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# Furrow-ridge mulching managements affect the yield, tuber quality and storage of continuous cropping potatoes

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**Abstract:** The effect of FP (a flat plot without mulch), FPM (a flat plot with film mulching), RM (on-ridge planting with full film mulching), and FM (on-furrow planting with full film mulching) on the tuber and its storage quality of continuous cropping potatoes was investigated. The results showed that with the increase of continuous cropping years, the potato yield was reduced year by year. The furrow-ridge mulching film can significantly increase potato yield and reduce small tubers. Among them, the yield of RM was the highest. From the perspective of tuber quality, RM had the highest dry matter content and starch content, while FP had the lowest. Meanwhile, the reducing sugar content of FP was always higher than that of other treatments. The amino acid content and vitamin C content of FPM, RM, and FM were higher than FP before and after storage. In addition, with the extension of storage time, the dry matter content, starch content, amino acid content, and vitamin C content of all treatments decreased, while the content of reducing sugar increased significantly. Thus, on-ridge planting with full film mulching (RM) can effectively improve potato yield and tuber quality before and after storage.

**Keywords:** *Solanum tuberosum* L.; cultivation pattern; potato production; quality evolution; continuous cropping obstacle

Potato is a dominant crop in the semi-arid region in the west of the Loess Plateau of China. However, there was the poor productive efficiency of potatoes due to scarce rainfall and frequent drought (Wang et al. 2005, Qin et al. 2013). The furrow-ridge mulching managements resulted in a great increase in yield, cultivated area, and benefits of potatoes in the semi-arid region in the Loess Plateau of China (Wang et al. 2005, Qin et al. 2014). However, total limited cultivated area and difficult crop rotation (insufficient heat and water) resulted in the prevalence of continuous potato cropping, so that the successive cropping obstacles occurred (Qin et al. 2014, 2016, 2017).

Some research showed that the continuous potato cropping caused the low soil organic content, worsened soil physico-chemical properties, and damaged soil microfloral structure, which resulted in the continuous cropping obstacles occurring with reduction of soil nutrient uptake and poor quality of tubers (Aparicio and Costa 2007, Qin et al. 2017). For this reason, some researchers proposed reducing or alleviating the damage of continuous cropping obstacles to the crops by changing such planting patterns as on-ridge planting with full mulch, on-furrow planting with full mulch, on-ridge planting with half mulch, and on-furrow planting with half mulch (Qin et al. 2016, 2017). Currently, there are more research reports on the furrow-ridge mulching planting patterns for drought resistance and increase of potato tuber yield, suggesting these patterns could exert the effects of rainfall collection, heat increase,

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improvement of the micro-ecological environment, and water-nutrient contents and use efficiency to increase the potato yield (Zhao et al. 2012, Zhou et al. 2012, Qin et al. 2014). However, very little research was conducted on the effects of the furrow-ridge mulching planting patterns on tuber quality and quality evolution during storage at the same time of improving potato yield. Herein, this study is intended to explore the effects of different mulching patterns and tuber storage time on the quality characteristics of continuous cropping potato tubers. In this way, it could provide the theoretical bases and technical supports for further designing a potential technique system on alleviating continuous cropping obstacles and improving the furrow-ridge mulching patterns.

## MATERIAL AND METHODS

**Description of the experimental site.** The field experiment was conducted in 2016, 2017, and 2018 at the experimental station (35°33'N, 104°35'E, elevation 1 874 m a.s.l.) of Rain-fed Agricultural Research Institute of Gansu Agricultural University, at Dingxi, Northwest China. The experimental site had a loessal soil with deep soil layer, high water-storing capacity, the wilting point at 7.3% and mid-level soil fertility, in the Chinese soil taxonomy (Chinese Soil Taxonomy Cooperative Research Group 1995), and had a Calcaric Cambisols in FAO soil map of the world (FAO 1990), which is typical of the Loess Plateau. The average long-term annual rainfall at Dingxi is 396 mm. Daily maximum temperatures can reach 38 °C in July, while minimum temperatures can drop to –22 °C in January. The annual average radiation is 5 929 MJ/m$^2$, and sunshine 2 477 h per year. The experimental area is located in the main potato producing area in Northwest China, and the basic chemical characteristics are suitable for potato growth. In addition, potatoes have a wide range of pH adaptation, which can meet the normal growth of potatoes despite a slightly higher pH level in the test site (Table 1).

