Review n. 39 – *Italus Hortus* 26 (3), 2019: 41-49 doi: 10.26353/j.itahort/2019.2.4149

Effect of growing conditions on the performance of potted plants in the interior plantscaping

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Ricezione: 30 novembre 2019; Accettazione: 9 dicembre 2019

Effetti delle condizioni di crescita sulle prestazioni in ambiente interno delle piante ornamentali in vaso

Riassunto. Le condizioni di crescita e gli interventi colturali sono responsabili della qualità delle piante ornamentali nelle fasi di commercializzazione e di utilizzazione in ambiente interno. I principali problemi in post-produzione per le piante in vaso sono rappresentati in quelle da fiore dall'abscissione dei boccioli e dei fiori stessi e nella caduta o ingiallimento delle foglie nelle piante da fogliame. Le condizioni colturali possono consentire l'accumulo di riserve utili per preservare la qualità ornamentale durante la catena di distribuzione e la fase di utilizzazione. Le perdite di qualità nelle piante da fogliame per interni sono dovute soprattutto alla precoce senescenza delle foglie connessa ad una mancata acclimatazione prima della commercializzazione. La caduta delle foglie, conseguente al trasferimento in spazi interni, si verifica quando le piante non hanno ridotto il punto di compensazione della luce. Per favorire questo processo tali piante sono di solito coltivate in serre ombreggiate per ottenere un migliore adattamento alle difficili condizioni degli ambienti interni. Le piante coltivate con più bassi livelli di radianza modificano i parametri morfofisiologici (ad es. distribuzione della biomassa, fotosintesi, architettura della chioma) per massimizzare l'assorbimento della luce. Condizioni di bassa disponibilità di luce possono anche migliorare le caratteristiche ornamentali delle piante, spesso legate alle caratteristiche delle foglie.

Parole chiave: abscissione, durata dei fiori, precommercializzazione, trattamenti, ingiallimenti.

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Introduction

The post-production quality of potted plants depends by the different growing conditions (Williams *et al.*, 1995), although it is not clear how and what extent these conditions influence post-production life.

The quality of potted ornamental is linked to the leaf colour, number of flowers, longevity of flowers, and leaves. All these parameters contribute to the visual appearance of ornamental plants (Toscano *et al.*, 2018).

The aesthetic quality loss of potted ornamental plants during the post-production stage is primarily affected by water stress, because of substrate moisture loss due to plant transpiration and evaporation from substrate surface. As a result, plant quality often declines during retail, reducing salability and grower profits (Jones, 2002; Startman *et al.*, 2007). The water stress in plants can induce the abscisic acid accumulation or the ethylene production with induction of leaf or flower senescence. The plant hormones imbalance can have negative effects on the ornamental quality. The increase of ethylene can induce leaf abscission with dramatic quality reduction. Leaf and flower abscission can occur during post-production stage. Studies performed on *Radermachera sinica* L. in a Simulated Indoor Environment (SIE) found that the tissue concentration of calcium (Ca) can prevent the leaf abscission acting on ABA and ethylene relationship (Dunlap *et al.*, 1991).

Sun grown *Ficus benjamina* had more carbohydrates than those grown under shade and increased the nitrogen content with lowered carbohydrate reserves (Milkes *et al.*, 1970). In *Coprosma* 'Coppershine' Hong and Suh (2012) found that the tissue nitrogen (N) concentration should be higher than 4% to prevent leaf abscission. The increase of fresh and dry weights combined with no leaf abscission after 18 days under SIE using 2 g of controlled release fertilizer (CRF) demonstrated that a steady availability of nutrients is required. In the same experiment more leaves abscised when plants were grown at high temperature (21°C) and under the highest irradiance (316 μmol m^{-2} s^{-1}) as compared to those grown at low temperature (15.5°C) and mid level of irradiance (218 μmol m^{-2} s^{-1}).

Other causes of decreased post-production life are wilted flowers, infection by grey mold (*Botrytis cinerea*) and yellowing of flower buds and leaves (Dresbøll, 2010).

