Effect of harvesting time and moisture on mechanical properties of garlic (*Allium sativum L.*) skin

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Abstract: Splitting or cracking of the outer skins reduces the garlic storage life-time and its marketability. To determine the parameters which affect the mechanical properties of garlic skin, white and pink bulbs were taken for this study. Bulbs were harvested in 3 stages, namely 10, 20 and 30 days after cutting off the irrigation. Bulbs were cured in shade at 23±1ºC for 2, 9, 16 and 23 days. Then, dried skins were treated for 5 days at the ambient temperature of 23ºC and relative humidity (RH) of 17%, 38%, 55%, 77% and 95%. The moisture content, thickness and strength, stiffness, stress and strain at breakage were measured. Results showed that at later harvesting and during curing, moisture content, thickness and burst pressure decreased. It was revealed that the multi-directional strength reached its maximum when the skin moisture content of white ecotype and pink cultivar reached 21.28% and 31.72%, respectively. The irrigation having been cut off, the skin strength reduced rapidly after 28 days for white ecotype and 18 days for pink cultivar. The skin strain increased and consequently stiffness decreased when moisture contents were higher than 20%. Moreover, moisture content, thickness, burst pressure and strain at breakage of skins increased with the increase of incubation in relative humidity while the stress and stiffness decreased. Furthermore, pink cultivar skins as compared to white skin were broken with less force easily.

Keywords: garlic, skin, moisture, cracking, strength, postharvest

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1 Introduction

One of the main factors affecting the market value of garlic bulb is the condition of its skin. Splitting of the outer skin adversely affects its quality and storability. During harvesting and the subsequent postharvest process, the bulbs are subjected to abrasive mechanical forces. Moisture content of skins and cloves of the garlic bulbs differed at three stages of harvesting including 10, 20 and 30 days after cut off irrigation. The later garlic bulbs are harvested, the more reduction of their moisture will have (Bayat et al., 2010). Over drying of the outer skins because of delay in harvesting causes the splitting and cracking of the outer skins during packaging and handling. During curing, as a complementary process for increasing shelf life of garlic, moisture content of roots, leaves, outer and inter skins of garlic bulbs decreases (Currah and Proctor, 1990). Garlic bulbs show many similarities to onion bulbs as regards biophysical properties. Because of the lack of studies on garlic skin, results of studies conducted on onion bulbs were taken for comparison.

Outer Skin of the bulbs prevents moisture loss and gas exchange during storage. The environmental conditions, especially relative humidity (RH) of the keeping place, play an important role for skin flexibility and extensibility (Brewester, 1994). At different RH contents of the environment, exchange phenomenon of moisture between air and skins of onions occurs. During postharvest storage, 30%-50% of onion skins split due to mechanical shock or physiological stress. Bulb surface and onion variety influenced the skin thickness such that thicker skins represent less cracking and higher tensile strength (Tanaka et al., 1985).

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Composition and structure of onion skins are other factors known for skin quality. Skins with higher moisture content are stronger in mechanical properties and weaker in stiffness (Hole et al., 2000). Relationship between skin abusing and physical properties of garlic skin has not yet been studied. Determination of the suitable moisture content during postharvest stages with the emphasis on harvesting, curing and storage of garlic skin is the main aim of this study.

2 Materials and methods

2.1 Sample Preparation

White ecotype of Iranian garlic and pink cultivar called Mazand were harvested from a field in Hamedan at 10, 20 and 30 days after cutting off irrigation. All bulbs were cured 23 days at ambient state with the temperatures of 23 ± 3℃ and relative humidity of 37±3 % on the wire shelves. Some factors including moisture content, thickness and skin resistance to breakage were measured in the seven-day intervals, starting from 2 days after harvesting.

2.1.1 Moisture content of outer skin

Two or three layers of the outer skins were peeled and weighted immediately then dried at 90℃ for 48 h until they reached constant weight. Moisture was calculated from the difference between the initial and final weight of the specimens (Hole et al., 2000).

2.1.2 Thickness of the outer skin

Thickness was measured by using a caliper with a sensitivity of 0.01 mm.

