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Analysis of changes in nutritional compounds of dried yellow chili after different processing treatments

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Dried yellow chili is highly appreciated by consumers due to its excellent quality and flavor. The quality of products is determined by the drying and storage methods. In this study, dried yellow chilis were processed by natural air drying and hot air drying methods and then stored under three conditions: ambient temperature, ambient temperature with light avoidance, and at 10 °C with light avoidance for 12 months. The changes in the bioactive compounds during this period were analyzed attempting to reveal correlations between the different treatments and these compounds, with the aim of providing references for maintaining the bioactive compounds of pepper products. The results showed that samples treated with hot air had higher levels of fatty acids, resulting in a more pronounced flavor. During storage, samples stored at 10 °C with light avoidance were more effective in preserving soluble solids, total protein content, total phenols, capsaicinoids and most fatty acids.

Keywords Dried yellow chili, Drying, Storage, Capsaicinoid, Carotenoid, Nutritional compounds

Hot pepper (*Capsicum annuum* L.) is one of the most important spices and vegetables in the world[1]. It is highly preferred by consumers due to its rich content of bioactive compounds, including capsaicin, ascorbic acid, carotenoids, amino acids and so on[2]. Carotenoids are closely related to the color of pepper fruits[3,4]. The oxidative degradation of carotenoids seems to be the main reason for fruit color loss[5]. Carotenoids in pepper are lipid soluble and mainly consist of capsorubin, capsanthin, zeaxanthin, β-cryptoxanthin and β-carotene[6]. These carotenoids have been reported to have significant health benefits, including radical scavenging activity, regulation of lipid metabolism, anti-cancer effects, and anti-radiation properties[7]. Among them, dried pepper is the most widely consumed spices in the world. Due to its natural colour, spicy taste and aromatic flavor, it is widely used in the industry and various culinary dishes[8]. Dried chilis are commonly processed into chilli rings, chilli flakes or dry dipping sauces and so on. In many regions of Yunnan, it is a common practice to fry the whole dried peppers directly, which is also considered a traditional delicacy. There are different types of dried pepper products available worldwide. Specifically in China, there are two main types: red dried pepper and yellow dried pepper. As an industrial raw material, yellow dried pepper is popular in the market because of its attractive color and excellent quality. In the meanwhile, the control of dried yellow peppers during processing and storage has a direct impact on the quality and taste of back-end products[9,10].

Drying is the most common and important way to preserve quality of aromatic and medicinal plants[11,12]. Drying is also an indispensable step in the processing of dried chilies, and the choice of drying method has a crucial impact on the quality and taste of dried pepper. Currently, the drying methods for pepper mainly include sun-drying, freeze-drying, natural air drying, hot air drying and so on. Extensive research has been conducted on different drying methods. Sun-drying is a traditional method but has certain drawbacks. It can cause degradation of carotenoids in dried pepper, affect their appearance color[13]. Freeze-drying is a high-end drying method that

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preserves both color quality and nutritional components effectively[14]. However, it requires expensive equipment and technical investment, making it less suitable for large-scale production. Natural air drying and hot air drying are the two most commonly used drying methods in production at present. Natural air drying is to hang the peppers in a well-ventilated place then drying by wind, this way is simple and low cost. Hot air drying is the use of professional equipment to generate hot air to heat and dry the peppers, which can quickly dry the peppers and maintain their appearance, quality and taste[15].

In most cases, after drying, chili peppers are not immediately sold or used for product processing but will be packaged and stored for a while. There have been a number of studies on changes in quality indicators of red dried peppers during storage, mostly in terms of capsaicinoids, polyphenols and color[13,16], while some studies have been conducted in terms of changes in flavor components[8,17,18]. However, there are no reports on the effects of drying and storage methods on the quality of yellow dried pepper. In this study, yellow peppers were dried in two different ways and then stored under three conditions for 12 months. We aimed to analyze the changes in bioactive compounds over time and elucidate the correlations between the different treatments and these compounds to offer guidance on maintaining the bioactive compounds in pepper products. This study will also propose coupling conditions for processing and storage, which are expected to serve as strategies to reduce or delay the loss of nutrients in dried yellow peppers.

Materials and methods

Materials and chemicals

The experimental material was "Qiuhuang Dried pepper NO.1", a variety independently bred by our laboratory (China National Variety Registration Certificate Number: GPD Pepper (2021) 530742), which is also a type of famous local pepper variety in Yunnan. The seeds were sown on January 20th in 2021, and transplanted in the Houshan Vegetable Test Base of Yunnan Agricultural University on 21st April. The planting method is to open deep furrow and build narrow ridge, plant double row on the ridge, the plant distance was 30 cm and the row distance was 50 cm. We collected pepper samples that were fully yellowed (60 days after flowering) on September 9th and then conducted natural air drying and hot air drying processes, respectively.

Standards of ascorbic acid, capsaicinoids and tridecanoic acid were purchased from the National Institutes for Food and Drug Control (Beijing, China). Carotenoids was obtained from Extrasynthese (Genay, France). Fatty acid methyl ester mixture (C4–C24) was purchased from Nu-check Prep, Inc. (Elysian, MN, USA). Methanol, ethanol, and other organic solvents of HPLC grade were obtained from MREDA (Beijing, China). All other chemicals used in this study were reagent grade.

Chemical compounds studied in this article: Ascorbic acid (PubChem CID: 54670067); β-Carotene (PubChem CID: 5280489); Zeaxanthin (PubChem CID: 5280899); Capsaicin (PubChem CID: 1548943); Dihydrocapsaicin(PubChem CID: 107982); Nordihydrocapsaicin(PubChem CID: 168836).

Drying methods

Natural air drying: Hang fresh pepper samples in a cool and ventilated place with nylon mesh bags for natural air drying to constant weight (13.71% moisture content), and divided into hermetically sealed bags (approximately 30 g per bag) for subsequent storage experiments. Hot air drying: The peppers were dried at 50 °C for 3 h in a blast drying oven to dehumidification, and then dried at 60 °C to constant weight[19] (12.46% moisture content). The dried peppers were divided into hermetically sealed bags (made from polyethylene terephthalate) with approximately 30 g per bag for subsequent storage experiments.

Storage and sampling

The peppers subjected to natural air drying and stored at ambient temperature are designated as FG, while those subjected to hot air drying and stored under similar conditions are denoted as HG (Note: the ambient temperature ranged from 15.8 to 22.4 °C and an average relative humidity of 73.5%,varying from 58 to 83% during the storage period).The natural air dried peppers stored at ambient temperature protect from light were referred to as FG-bg and the hot air dried peppers stored at ambient temperature protect from light were referred to as HG-bg. Natural air dried samples and storage at 10 °C protect from light were referred to as FG-10 °C and hot air dried samples and storage at 10 °C protect from light were referred to as HG-10 °C. During one year of storage, 7 sampling time point were taken (0, 1, 30, 60, 120, 210, and 360 days), of which 0 days represented fresh pepper fruit samples, the samples at other time points were dried pepper samples (Supplemental Figure S1).

During the storage period, weighed the samples after each sampling, calculated the moisture content of the samples, and then conducted other measurement experiments. All samples were in their intact pepper state during the storage period until each sampling was completed, the dried peppers removed seeds and stems were ground into powder by a mill in order to pass through a 40 mesh sieve (diameter is 0.425 mm) for subsequent testing. And the fresh samples, removed seeds and stems were treated with liquid nitrogen and ground into powder for immediate use in experiments.

Moisture content

The moisture content of the samples during the storage period were calculated as follows:

(1) $\text{Moisture content}(\%) = M_i + M_c$

(2) $M_c(\%) = (W_s - W_i)/W_i \times 100$

where M_i refers to the initial moisture content of samples before stored, M_c refers to the changes in moisture content of the samples during storage period, W_i refers to the initial weight of the sample before stored, and W_s refers to the weight of the sample during the storage period.

Color measurement

3nh NR110 automatic color difference meter (Shenzhen Sanenshi Technology Co., LTD.) was used to determine the brightness L*, a* and b* values of pepper peel. The chroma value [$C^* = (a^2 + b^2)^{1/2}$] and the hue Angle [$h° = \arctan(b^*/a^*)$] were calculated. The L* value measures the brightness of the fruit color, from 0 to 100 reflecting the change in brightness from black to white. The shift from $-a^*$ to $+a^*$ shows a decrease in green and an increase in red. The change from $-b^*$ to $+b^*$ represents a decrease in blue and an increase in yellow[20]. 10 healthy fruits of uniform size and color were selected for each sample, the upside, middle and downside of the central part toward the light surface were measured, and take the average value.

Physicochemical properties determination

All the measurements below were performed in triplicate. In addition, it is necessary to convert the determination results according to their moisture contents for further data analysis.