Table 1. Chemical properties of the soil before treatment application collected in March

| Year | pH | Available nitrogen | Available phosphorus | Available potassium |
|---|---|---|---|---|
| | | (mg/kg) | | |
| 2016 | 8.69 | 18.12 | 23.64 | 428.25 |
| 2017 | 8.5 | 17.16 | 21.3 | 391.5 |
| 2018 | 8.37 | 15.42 | 17.52 | 365.43 |

**Experimental design.** Field experimental design: this experiment as a locating continuous cropping trial in fields was designed with four treatments (Figure 1). The following four treatments were used in a randomised, complete block design with three replicates in each year: (1) a flat plot without mulch (FP) (Figure 1A); (2) alternating strip mulched with plastic film with a strip of bare land with no ridges (designated as FPM) (Figure 1B); (3) alternating fully mulched wide ridges with narrow ridges and ridge planting (designated as RM) (Figure 1C); (4) alternating fully mulched wide ridges with narrow ridges and furrow planting (designated as FM) (Figure 1D).

The potatoes were planted in different mulching patterns in 2013 as the first year of the experiment

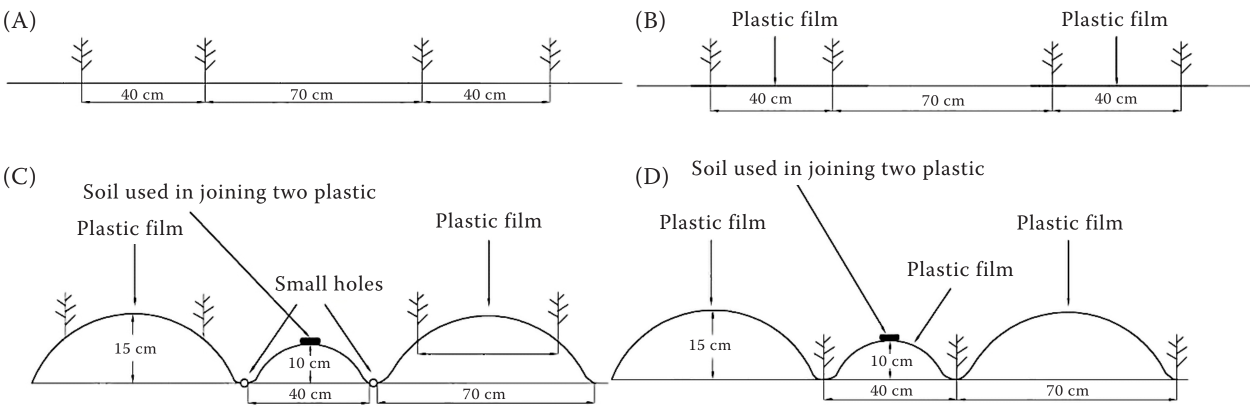


Figure 1. The schematic diagrams of different treatments in both experimental years. (A) FP – a flat plot without mulch; (B) FPM – alternating strip mulched with plastic film with a strip of bare land with no ridges; (C) RM – alternating fully mulched wide ridges with narrow ridges and ridge planting, and (D) FM – alternating fully mulched wide ridges with narrow ridges and furrow planting

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(the previous crop was Jerusalem artichoke), the first continuous cropping began in 2014, the third in 2016, the fourth in 2017, and the fifth in 2018. The potato cultivar Xindaping was planted at the density of 45 460 plants/ha on 25 April 2016, 26 April 2017, and 26 April 2018 using a dibbler. Plots were 16 m × 11 m in size. There was a buffering area between plots (100 cm) and between blocks (120 cm). All potatoes were harvested on 1 October 2016, 4 October 2017, and 2 October 2018. Nitrogen, phosphorus, and potassium were fertilised in the plots at a rate of 44.8 kg/ha, 11.76 kg/ha, and 57.6 kg/ha, respectively. Field management measures included weeding every 7 days, and when the occurrence of insect pest spraying drug control.

