.43 (±4.78)[b]	10.84 (±4.26)[c]	8.38 (±2.52)[a]	13.46 (±2.69)[b]	17.60 (±3.02)[c]	–	–	–

Note : All data represent the mean of three replications with 15 determinations; All data represent the mean of five determinations; [a,b,c]letters indicate the statistical difference in rows (significant level at 5%)

Generally, the smaller onion bulbs are, the larger the static–friction coefficients are. However, the effects of surface pressure on the static–friction coefficient were not observed in this experiment. Based on ANOVA analysis, surface material and onion size had a significant effect on the static–friction coefficient (P<0.05), whereas the surface pressure had no significant effect on it (P> 0.05).

The rolling resistance of agricultural products is an important factor in the design of moving and sorting equipment; the optimal slope (stability angle) is crucial when agricultural products roll up or down on an inclined surface and is related to damage of agricultural products.

Contrary to the static–friction coefficient, one of bulk characteristics of onion, the static–rolling resistance is the property for onion bulb, individually. An inclined surface shown in Fig. 1 was employed for this test; the platform was raised until the onion bulb began to roll from its initial equilibrium position (most stable state), when we considered the angle as the rolling resistance (or maximum angle of stability) (Kim *et al.*, 2006).

The static–rolling resistance of onion bulbs is significantly affected by the working surface, size and shape of onion bulb; therefore, we selected the working surfaces, the same as static–friction coefficient test and 3 levels of onion's size grade as experimental parameters. As shown in Fig. 5, the static–rolling resistances were large with the large onions on all working surface. Also, the static–rolling resistance was analyzed as large on the rubber,

medium on the plywood, and small on the galvanized steel with every size grade of onions. Table 3 shows that working surfaces and size grade were found to be statistically significant by ANOVA. These results are similar with Bahnasawy *et al.* (2004) that used the Egyptian onion as the test samples and reported that the static–rolling resistances of onion were large on the rubber, medium on the plywood and small on the galvanized steel. They concluded that the large onions had high static–rolling resistance regardless of the working surface.

Because of the large standard deviation of the static–rolling resistances as shown in Fig. 5, it should be analyzed qualitatively again. For this reason, sphericity was calculated from onion bulb's liner dimension, such as polar and equatorial diameter as in Table 1 (Mohsenin, 1986). With this sphericity, the static–rolling resistance was reanalyzed as in Figure 6.

Variations of the static–rolling resistances of onion bulbs were observed when the sphericity of onion bulb was changed. The static–rolling resistances of onion bulbs were generally decreased as the sphericity increased, but it was increased again starting from the 100–105 % of sphericity. This variation pattern of static–rolling resistance was caused by the changes of test onion bulb to the most stable posture on the test plate.

Airflow Resistance Characteristics

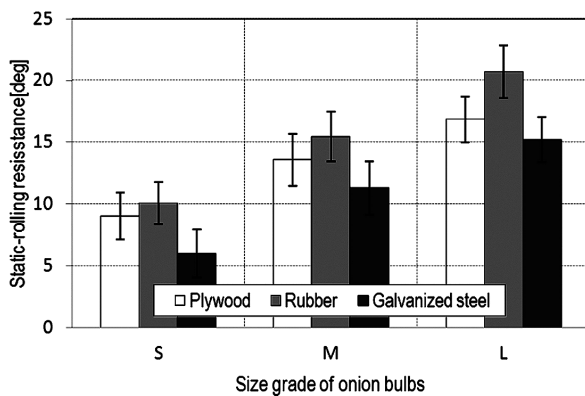The onion bulbs, sorted by the size following the

Fig. 5. Static–rolling resistance according to the working surface and the size of onion bulbs.

