Chapter 9 from Using Food Science and Technology to Improve Nutrition and Promote National Development, Robertson, G.L. & Lupien, J.R. (Eds), © International Union of Food Science & Technology (2008)

Postharvest Storage of Apples in China: A Case Study

Guipu Li MSc and Duo Li BMed MSc PhD
Department of Food Science and Nutrition
Zhejiang University
Hangzhou, Zhejiang Province, China
E-mail: duoli@zju.edu.cn

ABSTRACT

China, one of the biggest agricultural countries in the world, has a large production of fruits and vegetables each year. The fruit and vegetable industry has undergone rapid development in China over the last ten years. However, after harvest fruits and vegetables easily lose water and nutritional value due to continued respiration; they are also prone to decay because of contamination from spoilage and pathogenic microorganisms. It is therefore very important to keep postharvest fruits and vegetables fresh during storage to maintain their quality, safety and nutrition. The Chinese government has attached great importance to the safety and nutrition of fruits and vegetables. Three main storage methods are widely used in China: traditional storage, cold storage and controlled atmosphere (CA) storage. In this chapter a case study on apples is used to show how the application of storage technologies has maintained the quality, safety and nutrition of fresh apples in China.

FRUIT AND VEGETABLE PRODUCTION IN CHINA

China is the biggest country for fruit production and vegetable export. According to the Chinese Ministry of Agriculture, the area for vegetable cultivation has expanded rapidly in recent years from 11 thousand hectares in 1996 to 180 thousand hectares in 2006. The yield of vegetables was more than 300 million tons in 2007 and the export volume ranks first in the world. At the same time, the area planted in fruit has also increased quickly, from 8.7 thousand hectares in 1996 to 10.7 thousand hectares in 2006, and the total output from 46.53 million tons to 95.99 million tons, accounting for 17% of world fruit production.

At present, the development of the fruit and vegetable industry faces several serious problems in China [1]. One problem is that most fruits and vegetables are grown in relatively concentrated areas and their production is seasonal. Another problem is that the growth of fruit and vegetable production has exceeded the growth in demand in recent years. In addition, the transport of fruits and vegetables between northern and southern China has increased year after year, resulting in a large nationwide distribution of fruit and vegetable products. All of these problems show that a considerable portion of fruit and vegetable products cannot be consumed in a timely manner after harvest. Therefore it is particularly important to preserve these products until they can be consumed rather than go to waste. Effective storage can prolong the shelf life of fruits and vegetables and maintain their quality, safety and nutrition.

ROLE OF STORAGE IN ENSURING QUALITY, SAFETY AND NUTRITION

Postharvest fruits and vegetables remain physiologically active after harvesting. Respiration, which is the primary metabolism, can affect and constrain the life span of fruit and vegetable products, as well as quality and nutrition changes during storage. Continuing respiration after harvest of fruits and vegetables results in quality deterioration and nutrient reduction. Most fruits and vegetables are high in water content (between 65% and 96%), so they very easily lose weight due to transpiration of water during storage. This leads to a deterioration in the quality of fruits and vegetables and may even result in loss of their commercial value. Postharvest fruits and vegetables also produce ethylene during maturation. Ethylene, a ripening agent, can accelerate fruit and vegetable aging, and weaken antiviral and antimicrobial abilities. Post-harvest fruits and vegetables are also prone to decay because

of spoilage and pathogenic microorganism infestation during storage. All of these result in a decline in the quality, nutrition and safety of postharvest fruits and vegetables [2].

Generally speaking, effective storage can create environments with low temperature and high humidity, or low oxygen and high carbon dioxide, or low ethylene and asepsis, which are beneficial for fruit and vegetable preservation [1-4]. Low temperature and high humidity inhibit the enzyme activities which are necessary for respiration and the growth of spoilage and pathogenic microorganisms which make fruits and vegetables decay; it can also prevent water loss. Low oxygen and high carbon dioxide prevent fruits and vegetables from maturing by inhibiting respiration, while low ethylene and asepsis decrease the rate of maturation and the spoilage by microorganisms.

Thus effective storage can postpone fruit and vegetable ripening and senescence, inhibit respiration and transpiration, reduce the formation of ethylene, and increase their antiviral and antimicrobial abilities to maintain their quality, nutrition and safety as long as possible.