Total soluble solids (TSS)

TSS were determined by digital refractometer (PAL-1, ATAGO, Japan)[21]. Accurately weigh 1.0 g of the sample (fresh sample as well as dried sample), place it in pre-weighed a 10 mL centrifuge tube, add 5 mL of distilled water, immerse it in a boiling water bath for 15 min, remove the centrifuge tube out, let it cool to room temperature, weigh it accurately to 0.001 g, and then filter for determination. Calibrate the refractometer reading with distilled water and adjust the soluble solids to 0% at 20 °C; When the temperature is not at 20 °C, calibrate according to the calibration table. The TSS content was calculated as follows:

$$\text{TSS}\ (\%) = R \times m_1/m_0$$

where R is refractometer meter reading, m_1 is the weight of the test sample after dilution, and m_0 is the weight of the sample before dilution.

Total soluble protein

The total soluble protein content was determined by Coomassie brilliant blue G250 method[22].

Crude fat

Intact samples were ground and dried in a 60 °C oven for 2 h, then weighed 1.0 g for crude fat analysis. Crude fat was determined according to the Soxhlet extraction method[23].

Total phenols

The total phenols concentration was determined by Folin-phenol method[24], expressed relative to a standard curve of gallic acid, and presented as meq gallic acid/g sample dry weight.

Ascorbic acid

Ascorbic acid measurement used for titration method according to Nielsen[25] with a slight modification. In brief, 1.0 g crushed pepper sample was weighted and mixed with oxalic acid solution (20 g/L) to 100 mL, ultrasonic extraction for 5 min, then filtered for subsequent experiments (If the filtrate is colored, it can be removed with 0.4 g Kaolin); Accurately pipette 10 mL filtrate into a 50 mL conical flask and titrate with the indophenol dye solution until a pink color persists for 15 s. Conduct the blank experiment simultaneously. The ascorbic acid content was expressed as mg of ascorbic acid per 100 g sample dry weight.

Carotenoid extraction, identification, and determination

Carotenoid extraction was modified with reference to Ishida & Chapman[26]. 0.5 g fresh pepper (samples for 0 day) as well as dried pepper powder were quickly transfer to a 15 mL centrifuge tube with 10 mL of a mixture of absolute ethanol and dichloromethane (1:1, v/v). After homogenization, the sample suspension was incubated at 50 °C for 30 min, centrifuged at ×10,000*g* for 15 min at 4 °C, the supernatant was collected, and the volume was fixed to 10 mL with the above mixed solution. Subsequently, the final supernatant was filtered through a 0.45 μm nylon filter to obtain the filtrate for analysis. The entire extraction and analysis process is carried out away from light. Three repetitions were performed for each sample.

High-performance liquid chromatography (HPLC) was employed to separate and quantify the carotenoids as detaile described by Li et al.[21]. A HPLC instrument (Infinity II 1260, Agilent, Santa Clara, CA, US) equipped with Agilent Zorbax SB-C18 column (250 × 4.6 mm, 5 μm) and ultraviolet detector maintained at 30 °C[27] to identify carotenoids and quantify their relative mass. Methanol/acetonitrile (55:45, v/v) and methyl tert-butyl ether were used as the mobile phase which were mixed at a ratio of 90:10, maintained at a flow rate of 1.0 mL/min. The injection volume was 20 μL and was analyzed at 450 nm. The calibration curves were established by 1, 10, 20, 50 and 100 μg mL^{-1} solutions prepared by diluting zeaxanthin and β-carotene stock solutions dissolved in Methanol/acetonitrile (55:45, v/v). The limits of detection (LOD) of zeaxanthin was 0.017 μg mL^{-1} and the limits of quantification (LOQ) was 0.057 μg mL^{-1}, linearity was good ($R^2 = 0.9999$) within the studied range of concentrations. LOD of β-carotene was 0.013 μg mL^{-1} and LOQ was 0.043 μg mL^{-1}, linearity was good ($R^2 = 0.9982$) within the studied range of concentrations. Regression equations were used to compare the standards to determine the

amounts of each class of carotenoids, which were then expressed as μg g^{-1}. The HPLC chromatograms of the identified compounds and the standards are shown in Supplemental Figure S2.

Capsaicinoid extraction, identifycation, and determination

Capsaicin, dihydrocapsaicin and nordihydrocapsaicin contents were evaluated using the HPLC system as detailed previously according to the method described by Li et al.[21]. Identification of the peaks of the three capsaicinoids was carried out by comparison of their retention times with those obtained by injecting reference standards with known concentration under the same conditions. A mixed standard solution of capsaicin and dihydrocapsaicin were prepared to construct a calibration curve. The concentrations of mixed standard solutions are 20, 40, 60, 80, 100 and 160 μg mL^{-1}. The concentrations of nordihydrocapsaicin standard solutions were 10, 20, 25, 50 and 100 μg mL^{-1}. In this method, the LOD of capsaicin, dihydrocapsaicin, and nordihydrocapsaicin were 0.193 μg mL^{-1}, 0.127 μg mL^{-1}, and 0.047 μg mL^{-1}, respectively. And the LOQ were 0.645 μg mL^{-1}, 0.429 μg mL^{-1}, and 0.156 μg mL^{-1}, respectively. The linearity of capsaicin ($R^2 = 0.9989$), dihydrocapsaicin ($R^2 = 0.9991$) and nord ihydrocapsaicin($R^2 = 0.9987$) were good within the studied range of concentrations. The HPLC chromatograms of the identified compounds and standards are shown in Supplemental Figure S3.

Fatty acid composition determination

We determined the fatty acids of the samples on the first day and the 360th day after drying. According to method of Li et al.[21] to detect fatty acids in samples. Fatty acid composition was determined as fatty acid methyl esters (FAME) using the Agilent 7890B gas chromatograph system (Santa Clara, CA, USA) equipped with a flame ionization detector and an HP-5 column (30 m × 0.32 mm i.d.) for detection. All fatty acids were identified and quantified using authentic standards (Nu-Chek, Elysian, MN, USA). The GC chromatograms of the identified compounds and standards were shown in Supplemental Figure S4.

Statistical analysis

Color change and carotenoids data during storage were processed by IBM SPSS 26 and do statistical evaluation of results by using factorial ANOVA. The data of capsaicinoids and physiochemical indexes during the storage period were analyzed and plotted by GraphPad Prism 9.0 software. Microsoft Excel 2019 was used to analyze the fatty acid data and draw the stack chart. Correlation coefficients of variety indicators were calculated by Origin 2021 and correlation heat map was drawn, and correlation coefficients were calculated by Spearman correlation coefficient method. Pearson correlation heat map between quality indicators and samples was drawn based on R language and online software ImageGP[28].

Results and discussion

Moisture contents

The moisture content of samples treated with different methods during the storage period is shown in Table 1. Before the 210th day, the moisture content of the samples in the natural air drying and hot air drying treatment groups showed a steady increase in the trend. The moisture content of the natural air drying treatment group is higher than that of the hot air drying treatment group, but the increase rate of the hot air drying treatment group is greater than that of the natural air drying treatment group. After being stored for 210 to 360 days, the moisture content of all the samples showed a slow decreasing trend, but not significantly ($p > 0.05$).

The moisture content is closely related to the color, quality, and occurrence of fungal diseases during dried pepper storage. An increase in moisture content can lead to a dull color of chili peppers, resulting in a decrease in quality and promoting fungal propagation. Therefore, it is important to measure the moisture content during the storage of dried peppers[29–31]. In this study, the moisture content of each treatment samples increased significantly from the 60th day compared with the 1st day ($p < 0.05$). The moisture content reached its maximum on the 210th day and gradually decreases, which is because on the 210th day, it was the rainy season and the air humidity was relatively high.