Experimental design of storage: one part of tubers was used for quality analysis at once after harvest, the other part was placed for 180 days in a storehouse in Gansu Agricultural University respectively at a storing temperature of 4 °C and relative humidity of 80%. The quality analysis was performed every 60 days, and each treatment was in three replicates.

**Determining items and methods.** The yield was calculated based on plot yield, with 10 plants being taken from each plot at harvest mechanically, to assess tuber size and class. There were three classes: large ≥ 250 g, medium 50–250 g, and a small ≤ 50 g. The percentage of tubers in each size class was determined. The dry matter content was determined by the oven-drying method, the starch content by iodine colorimetric method, the reducing sugars content by 3,5-dinitrosalicylic acid (DNS) colorimetric method, the soluble protein content by CBB G-250, the amino acids content by ninhydrin colorimetric method, and the vitamin C content by the ultraviolet rapid analysis method (Zhang and Tian 2007).

**Data processing.** The data processing was done by Microsoft Excel 2010 (Microsoft 2010, Redmond, USA), and the variance analysis was conducted by IBM SPSS Statistics 19.0 (IBM 2010, Armonk, USA), where the last significant difference test ($LSD_{0.05}$) was employed for comparison of mean values from treatment and different storage time if the *F*-tests were significant at a probability level.

## RESULTS AND DISCUSSION

**Yield and yield components.** With the extension of continuous cropping years, the yield of FP decreased significantly. Besides, FP was significantly lower than that of FPM, RM, and FM (Figure 2). The yield of RM was significantly higher than that of other treatments, FM was significantly higher than FP and FPM in three years. The furrow-ridge and mulching significantly increased potato yield and may alleviate the continuous cropping obstacle of potato. RM always had a higher percentage of large tubers, 5, 4.8, and 3.43% higher than FP in the three years. The percentage of small tubers of FP was significantly higher than that of other treatments. That is, furrow-ridge and mulching could significantly reduce the percentage of small tubers (Table 2).

Previous studies indicated the furrow-ridge mulching management could improve soil water and heat conditions around crop root zones and facilitated growth and development of crops to increase potato yield and tuber quality (Zhao et al. 2012, Gan et al. 2013, Qin et al. 2014, Wang et al. 2015a). Particularly,

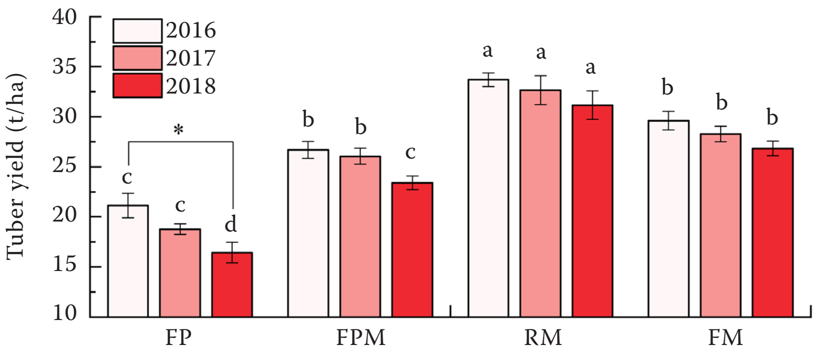


Figure 2. Effects of ridge-furrow mulching planting pattern on potato tuber yield. Values followed by different lowercase letters. *$P \leq 0.05$. The lowercase letters for different treatments in the same year, * for the same treatment in different years. The error line is the standard error. FP – a flat plot without mulch; FPM – alternating strip mulched with plastic film with a strip of bare land with no ridges; RM – alternating fully mulched wide ridges with narrow ridges and ridge planting; FM – alternating fully mulched wide ridges with narrow ridges and furrow planting

