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THE SHELF-LIFE OF THE TEA

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1. INTRODUCTION

Various chemical reactions leading to the deterioration of a food during storage are closely related to the water activity (Aw) of the food. Lipid oxidation, which can result in rancidity, is most rapid at low Aw, whereas non-enzymatic browning reactions show a peak rate when the Aw increases to the intermediate range. Enzyme activity is also maximum at intermediate Aw, whilst the microbial growth occurs only at higher Aw.

Regardless of the variety of the tea (fully fermented black tea, partially fermented Pouchong and Oolong teas or nonfermented green tea), the moisture content of tea leaves changes dramatically from about 75% at the beginning of tea making down to below 5% in the made tea. With this low moisture content, the Aw of the freshly made tea is less than 0.1 (1). The final step of tea making before packaging or marketing is mostly firing or baking at 100 ℃. The purpose of firing or baking is not only quickly reducing the moisture content of tea for easy transport or storage but also stopping or fixing many chemical reactions. For instance: inactivating the polyphenol oxidase (PPO) to stop the fermentation; stopping bioreactions caused by some other enzymes such as peroxidase (POD), lipoxygenase (LIP), etc.; fixing the conversion of chlorophyll to pheophytin and the reduction of astringency of fermented tea by combination of polyphenols with leaf proteins to develop the tea aroma (2). Therefore, basically the shelf-life of these freshly made teas with low Aw and firing or baking treatment usually is quite long if they are under proper storage condition (3).

The freshly made tea, however, usually is not packed immediately after being manufactured. Instead, it goes through the stalks trimming or grading step. In addition, it usually takes one week to several months between manufacturing and marketing. If tea is not properly stored, the shelf-life of tea may be easily shortened by high temperature, high humidity, light exposure and off-odor extraction.

Tea is characterized with its tissue rich in sponge-like structure. The moisture content of the tea leave is high when it is fresh. After drying, it has tremendous amount of empty space through entire tea leaves. The surface area is huge. Additionally tea has high contents of hydrophilic materials such as phenolic compounds, protiens, carbohydrates, pectin, etc. This provides teas with very strong absorbing ability to water or organic compounds from outside. The principle of making scented tea is based on this strong absorbing ability. Furthermore, many reactions such as lipid hydrolysis, auto-oxidative reactions, non-enzymatic browning, etc. may occur during storage (4,5,6). All these factors render the shelf-life of the tea shorter than expected.

Previous reports concerning the shelf-life of tea are scant in the literature, probably because of the low Aw of tea. Labuza reported the shelf-life and Q_{10} of black tea and instant tea under different temperatures (Table 1). The table shows that tea normally has quite a long shelf-life under a proper storage condition. The shelf-life of tea reported by various industrial sources is shown in Table 2. The shelf-life of tea with different forms are 1 to 3 years. Although the reports concerning the shelf-life of tea are few, tea is a flavor-emphasized product and its price depends heavily on the flavor quality. Any possible way causing the quality deterioration during storage may immensely decrease the price. Therefore, reports on tne changes of sensory quality, chemical components or price during storage are plenty in the literature. This report is a brief summary of the effects of changes in the sensory quality or chemical components of black, green and Pouchong teas during storage on the shelf-life.

TABLE 1
Shelf-life and Q_{10} of tea stored in different temperature condition.

Form of tea	Shelf-life (months)			Q_{10}	E_a
	40 °F	70 °F	90°F		(Kcal/mol)
Black, bags or loose in can/carton	36	18	12	1.49	6.53
Instant, envelope	36	18	9	1.63	8.03

TABLE 2
Shelf-life of tea reported by various industrial sources

Form of tea	Shelf-life (years)
Tea bags	1.5 or 1
Instant tea	1
Loose/carton tea	1
Mix tea	2
Mix, iced	3 or 1
Packaged/carton	2