Color

The appearance color of pepper is an important commodity character, and the detection data of color difference meter can reflect the appearance color difference between different samples. The factorial ANOVA shows that the main effect between drying method, storage method, and storage time is not significant ($p = 0.761$). But storage methods have a significant impact on the L* value ($p < 0.05$), especially in the later period of storage. The L* value of natural air drying treatment at 10 °C storage condition is significantly higher than that of other treatments. As shown in Table 2, the measured results of L* value (brightness) of the samples ranged from 24.82 to 54.64. The results showed that the L* value of the samples on day 1 after natural air drying and hot air drying were increased compared with that on day 0 (fresh samples), among which the L* value of the natural air drying treatment group increased more than that of the hot air drying treatment group. However, during the whole storage period, L* values of all samples showed a decreasing trend. According to the results of factorial ANOVA, the main effect between drying method, storage method, and storage time is not significant ($p = 0.341$). The inter subject effect of drying method and storage time is significant ($p < 0.05$), indicating a significant difference in the a* value between different drying methods with changes in storage time. As shown in Table 2, the a* value of natural air dried samples is significantly higher than that of hot air dried samples at each time point. Under the three storage conditions, the a* value of yellow dried pepper samples showed a decreasing trend after drying treatment and in the early storage period, its minimum value of 19.01 appeared in HG-bg (120).Interestingly, the a* value of all samples increased after 120 days. According to the factorial ANOVA of b* value, the interaction effect between drying methods, storage methods and storage time is significant ($p = 0.029$), which indicates that

	Numbers of samples	Average temperature during storage period (°C)	Moisture content (%)
FG (1)	35	19.5	14.66 ± 0.53^{c}
FG (30)	36	16.5	14.98 ± 0.53^{bc}
FG (60)	35	12.0	15.96 ± 0.84^{ab}
FG (120)	35	10.0	16.25 ± 0.92^{ab}
FG (210)	36	17.0	16.58 ± 0.70^{a}
FG (360)	35	22.5	16.34 ± 0.74^{a}
FG-bg (1)	35	19.5	14.53 ± 0.66^{c}
FG-bg (30)	36	16.5	14.86 ± 0.45^{bc}
FG-bg (60)	36	12.0	16.37 ± 0.41^{a}
FG-bg (120)	35	10.0	16.19 ± 0.94^{a}
FG-bg (210)	36	17.0	16.56 ± 0.82^{a}
FG-bg (360)	35	22.5	16.32 ± 0.87^{a}
FG-10 °C (1)	36	19.5	14.94 ± 0.44^{bc}
FG-10 °C (30)	36	16.5	15.40 ± 0.71^{ab}
FG-10 °C (60)	36	12.0	16.19 ± 0.95^{a}
FG-10 °C (120)	36	10.0	16.49 ± 0.84^{a}
FG-10 °C (210)	36	17.0	16.62 ± 0.70^{a}
FG-10 °C (360)	35	22.5	16.78 ± 0.93^{a}
HG (1)	42	19.5	13.54 ± 0.62^{d}
HG (30)	41	16.5	14.22 ± 0.50^{c}
HG (60)	42	12.0	14.73 ± 0.56^{c}
HG (120)	42	10.0	15.14 ± 0.82^{ab}
HG (210)	42	17.0	15.26 ± 1.03^{ab}
HG (360)	41	22.5	15.17 ± 1.05^{ab}
HG-bg (1)	41	19.5	13.62 ± 0.42^{d}
HG-bg (30)	42	16.5	14.12 ± 0.63^{cd}
HG-bg (60)	41	12.0	15.07 ± 1.05^{b}
HG-bg (120)	41	10.0	15.17 ± 0.95^{ab}
HG-bg (210)	42	17.0	15.27 ± 1.05^{ab}
HG-bg (360)	42	22.5	14.85 ± 1.05^{bc}
HG-10 °C (1)	42	19.5	14.07 ± 1.16^{cd}
HG-10 °C (30)	42	16.5	14.52 ± 0.64^{c}
HG-10 °C (60)	42	12.0	15.12 ± 1.06^{ab}
HG-10 °C (120)	41	10.0	15.20 ± 0.98^{ab}
HG-10 °C (210)	41	17.0	15.40 ± 0.77^{ab}
HG-10 °C (360)	42	22.5	15.24 ± 0.73^{ab}

Table 1. Data on the moisture contents of dried pepper samples during storage (mean ± standard deviation, n = 10). FG, natural air dried and storage at ambient temperature; HG, hot air dried and storage at ambient temperature; FG-bg, natural air dried and storage at ambient temperature protect from light; HG-bg, hot air dried and storage at ambient temperature protect from light; FG-10 °C, natural air dried and storage at 10 °C protect from light; HG-10 °C, Hot air dried and storage at 10 °C protect from light. FG/HG/FG-bg/HG-bg/FG-10 °C/HG-10 °C (1), (30), (60), (120), (210) and (360) represent samples treated via the different drying and storage methods for 1, 30, 60, 120, 210 and 360 days, respectively. Different small letters represent significant differences between different storage days ($p < 0.05$).

during storage period, the b* values of natural air dried at 10 °C storage condition were significantly higher than those of other treatment groups. In specifically, the b* value decreased after drying in the early stage of storage, with a minimum value of 29.03 occurring at the 60th day of storage after drying at room temperature. After that, the b* value increased in all treatments. Finally, after 360 days of storage, the samples of natural air dried and stored at 10 °C (FG-10 °C 360) retained the most L* (35.14), a* (31.63) and b* values (60.58).

The drying process has a significant impact on the color of materials[32]. Compared with fresh yellow pepper samples, L* values of all samples increased after natural air drying and hot air drying, indicating that drying treatment can improve the brightness of pepper fruits, which is consistent with previous research results[33]. The a* and b* values decreased firstly and then increased, indicating that the color of the sample changed from "green blue" to "red yellow", which was due to the non-enzymatic browning caused by the Maillard reaction[34] during natural air drying and hot air drying treatment, which made the color of the sample darker. However, with the increase of storage time, the main substance of browning, such as the gradual decomposition of furfural substances, resulting in a lighter sample color, a* values and b* values increase.