Table 4. Size grade and size mixing ratio of onion bulbs

Mixing ratio (number base)	Bulk density (kg/m³)	Porosity[1](%)
whole EL	526.5	41.5
whole L	558.0	38.0
whole M	576.0	36.0
EL:L:M = 1:1:1	549.2	39.0
EL:L:M = 1:2:3	566.1	37.1
EL:L:M = 2:3:1	549.9	38.9
EL:L:M = 3:2:1	531.8	40.9

Note : 1) $P(\%)=(1-D_B/D_T)\times100$, [$D_B$=bulk density (kg/m³), D_T=true density (kg/m³)]

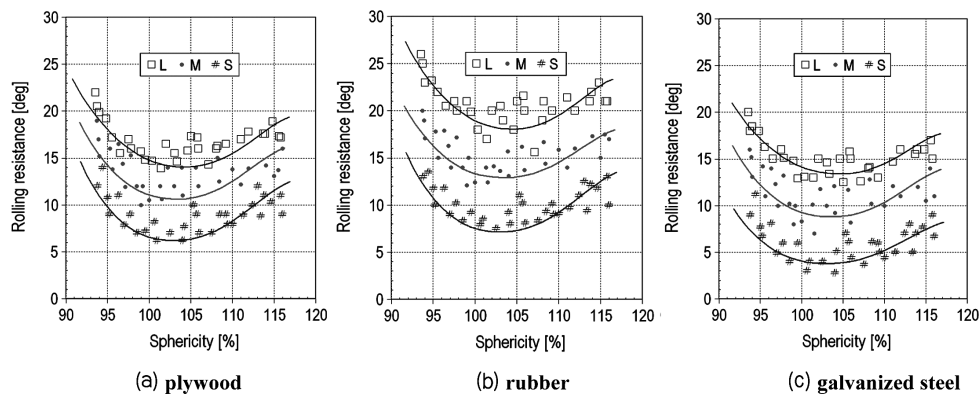(a) **plywood**   (b) **rubber**   (c) **galvanized steel**

Fig. 6. Static–rolling resistance according to sphericity of onion bulbs.

Korean Grading Standard of onions (NAQS, 2007), were stacked to analyze the static pressure drop. These onions were selected and mixed with the ratio shown in Table 4. Static pressure drop according to the superficial air velocity and the stacking depth are shown in Fig. 7.

The static pressure drop was increased as the stacked height and superficial air velocity increased, regardless of the mixing ratios of size. More specifically, in characteristics of static pressure drop by size grades, the

(a) stacking depth, 30 cm

(b) stacking depth, 60 cm

(c) stacking depth, 90 cm

Fig. 7. Airflow resistance according to the size grade and the mixing rate of size grade of onion bulbs.

increasing rate of it according to the stacking height and superficial air velocity was large when size grade was low.

The high correlation between the static pressure drop of onion and porosity can be expected from the proportionality between the size of onion bulb and porosity in Table 4. In characteristics of static pressure drop by the mixing ratios of size, when the mixing ratio in porosity was large, it was low, and the increasing rate of it according to the stacking height and superficial air velocity was low.

Static pressure drop (Pa) and pressure drop per unit stacking depth (Pa/m) was modeled as a function of superficial air velocity (CMM/m²) and stacking depth (cm) (Table 5).

SUMMARY AND CONCLUSIONS

Onion is one of the major vegetables and is also the number one crop from the perspective of storage amount in South Korea. However, the post–harvest processing for onions has been accomplished mainly with net package, causing high cost and low efficiency.

Thorough process including the collection of onion bulbs, carrying, handling, and storage should be performed to achieve low cost and high efficiency in the post–harvest operations.

This study evaluated the friction coefficient and rolling resistance between the working surface such as plywood, rubber or galvanized steel plate and onion bulbs. In addition, the airflow resistance was analyzed with the mixing ratios of size and the size grade for the stacked onion bulbs in bulk state. Results of this study are necessary when designing post–harvest bulk handling system of onions.

The results are summarized as follows.