Environmental effects

Effect of temperature during cultivation

Temperature of growing environments has direct effect on plant growth and flowering. Few papers have been focused on the relationship between air temperature and post-production performances. It is well known that air temperature significantly affects plant growth (Chen *et al.*, 2005b). The effect of temperature is important because has direct effect on photosynthesis and respiration. However, temperature is not an important factor during foliage plant acclimatization (Nell and Barrett, 1990). For this reason, the temperature is not deeply analyzed and/or investigated in interaction with light and fertilization level in ornamental plants. In *Coprosma* 'Coppershine' plants, used as indoor or garden plant, the post-production leaf abscission can be reduced by growing with an increased fertilizer level at high temperature (Hong and Suh, 2012). The result is strictly linked to the thermal requirements of the species. So, in the most widely utilized tropical tree in the interior landscape industry, *Ficus benjamina*, plants were exposed for six months to 15, 20, and 25°C combined with photon flux densities (PFD) of 40, 80 and 180 μmol $m^{-2}s^{-1}$ (Kubatsch *et al.*, 2005). These plants during post-production were placed in an interior environment at 18 μmol $m^{-2}s^{-1}$ PFD and 20°C for six months. Plant growth characteristics were nearly the same among acclimatization treatments. However, temperature and irradiance during acclimatization influenced internode lenght growth and leaf carotenoid content, and hence quality features, after plants were placed in an interior environment. Sometime the temperature level, during the production phase, from 20 to 24°C, is adopted to evaluate the interior performance of plants (Chen *et al.*, 2001). In flowering potted plants, the reduction of temperature during production phase decreased the leaf drop of 'Annette Hegg Supreme' poinsettia (Staby and Kofranek, 1979).

Light and temperature effects are difficult to separate. High temperature and drought effects make difficult to analyze the influence of thermal level on postharvest performance. It is known, for instance, that the optimum temperature for plant growth decreases by decreasing irradiance (Biörkman, 1980). In bedding plants, numerous reports recommended that production temperature should be reduced to 14-16°C for 2-3 weeks before marketing. This procedure is designed to intensify flower colour, but no data are available on the effect on flower longevity (Nell and Barrett, 1990). The response is dependent to different species and cultivars. In cyclamen, for instance, the flower longevity was increased by growing plants at 17°C compared to 13°C (Molinar and Williams, 1977).

To investigate the effects of light availability and the climatic conditions on the growth and quality, plants of *Ficus benjamina* 'Danielle' were grown under different shading conditions (from 0 to 80% reduction of the incident irradiance inside the greenhouse) in two cultivation periods (from May to October and from December to May). Depending on climatic conditions, the light reduction resulting from shading reduced the plant growth and compactness more in the growth period characterized by the highest values of global radiation and temperature, whereas the quality of the plants was improved by shading in both of the growth periods (Scuderi *et al.*, 2012).

Light intensity during cultivation

Light intensity during cultivation has direct influence on the successful acclimatization to indoor environments (Conover and Poole, 1984; Sawwan and Ghunem, 1999; Yeh and Wang, 2000; Chen *et al.*, 2005a). Foliage plants are usually grown in shaded greenhouses because light reduction have positive effect on indoor conditions adaptation (Bulle and de Jongh, 2001; Scuderi *et al.*, 2005). Light acclimatization can be achieved using two different methods (Chen *et al.*, 2005b): grow the plants under relatively high light conditions to near-finished sizes and then reduce light level for 4 to 5 weeks or longer before shipping to market for interiorscaping. Another method is to grow plants initially under constant reduced light levels until marketable sizes are reached, but this method hampers the plant growth (Scuderi *et al.*, 2008).

Light reduction during acclimatization improves the plant interior performance by lowering the light compensation point, thus reducing leaf abscission and maintaining the aesthetic values during interiorscape (Fonteno and McWilliams, 1978; Reyes *et al.*, 1996; Yeh and Wang, 2000; Chen *et al.*, 2005a). Light compensation point represents the equilibrium between photosynthesis and respiration. It means that the amount of carbon dioxide assimilated through the photosynthesis is equal to the amount of carbon dioxide released from the respiration. The reduction light compensation point means that plants reduce respiration and even if the photosynthesis activity is low under low light conditions, the net photosynthesis is positive. In fact, the plant growth depends from the difference between photosynthesis and respiration in 24 h period.