	L*	a*	b*	C*	h°
FG (0)	48.80 ± 0.89^{c}	35.38 ± 1.54^{a}	84.12 ± 2.10^{a}	91.27 ± 1.88^{a}	67.18 ± 1.14^{a}
FG (1)	54.64 ± 1.63^{a}	32.69 ± 2.01^{b}	51.72 ± 1.83^{d}	61.20 ± 2.03^{cd}	57.71 ± 1.98^{e}
FG (30)	52.47 ± 1.58^{b}	30.88 ± 1.72^{c}	37.83 ± 1.42^{g}	48.85 ± 1.65^{gh}	50.79 ± 1.76^{j}
FG (60)	50.67 ± 2.07^{bc}	27.26 ± 1.76^{e}	39.22 ± 1.43^{g}	47.78 ± 1.77^{h}	55.22 ± 1.71^{g}
FG (120)	47.03 ± 1.52^{cd}	25.45 ± 1.96^{f}	41.72 ± 1.35^{fg}	48.91 ± 1.22^{h}	58.63 ± 2.39^{de}
FG (210)	40.69 ± 1.69^{g}	26.59 ± 1.20^{e}	44.21 ± 1.72f.	51.59 ± 1.71^{f}	58.97 ± 1.34^{de}
FG (360)	31.20 ± 1.46^{i}	28.30 ± 2.95^{d}	53.77 ± 5.10^{c}	61.30 ± 2.91^{c}	61.78 ± 4.93^{c}
FG-bg (0)	48.80 ± 0.89^{c}	35.38 ± 1.54^{a}	84.12 ± 2.10^{a}	91.27 ± 1.88^{a}	67.18 ± 1.14^{a}
FG-bg (1)	54.64 ± 1.63^{a}	32.69 ± 2.01^{b}	51.72 ± 1.83^{d}	61.20 ± 2.03^{cd}	57.71 ± 1.98^{e}
FG-bg (30)	52.27 ± 1.74^{b}	30.67 ± 1.38^{c}	39.73 ± 1.62^{g}	50.21 ± 1.75^{g}	52.33 ± 1.38^{i}
FG-bg (60)	50.31 ± 1.41^{bc}	26.64 ± 1.73^{ef}	40.32 ± 1.72^{fg}	48.35 ± 1.69^{h}	56.54 ± 2.08^{f}
FG-bg (120)	46.33 ± 1.83^{d}	24.62 ± 1.57^{f}	41.44 ± 1.92^{fg}	48.23 ± 1.96^{h}	59.28 ± 1.81^{d}
FG-bg (210)	39.33 ± 1.88^{g}	27.03 ± 1.54^{e}	43.02 ± 1.66^{f}	50.80 ± 1.67^{fg}	57.86 ± 1.69^{e}
FG-bg (360)	28.83 ± 2.11^{j}	30.64 ± 3.81^{c}	49.69 ± 7.96^{d}	59.31 ± 5.85^{cd}	56.28 ± 7.59^{f}
FG-10 °C (0)	48.80 ± 0.89^{c}	35.38 ± 1.54^{a}	84.12 ± 2.10^{a}	91.27 ± 1.88^{a}	67.18 ± 1.14^{a}
FG-10 °C (1)	54.64 ± 1.63^{a}	32.69 ± 2.01^{b}	51.72 ± 1.83^{d}	61.20 ± 2.03^{cd}	57.71 ± 1.98^{e}
FG-10 °C (30)	52.80 ± 1.70^{b}	30.88 ± 1.82^{c}	44.06 ± 1.27^{f}	53.82 ± 1.79^{e}	54.99 ± 1.39^{h}
FG-10 °C (60)	51.28 ± 1.60^{bc}	27.27 ± 1.46^{e}	41.13 ± 1.19^{fg}	49.37 ± 1.31^{gh}	56.46 ± 1.57^{f}
FG-10 °C (120)	48.19 ± 1.93^{cd}	25.47 ± 1.61^{f}	43.51 ± 2.11f.	50.46 ± 1.63^{fg}	59.63 ± 2.36^{d}
FG-10 °C (210)	42.97 ± 1.69^{f}	27.93 ± 1.37^{de}	47.87 ± 1.24^{e}	55.44 ± 0.75^{e}	59.73 ± 1.74^{d}
FG-10 °C (360)	35.14 ± 1.94^{h}	31.63 ± 1.96^{bc}	60.58 ± 4.22^{b}	68.48 ± 3.46^{b}	62.24 ± 2.73^{c}
HG (0)	48.80 ± 0.89^{c}	35.38 ± 1.54^{a}	84.12 ± 2.10^{a}	91.27 ± 1.88^{a}	67.18 ± 1.14^{a}
HG (1)	49.77 ± 1.56^{c}	20.16 ± 1.62^{h}	28.41 ± 1.38^{i}	34.87 ± 1.32^{n}	54.58 ± 3.25^{h}
HG (30)	47.21 ± 1.98^{cd}	19.93 ± 1.07^{i}	28.72 ± 1.22^{i}	34.98 ± 1.10^{k}	55.23 ± 1.95^{g}
HG (60)	45.10 ± 1.81^{e}	19.47 ± 1.09^{i}	29.03 ± 1.55^{i}	34.97 ± 1.46^{k}	56.13 ± 1.99^{f}
HG (120)	40.82 ± 1.53^{g}	19.24 ± 2.69^{i}	29.53 ± 1.54^{i}	35.33 ± 1.80^{k}	56.69 ± 3.72^{f}
HG (210)	34.67 ± 1.35^{h}	21.84 ± 1.44^{g}	33.38 ± 2.01^{h}	39.89 ± 1.66^{j}	56.81 ± 2.57^{f}
HG (360)	25.44 ± 1.78^{k}	25.73 ± 3.60^{f}	43.85 ± 7.13^{f}	51.67 ± 3.75^{f}	58.59 ± 8.60^{de}
HG-bg (0)	48.80 ± 0.89^{c}	35.38 ± 1.54^{a}	84.12 ± 2.10^{a}	91.27 ± 1.88^{a}	67.18 ± 1.14^{a}
HG-bg (1)	49.77 ± 1.56^{c}	20.16 ± 1.62^{h}	28.41 ± 1.38^{i}	34.87 ± 1.32^{n}	54.58 ± 3.25^{h}
HG-bg (30)	47.24 ± 1.50^{cd}	19.87 ± 1.73^{i}	28.86 ± 1.61^{i}	35.08 ± 1.50^{k}	55.44 ± 2.98^{g}
HG-bg (60)	45.15 ± 1.86^{e}	19.30 ± 1.06^{i}	29.43 ± 1.69^{i}	35.22 ± 1.39^{k}	56.70 ± 2.33^{f}
HG-bg (120)	40.92 ± 2.08^{g}	19.01 ± 1.70^{i}	30.09 ± 1.47^{i}	35.63 ± 1.36 k	57.51 ± 2.49^{e}
HG-bg (210)	34.48 ± 1.89^{h}	22.16 ± 1.64^{g}	31.67 ± 2.62^{h}	38.66 ± 1.79^{j}	55.01 ± 3.59^{gh}
HG-bg (360)	24.82 ± 1.61^{k}	26.89 ± 2.16^{ef}	42.78 ± 4.55^{f}	51.20 ± 2.78^{fg}	57.04 ± 4.81^{ef}
HG-10 °C (0)	48.80 ± 0.89^{c}	35.38 ± 1.54^{a}	84.12 ± 2.10^{a}	91.27 ± 1.88^{a}	67.18 ± 1.14^{a}
HG-10 °C (1)	49.77 ± 1.56^{c}	20.16 ± 1.62^{h}	28.41 ± 1.38^{i}	34.87 ± 1.32^{n}	54.58 ± 3.25^{h}
HG-10 °C (30)	47.51 ± 1.83^{cd}	19.92 ± 1.81^{i}	29.01 ± 1.51^{i}	35.23 ± 1.67^{k}	55.55 ± 2.72^{g}
HG-10 °C (60)	45.64 ± 1.75^{de}	19.44 ± 1.63^{i}	29.68 ± 1.42^{i}	35.50 ± 1.74^{k}	56.81 ± 2.06^{f}
HG-10 °C 120)	41.85 ± 1.80^{fg}	19.19 ± 1.52^{i}	30.24 ± 1.61^{i}	35.87 ± 1.12^{k}	56.37 ± 1.89^{f}
HG-10 °C (210)	35.68 ± 1.54^{h}	21.48 ± 1.21^{g}	39.15 ± 1.57^{g}	44.67 ± 1.56^{i}	61.24 ± 1.58^{c}
HG-10 °C (360)	30.92 ± 2.00^{i}	24.92 ± 2.34^{f}	53.30 ± 4.19^{c}	59.20 ± 3.06^{d}	64.33 ± 3.94^{b}

Table 2. Date of CIE L^*, a^*, b^* of pepper fruit in different storage times (mean ± standard deviation, n = 10). FG, natural air dried and storage at ambient temperature; HG, hot air dried and storage at ambient temperature; FG-bg, natural air dried and storage at ambient temperature protect from light; HG-bg, hot air dried and storage at ambient temperature protect from light; FG-10 °C, natural air dried and storage at 10 °C protect from light; HG-10 °C, hot air dried and storage at 10 °C protect from light. FG/HG/FG-bg/HG-bg/FG-10 °C/HG-10 °C (0) represent fresh samples, FG/HG/FG-bg/HG-bg/FG-10 °C/HG-10 °C (1), (30), (60), (120), (210) and (360) represent samples treated via the different drying and storage methods for 1, 30, 60, 120, 210 and 360 days, respectively. Different small letters represent significant differences between different storage days ($p < 0.05$).

Carotenoids

Carotenoids are important chemicals in plant Reactive Oxygen Species (ROS) scavenging activity, and are also the main colorant of pepper fruits[1]. Carotenoids in capsicum mainly include capsanthin, capsorubin, β-carotene,

cryptoxanthin, zeaxanthin and their isomers[16]. In this study, Capsanthin and capsorubin were not detected in the yellow dried pepper in this experiment, and β-carotene and zeaxanthin were the main components of its pigment. The changes of carotenoids during drying and storage were shown in Fig. 1. Compared with fresh samples, the zeaxanthin content after natural air dried decreased from 31.31 to 30.87 μg g^{-1} dw. However, after hot air dried the sample's zeaxanthin content increased from 31.31 to 33.40 μg g^{-1} dw. During storage, the zeaxanthin content of all samples showed a decreasing trend (Fig. 1A), and the loss was nearly half at 210 days of storage, and then continued to decrease. Finally, after 360 days of storage, the zeaxanthin content of samples under dark storage conditions at room temperature was the most retained, which were 8.26 μg g^{-1} in FG-bg (360) and 7.76 μg g^{-1} in HG-bg (360), respectively. The factorial ANOVA showed that both drying method and storage time have significant main effects on zeaxanthin, while drying method, storage method, and storage time have no significant interactive effects. This is also consistent with the measurement results, under the same dark conditions, the content of zeaxanthin in the natural air dried treatment is significantly higher than that in the hot air drying treatment. The β-carotene of all samples showed a decreasing trend after drying and during the first 210 days of storage (Fig. 1B). After drying, the β-carotene content in natural air dried and hot air dried samples decreased by 15.73% and 15.01%, respectively. After 210 days of storage, the β-carotene content of the samples decreased to the lowest point, and then fluctuated. After 12 months of storage, the highest retention of β-carotene content in FG-10 °C (360) was 774.26 μg g^{-1}, while the lowest retention of HG-bg (360) was 133.08 μg g^{-1}. This indicates that bioactive components in dried vegetables can be better preserved under low temperature condition, which is consistent with previous research[35]. The factorial ANOVA showed that drying method, storage method, and storage time have significant interactive effects on β-carotene, which can be understood that the combination of natural air drying and low temperature storage is more beneficial for retaining β-carotene at the same storage time.

In this study, during 12 months storage, β-carotene and zeaxanthin generally showed a downward trend, especially after 210 days of storage, the content loss rate of both increased sharply. Interestingly, zeaxanthin in dried yellow pepper increased on the first day after drying, which should be due to plastids damage caused by hot air at high temperature during drying, which resulted in better availability and extraction of pigments in the samples[27]. On the other hand, this rise is most likely due to the relevant enzymes involved in carotenoid biosynthesis, which remain active until water activity drops to very low levels[9].