MAIN FRUIT AND VEGETABLE STORAGE METHODS USED IN CHINA

Three main methods are currently used for storage of fruits and vegetables in China: traditional storage, cold storage, and controlled atmosphere (CA) storage [1].

Traditional storage

Traditional storage is the most widely used method, particularly in North China where the average temperatures are quite low (annual range 4-13°C). It is applied to the majority of low-value fruits and vegetables and includes simple preservation and ventilation preservation. Simple preservation is one of the traditional fresh-keeping technologies in China and uses storage facilities with a simple structure, requiring fewer building materials, having low construction costs and making use of local climatic conditions such as kiln, cave, trench and shed. Ventilation preservation takes advantage of natural low temperatures to reduce the temperature in the storage room resulting in a low storage cost and easy management. Generally, simple preservations such as kiln storage, cave storage, trench storage, well storage, and burying storage are widely used in the vast rural-producing areas, while ventilation preservation is mainly used in sales areas. Figures 1 and 2 show well storage of sweet potatoes and kiln storage of bananas, respectively.

Figure 1: Well storage of sweet potatoes

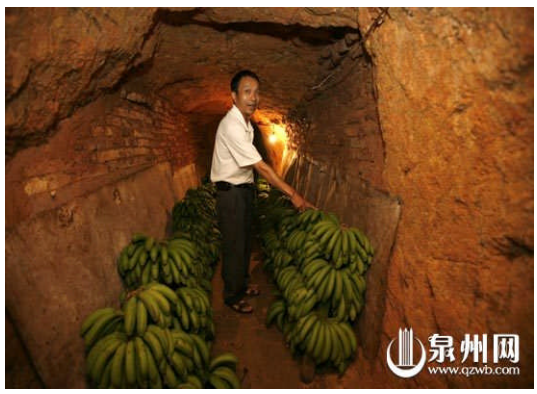

Figure 2: Kiln storage of bananas

Cold Storage

Cold storage involves controlling the temperature in a storage room using mechanical refrigeration. It is used for more than 30 percent of the total fruit and vegetable storage in China. Figure 3 shows cold storage of vegetables in a large cold storage room.

Figure 3: Cold storage of vegetables in a large cold storage room

Controlled Atmosphere (CA) Storage

CA storage is an effective storage method which can achieve the purpose of fruit and vegetable fresh-keeping through naturally or artificially regulating and controlling the temperature, oxygen concentration and carbon dioxide concentration in a permanent storage room. CA storage, though starting very late, has developed rapidly in China. Many large-scale commercial CA storage rooms have been built in China and are used for preserving a variety of fruits and vegetables, especially high-value products such as apples, kiwi fruit, litchis, longan, green cauliflower, mushrooms and peas. Figures 4 and 5 show commercial CA storage facilities in Fujian and Hunan provinces, respectively.

Figure 4: Large-scale commercial CA storage facility in Fujiang province

Figure 5: Medium-scale commercial CA storage facility in Hunan province

CASE STUDY - STORAGE OF APPLES IN CHINA

The annual production of apples in China is about 25 million tons, accounting for 34 percent of the total world production. Of this quantity, approximately 4% are exported, the main export markets being Russia, Philippine, Indonesia and the European Union. The storage and transport processes for apples in China [1;2;5] are presented in Figure 6.

Harvest

Different varieties of apples have different harvest times in China. Usually, the harvest time of early-maturing varieties is about 100 days after florescence, mid-maturing varieties about 100 to 140 days, and late-maturing varieties about 140 to 175 days. Apple which are going to be stored for any length of time should be harvested in advance, usually about 7 to 10 days ahead of the standard harvesting period.

Postharvest Treatment

Precooling and prestorage
In China, apples are harvested from September to October. During this period, the temperature is relatively high so the crop should be precooled by mechanical refrigeration as soon as possible. However, because there is a lack of large refrigeration equipment in China, it is usually precooled by the natural cold weather at night in most areas.

Chemical treatment
Chemical treatment is necessary for precooled apples because it can reduce the incidence of physiological disease and improve the storage performance of apples. In China, precooled apples are often immersion-cleaned by chemical solutions before the preservation process. Many kinds of chemical solutions are used for immersion-cleaning, including calcium chloride solution (3%-6%), ethoxyquin solution (0.25%-0.35%) and thiabendazole solution (1000-2500 mg/kg).