The cultivation under low light conditions can allow a better performance during the utilization phase. Extensive researches have been carried out on *Ficus benjamina* L., a species grown and commercialized as plant for indoor use, to study foliage abscission or leaf loss when plants grown under full sun conditions were transferred directly to a SIE without acclimatization (Steinkamp *et al.*, 1991). Shade modifies plant foliage parameters (i.e. total leaf area, chlorophyll content) and improves photon absorption under low radiation availability. The post-production quality of *Ficus benjamina* L. can be improved by progressive reduction of light intensity before selling. This acclimatization to low light environment allows the lowering of light compensation point and better performance indoor. However, shade modifies plant foliage parameters (i.e. total leaf area, leaf size, lamina angle, chlorophyll content) (Scuderi *et al.*, 2003) and improves photon absorption under low radiation availability (Schiefthaler *et al.*, 1999). The plant production under accentuated shading, for the entire growth cycle, has direct effect on the cultivation cycle length with reduced profit for growers (Veneklaas *et al.*, 2002; Scuderi *et al.*, 2010).

Plant production under reduced light levels is not advisable for all ornamental plants because induce several morphological changes such as internode elongation, with impact on the visual appearance, especially of some woody ornamental plants, like *Ficus* and *Schefflera* (Kubatsch *et al.*, 2005). The internode elongation as response to low light conditions can be attenuated by plant growth retardants that can be applied as a foliar spray or soil drench (Davis, 1987). These plant growth regulators (PGRs) are inhibitors of gibberellins such as paclobutrazol. This PGR has been successfully used for controlling the height of *Caladium·x hortulanum* Bird., *Codiaeum variegatum* (L.) Blume, *Schefflera actinophylla* Endl., *Euphorbia pulcherrima* Wind., and *Impatiens wallerana* (L.) Hook. f. (Barrett *et al.*, 1994) as well as *F. benjamina* (Barrett and Nell, 1983). *Pachira aquatica* Aubl. plants grown under low light levels (between 285 and 350 mmol $m^{-2}s^{-1}$) did not significantly change canopy height, width, or internode length, but showed a modification of the photosynthetic light response curve and a lowered light compensation point. The ornamental value and interior performance of *P. aquatica* plants has been significantly improved by the use of foliar spraying of paclobutrazol applied at a concentration between 50 and 150 $mg \cdot L^{-1}$ (Li *et al.*, 2009).

The acclimatization of plants for interior light levels can be also related to fertilization rates which affected leaf morphology structure, and abscission (Johnson *et al.*, 1979). It has been found that leaf abscission was severe when plants grown under full sun and high rates of nitrogen fertilization and subsequently transferred to interior conditions without acclimatization (Conover and Poole, 1975a, 1975b; Turner *et al.*, 1987). However, the level of irradiance for optimum growth and acclimatization may differ among the ornamental species.

In flowering plants, light acclimatization practices have a negative impact on flower longevity (Field, 1986; Nell and Barrett., 1990), because influence the carbohydrates content. The light intensity used during cultivation can affect the reserve accumulation in the plants and subsequently the flower production during the indoor permanence. Two cultivars, 'White Princess' and 'Royal Dane', of *Exacum affine* potted plants were grown under two supplementary light conditions, 70 or 100 µmol m^{-2} s^{-1}. The higher light intensity stimulated the plant growth and reduced the growing cycle and increased the flower production during the post-production period in an interior environment (Serek and Trolle, 2000). Plants will not be able to provide enough energy to produce new flowers, unless there is sufficient light for net photosynthesis (Reid *et al.*, 2002).

The post-production performance of ornamental plants in indoor environments can vary among species, therefore it is very important to identify selection criteria. In general, the indoor plants should be characterized by low light compensation point and low light requirements for net photosynthesis. Flowering plants for indoor environments should be characterized by high carbohydrates accumulation in order to guarantee a good flowering rate even under sub-optimal light conditions. *Salvia splendens* plants, placed in indoor environment, showed good flowering until two weeks and almost three weeks (19 days) if treated with benzyladenine (Ferrante *et al.*, 2006). The challenge is therefore to identify species with high low-light photosynthesis rates, and reduced respiration rate (Reid *et al.*, 2002).