2.2 Resistance of skin to breakage

In order to measure skin resistance against cracking (i.e. multi directional forces), some changes were made in an instrument made by Voisey and Lyall (1965) which had been used for measuring skin strength in onion by Hole et al. (2000). The skin pieces of the two outer layers of bulbs with the minimal diameter of 50 mm were placed on compact rubber (with the height of 15.94 mm and diameter of 60.20 mm) which had been stuck on a metal cylinder (with the height of 170.00 mm and the inner diameter of 53.7 mm). Both sides of the cylinder were closed, however, to pass the air a hole which was designed with the diameter of 10 mm in the upper side of the cylinder was pierced through the rubber from top to down. A metal plate was fixed firmly by 3 nuts and screws on skins, which were placed on the surface of the rubber. Compressed air at a rate of 0.03 to 0.05 MPa s^{-1} from the lower part of cylinder was entered and the pressure was increased gently and at breakage point was dropped suddenly and read from the pressure gauge (Figure 1).

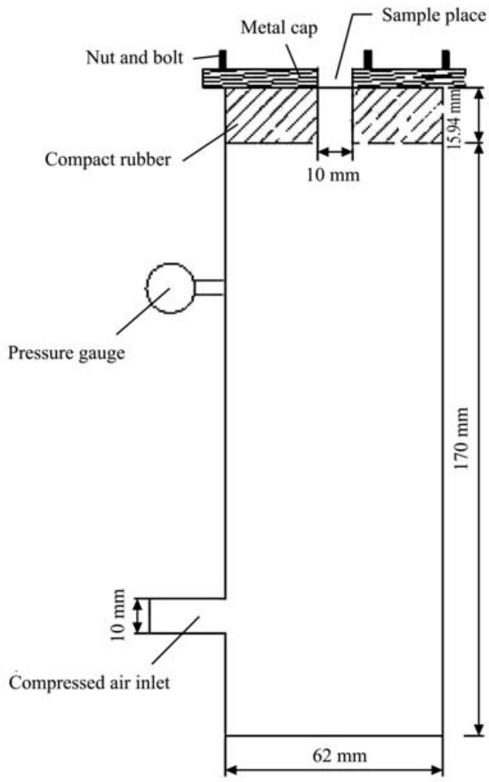


Figure 1 Instrument for measuring strength in garlic skin

The stiffness, stress and strain at breakage (i.e. unidirectional forces) were measured by the method introduced by Hole et al. (2000). For this reason, skin pieces (35 × 5 mm) from perpendicular axis of the outer skin of bulb were cut. The samples were fixed by tape stickers on cards (70 × 20 mm) with a rectangular hole (20 × 7 mm) inserted in the middle of each (Figure 2). By the means of an instron (Hounsfield – H5KS), the samples were stretched at the rate of 5 mm/min. Before the test, two sides of the middle hole were cut carefully by scissors and skin was stretched until the fracture occurred. Stress (force / cross sectional area of skin), strain (extension / original length) and stiffness or Young's modulus (stress / strain) were calculated (Mohsenin, 1986).

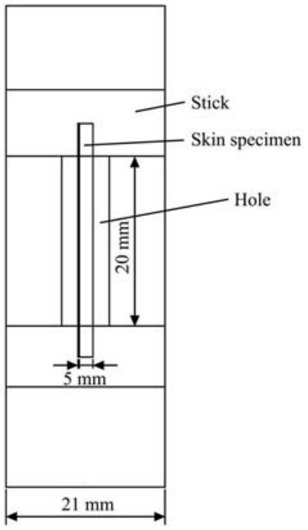


Figure 2 Skin on the cards for extension test

2.3 Effect of RH of environment on the moisture content of skin and strength to breakage

Well dried specimens of garlic skin were incubated at different RH from 17% to 95% at constant temperature of 23 ± 1℃ for 5 days. Pieces of skin were placed in closed chambers (12 × 12 × 12 cm) containing silica gel with RH of 17%, water with RH of 95% and three other saturated salts including $MgCl_2{\cdot}6H_2O$ with RH of 38%, $Ca(NO_3)_2{\cdot}4H_2O$ with RH of 55% and NaCl with RH of 73% (Nyqvist, 1983). Stress, strain and stiffness were measured as explained in the above section by means of an instron.