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Table 2. Yield components of potato under different cropping patterns

| Treatment | 2016 | | | 2017 | | | 2018 | | |
|---|---|---|---|---|---|---|---|---|---|
| | large tubers | medium tubers | small tubers | large tubers | medium tubers | small tubers | large tubers | medium tubers | small tubers |
| | (%) | | | | | | | | |
| FP | 11.47$^{b}$ | 55.50$^{b}$ | 33.03$^{a}$ | 10.70$^{c}$ | 57.60$^{b}$ | 31.70$^{a}$ | 12.30$^{b}$ | 55.63$^{b}$ | 32.07$^{a}$ |
| FPM | 14.70$^{a}$ | 60.20$^{a}$ | 25.10$^{b}$ | 13.50$^{b}$ | 61.80$^{a}$ | 24.70$^{c}$ | 12.87$^{b}$ | 57.00$^{b}$ | 30.13$^{b}$ |
| RM | 16.47$^{a}$ | 56.37$^{b}$ | 27.17$^{b}$ | 15.53$^{a}$ | 61.47$^{a}$ | 23.00$^{c}$ | 15.73$^{a}$ | 59.87$^{a}$ | 24.40$^{d}$ |
| FM | 14.87$^{a}$ | 57.60$^{ab}$ | 27.53$^{b}$ | 14.50$^{ab}$ | 57.10$^{b}$ | 28.40$^{b}$ | 14.10$^{ab}$ | 59.17$^{a}$ | 26.73$^{c}$ |

Value followed by different lowercase letters in the same column are significantly different at $P \leq 0.05$. FP – a flat plot without mulch; FPM – alternating strip mulched with plastic film with a strip of bare land with no ridges; RM – alternating fully mulched wide ridges with narrow ridges and ridge planting; FM – alternating fully mulched wide ridges with narrow ridges and furrow planting

the fully mulched ridge planting technique enabled continuous cropping potatoes to remain a higher tuber yield and sound quality, and improved soil microbial flora structure and diversity so as to facilitate maintenance of good soil quality (Qin et al. 2016, 2017). This is similar to the results of our study.

**Tuber dry matter content.** Before storage, the dry matter content of furrow and ridge mulching was significantly higher than FP, and the dry matter content of RM was the highest. According to Wang et al. (2015b), the furrow-ridge and mulching patterns could substantially promote the growth of continuous cropping potatoes and increase the amount of dry matter of tubers in the first and second years of continuous cropping compared with the planting without mulch. Shen et al. (2013) showed that the dry matter content of tubers decreased to some extent for potatoes that were planted in a three-year continuous cropping way. In this study, the dry matter content of tubers was decreased with the extension of continuous cropping years. However, the on-ridge planting with full mulch (RM) created the maximum dry matter content of tubers within three experimental years, which was significantly higher than the planting without mulch (Figure 3A). The experimental results were consistent with previous results. Hence, three years or more of potato continuous cropping could lead to a decrease of dry matter accumulation, but the on-ridge planting with full mulch (RM) could overcome the loss for the decrease of dry matter from continuous cropping potatoes.

**Starch content.** It was known from Figure 3B that FP produced minimum starch content, which was significantly lower than other treatments in 2016–2018. Before storage, the starch content of RM was 31.4, 42.3, and 46.1% higher than FP. After 180 days of storage, RM was 51.7, 51.9, and 58.4% higher than FP in 2016–2018. The starch content of tubers after stored at 4 °C decreased in all treatments in 3 years.

