Effects of Harvesting Stages on Weight Loss and Sprouting of Garlic Bulbs Stored at Room-Temperature

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Summary

Physiological maturity is very important for long term storage of quality garlic bulbs. In order to study the impact of harvesting stages on weight loss and sprouting during room temperature storage this experiment was carried out in Great Leaf Black (GLB) and Ho-mei (HM) garlic varieties. Bulbs of these two varieties of garlic were harvested at various defined harvesting stages, i.e., leaf turn yellow (immature), 50% leaf dry (optimum maturity) and 100% leaf dry (over-mature). Both varieties exhibited distinct morphological variation with the harvesting stage. Bulbs of 'GLB' harvested when immature, exhibited excess weight loss, ovoid–shaped bulbs, wrinkled wrapper skin and browning in comparison with 'HM'. 'HM' reached optimum maturity at the stage at which 50–70% of the leaves were dry while at the 100% leaf dry stage splitting and deformation of bulbs were observed. Bulbs of 'GLB' harvested at the 50% leaf dry stage were not fully mature. Loss of weight of immature bulbs was high during curing. Inner sprout growth and weight loss during storage showed that the internal metabolism was initiated started after 3 months of storage, and the internal sprouting index exceeded the crossed threshold level after 5–6 months.

Introduction

Identification of optimum time of harvest is very important in crop production. Garlic (*Allium sativum* L.) is ready for harvesting when plant tops are dry and fallen, and stems (necks) have begun to soften and are partly dry (Kamenetsky, 2007; Rubatzky and Yamaguchi, 1997).

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The time of harvest of garlic is governed by its subsequent use. Harvesting at the optimum stage of physiological maturity is important to obtain successful planting material, Too early a harvest produces small bulbs that exhibit rapid weight loss and cracking of the bulb wrapper skins, while delayed harvest results in loose (split), discolored and sunburned bulbs, and occasionally cloves even begin to sprout. Both early and delayed harvest cause a deterioration in the market potential (Grieve, 2006; Hickey, 2006; Kamenetsky, 2007). The time of harvest is also affected by the environment and differs with variety, and in garlic can it occur between 95 and 140 days from sowing (Nuevo and Bautista, 2001).

Garlic bulbs go to natural state of dormancy at physiologically mature stage. Maturity stage is also one of the factors responsible for dormancy breakage. For immature bulbs, dormancy is readily broken by maintenance at 35°C, but for fully mature bulbs, dormancy rapidly depletes at 5-10°C (Brewster, 1994; Kamenetsky, 2007; Rubatzky and Yamaguchi, 1997). Dormancy state at the optimum harvest stage renders growth of this crop impossible immediately after harvest, even in an ideal environment (Hannan and Sorensen, 2002; Tabor *et al*. 2004). Dormancy maintenance is important for storage, transport and marketing (Cantwell *et al.*, 2003; Vazquez-Barrios *et al*., 2006).

The potential storage life of garlic differs with variety, and therefore the period for which garlic can be kept in storage varies, even under the same storage conditions. The recommended conditions for commercial storage depend on the expected storage period (Cantwell *et al*., 2003; Hardenburg *et al*., 1986; Wien, 1997). In an ideal storage environment (–1 to 0°C and a RH 60–70%), cured and cleaned garlic bulbs can be kept for up to 12 months (Hannan and Sorensen, 2002). At room temperature (20–30°C), the storage life of garlic is one or two months while at 0°C, properly cured garlic can retain its high quality for 6 months. Sprouting is most rapid at temperatures between 4 and 18°C, and is followed by loss of quality. Under high-temperature storage (>25°C) managing weight loss and decay is a greater problem than dormancy. As with temperature, humidity also plays a vital role in the storage environment, and the maintenance of low humidity (no more than 65–70% RH) is critical for successful storage, as high humidity favors both decay and root growth (Brecht, 2003; Hickey, 2006; Vazquez-Barrios *et al*., 2006).