2.4 Statistical analysis

The results were analyzed statistically by factorial experiment in randomized complete block design. All mean data were reported of triplicate experiments.

3 Results

3.1 Effect of harvesting and curing time on physical and mechanical properties of skin

The loss of the moisture content due to the delay in harvesting and curing decreased the thickness and surface area of skins which in turn resulted in decreasing the burst pressure (Table 1).

Table 1 Moisture content, thickness and burst pressure of garlic skin at different stage of harvesting

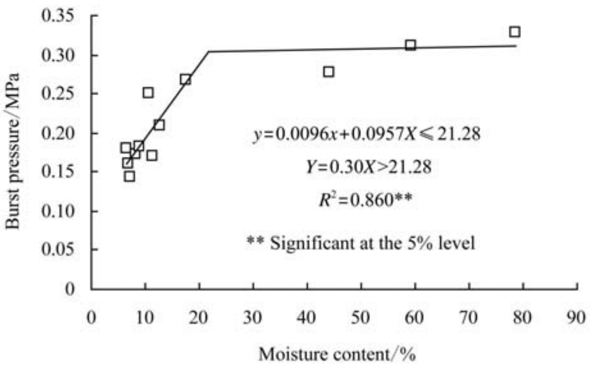
Garlic ecotype	Curing time (days)	10 days after cut off irrigation			20 days after cut off irrigation			30 days after cut off irrigation		
		Moisture content/%	Thickness /mm	Burst Pressure/MPa	Moisture content/%	Thickness /mm	Burst Pressure/MPa	Moisture content/%	Thickness /mm	Burst Pressure/MPa
White	2	78.74	0.256	0.327	44.17	0.177	0.277	17.68	0.193	0.267
	9	59.38	0.193	0.310	12.62	0.170	0.210	9.03	0.173	0.183
	16	10.81	0.203	0.250	11.21	0.163	0.170	8.42	0.173	0.173
	23	6.67	0.172	0.180	7.40	0.150	0.143	7.00	0.177	0.160
	Mean	38.90	0.206	0.267	18.85	0.165	0.200	10.53	0.179	0.196
	Standard deviation	31.14	0.033	0.065	15.09	0.020	0.062	4.49	0.017	0.054
Pink	2	71.28	0.178	0.263	27.32	0.157	0.227	10.72	0.147	0.123
	9	33.07	0.172	0.183	10.96	0.139	0.140	9.44	0.147	0.123
	16	10.15	0.158	0.150	7.45	0.120	0.117	7.49	0.151	0.127
	23	7.35	0.155	0.130	5.48	0.137	0.127	4.88	0.117	0.097
	Mean	30.45	0.166	0.182	12.81	0.138	0.153	8.13	0.140	0.118
	Standard deviation	25.89	0.016	0.054	10.76	0.016	0.048	3.04	0.019	0.038

Note: LSD ($p \leq 0.05$): moisture content = 7.676, Thickness = 0.025, Burst pressure = 0.052.

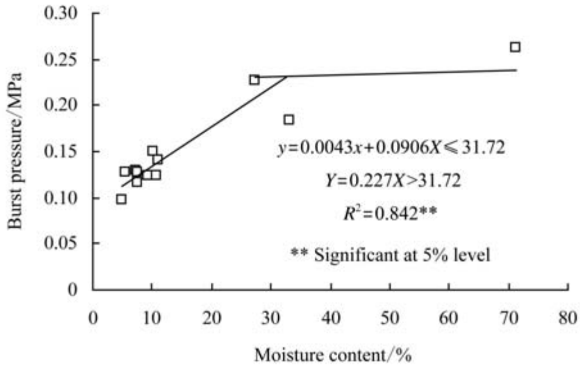
Regression relationship between skin moisture content and burst pressure showed that from the original moisture content to 21.28% and 31.72% for white and pink bulbs, respectively, burst pressure increased sharply. At higher moisture contents, burst pressure was relatively constant and showed minor changes (Figure 3). In constant moisture content, maximum burst pressure at breakage for white was more than that for pink skins.