Capsaicinoids

Capsaicinoids rich in capsicum are important bioactive substances, which not only affect the taste of capsicum, but also have extensive pharmacological properties[36]. Therefore, the content of capsaicin substances is an important indicator of capsaicin commodity quality, and its level mainly depends on the concentration of capsaicin, dihydrocapsaicin and nordihydrocapsaicin monomer, the sum of which accounts for about 97.5% of capsaicin substances[37]. In this study, although the contents of three main monomers in capsaicinoids fluctuated to varying degrees from drying treatment to the end of 360 days of storage, overall, the total amount of capsaicin substances in all samples showed a downward trend (Table 3). After natural air drying, the capsaicin content in the samples decreased from the initial 1639.27 μg g^{-1} to 1249.68 μg g^{-1}, a decrease of 23.78%. Dihydrocapsaicin and nordihydrocapsaicin also decreased by 24.46% and 21.43%, respectively. After hot air drying, the content of capsaicin in the samples decreased from the initial 1639.27 μg g^{-1} to 1322.67 μg g^{-1}, which decreased by 19.3%. Dihydrocapsaicin and nordihydrocapsaicin also decreased by 19.2% and 16.8%, respectively. Finally, the highest

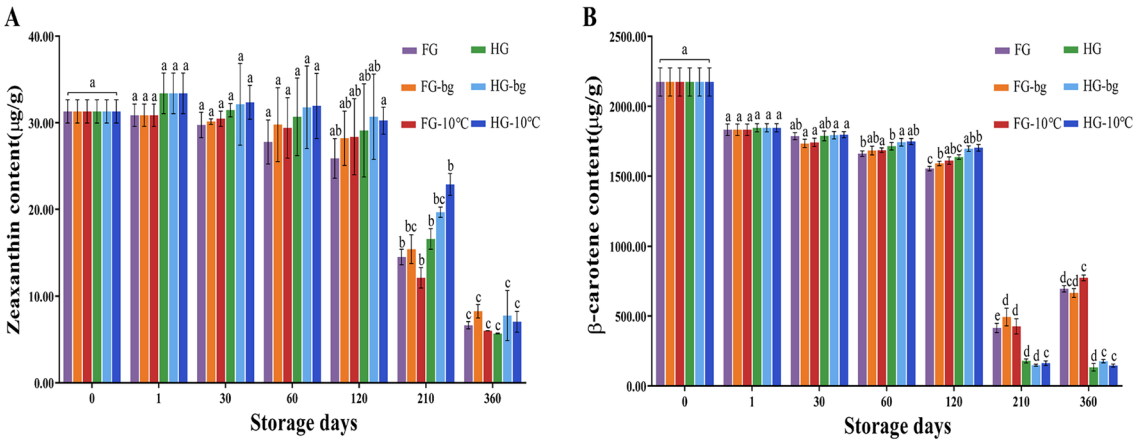

Fig. 1. Carotenoids content changes of dried yellow peppers during storage. FG: Natural air dried and storage at ambient temperature, HG: Hot air dried and storage at ambient temperature, FG-bg: Natural air dried and storage at ambient temperature protect from light, HG-bg: Hot air dried and storage at ambient temperature protect from light, FG-10 °C: Natural air dried and storage at 10 °C protect from light, HG-10 °C: Hot air dried and storage at 10 °C protect from light. FG/HG/FG-bg/HG-bg/FG-10 °C/HG-10 °C(0) represent fresh samples, FG/HG/FG-bg/HG-bg/FG-10 °C/HG-10 °C (1), (30), (60), (120), (210) and (360) represent samples treated via the different drying and storage methods for 1, 30, 60, 120, 210 and 360 days, respectively. Note: In the same color bars, the different lowercase reveal significant differences ($p < 0.05$) of dried pepper samples during storage.

	Capsaicin	Dihydrocapsaicin	Nordihydrocapsaicin
FG(0)	1639.27	2328.54	698.10
FG(1)	1249.68	1775.46	552.01
FG(30)	1212.97	1704.80	543.00
FG(60)	1176.27	1634.14	527.02
FG(120)	1102.86	1492.82	515.01
FG(210)	992.74	1280.84	253.35
FG(360)	759.14	981.69	144.34
FG-bg(0)	1639.27	2328.54	698.10
FG-bg(1)	1249.68	1775.46	552.01
FG-bg(30)	1204.96	1685.48	544.38
FG-bg(60)	1160.23	1595.50	535.22
FG-bg(120)	1070.78	1415.53	524.13
FG-bg(210)	936.61	1145.59	186.22
FG-bg(360)	643.66	774.18	111.15
FG-10 °C(0)	1639.27	2328.54	698.10
FG-10 °C(1)	1249.68	1775.46	552.01
FG-10 °C(30)	1215.97	1690.53	548.38
FG-10 °C(60)	1182.26	1605.60	539.28
FG-10 °C(120)	1114.83	1435.75	528.14
FG-10 °C(210)	1013.70	1180.97	233.18
FG-10 °C(360)	958.29	1160.58	188.64
HG(0)	1639.27	2328.54	698.10
HG(1)	1322.67	1880.31	581.24
HG(30)	1238.02	1742.81	557.41
HG(60)	1153.37	1605.31	541.00
HG(120)	984.07	1330.30	522.00
HG(210)	730.12	917.80	169.73
HG(360)	558.62	618.98	99.71
HG-bg(0)	1639.27	2328.54	698.10
HG-bg(1)	1322.67	1880.31	581.24
HG-bg(30)	1242.58	1749.60	567.22
HG-bg(60)	1162.49	1618.90	548.30
HG-bg(120)	1002.31	1357.48	531.21
HG-bg(210)	762.04	965.36	198.70
HG-bg(360)	649.07	815.67	128.03
HG-10 °C(0)	1639.27	2328.54	698.10
HG-10 °C(1)	1322.67	1880.31	581.24
HG-10 °C(30)	1259.55	1766.04	569.10
HG-10 °C(60)	1196.42	1651.77	551.38
HG-10 °C(120)	1070.17	1423.23	540.29
HG-10 °C(210)	880.80	1080.42	220.24
HG-10 °C(360)	510.32	622.71	88.89

Table 3. Capsaicinoids contents of samples during storage (μg/g). FG, natural air dried and storage at ambient temperature; HG, hot air dried and storage at ambient temperature; FG-bg, natural air dried and storage at ambient temperature protect from light; HG-bg, hot air dried and storage at ambient temperature protect from light; FG-10 °C, natural air dried and storage at 10 °C protect from light; HG-10 °C, hot air dried and storage at 10 °C protect from light. FG/HG/FG-bg/HG-bg/FG-10 °C/HG-10 °C (0) represent fresh samples, FG/HG/FG-bg/HG-bg/FG-10 °C/HG-10 °C (1), (30), (60), (120), (210) and (360) represent samples treated via the different drying and storage methods for 1, 30, 60, 120, 210 and 360 days, respectively.

capsaicinoids retention was in FG-10 °C (360), 958.29 μg g^{-1} in capsaicin, 1160.58 μg g^{-1} in dihydrocapsaicin and 188.64 μg g^{-1} in nordihydrocapsaicin, respectively. In general, capsaicin in all samples showed a decreasing trend, and the retention of capsaicin in the natural air drying treatment group was higher than in the hot air drying treatment group. This should be due to the damage caused by heat treatment in the hot air drying process to the tissue cells of the pepper samples, which changed the conformation of molecules in the pepper matrix, so that capsaicin substances were exposed and fully combined with oxygen and enzymes. As a result, the decomposition

rate was accelerated and the content was reduced[7,14]. Storage conditions at low temperature and protect from light were more conducive to the retention of capsaicinoids in dried pepper.