Estimation of the right time to harvest is very important, and leaf or foliage drying or browning or the start of collapse and neck-softening are not always accurate indicators of maturity stage. For utility reasons, the stage at which garlic is harvested is necessarily a compromise between yield, storage life and quality (Bachmann and Hinman, 2008; Brecht, 2003; Brewster, 1994; Dhatt and Mahajan, 2007; Grieve, 2006). It is important to select a suitable variety, harvesting time and store conditions in order to maintain quality and ensure the long-term supply of garlic (Cantwell, *et al*., 2003). The objective of this study was to observe and analyze

the effects of maturity stages at harvest on the growth, development and storability of garlic under ambient storage conditions.

Materials and Methods

Site and materials

Experiments were carried out at an experimental field of the Horticulture (Olericulture) Department, National Chung Hsing University, Taichung. Bulbs of two garlic varieties, Great Leaf Black (GLB) and Ho-mei (HM), were obtained from Taichung District Agricultural Research and Extension Station (DARES), Taichung, Changhua, for use in the study.

Research design

The garlic used for experiment was of last year's harvest and was stored under a room-temperature environment/at ambient temperature (25±1°C). Before sowing, cloves were separated from the bulbs, and its weight was between 2.0 and 3.0 g for both varieties.

The experimental field was set in a randomized complete block design (RCBD) of three treatments and four replications and the same bulk area was separated into two partitions for the two varieties. Three harvest stages were selected as the three experimental treatments for both varieties namely leaf turning yellow (LTY considering as early or immature stage), the 50% leaf dry stage (50% LD, indicating optimum maturity, i.e., the control harvesting stage), and the 100% leaf dry stage (100% LD, when all leaves and pseudostem look dry indicating over-maturity). Each replication was divided into three plots (100.0 cm x 100.0 cm). For each treatment, 40 healthy, cloves of uniform size, well-wrapped with outer scale, were selected from the outer whorl of the bulb. Cloves were sown in each treatment plot (ten cloves to a row and four rows) on the 12th of October in 2008. From each treatment, six plants were subsequently selected as sample plants. A mulch of well-dried paddy straw was placed on the bed in-between rows after 50% of the plants had emerged. All crop- growing operations were conducted in accordance with the practice of local farmers.

Crops were first harvested in February and last harvested in April. After harvest, crops were maintained in room-temperature storage until December.

Measurements

1. Sprouting degree, internal sprouting index and inner sprout ratio

Sprouting degree was measured twice (before sowing once and after harvest once). Before sowing cloves were separated from each sample bulb. The outer scales were removed and clove length (mm) was measured. A longitudinal vertical cut was made through the centre of the clove

to expose the inner sprout, the length of which was measured in mm using a Vernier caliper (taken as the inner sprout length). The ratio of inner sprout length to clove length was taken as the inner sprout ratio or internal sprouting index and was converted to a percentage to find the sprouting degree.

After harvesting from each treatments and replications, three cloves of six sampled bulbs were selected every month during storage for inner sprout ratio calculation, starting in February and ending in December of the harvest year.

2. Bulb weight

After the plant weight was obtained, the roots were trimmed off and the pseudostem cut at 2.5 cm above the bulb. The fresh bulb weight (FBW) was then recorded in grams (g), and the dry bulb weight (DBW) was obtained after curing of the fresh bulb for 4 weeks under partial sunlight.

The weights of the 6 harvested sample bulbs taken from all treatments were measured at one month intervals between February and December during storage, and loss of weight was calculated by subtracting bulb weight in the current month from that of the previous month.

Data analysis

Standard error was calculated, following the process of Gomez and Gomez (1984). One-way analysis of variance (ANOVA) was applied followed by Fishers LSD test at $P \leq 0.05$ using SAS software (Version 9.1, Institute, Cary, NC).

Results

The experiments were performed in 2008. The harvested products were maintained under storage at room temperature for 9 months from February in order to observe the weight loss and sprout growth. There was no significant difference in fresh bulb weight between bulbs harvested at the three different stages for the 'GLB', the weight ranging from 39.2–41.8 g, but for the 'HM', the fresh bulb weight at the 100% LD stage of harvest (29.0 g) differed significantly at the other two harvest stages (Table 1). Bulbs of the 'GLB' were comparatively larger than those of the 'HM' at all stages of harvest.