3.2 Stress and strain at unidirectional fracture of garlic skin

Although no significant difference between stress at the different times of harvesting and curing was observed, stress at the third stage of harvesting (30 days after cutting off irrigation) was less than that in the first and second stages, making it easy to fracture (Table 2). Stress in the skins of the white bulb was more than that in the pink one.



a. White skins



b. Pink (b) skins

Figure 3 Regression relationships between moisture content and burst pressure at breakage for white and pink skins

Table 2 Stress, strain and stiffness of garlic skin at different stage of harvesting

Garlic ecotype	Curing time (days)	10 days after cut off irrigation			20 days after cut off irrigation			30 days after cut off irrigation		
		Stiffness /MPa	Strain /%	Stress /MPa	Stiffness /MPa	Strain /%	Stress /MPa	Stiffness /MPa	Strain /%	Stress /MPa
White	2	3.41	16.96	20.80	4.57	8.03	95.18	4.48	1.24	415.53
	9	6.20	11.97	81.01	5.64	3.77	142.48	4.77	1.24	388.05
	16	5.41	3.06	205.57	4.82	0.97	503.09	3.86	1.29	315.89
	23	4.56	1.27	360.37	6.71	1.96	363.81	4.59	1.12	414.97
	Mean	4.92	8.32	166.94	5.43	3.68	276.14	4.42	1.23	383.61
	Standard deviation	1.93	7.27	141.64	2.63	4.71	193.68	1.08	0.338	118.90
Pink	2	4.51	7.43	76.22	3.96	1.15	358.60	2.75	0.88	328.04
	9	2.48	4.39	91.87	5.23	1.59	405.05	2.31	1.46	164.36
	16	3.27	2.43	147.87	6.33	1.48	427.07	1.72	1.29	127.61
	23	5.29	1.38	398.29	6.88	1.90	361.24	4.68	0.76	600.48
	Mean	3.88	3.91	178.56	5.60	1.53	387.99	2.86	1.10	305.12
	Standard deviation	1.66	3.64	144.49	1.69	0.573	121.51	1.63	0.36	224.80

Note: LSD ($P \leq 0.05$) : Stress = 3.12, Strain = 4.84, Stiffness = 200.10.

Strain with delay in harvest and during curing was decreased and skin of white bulbs showed more values than that of pink one. The slope of linear regression between moisture and strain (Figure 4) for white skin was about twice as much as that for the pink skins. Stiffness of white and pink skins increased with delay in harvesting and curing time but differences at the end of curing were not significant.

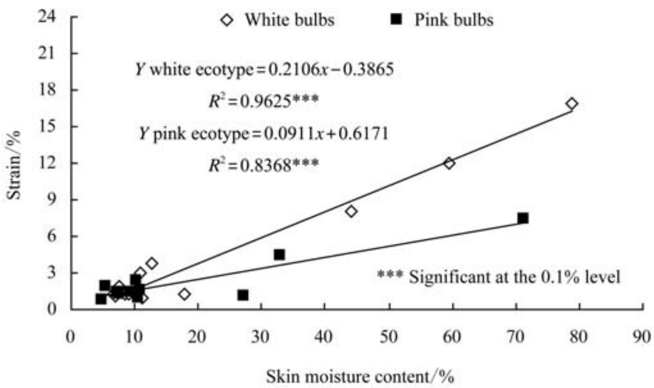
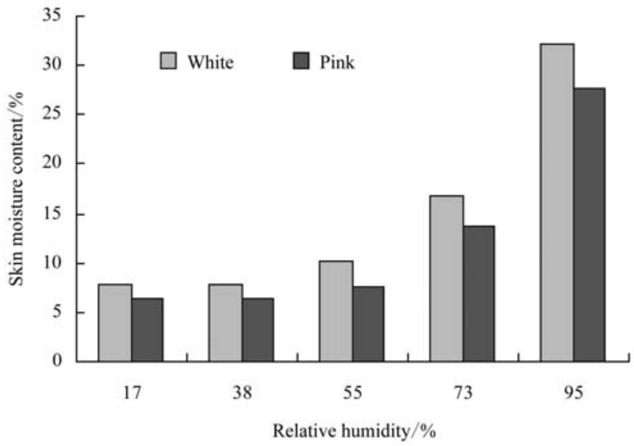