Classification
Classification or grading of apples can be carried out either before or after storage but prior to sale and can be done mechanically or manually, the latter being more common in China. Many classification indices have been confirmed, but color, size, mechanical damage, diseases and pests are the four basic

ones in China. Most varieties of apples are classified according to these four indices. Figures 7 and 8 show mechanical and manual classification of apples, respectively.

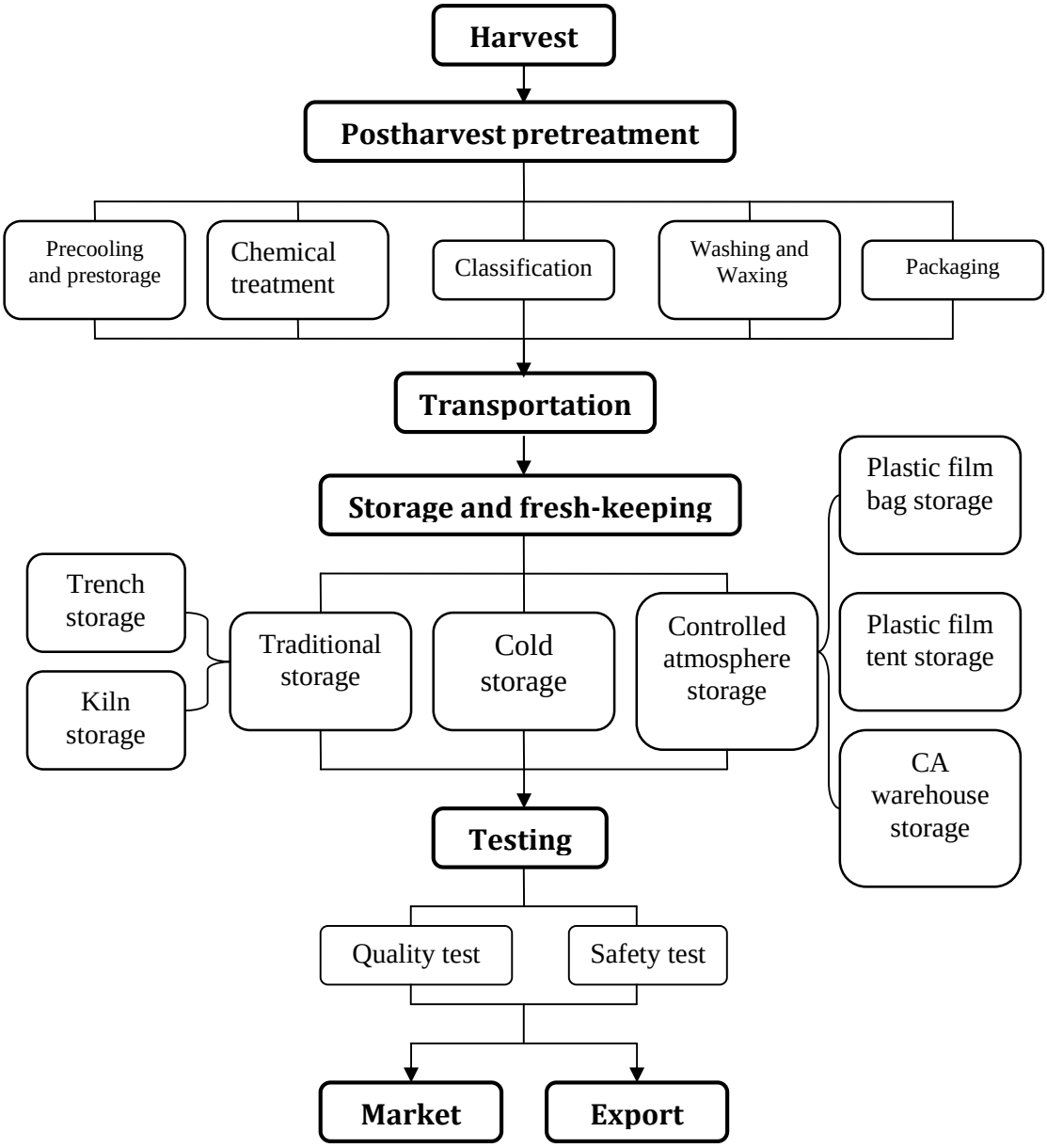

Figure 6: Storage and transport processes for apples in China

Figure 7: Machinery classification of apples

Figure 8: Manual classification of apples

Washing and waxing

The purpose of apple washing is cleaning and sterilization before the processes of transportation and storage. The chemical solutions used for washing apples are hydrochloric acid (1%) or 200-500 mg/kg of potassium permanganate solution or 200 mg/kg bleaching powder. Wax treatment can inhibit water and weight loss of apples during transportation and storage; it can also increase the brightness of the fruit surface. Many kinds of machines are used for apple washing and waxing in China (see Figure 9). Figure 10 and 11 show the washing and waxing process for apples.