Cultivation management

The majority of potted ornamental plants are grown using substrates in soilless systems. The composition of growing media can affect plant growth and could be a determinant factor between profit and crop loss (Sheehan and Tjia, 1976). Medium composition was previously found to affect the performance of pot-grown plants under interior conditions (Wang and Sauls, 1988). Wang and Blessington (1990) suggested that media with up to 75% composted cotton burrs may be used satisfactorily for the cultivation of poinsettia plants with excellent post-production quality. Of course, the plant response to growing media is strictly linked to irrigation and nutrition level during cultivation; probably in relation to diffusion of media alternative to peat moss this topic should be deeply analyzed. A major cause of post-production quality loss is drought stress resulting from sub-optimal watering (Barret and Campbell, 2006). During production plants are watered ‘optimally’, yet during post-production they often wilt due to limited water within the pot and higher water consumption by flowering plants (Williams *et al.*, 1999). In *Rosa x hybrida* the percentage of senescent flowers and flower buds were either lower or not influenced by reduced production water availability if the plants were watered well during a keeping quality test (Williams *et al.*, 2000).

The ability of a plant to cope drought may be modified by exposure to stressful conditions during cultivation (Kramer, 1983). Acclimatization is recommended for bedding plants (Eakes *et al.*, 1991) and woody species (Edwards and Dixon, 1995a, 1995b) to improve plant survival after transplanting. Potted miniature roses (‘Charming’ and ‘Bianca Parade®’), grown with cyclic water availability, have higher tolerance to subsequent water stress better than plants grown with a constant water supply (Williams *et al.*, 2000). During cultivation, reducing water availability decreased net photosynthesis (Pn), induced stomatal closure, and subsequently stomatal conductance (Ci) reduction available for CO_2 fixation (Williams *et al.*, 1999). After two weeks under indoor conditions all plants had a lower Pn despite a slightly increase of Ci if compared to cultivation stage. The data indicate that all plants show an acclimatization response to the low light conditions.

Williams *et al.* (2000) showed that rose plants, which experienced stressful conditions during production, were better acclimatized to adverse post-production conditions. A possible explanation for this is that the plants developed better stomatal control either due to closing earlier or more completely in response to stress, and consequently they can regulate transpiration more efficiently than control plants (Edwards and Dixon, 1995a, 1995b). Eakes *et al.* (1991) found that imposing a mild drought stress to induce osmotic adjustment improved the drought tolerance of salvia during post-production stage. However, this conditioning technique resulted in reductions in plant size and may not slow down water use enough to prolong the shelf-life during retail.

Deficit irrigation (DI) is the application of water at a rate and volume lower than the evapotranspiration rate and may be used in potted ornamental plants to improve plant quality, by reducing excessive vigour and promoting a more compact habit (Cameron *et al.*, 2006); the degree and duration of the water stress imposed in each species in field conditions are also critical to reach this purpose (Álvarez *et al.*, 2009, 2013).

It has been shown in potted roses that calcium (Ca) and ammonium (NH_4^+) concentrations in the nutrient solution affected the longevity of the flowers (Starkey and Pedersen, 1997). In general, the positive effect of the Ca concentration in the plant could be due to the reduction of NH_4^+ uptake with an extended longevity of flowers and leaves of potted roses (Nielsen and Starkey, 1999). Starkey and Pedersen (1997) found that the concentration of Ca in flowers of potted roses was inversely correlated with the incidence of grey mold. This finding has an important practical application for improving the post-production performance. Apart from influencing Ca uptake, NH_4^+ can negatively affect the longevity of flowers of potted roses, due to a decrease in pH during cultivation and a consequent inhibition of root growth at pH values below 5 (Starkey and Pedersen, 1997). Ter Hell and Hendriks (1995) also showed the negative effect of NH_4^+ as N source compared to nitrate (NO_3^-) on bud drop in potted roses, *Impatiens* New-Guinea hybrids, and leaf drop in poinsettia (*Euphorbia pulcherrima*).

Poole and Conover (1979) showed that high fertilizer levels during cultivation increase leaf drop after dark storage. Increased N concentration in the plant may cause a decrease in the content of carbohydrates that may lead to an earlier depletion of reserves with negative effects on the postharvest life (reduction of leaves and flowers longevity). In the commercial pot plant production of *Campanula carpatica*, the fertilization strategy influenced the postharvest flower keeping quality (Dinesen *et al.*, 1997). High levels of complete fertilizers or high-N fertilizer significantly decreased the flower longevity compared with the plants irrigated with low concentration or pure water (Serek, 1990). In *Hibiscus rosa-sinensis* reduced P and N availability during cultivation improved the post-production stress tolerance by significantly reducing the number of senescent flower buds and increasing the number of open flowers compared with chemically growth regulated plants (Hansen and Petersen, 2004).