Wu et al. (2010) demonstrated that both flat plots with mulch and on-ridge planting with full mulch contributed to a higher tuber starch content than the planting without mulch. For this reason, the planting with mulch could provide good soil water and heat conditions for starch accumulation and growth of potatoes. However, their studies did not include the continuous cropping conditions of potatoes. Wu et al. (2012) found that the potato had the highest starch content when stored at 9–12 °C for 60 days or 120 days, which may be due to the combined results that the potato had a low respiration intensity, low physiological and biochemical activity and low-temperature saccharification effect.

**Tuber reducing sugars content.** With the increase of storage time, the content of reducing sugar in each treatment was on the rise (Figure 3C). The reducing sugars content of FPM, RM, and FM were significantly lower than FP when the storage time was less than 120 days in 2016–2018. The reducing sugars content of FP was significantly higher than FPM and RM after 180 days in 2016–2018. There was no significant difference in reducing sugar content among the three furrow and ridge mulching treatments except FP.

Wang et al. (2015b) found that in the continuous cropping condition, the on-ridge planting with half mulch contributed to a higher reducing sugars content than the other treatments. The reducing sugar content of tubers keeps increasing with the change of storage

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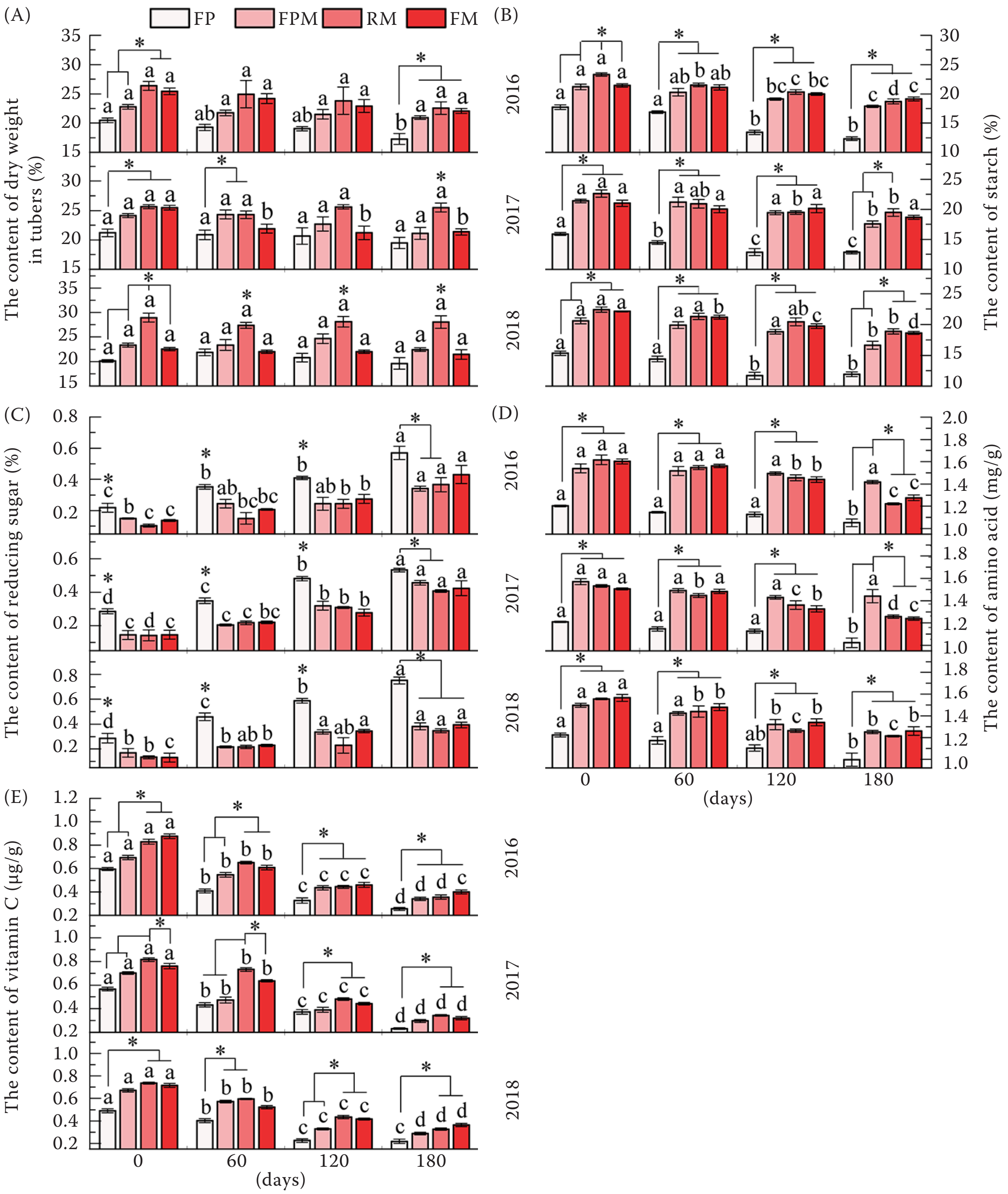