Figure 9: Equipment used for apple washing and waxing

Figure 10: Apple washing

Figure 11: Apple waxing

Packaging

Wrapping papers containing diphenylamine or ethoxyquin are widely used for the inner packaging of apples in China. As for the outer packaging, cartons are the main choice. Generally, cartons made of yellow paperboard are used for domestic packaging of apples, while cartons made of high-strength corrugated paperboard are used for export packaging in China (see Figure 12).

Transportation

During transportation of apples, mechanical damage should be avoided and respiration should be reduced as much as possible. The predominant vehicles used for short-haul transportation in China are trucks and sometimes tractors; animal-drawn and manpower vehicles are also used. Truck and railway transport are the main methods of long-distance transportation; refrigerated rail cars are also used but they are not very common.

Figure 12: Manual packing of high-grade export apples in China

Storage

The main storage methods used for apples are traditional storage in northern China, and cold storage in southern China. CA storage is commonly used to preserve some of the top quality varieties.

Traditional storage

Traditional storage is a major method used for preserving apples in northern China. It has the advantage of low cost over other methods. Two main ways of traditional storage are used, one is called trench storage (Figure 13), and the other kiln storage (Figure 14). Trench storage is suitable for preserving late-maturing varieties. Trenches used for preserving apples are about 1-1.5 meters in width, 1 meter in depth and 20-25 meters in length. Before use trenches are filled with wet sand at a thickness of 3-7 cm. Then apples are placed in the trenches at a thickness of 33-67 cm and the trenches covered with a reed mat or maize straw in order to maintain and control the temperature. Although trench storage is simple, it is very effective. The storage period of apples preserved in trenches can be 5 months.

Kiln storage is widely used in apple-producing areas in Loess Plateau in China. There are many discarded kilns in Shaanxi and Shanxi province. Local fruit growers make full use of these kilns to preserve apples. Usually, kilns used for preserving apples are about 3-3.3 meters in width, 3-3.5 meters in height and 30-50 meters in length. During the night, both the doors and air vent are opened in order to take full advantage of natural low temperatures at night to lower the kiln temperature. During the day, both the doors and air vent are closed so as to prevent hot air entering the kiln. In this way, the air temperature of kilns can maintain 0-6°C during the whole year. Generally, kiln storage of postharvest apples begins in the autumn and ends in the spring, or even summer.

Cold storage

Cold storage is the primary way to preserve apples in southern China because of the natural high air temperatures. Usually, apples are stored in refrigerated (-1 to -3°C) warehouses（Figure 15）within 1-2 days after harvest and the temperature of the apples is lowered to -1 to 5°C after 3-5 days. The relative humidity in refrigerated warehouses should be controlled at 90-95% during storage. This method of storage can keep apples fresh for more than 6 months.

Figure 13: Trench storage of apples

Figure 14: Kiln storage of apples

Figure 15: Large-scale refrigerated warehouse

Controlled atmosphere storage

The most widely used CA storage of apples at present in China is simple CA storage (also called spontaneous regulating CA storage or film packaging storage). It is a very common but effective method and includes plastic film bag storage (Figure 16) and plastic tent storage (Figure 17). CA warehouse storage (Figure 18), due to its high cost, accounts for a relatively small proportion and is mainly used for high-grade export apples.

Figure16: Plastic film bag storage

Figure17: Plastic tent storage

Figure 18: High-grade export apples stored in CA warehouse

Quality of Fresh Apples after Storage

The harvest quality of apples, including appearance, taste, texture, safety and nutritional value, declines due to continuing respiration, ethylene production and the occurrence of post-harvest diseases. Quality cannot be improved, but it can be largely maintained during storage. Generally, the main features of quality maintenance during storage are successful control of skin background color and weight loss, high retention of flesh firmness, and retention of soluble solids and acid to give the desired sugar to acid ratio. Therefore, an effective storage method should prevent all of the above quality changes.