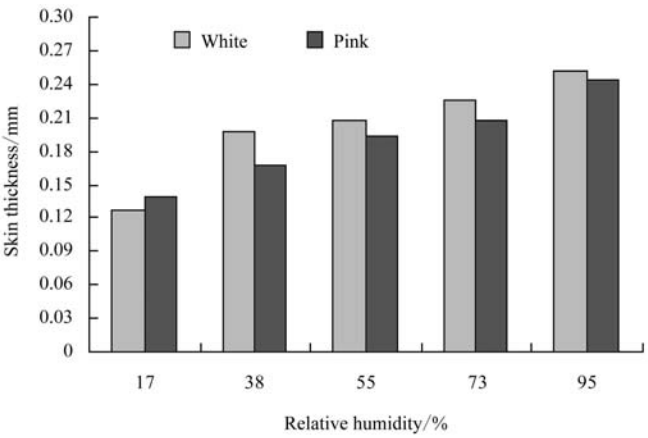
Figure 4 Relationship between moisture content and strain of garlic skin

3.3 Effect of relative humidity of incubation on skin strength

Moisture content absorbed by skins increased at higher RH of incubation (Figure 5). At RH of 95%, the skin of white and pink bulbs with 32.1% and 27.76%, respectively, showed the greatest content of moisture. Differences at the RH of 17% and 38% for white bulbs and at 17%, 38% and 55% for pink bulbs were not significant ($p \leq 0.05$). Thickness of skins increased with the increase of moisture content and RH of incubation.



a. Moisture content



b. Thickness

Figure 5 Moisture content (a) and thickness (b) of skins at different relative humidity at 5 days of incubation

Burst pressure at breakage increased with the increase of RH of incubation. The slope of regression line between RH of incubation and burst pressure at breakage (Figure 6) was relatively equal and showed minor differences.

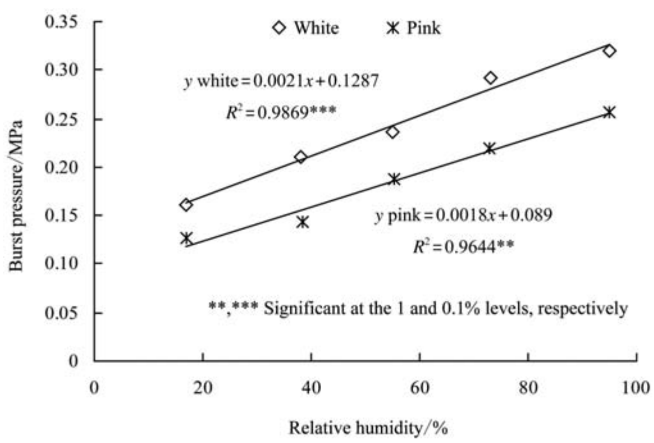


Figure 6 Relationship between relative humidity of incubation and burst pressure of garlic skin

Stress at breakage for higher RH of incubation decreased while the strain increased. Strain of both skins at RH of 17%, 38% and 55% of incubation was not significant but at 73% and 95%, the greatest deformation was seen. Strain at RH of 95% for white and pink skins was 7.34% and 8.58% respectively; consequently, the elongation of pink skin was more than that of white skin.