Figure 3. The quality of potato tuber in different treatments and Pearson correlation analysis. (A) The dry matter content of potato tuber; (B) the starch content of potato tuber; (C) the reducing sugar content of potato tuber; (D) the amino acids content of potato tuber, and (E) the vitamin C content of potato tuber. Values followed by different lowercase letters.*$P \leq 0.05$. The lowercase letters for the same treatment in different storage time, *for different treatments in the same storage time. The error line is the standard error. FP – a flat plot without mulch; FPM – alternating strip mulched with plastic film with a strip of bare land with no ridges; RM – alternating fully mulched wide ridges with narrow ridges and ridge planting; FM – alternating fully mulched wide ridges with narrow ridges and furrow planting

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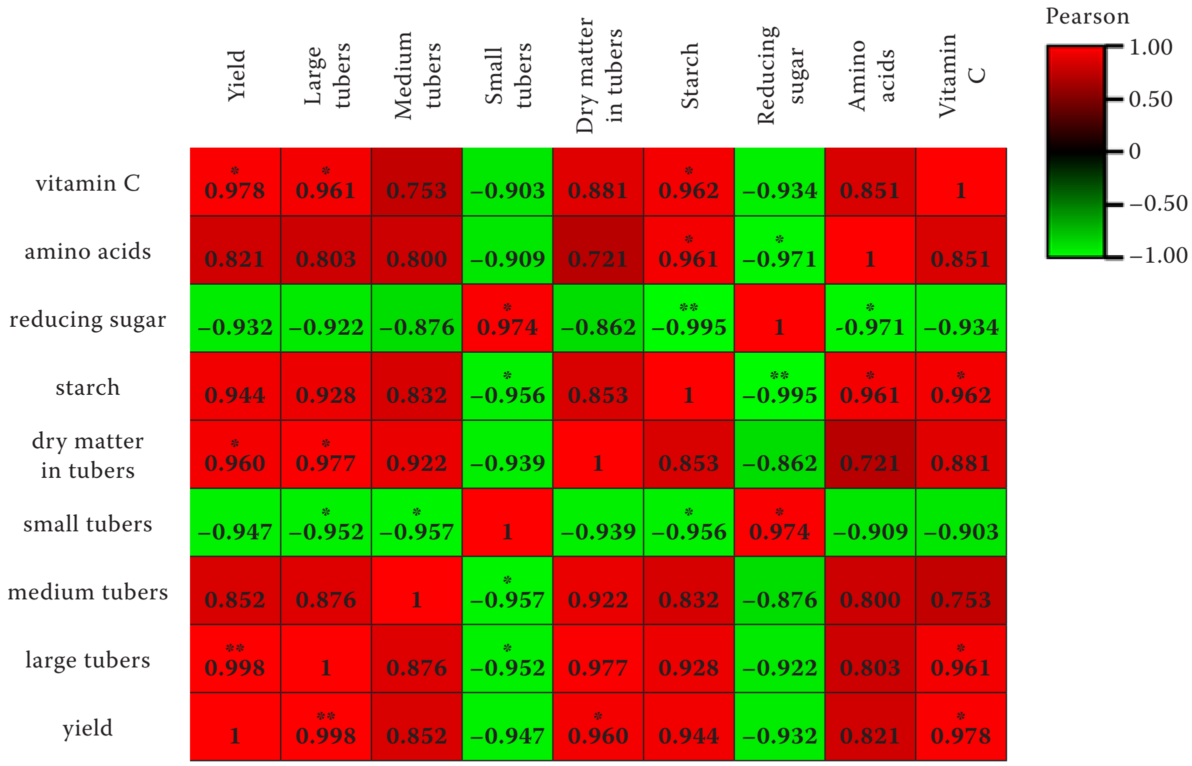