In pot roses, flower life was reduced by 3 days (15%) when the vapour pressure deficit (VPD) decreased from 810 to 220 Pa. On the contrary flower life increased by 9 days (46%) when the K:Ca ratio decreased from the highest to the lowest delaying flower senescence. The increased longevity was associated with an increase in Ca and reduction of K concentration of the flowers (Mortensen *et al.*, 2001). The post-production life of potted roses is mainly determined by the ratio of wilted flowers and abscised leaves. The enrichment of Ca concentration in the nutrient solution leads to an increase of Ca concentration in the plant with subsequent increased postharvest quality expressed as a reduction of the percentage of wilted flowers on day 21 during the postharvest period (Nielsen and Starkey, 1999).

Acclimatization and hardening

The genetic background determines the plant responses to acclimatization and influences their performance under indoor environments. (Chen *et al.*, 2001). The adaptation of flowering and foliage plants to low light conditions of indoor environments has been studied in different species (Chen *et al.*, 2005a). *Ficus benjamina* ‘Common’, a green-leafed plant, has as adaptation strategy the increase of specific leaf area, internode length, and chlorophyll b content.

Ficus benjamina plants showed a significant leaf drop under indoor conditions and this was increasingly evident for the plants grown under lower radiation during the cultivation period. The leaf drop is associated with a reduction in the assimilate rate, more evident in non-acclimated plants and leads to a reduction in leaf starch content (Scuderi *et al.*, 2005).

Variegated-leafed *Dieffenbachia maculata* ‘Camille’ responded to indoor conditions by decreasing leaf area, degree of variegation, and increasing chlorophyll content in the yellow-white leaf areas. Individual leaves of a flowering foliage plant such as, *Anthurium* × ‘Red Hot’, under interior conditions showed a good net photosynthesis (Pn) and delayed leaf senescence. During the indoor vegetation produced new leaves and flowers. Additionally, the canopy configuration of both *Anthurium* and *Dieffenbachia* changed for increasing the light interception. All plants studied apparently maximized net photosynthesis under the low light conditions (Chen *et al.*, 2005a). The shading levels, ranging between 50 and 90% during cultivation stage showed more influence on the garden croton plant response than weeping fig to interior environments (Scuderi *et al.*, 2010). The differences in biometric characteristics evaluated at the beginning and at the end of the trial showed that keeping the plants for eight weeks led to a reduction of total dry biomass mainly related to the variation in the number of leaves that in croton represent a high proportion of plant biomass. These variations were more evident for the plants grown under the highest radiation availability.

Comparing two species (*Brassaia actinophylla* and *Schefflera arboricola*), Braswell *et al.* (1982) found that the second species adapted readily to the interior environments. The *B. actinophylla* showed a reduction of quality after three months of exposure to interior light levels ranging from 414 to 828 $\mu E\ m^{-2}s^{-1}$.

Treatments with plant growth regulators

Plant Growth Regulators (PGRs) are a group of organic molecules that alter the growth and development of plants at very low concentration. They are naturally occurring (plant hormones) or synthetic compounds (synthetic hormone analogs, inhibitors of hormone biosynthesis or translocation and hormone receptor blockers) widely used in ornamental species to obtain specific advantages, such as the control of plant growth (height, lateral branching, flowering) and increase the stress tolerance of plants during shipping and handling and retail marketing.

In ornamental sector, the control of plant height is important to maintain compactness and aesthetic appearance, as well as to prevent damage during transportation and marketing of these commodities (Çelikel *et al.*, 2016). The use of growth retardants, such as daminozide, flurprimidol, chlormequat chloride, paclobutrazol, etephon and ancymidol, have been reported to reduce shoot height in several ornamental species due to their direct control on stem, petiole and flower stalk tissues, by inhibiting the production of gibberellins (Miller, 2010; Miller, 2012; Demir and Çelikel, 2013; Whipker and Latimer, 2013; Wanderley *et al.*, 2014; Miller and Olberg, 2016; Currey *et al.*, 2016).