The bulb weight after curing differed significantly in both varieties harvested at different stages (Table 1). In both 'GLB' and 'HM', great weight losses of 23.38% and 19.88%, respectively were observed in bulbs harvested at the LTY stage, while low weight losses of 1.2% and 0.97%, respectively, occurred during curing of the bulbs harvested at the 100% LD stage (Table 2).

Weight and weight loss % of bulbs of both varieties harvested at all three stages were analyzed after 9 months of storage (Figure 1). 'GLB' bulbs harvested at the LTY stage exhibited a 36.65% weight loss, while 'HM' bulbs harvested at the same stage showed a 36.99% weight loss. Both varieties exhibited the lowest weight loss after 9 months of storage when harvested at the 100% LD stage at 8.68% for 'GLB' and 7.96% for 'HM' (Figure 1).

Table 1. Weight of 'GLB' and 'HM' garlic bulbs at three harvest stages and after 9 months storage under room-temperature (2008).

Variety	Harvest stages	Bulb weight (g)			Bulb weight loss in 9 months (%)
		at harvest	after curing	after 9 months	
'GLB'					
	Leaf turn yellow	40.2a[x]	30.8c	25.5c	36.65a
	50% Leaf dry	39.2a	36.8b	33.6b	14.33b
	100% Leaf dry	41.8a	41.3a	38.2a	8.68c
'HM'					
	Leaf turn yellow	22.8b	18.3c	14.4c	36.99a
	50% Leaf dry	22.7b	21.4b	18.5b	18.42b
	100% Leaf dry	29.2a	28.9a	26.9a	7.96c

[x] Mean values within same column and same variety with same small letters indicates non-significant as differentiated by the Fishers LSD test at $P \leq 0.05$.

Table 2. Effect of harvest stages on weight loss of 'GLB' and 'HM' garlic bulbs during curing (2008).

Variety	Harvest stages	Weight loss during curing (%)
'GLB'		
	Leaf turn yellow	23.38a[x]
	50 % Leaf dry	6.17b
	100 % leaf dry	1.20c
'HM'		
	Leaf turn yellow	19.88a
	50 % Leaf dry	5.57b
	100 % leaf dry	0.97c

[x] Mean values within same column and same variety with same small letters indicates non-significant as differentiated by the Fishers LSD test at $P \leq 0.05$.

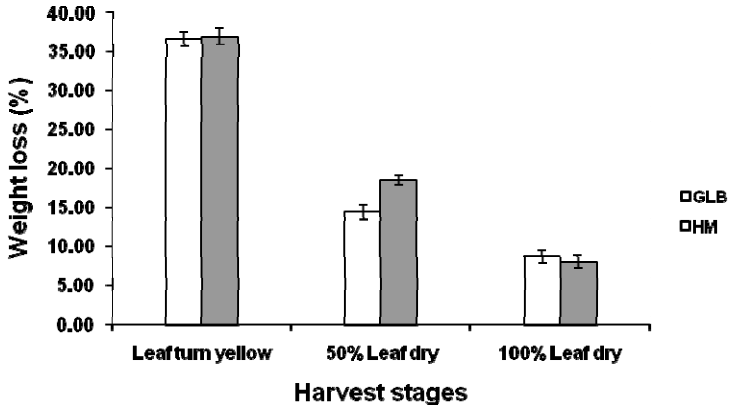

Figure 1. Weight loss of 'GLB' and 'HM' garlic bulbs harvested at three harvest stages and stored for 9 months (2008).
[I] represents standard error bar.

An internal sprouting index of 0.2–0.3 was taken as the baseline value, an index of 1 was taken as representing emergence of the sprout from the clove; and an index of 0.5 to 0.7 was taken as the threshold index, or critical point of sprouting. For bulbs of both varieties harvested

at all stages, the internal sprouting index fell in the baseline range. After 9 months of storage, the internal sprouting index of 'GLB' differed significantly between bulbs harvested at the three different stages (Table 3). In the 'HM', bulbs harvested at the LTY and 50% LD stage exhibited emergence (a sprouting index of 1) at the ninth month, while those harvested at the 100% LD stage exhibited a significantly different value of 0.86 (Table 3). This result demonstrated that the 'HM' garlic sprouts comparatively more rapidly than the 'GLB'.