Fatty acid composition

Fatty acid is an important quality index in capsicum, which is not only indispensable for human health, but also the chemical transformation of fatty acid is one of the forming factors for the production of characteristic volatile compounds in capsicum[34]. In order to better understand the changes of fatty acid contents in yellow dried pepper after long- term storage, the fatty acid contents of samples on the first day after air drying and drying and 360 days after storage under different conditions were determined in this experiment (Table 4). Compared with the first day after drying, the detected types of fatty acids in the samples after 360 days of storage did not change, which were still 18 kinds of fatty acids. Among them, there were 10 kinds of saturated fatty acids, 3 kinds of monounsaturated fatty acids and 5 kinds of polyunsaturated fatty acids. Although the types of unsaturated fatty acids were less than saturated fatty acids, the content of total unsaturated fatty acids was higher than that of total saturated fatty acids, and the total unsaturated fatty acids accounted for 50.13% (HG1) to 60.03% (FG360) of the total fatty acids in the samples. In terms of fatty acid monomer content, the contents of palmitic acid (C16:0), α-linolenic acid (C18:3n3) and arachidonic acid (C20:4n6) ranked the top three successively. Interestingly, the contents of C16:0 and C18:3n3 in all samples increased significantly after 360 days of storage, and the content of C18:3n3 exceeded that of C16:0, accounting for the highest proportion in the total fatty acids. HG360 (1.98 g·100 g^{-1} dw) and FG360 (1.94 g·100 g^{-1} dw) had the highest C18:3n3 content in the samples, respectively. In addition, γ-linoleic acid (C18:3n6) and pentadecenic acid (C15:1) increased the most in samples stored at 10 °C. As an essential fatty acid, C18:3n6 plays a variety of important physiological functions in the human body, and its content of gamma-linoleic acid increased by 185.9% and 236.1% at FG-10 °C (360) and HG-10 °C (360), respectively. In addition to eicosapentaenoic acid (C20:5), the other 4 kinds polyunsaturated fatty acids detected in the samples of yellow dried pepper were increased in varying degrees. The content of C20:5 in all samples decreased after 360 days of storage, among which the content of FG-bg (360) and HG-bg (360) decreased respectively by 17.42% and 34.02%.

In this study, the contents of C16:0,C18:3n3 and C20:4n6 ranked the top three respectively, which was consistent with the results of previously discussed[38], indicating that palmitic acid and alpha linolenic acid were the main fatty acids in dried chili peppers. Our experimental results showed that during long-term storage of yellow pepper, most fatty acid contents would increase, while a small amount of polyunsaturated fatty acid would be lost. Compared with other storage conditions, samples stored at low temperature at 10 °C better retained various fatty acid abundances.

Fatty acids	FG (1)	HG (1)	FG (360)	FG-bg (360)	FG-10℃ (360)	HG (360)	HG-bg (360)	HG-10℃ (360)	LOD (g/100 g)	LOQ (g/100 g)
C12:0	0.0177	0.0115	0.0288	0.0292	0.0293	0.0157	0.0156	0.0167	0.0021	0.0066
C14:0	0.0802	0.0643	0.1197	0.1225	0.1197	0.0876	0.0950	0.0921	0.0012	0.0033
C15:1	0.0264	0.0188	0.0202	0.0233	0.0261	0.0196	0.0207	0.0284	0.0012	0.0033
C15:0	0.0067	0.0047	0.0082	0.0094	0.0097	0.0082	0.0095	0.0108	0.0012	0.0033
C16:1	0.0096	0.0080	0.0090	0.0104	0.0121	0.0093	0.0107	0.0133	0.0012	0.0033
C16:0	0.8895	0.9137	1.3422	1.4445	1.3796	1.5565	1.7654	1.5044	0.0021	0.0066
C17:0	0.0146	0.0142	0.0141	0.0149	0.0149	0.0145	0.0186	0.0166	0.0021	0.0066
C18:3n6	0.0264	0.0221	0.0421	0.0478	0.0491	0.0493	0.0521	0.0522	0.0021	0.0066
C18:2n6c	0.0319	0.0303	0.0990	0.0592	0.0676	0.1016	0.0644	0.0831	0.0021	0.0033
C18:1n9c	0.1120	0.0673	0.3025	0.1682	0.2009	0.2756	0.1795	0.2578	0.0021	0.0066
C18:3n3	0.8628	0.6613	1.9406	1.7522	1.7751	1.9828	1.8606	1.8829	0.0021	0.0033
C18:0	0.3026	0.2766	0.3645	0.3858	0.3260	0.3648	0.4181	0.3391	0.0021	0.0066
C20:5	0.1250	0.1346	0.1242	0.1032	0.1217	0.1253	0.0888	0.1156	0.0021	0.0033
C20:4n6	0.4773	0.4207	0.4012	0.4538	0.4162	0.4230	0.4481	0.4442	0.0021	0.0033
C20:0	0.0403	0.0342	0.0366	0.0444	0.0386	0.0356	0.0429	0.0351	0.0021	0.0066
C22:0	0.0278	0.0206	0.0262	0.0334	0.0222	0.0180	0.0248	0.0213	0.0021	0.0066
C23:0	0.0040	0.0043	0.0037	0.0049	0.0087	0.0040	0.0046	0.0044	0.0021	0.0033
C24:0	0.0127	0.0120	0.0139	0.0162	0.0139	0.0114	0.0144	0.0134	0.0021	0.0066
Total saturates	1.3961	1.3561	1.9580	2.1054	1.9626	2.1164	2.4090	2.0539	–	–
Total monounsaturates	0.1480	0.0941	0.3318	0.2019	0.2391	0.3045	0.2109	0.2995	–	–
Total polyunsaturates	1.5234	1.2691	2.6070	2.4162	2.4297	2.6820	2.5140	2.5780	–	–
Total fat	3.0675	2.7193	4.8968	4.7235	4.6314	5.1029	5.1340	4.9314	–	–

Table 4. Fatty acid compositions of dried pepper samples during storage (g/100 g of sample DW).

Physicochemical compounds

TSS

After drying treatment, the TSS content of all samples decreased to varying degrees compared with fresh sample, as shown in Fig. 2A, where the content of the hot air drying treatment group was reduced from 25.60 to 18.26% and that of the natural air drying treatment group to 16.53%.The TSS content of the sample decreased due to the hydrolysis or decomposition reaction of some soluble sugars and organic acids at high temperature, thus reducing the content of soluble solids. In addition, water loss will also affect the content of soluble solids[39].During the whole storage period, the TSS content of all samples showed a trend of first increasing and then decreasing at the turning point of 120 days, which was related to the increase of respiration and evaporation rate of the pepper sample in the early storage period, and the starch in the pepper pulp was degraded into soluble sugar[40,41]. However, with the increase of storage time and the composition and transformation of soluble sugar and other substances, the TSS of the sample showed a decreasing trend. After 12 months of storage, the samples stored at 10 °C by natural air drying (FG-10 °C) retained the highest TSS content (16.24%), and the samples stored at HG-bg by drying and light shielding (12.09%) retained the lowest TSS content among all the samples.

Total protein

The total protein content of the sample initially decreased during the storage period, then increased after 120 days, and then slowly decreased after 210 days of storage, as shown in Fig. 2B. The significant decrease in protein content during drying and pre-storage was due to the large number of proteins involved in the Maillard reaction and hydrolysis. However, the free amino acids or peptide chains in the protein hydrolysates may react more strongly with the staining agent, resulting in an increase in total protein content during the middle stage of storage. In addition, due to the decrease in water content in dried pepper samples during storage, this decrease in water content is also reflected by the increase in the proportion of protein content[42]. Then the total protein continued to degrade under the action of protease. Finally, after 12 months of storage, the total protein content of samples stored at 10 °C had the least degradation, and the content of FG-10 °C (360) was 3.79 g·100 g^{-1} dw, and the content of HG-10 °C (360) was 3.15 g·100 g^{-1} dw.