The application of growth retardants does not only control excessive vegetative growth, but also they have been shown to increase overall plant ornamental value by enhancing the green color of the foliage (Kahar, 2008, Mansuroglu *et al.*, 2009; Lenzi *et al.*, 2015), strengthening the flower stems (Bañón *et al.*, 2003; Warner and Erwin, 2003), and stimulating flowering (Mishra *et al.*, 2005; Thompson *et al.*, 2005). Additionally, the use of these regulators has been shown to promote tolerance against environmental stresses (i.e.: extended periods of low light levels and water stress), that these products encountered during transport, retail marketing and in interior environments, leading an enhancement of shelf life and posthaverst quality (Peterson and Blessington, 1982; Barrett and Neil, 1983; Latimer 2001; Ahmad *et al.*, 2015; Toscano *et al.*, 2018; Demir and Çelike, 2019).

In ethylene sensitive ornamental species, the best strategies to avoid the physiological effects of ethylene as well as to prevent premature wilting, leaf yellowing, premature flower opening, flower senescence, abscission and premature death, are the treatments with ethylene action inhibitors such as silver thiosulfate (STS) or 1-methylcyclopropene (1-MCP). These PGRs protect the plants from endogenous and exogenous ethylene exposure (i.e.: presence of this gas as a atmospheric pollutant in the storage or transportation environments or produced by adjacent crops) by blocking its action, thus preventing leaf, bracts and flowers senescence in many ethylene sensitive cut flowers, potted flowers, bedding, nursery and foliage plants (Serek *et al.*, 1994; Tjosvold *et al.*, 1994; Cameron and Reid, 2001; Fan *et al.*, 2009; Macnish *et al.*, 2011; Ferrante *et al.*, 2012; Karami *et al.*, 2012).

Postharvest chain conditions can induce leaf yellowing disorder due to suboptimal environmental condition (mainly presence of ethylene, darkness and/or low light) and compromise the commercial value of several cut foliage, cut flowers, and potted plants.

Postharvest treatments with cytokinins are able to delay early symptoms of leaf yellowing in these products, (Serek and Andersen, 1993; Mutui *et al.*, 2003; Ferrante *et al.*, 2006; Janowska and Stanecka, 2011). In particular the Thidiazuron (N-phenylN'-1,2,3-thiadiazol-5-yl urea, TDZ), a synthetic compound with a strong cytokinin-like activity has been shown to reduce effectively the quality losses of cut foliages (Bulgari, 2015), cut flowers (Ferrante *et al.*, 2002, 2003, 2005) and potted plants sensitive to leaf yellowing (Jiang *et al.*, 2008, 2009).

Conclusion

The post-production quality of ornamental plants depends from the environmental conditions during cultivation, cultivation systems, irrigation and fertilization managements. Among the environmental parameters the most important are light intensity and temperature. Both play a crucial role on the modulation of photosynthesis and respiration in the plants and reserves accumulation. The quality preservation of ornamental plants during the post-production stage or indoor environments depend on hardening or acclimatization strategies that must be accurately optimized for the different species.

Abstract

The growing conditions and cultivation managements are responsible for the ornamental quality of plants at commercial stage and on post-production quality such as in indoor plantscaping. The major post-production disorders are represented by bud and flower abscission in the flowering potted plants or leaf abscission or yellowing in the foliage potted plants. Pre-harvest conditions can allow the accumulation of reserves and preserving the ornamental quality during the distribution chain and at the utilization stage. The quality losses of foliage potted plants intended for indoor use are mainly due to leaf senescence usually linked to an inadequate hardening before commercialization.

The foliage plants that are transferred to indoor conditions can easily lose their leaves. This phenomenon occurs when plants have not lowered the light compensation point. To support this process the foliage plants are usually grown in shaded greenhouses; these plants, in fact, benefit from the irradiance reduction during the production phase to obtain a better adaptation to the harsh conditions of indoor environments. The shaded plants modify morpho-physiological parameters (i.e. biomass partitioning, photosynthetic response, canopy architecture) to better maximize photon absorption under low radiation availability. The shading conditions could also improve the ornamental characteristics of the plants, often linked to the leaf characteristics.

Key words: abscission, flower life, pre-commercialization, treatments, yellowing.

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