The trend in weight loss after 9 months of storage was similar for both varieties, in that bulbs harvested at the LTY and 50% LD stages exhibited greater weight loss than those harvested at the 100% LD stage during curing (Figure 2. A and 3. A). Weight loss was static until the third month of storage, after which both varieties exhibited a similar weight loss of bulbs harvested at the respective stages (Figure 2. A and 3. A).

Table 3. Internal sprouting indices of 'GLB' and 'HM' garlic bulbs at three harvest stages and after 9 months storage under room-temperature (2008).

Variety	Harvest stages	Internal sprouting index			Internal sprouting index change in 9 months
		at harvest	after curing	after 9 months	(%)
'GLB'					
	Leaf turn yellow	0.24a[x]	0.24a	0.89b	72.97b
	50% leaf dry	0.23b	0.24a	0.94a	75.45a
	100% leaf dry	0.24a	0.24a	0.83c	70.62c
'HM'					
	Leaf turn yellow	0.23b	0.23b	1.00a	77.11a
	50% leaf dry	0.24a	0.24a	1.00a	76.09b
	100% leaf dry	0.22b	0.22b	0.86b	74.03c

[x] Mean values within same column and same variety with same small letters indicates non-significant as differentiated by the Fishers LSD test at $P \leq 0.05$.

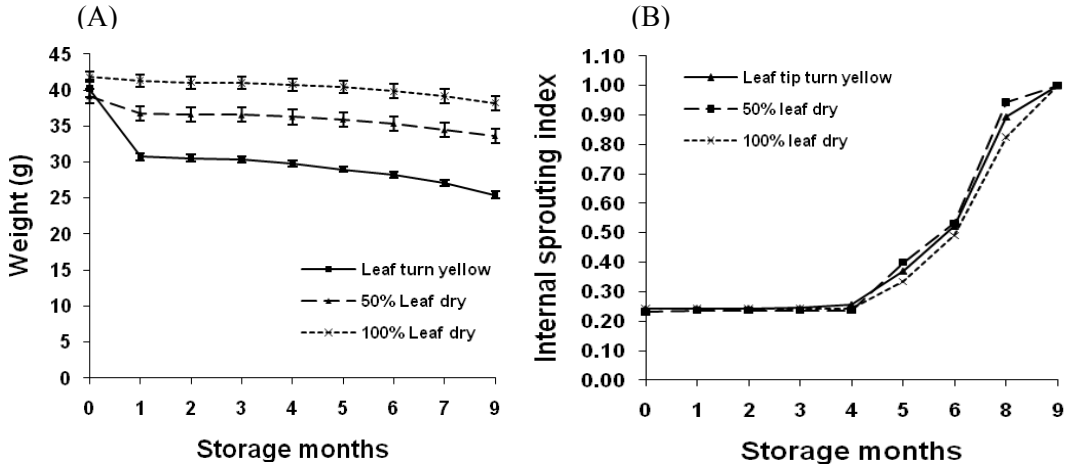

Figure 2. Weight loss (A) and internal sprouting index (B) of 'GLB' garlic bulbs harvested at three harvest stages and stored for nine months (2008).
I represents standard error bar.

The internal sprouting index of garlic bulbs of both varieties after harvesting at all stages of maturity increased after the fourth month of storage and crossed the threshold internal sprouting index of 0.5 after 5–6 months of storage (Figure 2. B and 3. B). In 'HM', a lower internal sprouting index was observed for bulbs harvested at the 100% LD stage in comparison with those harvested at the other two stages of maturity (Figure 3. B).