Figure 4. Pearson correlations coefficients among potato yield components and tuber quality under different ridge and furrow film mulching treatments. *$P \leq 0.05$; **$P \leq 0.01$

time. This was related to the low-temperature saccharification due to enzymatic changes and damaged biological membrane in tubers; the accumulation of reducing sugars could affect the improvement of the tuber processing quality (Hammond et al. 1990).

**Tuber amino acids content.** With the increase of storage time, the content of amino acids in all treatments showed a downward trend (Figure 3D). FP was significantly less than other treatments before and after storage. The amino acid content of FPM was significantly higher than that of other treatments and was 35.2% and 41.2% higher than that of FP when stored for 180 days in 2016 and 2017. Potatoes showed decreases in aspartic and glutamic acids and increases in several other amino acids. Increases or decreases in both organic and amino acids were usually greater in potato stored at 21.1 °C than those stored at 12.8 °C (Sweeney et al. 1969), indicating the amino acids content was not only closely related to storage temperature but also the types of amino acids.

**Tuber vitamin C content.** After storage, vitamin C content in all treatments decreased significantly (Figure 3E). The vitamin C contents of RM and FM were significantly higher than that of FM in 2016 and 2017. The vitamin C content of RM was 39.1% higher than FP before storage and 39.6% higher than FP after storage for 180 days in 2016. Besides, this percentages were 44.0% and 47.8% in 2017, 50.3% and 50.0% in 2018. RM and FM performed better than other treatments. The vitamin C content was an important index to evaluate potato product quality. The furrow-ridge planting with mulch could increase the vitamin C content in potato tubers (Wang et al. 2015a). In different continuous cropping years, RM produced a higher vitamin C content of tubers (Figure 3E). Yamaguchi et al. (1960) showed that the vitamin C content of tubers decreased when the tubers were stored at a low temperature. There was a significant decrease in ascorbic acid in potatoes stored at both 21.1 °C and 12.8 °C (Sweeney et al. 1969). In this study, vitamin C content in all treatments decreased significantly after storage.

**Pearson correlation and cluster analysis.** Pearson correlation coefficient was used to measure the correlation between two different indices. Large tubers, dry matter content, vitamin C content were significantly positively correlated with yield (Figure 4). The small tubers were significantly negatively correlated with large tubers, medium tubers, and starch content,