Traditional storage, the major method used in apple-producing areas in northern China, can prevent most of the quality changes of apples for 2-5 months (during autumn and winter), while cold storage, the primary method used in southern China, can keep the quality of apples for 3-5 months, and for some varieties more than 6 months. Both traditional storage and cold storage can create a low temperature environment for apples. Temperature is the single most important factor in maintaining quality of apples during storage. Low temperature (0-5°C) can reduce post-harvest respiration, and consequently quality deterioration and nutrient reduction. Cold storage can also create a high humidity (85-95%) environment, which prevents weight loss due to transpiration of water during storage. CA storage, the most effective storage method used in China, can create environments not only with low temperature and high humidity, but also low oxygen and high carbon dioxide. Thus it can maintain almost all the quality features of apples during storage. Today, many combined preservation methods such as traditional storage

combined with plastic bag preservation and chemical treatment, cold storage plus plastic bag preservation and chemical treatment, and CA storage plus chemical and physical treatment, are widely applied in apple storage in China. These combined methods are more effective than a single one.

Much research has been done on post-harvest storage of apples in China. Table 1 summarizes the results of some of this research on quality changes of fresh apples during storage under different conditions.

Safety of Apples after Storage

The safety problems of apples during storage are mainly the result of contamination by spoilage and pathogenic microorganisms. Usually, they exist in post-harvest fresh apples and continue to grow and breed during storage. Spoilage organisms make apples decay, while pathogenic microorganisms produce a variety of apple diseases. Rotten or diseased apples are unsafe, as they could have poisonous and harmful substances produced by spoilage and pathogenic microorganisms during storage.

Effective storage should inhibit the growth and propagation of spoilage and pathogenic microorganisms, or even destroy them. Many storage methods used in China, including traditional storage, cold storage, CA storage and combined storage, can get good results in controlling spoilage and pathogenic microorganism infestation during storage, as they can create environments with low temperatures which are unsuitable for the growth and reproduction of spoilage and pathogenic microorganisms.

Nutritional Quality of Apples after Storage

The nutritional value of fresh apples is very high, being rich in carbohydrates, vitamins and trace elements. However, the nutritional quality of post-harvest apples is prone to decrease during storage due to respiration and transpiration. Among all the nutrients, organic acids, sugars and water are most vulnerable. Post-harvest respiration consumes organic acids and sugars, while transpiration results in water loss. Organic acids and sugars have a direct impact on the taste (sweetness) of fresh apples. Water content affects the appearance, firmness and taste of fresh apples. Researchers have demonstrated that organic acids, sugars and water content of fresh apples decrease very quickly during room temperature storage (20-25°C) [15]. Vitamins, especially vitamin C, are also very easily lost due to oxidation. Significant decreases in vitamin C content (from 9.5 mg to 2.9 mg per100g), were found in fresh apples after two months of storage at room temperature (20°C) [16].

Effective storage should prevent loss of nutrients during the whole storage period. In China, many storage methods can achieve good results in maintaining nutritional quality. Table 2 shows the effects of different storage techniques used in China on the nutritional quality of fresh apples during storage.

CONCLUSIONS FROM CASE STUDY

China, the largest apple producer in the world, has always attached great importance to the storage of apples. Effective storage can maintain the quality, safety and nutritional value of apples for a long time. Many storage methods have been used to preserve apples in China, of which traditional storage, cold storage and CA storage are the most widely used. Traditional storage, the major method used in apple-producing areas in northern China, can prevent most of the quality changes of apples for 2-5 months. It takes full advantage of natural low temperatures in northern China to keep apples fresh during autumn and winter. Cold storage, the most widely used method for preserving apples all over China, especially southern China, can maintain apple

quality, safety and nutritional value for nearly 6 months. Although it costs more than traditional storage, it can be used at any time and in any place. CA storage, one of the most expensive storage methods used in China, can achieve even better results in apple preservation but because of its high cost, it is only used for the preservation of high-grade export apples.

Overall, China is doing very well in apple storage although there are still certain gaps between China and some developed countries. Improved storage methods need to be developed so that the positive effects of storage can be further improved.