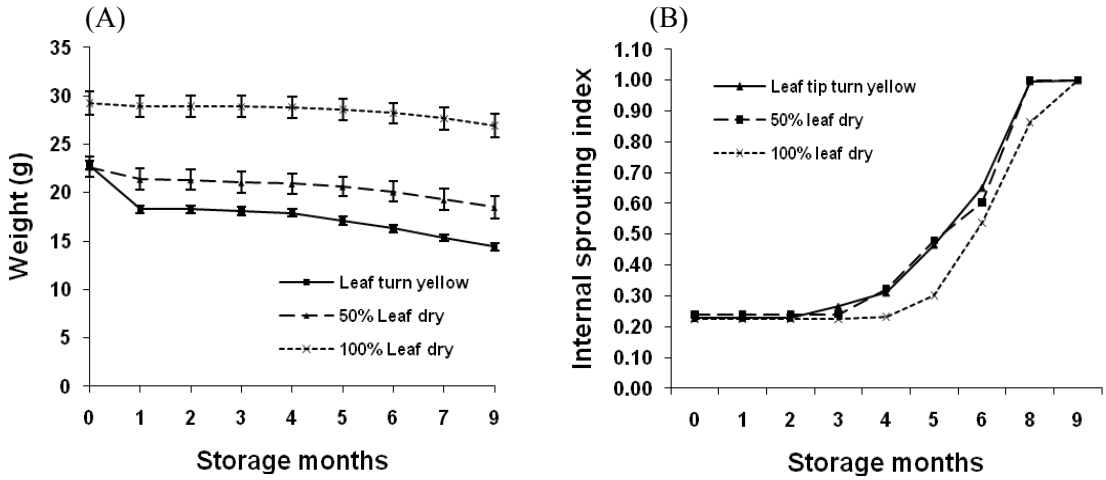

Figure 3. Weight loss (A) and internal sprouting index (B) of 'HM' garlic bulbs harvested at three harvest stages and stored for nine months (2008).
I represents standard error bar.

Discussion

Harvesting stage

Three different stages of maturity at harvest were categorized on the basis of crop morphology: the leaf turning yellow (LTY) stage was taken to indicate the immature or pre-mature stage; the 50% leaf dry (50% LD) stage indicated the optimum harvest stage; and the 100% leaf dry (100% LD) stage indicated over maturity. Variation in maturity stage occurs because varieties differ in terms of their morphological characteristics; this kind of morphological diversity at harvesting maturity in different varieties were discussed in depth by Nuevo and Bautista (2001) and Portela *et al*. (2005).

The studies have confirmed the optimum harvest time of garlic to be when 50–70% of plants exhibit neck softening and the same percentage of leaves have dried: they also mentioned that soil wetness should not be present during harvesting in order to ensure a high quality product. (Brecht, 2003; Grieve, 2006; Kamenetsky, 2007; Natale, 2005; Nuevo and Bautista, 2001; Portela *et al*., 2005). Ledesma *et al*. (1997) specified the optimum harvest stage with respect to minimum dry weight and bulbing index. Nuevo and Bautista (2001) and Portela *et al*. (2005) asserted that greater weight loss during curing, incomplete growth, ovoid-shaped bulbs, poor storability and low yield are signs of an immature harvest, while late harvesting or over-mature harvesting were symbolized by bulb-wrapper scale destruction, splitting of cloves, sprouting (if harvesting coincides with rain) and a defective color, as well as poor storability (Brecht, 2003; Grieve, 2006; Kamenetsky, 2007; Nuevo and Bautista, 2001). Our observations and results were concurrent with these previously described indicators of the different stages of maturity, the effect of rain during harvest, and the results of harvesting at late and early stages of maturity.

Curing

The drying and curing of garlic bulbs prior to storage is important, with between one and three weeks of curing being essential after harvest (Grieve, 2006; Hannan and Sorensen, 2001; Hickey, 2006; Kamenetsky, 2007; Rubatzky and Yamaguchi, 1997). Hence, in this study, all harvested bulbs were cured for 4 weeks. Pezzutti and Crapiste (1997) reported that early harvesting results in severe weight loss during curing and causes a change in skin color and our observations of bulbs harvested early (during the LTY stage) were consistent with this prior report, the color of the outer cover of the garlic harvested when immature in this study having changed to brown. The qualities of the garlic harvested at optimum maturity in this study were attractive.