Table 3 Stress, strain and stiffness of garlic skin at different relative humidity of incubation

Garlic ecotype	Relative humidity/%	Stress /MPa	Strain /%	Stiffness /MPa
White	17	7.92	0.862	913.99
	38	3.33	1.029	351.00
	55	1.91	0.852	237.39
	73	3.00	1.440	217.05
	95	1.35	7.343	18.47
	Mean	3.50	2.305	347.58
	Standard deviation	2.41	2.528	313.79
Pink	17	4.65	1.310	388.49
	38	4.79	1.420	357.30
	55	4.23	1.299	354.03
	73	2.37	1.330	182.11
	95	2.59	8.580	30.79
	Mean	3.73	2.795	262.54
	Standard deviation	1.15	2.893	145.96

Note: LSD ($P \leq 0.05$) : Stress = 0.69, Strain = 0.19, Stiffness = 53.05.

4 Discussion

Skins with lower moisture content showed lower multi directional strength to cracking just as for onion skins reported by Hole et al.(2000). Moisture content of white skins lower than 21% and pink skins lower than 32% cause skin breakage to occur easily; similar results were observed for onion skins at moisture content lower than 20% (Currah and Proctor, 1990). Maximum pressure at breakage of white skin (with 0.3 MPa) is more than that for the pink skin (with 0.23 MPa) which represented higher strength to breakage. This phenomenon is related to lower moisture content and thickness of pink skin as important factors for less strength. Composition and structure of skins have been known as other effective factors for quality of skins as referred to onion skins by Hole et al.(2000).

Calculated data showed that about 28 days after the irrigation cutting off, the moisture content of the outer layers of white skin bulbs reached 21%; consequently, harvesting of bulbs should be ended until 28 days after cutting off irrigation. After 12 and 5 days of curing, moisture content of the outer skins at the first and second stages of harvesting (10 and 20 days after irrigation cutting off) respectively reached critical content. Skin cracking of white bulbs with moisture content of 17.68% was observed if it took 30 days after cutting off irrigation. To harvest garlic bulbs when the tip of leaves turns yellow, it is more suitable than the browning of leaves (Jitendra et al., 1995). Yellowing of the tip of leaves occurs simultaneously 10 days after cutting off irrigation (Bayat et al., 2010).

Harvesting of pink bulbs should be done until 18 days when the irrigation is cut off, about 10 days earlier than that of white ones. 7 days after curing at the first stage of harvesting, the moisture content of pink bulbs reaches 32%. At the second and third stages of harvesting, the moisture content reduces to 27% and 11%, respectively, that are lower than the same content for cracking.

At moisture contents higher than 20%, more extensibility and flexibility were seen because dried skins were not extended as well as humid skins and fracture occurred with the small amount of force.

At higher relative humidity, the air of intracellular was replaced with water like any other viscoelastic properties of biological materials that caused the increment of the moisture content, thickness and burst pressure at breakage of garlic skin which were similar to the results of Hole et al.(2000) on onion skins. Linear regression relationship between relative humidity of incubation and burst pressure at breakage showed that the linear slope of white ecotype is more than that of the pink one because of more strength of white skin at breakage (Figure 6). The relative humidity of incubation was increased due to the increasing of skin moisture content; stress at breakage of garlic skin decreased while strain increased (Table 3). At higher relative humidity for white ecotype, the increasing of the length of skin is more than that of the pink one. Moreover, stiffness of skins at higher humidity of incubation decreased. Although at RH of 95%, skins with highest content of absorbed moisture showed the most flexibility and strength to cracking. Storage at this condition causes the microorganisms to grow easily. RH of 55% to 73% is the most suitable RH for postharvest operation like curing, storage, packaging and distribution. Therefore, RH between 60% and 70% was determined as the best conditions for curing, storage and packaging of garlic. Storage of garlic bulbs at higher humidity tolerated spoilage by microorganisms as reported by Brewester (1994) and Shiina et al. (2005).

5 Conclusions

Due to the outer skins of white and pink bulbs at moisture contents of about 21% and 32% respectively showed the most strength to cracking, during harvesting and the subsequent postharvest stages special conditions should be imposed to keep the skin moisture content not to lower than mentioned values.

The harvesting process should come to an end within maximum 28 and 18 days for white and pink garlic respectively to reduce physical losses because of delay in harvesting and handling from field to storage.

It could be possible to decrease the physical losses by controlling the duration of curing.

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