REFERENCES (in Mandarin)

1. Wang, X.Y. Food storage and fresh-keeping; Zhejiang Science and Technology Press: Hangzhou, China, 2002.
2. Wu, J.Z.; Zhang, Z.Q. Storage and process of fruits and vegetables. Chemical Industry Press: Beijing, China, 2001.
3. Li, X.H.; Cheng, L. Practical post-harvest technology of fruits and vegetables. Science and Technology Literature press, Shanghai, China, 2001.
4. Li, J.Q. Fruit and vegetable preservation handbook. Chinese Light Industry Press: Beijing, China, 2003.
5. Zhou, J.S. Storage and fresh-keeping for apples. Fruit Growers' Friend 2006, (12), 34-35.
6. Wang, J.S.; Wang, S.P. Study on kiln storage of apples. Ningxia Nonglin Keji 1997, (2), 28-32.
7. Dongfang, H. Studies on changes in quality and physiology- biochemistry of Fuji apple as i nfluenced by 1-MCP and storage regimes. MSc thesis 2003, Northwest Sci-Tec University of Agriculture, Shanxi Province, China.
8. Zhu, X.Q.; Liu, C.J. Effects of MA plus natural preservative treatment on storage quality of Red Fuji apple. Hebei Fruit 2006, (5), 5-6.
9. Wang, Z.H.; Wang, W.H. Effects of 1-MCP treatment combined with different packages on storage quality of apples. Jiangsu Agricultural Science 2008, (1), 192-194.
10. Guo, Y.; Ma, S.S.; Zhu, Y.H. Effects of 1-MCP treatment on postharvest physiology and storage quality of Pink Lady apple with different maturity. Journal of Fruit Science 2007, 24(4), 415-420.
11. Jiang, X.J.; Yi, K.; Liu, Z. Effect of 1-MCP treatment on storage characteristic of Anglin apple. Shanxi Fruit, 2008, (6), 9-10.
12. Ma, H.; Fan, Z.H.; Zhen, W.J. Storage quality of the bagged fruits of gala apple. Henan Agricultural Science 2007, (2), 89-91.
13. Xie, D.S.; Xie, C.Y.; Li, C.Y. Effect of CA storage on quality and nutrients of Jinhong apple. Journal of Fruit Science, 1990, 7 (4), 211-216.
14. Qu, J.F.; Wang, C.L.; Gao, Y.L. Studies on CA storage of apples. Tianjin Agricultural Science, 1993, (2), 22-24.
15. Liu, Q.H.; Xiao, Y.P.; Wang, X.A. Analysis of nutritive composition of apples during natural storage period. Acta Botanica Boreali-Occidentalia Sinica, 2001, 21 (4), 668-672.
16. Wang, Z.J.; Gu, Z.X.; Fang, W.M. Effect of room temperature storage on change of quality and physiology of apple fruit. Journal of Nanjing Agricultural University, 1998, 21 (4), 107-111.
17. Gong, M.B.; Wei, S.W.; Yu, Q.J. Studies on fresh-keeping technologies high quality apples. Northern Horticulture, 1994, (4), 26-27.
18. Li, P.X.; Wang, W.; Hu, H.L. Effect of calcium hypochlorite treatment on storage quality and physiology of Red Fuji apple. Jiangsu Agricultural Science, 2008, (6), 231-233.
19. Chen, D.S.; Su, X.G.; Zhen, Y.H. Effect of 1-MCP treatment on storage quality of Red Fuji apple. Shipin Kexue, 2003, 24 (9), 143-146.
20. Sun, X.S.; Wang, Z.H.; Wang, W.H. Effect of 1-MCP treatment on storage quality of Starkrimson apple. China Fruits, 2004, (5), 9-11.

21. Lv, T.X.; Jiang, X.J.; Yi, K. Effect of 1-MCP treatment on storage quality of 'Yueshuai' apple. Nanfang Guoshu, 2008, (1), 7-9.