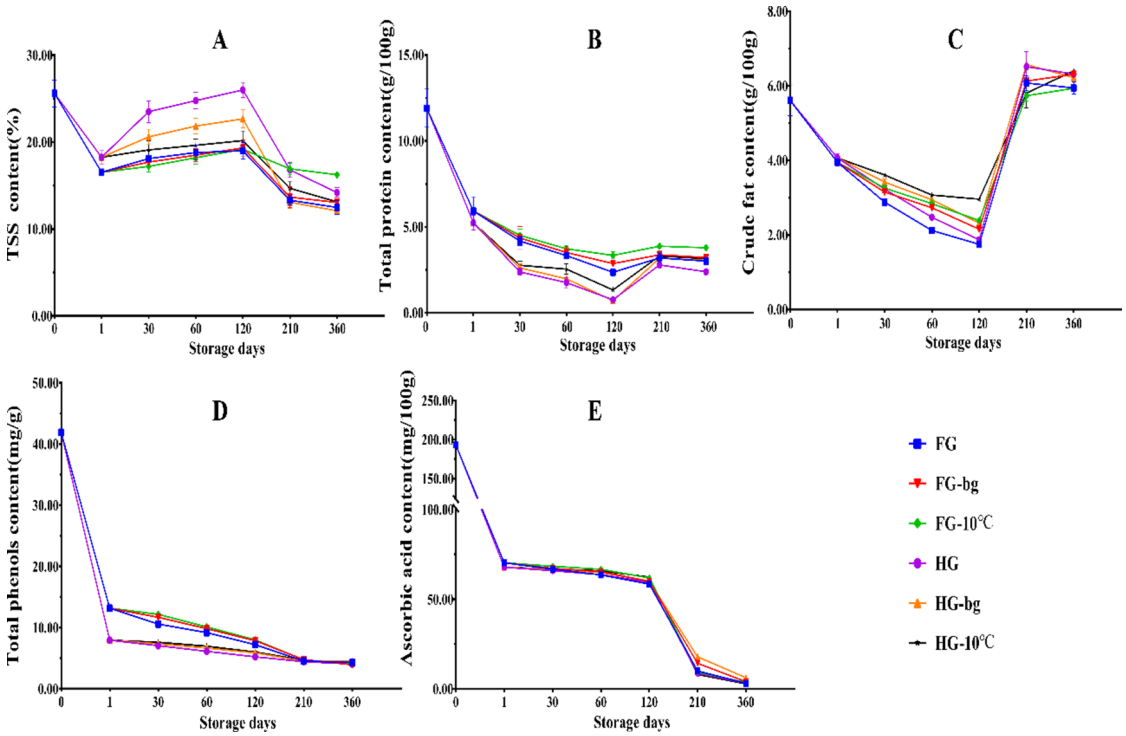

Fig. 2. Changes in total soluble solids (**A**), total protein (**B**), crude fat (**C**), total phenols (**D**) and ascorbic acid (**E**) during storage. FG: Natural air dried and storage at ambient temperature, HG: Hot air dried and storage at ambient temperature, FG-bg: Natural air dried and storage at ambient temperature protect from light, HG-bg: Hot air dried and storage at ambient temperature protect from light, FG-10 °C: Natural air dried and storage at 10 °C protect from light, HG-10 °C: Hot air dried and storage at 10 °C protect from light. FG/HG/FG-bg/HG-bg/FG-10 °C/HG-10 °C (0) represent fresh samples, FG/HG/FG-bg/HG-bg/FG-10 °C/HG-10 °C (1), (30), (60), (120), (210) and (360) represent samples treated via the different drying and storage methods for 1, 30, 60, 120, 210 and 360 days, respectively.

Crude fat

As shown in Fig. 2C, the crude fat content of all samples fluctuated significantly before and after 120 days of storage. After drying treatment and 120 days before storage period, the crude fat content showed a decreasing trend, during which the samples stored at low temperature (FG-10 °C and HG-10 °C) had the lowest decreasing rate. After that, the crude fat content of all samples increased significantly, and the growth rate of crude fat content of samples in the natural air drying group slowed down and tended to be stable after 210 days of storage, while the hot air drying group reached the peak value after 210 days of storage and then slowly decreased. Interestingly, after 12 months of storage, compared with room temperature storage and low temperature storage, the crude fat content of dried pepper samples stored at room temperature under dark storage conditions was higher, and the contents of FG-bg (360) and HG-bg (360) were 6.31 g·100 g^{-1} dw and 6.41 g·100 g^{-1} dw, respectively.

We believe that during the storage process of yellow dried pepper samples, the initial decrease in crude fat content is due to the gradual evaporation of water in dried pepper in a dry environment and the decomposition of a certain amount of fat under the action of enzymes, resulting in a decrease in crude fat content in the sample[43]. The reason for the increase of crude fat content in the middle stage of storage may be due to the hydrolysis and lipid peroxidation reaction of fatty acids in dried pepper during storage, which releases more free fatty acids and other oxidation products, leading to the increase of crude fat content[44]. It's worth noting that the initial moisture content of samples could affect the determination of the crude fat as well. For instance, if the moisture content in the samples collected during the first 120 days were higher than that in the samples collected later, it could create interference in the analysis. Under low-temperature storage, the activity of enzymes decreases, and the hydrolysis and oxidation reaction rate also decrease, which may explain why the ether extract content increases more under room temperature and light avoidance conditions. With the increase of storage time, these reaction rates will gradually slow down, and the crude fat content will gradually stabilize.

Total phenols

Phenols have good antioxidant and antibacterial effects, is beneficial to human health, and is an important nutritional quality index in peppers[37,45]. Drying results in a significant decrease in phenolic content[46], while heating results in a greater breakdown of phenols, so hot air drying results in a greater loss of total phenolic content. In this experiment, the total phenols content of all samples showed a decreasing trend during the whole process from drying treatment to storage (Fig. 2D). Compared with fresh samples, the total phenols content in samples after natural air drying and hot air drying decreased significantly, by 68.54% and 81.02%, respectively. During storage, the total phenol content of all samples showed a slow decline trend, which was similar to the study of Goulas et al.[47]. After 210 days of storage, the loss rate of total phenols content in all samples was further reduced, but no violent decomposition occurred. In general, compared with the hot air drying treatment group, the samples in the natural air drying treatment group retained higher total phenols content, among which the samples stored at 10 °C (FG-10 °C) retained the highest total phenols content of 4.33 mg g^{-1} dw. Similarly, the sample stored at 10 °C (HG-10 °C) in the hot air drying treatment group also had the highest total phenols retention of 4.21 mg g^{-1} dw. It was believed that during long-term storage, hydroxy-cinnamic acid derivatives, flavonols and other components related to the content of total phenols would be significantly lost, resulting in a decrease in total phenols content. Low temperature storage is conducive to maintaining the total phenols content in capsicum.

Ascorbic acid

Ascorbic acid (AsA) is abundant in chili peppers, but its content is also susceptible to temperature, oxygen, pH, metal and other parameters[48]. Therefore, ascorbic acid content is often used as an indicator to evaluate the nutritional loss of fruits and vegetables during processing and storage[49]. As can be seen from Fig. 2E, ascorbic acid content of all pepper samples decreased sharply after drying treatment, and then showed a downward trend during storage. The loss rate increased significantly after 120 days of storage and slowed down after 210 days of storage. After 360 days of storage, under dark storage conditions, there was no significant difference between natural air drying and hot air drying. HG-bg (360) showed the highest AsA retention of 6.23 mg 100 g^{-1} dw, followed by FG-bg (360) with 4.03 mg 100 g^{-1} dw. In this study, after drying treatment, the ascorbic acid content decreased sharply, which was consistent with the research findings of Kaur et al.[50]. And the reason was drying treatment accelerated the oxidation of ascorbic acid in the sample. After 120 days of storage, the decrease rate of ascorbic acid content in samples increased sharply, which could be attributed to the destruction of cell structure, resulting in more release of ascorbic acid and rapid oxidation to dehydroascorbic acid[16]. Finally, samples under dark storage conditions retained more ascorbic acid, indicating that light is an important factor affecting the ascorbic acid retention in dried capsicum during storage, and dark storage conditions are more conducive to the retention of ascorbic acid in dried capsicum.

Correlation analysis of quality indicators

We conducted correlation analysis on the above quality indicators, in order to understand whether the changes of each index in the storage process of yellow dried pepper are correlated (Fig. 3). The L* value was significantly positively correlated with total soluble solids, total phenols, capsaicin, dihydrocapsaicin, nordihydrocapsaicin, zeaxanthin and β-carotene. The a* value significantly positively correlated with β-carotene ($r = 0.50$, $p < 0.05$). b* values significantly negatively correlated with zeaxanthin ($r = -0.33$, $p < 0.05$). TSS, total phenol, ascorbic acid, capsaicinoids and carotenoids positively correlated or significantly positively correlated. Crude fat negatively correlated with the above indexes (significantly negatively correlated with zeaxanthin and total phenols). Ascorbic acid significantly positively correlated with capsaicinoids, zeaxanthin and β-carotene. Capsaicinoids (capsaicin, dihydrocapsaicin and nordihydrocapsaicin) significantly positively correlated with zeaxanthin and β-carotene.

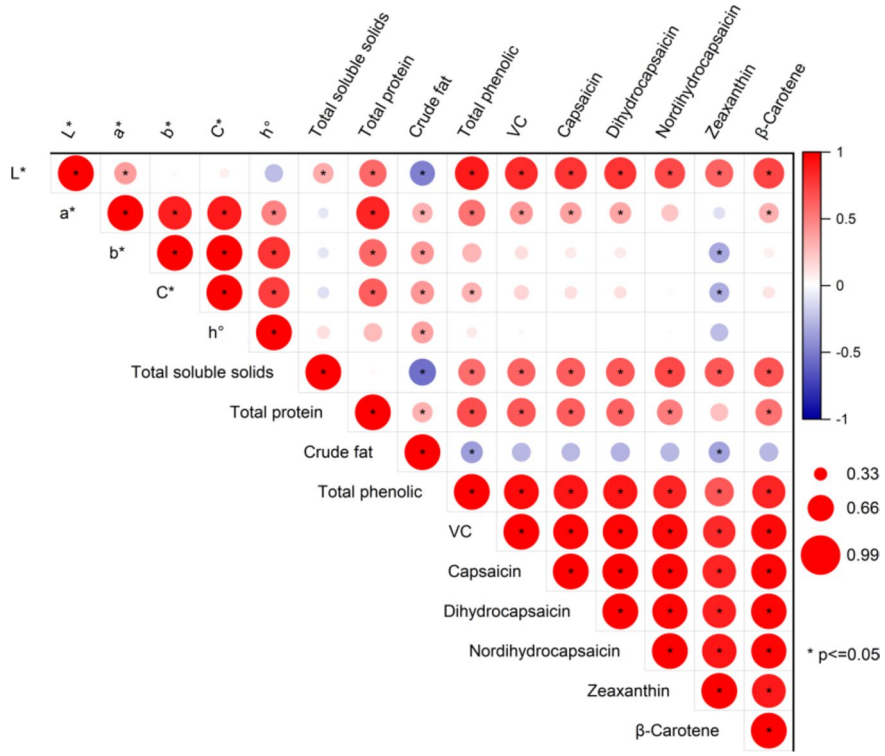

Fig. 3. Correlation analysis of quality indicators Blue means negative correlation, red means positive correlation. The depth of the color represents the level of correlation (the higher the correlation, the darker the color). The size of the circle also indicates the level of the correlation coefficient, and the higher the correlation coefficient, the larger the circle. Statistical significance is indicated as *, $p <= 0.05$.