Storability and sprouting

Weight loss % during curing and after 9 months of storage was greatest in bulbs harvested

at the LTY stage (early harvest) for both varieties, which was in accordance with the results of Nuevo and Bautista (2001) and Vazquez-Barrios *et al*. (2006), the weight losses of bulb, harvested at optimum maturity, during curing and storage observed in the study also matched their results, though the % loss was greater than reported in their studies. The differences in curing weight loss % may have arisen owing to varietal differences, variation in the time of planting, and differences in the micro-climate of the growth area. Cantwell *et al*. (2003), Tabor *et al*. (2004) and Vazquez-Barrios *et al*. (2006) asserted that sprout growth and weight loss are correlated. We found that there was weight loss in both varieties under all treatments throughout the first month (during curing), while internal sprouting index remained constant during that period and then began to increase after three months in both varieties in correlation with weight loss, findings were in accordance with these previous reports. Sprouting and weight loss of bulbs harvested at the 100% LD (over-mature) stage were comparatively slower in the 'HM' variety, possibly wooing to varietal diversity. We observed significant difference in internal sprouting index and weight loss after 9 months of storage between bulbs harvested at the three stages of maturity in both varieties. The nature and trend of weight loss during storage reflects other factors are also responsible for weight loss rather than only sprouting.

At sowing the internal sprouting degree of 'GLB' and 'HM' was recorded to be around 50% and around 60% ('HM'), respectively. Portela *et al*. (2005) and Vazquez-Barrios *et al*. (2006) demonstrated that a sprouting degree of 50–70% reflects the shelf-life threshold in garlic, and therefore the sprouting degrees observed in our study indicated that our planting materials were sowed at the appropriate time.

Vazquez-Barrios *et al*. (2006) demonstrated a 23.7% weight loss of a garlic bulb harvested at optimum maturity and stored for 180 days under perfect storage conditions. Their work also confirmed that an optimally-harvested garlic bulb, when kept at 30°C for 170 days, could attain a sprouting degree of 78%, while bulb also harvested at the optimum maturity attained 100% sprouting degree with a weight loss of 3.5–5% under perfect storage. The weight losses during 9-month storage of bulbs harvested at the 50% LD and 100% LD stages were between 8 and 19%, which indicated our storage process was sufficient to maintain garlic harvested at optimum maturity for a long time.

These experiments to investigate harvest-stage morphology, weight loss and sprout growth under normal room-temperature storage showed that in 'HM' and 'GLB' garlic harvested at optimal maturity, sprouts emerge from the clove after 8–9 months. Inner sprouts began to grow after 3–4 months and reached the sprouting threshold (50%) after 5–6 months. Curing and harvesting at the correct time is very essential for successful long term storage. Our results showed the quality of the 'HM' to be optimum when harvested at the 50–70% LD stage, as when

harvested at the 100% LD stage this variety is prone to the development of rough and split bulbs. Rain during the late stage of harvesting caused increased sprouting, rotting and splitting of bulbs of both varieties, however the 'GLB' was more prone to rotting and the 'HM' was more prone to splitting and sprouting.

'GLB' bulbs required comparatively long harvest duration, our results suggesting that garlic of this variety should be harvested at the time at which 100% of the leaves become dry. Bulb growth was observed to occur until the time at which 50% of the leaves became dry. For both varieties, curing for 3–4 weeks and a good wrapping scale is advisable for long-term storage.

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三種採收時期對大蒜蒜球貯藏於室溫下之重量損失及發芽之影響

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關鍵字： 蒜球、採收時期、未成熟、最適成熟度、過熟

摘要：'大片黑'(GLB)及'和美'(HM)大蒜品種之蒜球於不同採收時期收穫，即葉片轉黃(未成熟)，50%葉片乾枯(最適成熟度)和100%葉片乾枯(過熟)，兩品種在不同採收時期有不同型態變化。'大片黑'葉片於轉黃採收時，會造成蒜球重量明顯下降，形狀會呈現卵圓形，表皮皺縮且色澤較'和美'蒜球呈褐色。'和美'之葉片約50-70%乾枯時達最適成熟度，在100% 葉片乾枯期採收會使蒜球開裂或變形。'大片黑'之鱗莖較大，其植株生長勢較'和美'者佳，但後者成熟較快速。在貯藏期間蒜球內芽體生長且重量下降，顯示於貯藏三個月後，蒜球內部開始進行代謝作用，經5-6個月後內部發芽指數會超過臨界值，此時則無法再繼續貯藏。

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