Table 1: Effect of different storage methods on quality of fresh apples during storage

Cultivar	Storage method	Storage quality							Reference
		Storage period (months)	Rotten rate (%)	Weight loss (%)	Flesh firmness (kg/cm^2)		Soluble solids (%)		
					Before	After	Before	After	
Golden delicious	Trench storage	5	2.86	12.1	9.99	3.22	16.34	14.76	6
	Kiln storage + Plastic bag preservation	5	0.75	5.2	9.99	5.37	16.34	13.10	
Qinguan	Trench storage	5	7.12	9.0	12.88	3.80	12.80	12.18	6
	Kiln storage + Plastic bag preservation	5	0	4.5	12.88	4.90	12.80	12.92	
Marshal	Trench storage	5	5.56	14.3	9.80	2.84	12.34	12.96	6
	Kiln storage + Plastic bag preservation	5	0	5.7	9.80	4.18	12.34	13.94	
Red fuji	Kiln storage	6	13.3	10.1	13.2	8.6	13.4	13.0	6
	Kiln storage + Plastic bag preservation	6	1.3	4.9	13.2	11.0	13.4	12.8	
	Cold storage	5			8.0	6.9	14.1	15.2	7
	Cold storage + 1-MCP treatment	5			8.0	7.8	14.1	15.0	
	CA storage	6			8.0	6.6	14.1	15.1	
	CA storage + 1-MCP treatment	6			8.0	7.7	14.1	15.3	
	Plastic bag preservation	5	19.7	12.14	12.41	8.49	12.58	11.54	8
	Plastic bag preservation + Polysaccharide treatment	5	10.8	3.75	12.41	8.78	12.58	12.05	
Starkrimson	Kiln storage		27.1	15.8	10.5	4.6	10.8	8.6	6
	Kiln storage + Plastic bag preservation		4.3	8.6	10.5	6.8	10.8	10.7	
	Cold storage	4			8.88	7.98	11.20	10.73	9
	Cold storage + 1-MCP treatment	4			8.88	8.80	11.20	11.92	
Pink Lady	Cold storage	6			8.4	5.9	13.8	16.1	10
	Cold storage + 1-MCP treatment	6			8.4	8.1	13.8	15.2	
Anglin	Cold storage	7			10.5	6.2	14.3	13.3	11
	Cold storage + 1-MCP treatment	7			10.5	9.4	14.3	12.3	
Gala	Cold storage + Plastic bag preservation	3		2.07	10.10	6.81	14.0	13.68	12
Jinhong	Kiln storage	4	45.79		10.48	5.17	12.45	11.23	13
Golden Marshal	Cold storage	8	16.2	8.7	16.2	10.5	12.1	13.3	14
	CA storage	8	1.8	1.0	16.2	14.8	12.1	12.8	

Table 2: Effect of different storage methods on nutritional quality of fresh apples during storage

Cultivar	**Storage method**	Storage period (months)	**Nutritional quality**						Reference
			Total sugars (%)		Total acids (%)		Vit C content (mg/100 g)		
			Before	After	Before	After	Before	After	
Red Fuji	Cold storage	5			0.34	0.14	12.41	5.83	17
	Cold storage + PVC bag preservation	5~6			0.385	0.231	14.84	9.34	
	Cold storage + $Ca(ClO)_2$ treatment	6			0.41	0.29	13.12	11.98	18
	1-MCP treatment	5			0.30	0.98	19.52	12.01	19
Starkrimson	Cold storage	6			0.242	0.121			20
	Cold storage + 1-MCP treatment	6			0.242	0.201			
	Cold storage + PVC bag preservation	5~6			0.376	0.253	9.89	5.47	17
Jinhong	Kiln storage	4	9.21	9.70	0.77	0.43	8.150	2.078	14
	Kiln storage + Plastic bag preservation	4	9.21	10.85	0.77	0.57	8.150	2.987	
	Kiln storage + Plastic tent preservation	4	9.21	10.23	0.77	0.54	8.150	5.048	
Gala	Cold storage + Plastic bag preservation	3	12.20	8.89	0.33	0.10			12
Jonagold	Cold storage + PVC bag preservation				0.321	0.249	15.12	11.04	17
Anglin	Cold storage	7	10.98	8.23	0.28	0.07			11
	Cold storage + 1-MCP treatment	7	10.98	9.23	0.28	0.19			
Golden Marshal	Cold storage + PVC bag preservation	6			0.658	0.433	10.52	7.24	17
Yue Shuai	PE bag preservation	3	11.45	9.25	0.319	0.168			21
	PE bag preservation + 1-MCP treatment	3	11.45	10.05	0.319	0.225			
	Cold storage + PE bag storage	7	11.45	8.72	0.319	0.110			
	Cold storage + PE bag storage + 1-MCP treatment	7	11.45	9.61	0.319	0.208			