Correlation analysis showed that crude fat and fatty acid content were positively correlated, and the content increased to varying degrees during storage, which may also be the reason why yellow dried pepper, different from other red dried peppers, showed special flavor during storage. Ascorbic acid was positively correlated with zeaxanthin and β-carotene, indicating that carotenoids content were positively correlated with antioxidant content, which is consistent with previous research findings[51]. Capsaicinoids (capsaicin, dihydrocapsaicin and nordihydrocapsaicin) were positively correlated with zeaxanthin and significantly positively correlated with β-carotene, which was consistent with our previous findings[21], suggesting that the presence of capsaicinoids in peppers had a positive impact on the stability of carotenoids during drying and storage. In addition, to enhance the understanding of the mutual influence between different nutritional components and to improve research quality, the application of mathematical modeling in future research would be a viable solution.

Hierarchical cluster analysis

In order to study the effects of different drying methods and storage conditions on the quality of yellow dried pepper, the hierarchical cluster analysis method was used to describe the relationship between yellow dried pepper samples and quality indexes, and the research results were shown in the form of heat map (Fig. 4). According to the clustering results, all the samples were divided into four groups. Samples of 0 days (i.e. fresh samples) were grouped into one group (cluster I), samples of natural air drying and hot air drying treatment and storage from 1 to 120 days were grouped into one group (cluster II), samples of natural air drying and storage for 210 and 360 days were grouped into one group (cluster III), and samples of hot air drying and storage for 210 and 360 days were grouped into one group (cluster IV). In each group, the samples of the natural air drying treatment group and the hot air drying treatment group were well clustered together, respectively, indicating that compared with the storage conditions, the drying method had a stronger effect on the quality of the sample. The results of factorial ANOVA also indicate that the effect of natural air drying treatment is significantly higher than that of hot air drying treatment under three storage conditions during the storage period. Compared with cluster I samples, cluster II samples in addition to L value, all the index content has been reduced to varying degrees, and the drying treatment of samples a*, b*, C* values are reduced more. The quality changes of cluster III and cluster IV samples were similar. Compared with cluster I samples, the contents of β-carotene, zeaxanthin, capsaicin, dihydrocapsaicin, nordihydrocapsaicin, ascorbic acid and TSS of the samples in these two groups were significantly decreased, indicating that the quality of dried yellow pepper stored for a long time (more than 210 days) would be affected.

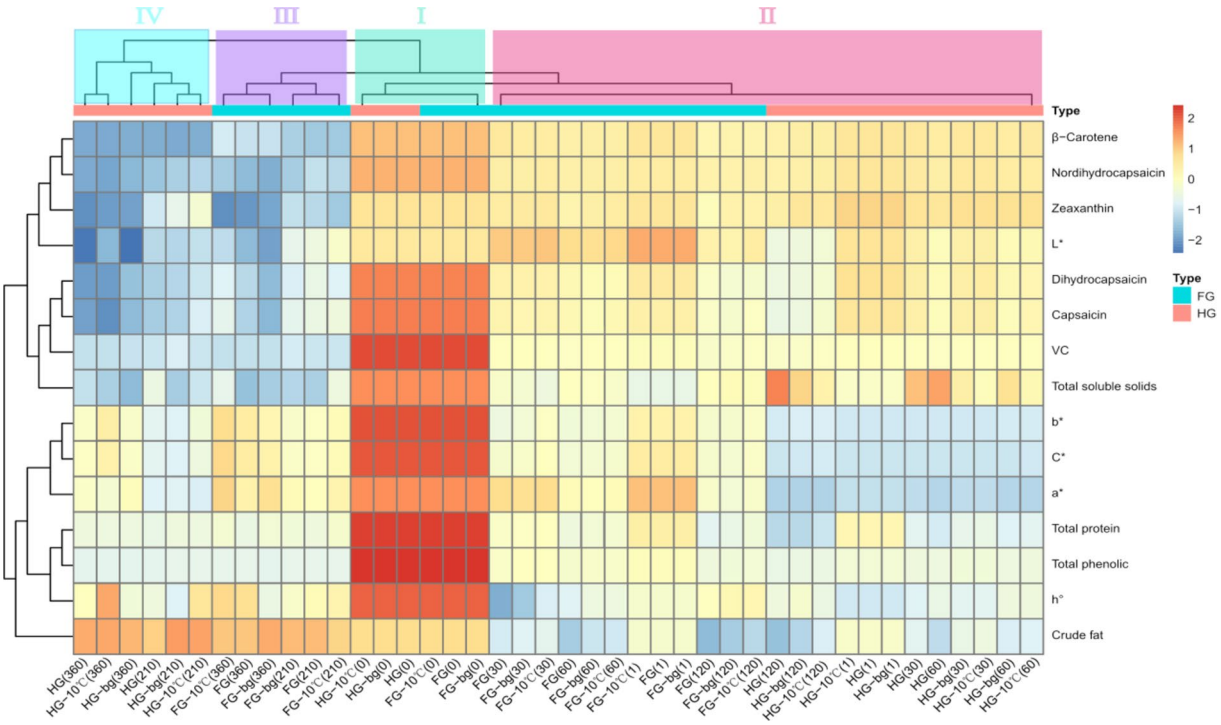

Fig. 4. Hierarchical cluster analysis of the quality properties of dried pepper subjected to different drying methods and storage conditions. FG: Natural air dried and storage at ambient temperature, HG: Hot air dried and storage at ambient temperature, FG-bg: Natural air dried and storage at ambient temperature protect from light, HG-bg: Hot air dried and storage at ambient temperature protect from light, FG-10 °C: Natural air dried and storage at 10 °C protect from light, HG-10 °C: Hot air dried and storage at 10 °C protect from light. FG/HG/FG-bg/HG-bg/FG-10 °C/HG-10 °C (0) represent fresh samples, FG/HG/FG-bg/HG-bg/FG-10 °C/HG-10 °C (1), (30), (60), (120), (210) and (360) represent samples treated via the different drying and storage methods for 1, 30, 60, 120, 210 and 360 days, respectively.

Conclusion

Our experimental results show that, compared with fresh pepper samples, the appearance color of yellow pepper samples after natural air drying and hot air drying has different degrees of "Browning", and the contents of TSS and protein in the sample are greatly reduced, which is due to the Maillard reaction of sugars and proteins in the sample, thus giving the dried pepper attractive color and pleasant flavor. This phenomenon is more obvious in the hot air dried pepper samples. The abundance of ascorbic acid and fatty acids was also higher in the hot air dried group. The results of the storage experiment showed that the storage condition of 10 °C at low temperature and protect from light was more conducive to the retention of TSS, total protein, total phenol, capsaicinoids (capsaicin, dihydrocapsaicin and nordihydrocapsaicin) and most of the fatty acids of dried pepper, which had a positive effect on the shelf life of yellow dried pepper, and was the optimal condition for storage. In addition, many indexes such as soluble solid, total protein, crude fat, β-carotene and capsaicin showed some irregular changes after 210 days of storage, indicating that the change of pepper quality after 210 days is uncontrollable under the above storage conditions, the interference factors increase, and the storage quality cannot be guaranteed. Therefore, it is suggested that the storage period of yellow pepper raw materials should not exceed 210 days, and it is appropriate to process and sell as soon as possible. In order to better explore the dynamic change of variety index of dried pepper during storage, we will add a sampling time point between 120 and 210 days of storage in the future experimental design, so as to obtain a more accurate data model and provide a better scheme to ensure the processing and storage quality of dried yellow pepper.

Data availability

All data generated or analysed during this study are included in this published article[Please refer to Supplementary files].

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Competing interests

The authors declare no competing interests.

Additional information

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