(1) The static–friction coefficient ranged from 0.35 to 0.46 for all experiment condition. The highest value was obtained on the plywood surface (0.46±0.06) followed by the rubber (0.41±0.03) and galvanized steel surface (0.35±0.03). This friction coefficient decreased with the onion bulb size.

(2) The static–rolling resistance ranged from 8.4° to 17.6° for all sizes, and, unlike the friction coefficient, increased with the onion bulb size. The
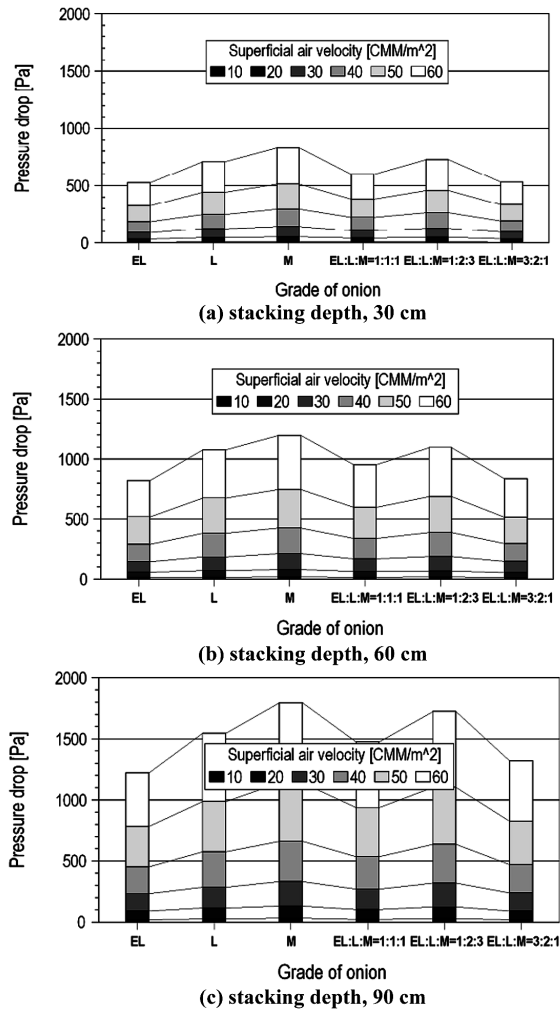
Table 5. Airflow resistance models for the stacked onions

Mixing rate (number base)	PD=a (SV)[b] (SD)[c]			r²	PD'=a' (SV)[b']		r²
	a	b	c		a'	b'	
Whole EL	0.0114	1.7167	0.7838	0.9958	0.4030	1.7650	0.9528
Whole L	0.0187	1.7265	0.7187	0.9974	0.5367	1.7612	0.9388
Whole M	0.0188	1.7472	0.7307	0.9934	0.5653	1.7837	0.9277
EL:L:M = 1:1:1	0.0088	1.7321	0.8717	0.9958	0.5712	1.7144	0.9716
EL:L:M = 1:2:3	0.0136	1.7096	0.8268	0.9933	0.6168	1.7381	0.9547
EL:L:M = 3:2:1	0.0056	1.8048	0.8832	0.9938	0.3638	1.8005	0.9692

Note : PD=pressure drop (Pa), PD'=pressure drop per unit stacking depth (Pa/m), SV=superfical air velocity (CMM/m²), SD=stacking depth (cm)

highest values of rolling angles were obtained on the rubber surface (15.43±4.78) followed by the plywood (13.77±3.77) and galvanized steel surface (10.84±4.26).

(3) The airflow resistance increased as the onion size decreased, and a low porosity produced a higher pressure drop in all mixing rate of onion size. The pressure drop in stacked onion was also proportional to the superficial air velocity. Equation developed for prediction of pressure drop with superficial air velocity (SV) and stacking depth (SD) (r^2=0.99) was better than one with stacking depth (SD) (r^2=0.95) only.

POSTSCRIPT

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