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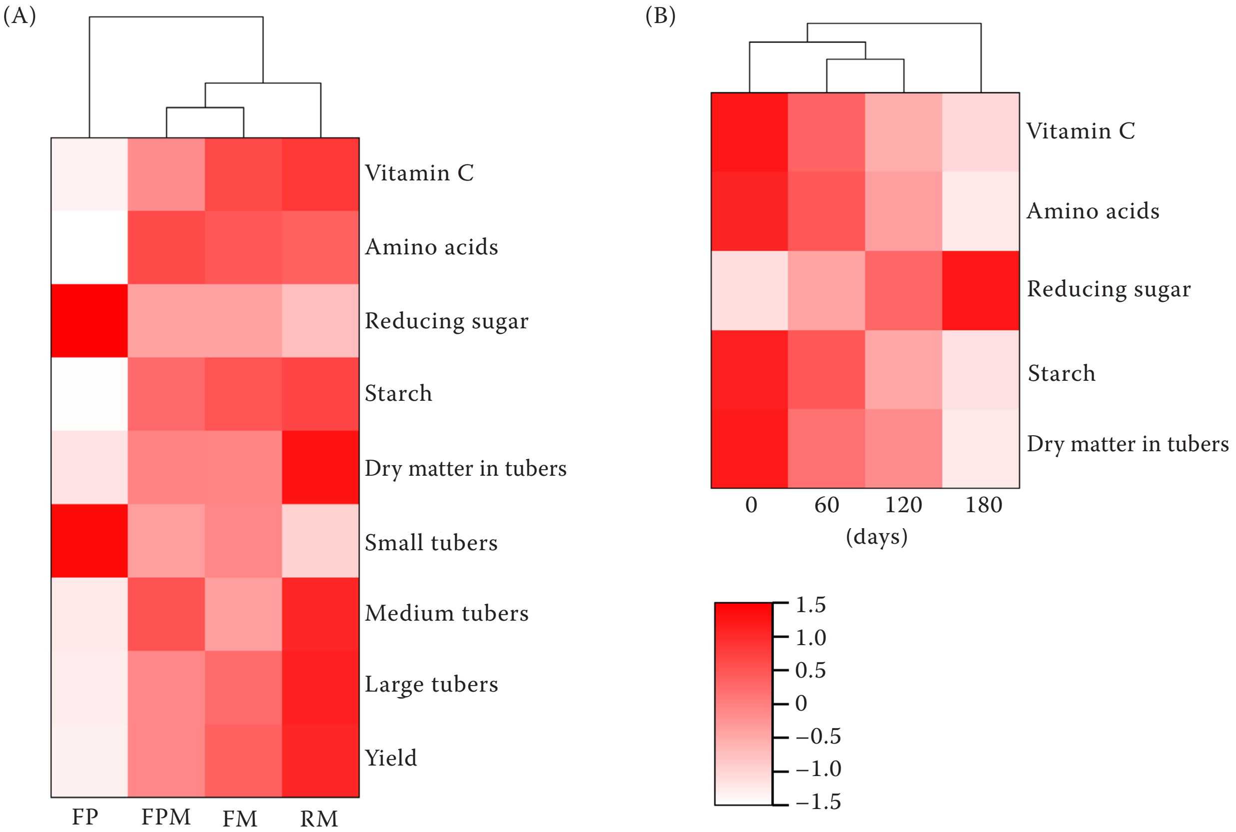


Figure 5. Cluster analysis is based on potato yield components and tuber quality for different treatments and storage time. (A) Cluster analysis for different treatments, and (B) cluster analysis for storage time. FP – a flat plot without mulch; FPM – alternating strip mulched with plastic film with a strip of bare land with no ridges; RM – alternating fully mulched wide ridges with narrow ridges and ridge planting; FM – alternating fully mulched wide ridges with narrow ridges and furrow planting

whereas was significantly positively correlated with the content of reducing sugar. Starch content was significantly negatively correlated with reducing sugar content and positively correlated with amino acid content and vitamin C content.

Cluster analysis was performed for different treatments according to the performance of yield and quality (Figure 5A). It was shown that the performance of various indicators of FP was quite different from FPM, RM, and FM. Meanwhile, FPM and FM had a better similarity. Combined with the experimental data, we concluded that the yield and quality indexes of RM and FM were superior to those of FP and FPM. Furthermore, according to the performance of storage quality, the cluster analysis was carried out for different storage time (Figure 5B). Compared with before storage and storage after 180 days, the tuber quality of 60 days and 120 days of storage period were similar. After the storage period reaches 180 days, the potato quality had a bigger difference. Therefore, in order to maintain good quality, the storage time should not exceed 180 days.

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