2. Changes in tea quality during the early stage of storage -- maturation of tea.

Differing from fresh raw foods, the deterioration in the quality of tea does not start at the beginning of storage. In contrast, newly made tea (non-fermented, partial fermented or fully fermented tea) may undergo a period of maturation (also called after-fermentation). During this period of time, the raw green taste or harsh flavor of newly made tea gradually disappears and the tea liquor (also called tea infusion) becomes smooth or has a balanced flavor (6,7,8). For example, the famous Japanese tea, Gyokuro (Pearl Dew), does not have its unique and characteristic flavor when it is freshly made until stored for some time. The mechanism of tea maturation has not been elucidated. Some researchers believe that it is caused by the auto-oxidation of carotenoids forming ionone and ionone derivatives that contribute to the unique flavor of Gyokuro. Similar to the famous Chinese Longjing tea, its raw green flavor disappears and the unique flavor appears after a period of storage time. For black tea, the quality and price of freshly made black tea may significantly increase after a period of storage time (4,6). Wickremasinghe and Perera (4) ascribed this to the possible combination of the astringent polyphenols with proteins, a reaction that may also be promoted by moisture. Cloughley (6) pointed out that the distinct, but relatively slight increase in theaflavin (TF) content during the first few weeks of storage is reflected in increased valuation. This brief period of elevated TF content corresponds to the putative post-manufacture maturation phase, when the slightly harsh taste of fresh tea associated with the unoxidized flavanols is replaced by a more mellow character. Cloughley (6) also indicated that this maturation is related to the residual PPO activity as other workers have clearly shown a residual activity of enzymes in dried tea (6,9).

Evidence exists that the maturation of freshly made tea may occur and this maturation does increase price and quality of made tea. Wickremasinghe and Perera (4) reported that the quality of black tea reaches the peak after 2 weeks storage but declines with increasing storage time. Cloughley (6), on the other hand, showed that the price and quality of black tea as well as the content of theaflavins reach the peak after storage of 4 to 6 weeks. However, the mechanism of maturation is not yet clear. There is a need to know the maturation time of the tea to reach the quality peak. The maturation varies with different kinds of tea, different clonal teas(10), packaging and storage conditions. The relationship between the maturation of freshly made tea and the shelf-life of tea deserves further investigation.

3. Prolonged storage of made tea

Quite a few chemical reactions occur in the tea during prolonged storage so that the quality deterioration of tea is hardly avoided. The rate of deterioration varies with different types of tea and different storage conditions. The non-fermented tea usually is less stable than the fermented tea during storage (11,12). The loose tea deteriorates more easily than the compressed tea. The string type tea is less stable than the firm type one. Even different variety and tea-making season may cause different shelf-life of tea. The reasons for the non-fermented tea less stable may be due to (i) most of components in the non-fermented tea are unoxidized whereas most of components in fermented tea are oxidized and at the high oxidizing level and (ii) the relative amount of flavor components is 4-5 times more in fermented tea than in non-fermented one (13). A slight change in components of non-fermented tea is more than enough to cause the change of flavor quality. The reason for loose tea or unpacked tea less stable should be due to the big surface area of tea exposed to air.

3.1. The changes in quality and chemical components of black tea during storage.

Up to now, black tea still ranks the top in the tea production in the world. The total world production of tea per year is around 2.48 millions tons. More than 70% of this production is black tea which is around 1.8 millions tons (14). Because black tea is fully fermented and most of components are oxidized, black tea has much longer shelf-life than any other kinds of tea.

Wickremasinghe and Perera (4) have investigated the changes in quality and chemical components of black tea packaged in two different conditions, transparent with moisture-proof and dark with non-moisture-proof during storage. The results show that the quality of these two black tea samples deteriorates with the prolonged storage time without much difference. Therefore, they concluded that high moisture content of made tea is not the sole factor responsible for deterioration on storage. The deterioration rates of black tea samples in transparent with moisture-proof condition are faster than those in dark with non-moisture-proof condition at the early storage stage. This fact indicated that light more easily causes the quality deterioration of black tea during storage. It is proposed that lipid oxidation and non-enzymatic browning reactions are mainly responsible for the deterioration of tea stored in the exposure of light, possibly due to photochemical effects. These reactions are initially more detrimental to the valuation of tea than those due to increased moisture alone. During storage, the contents of theaflavin and epicatechin gallate decrease in black tea under these two packaging conditions, but amino acids and polyphenols are inversely proportional to thearubigins and show an undulating pattern. The breakdown and build up of thearubigins result in an increase of theanine and a reduced level of epicatechin gallate. The authors believed these are the causes for black tea to become "soft" after storage.

Stagg has investigated in more detail the changes in chemical components of black tea during storage. As he pointed out, the deterioration of black tea characterized by losses of flavor and astringency and sometimes by the acquisition of undesirable "taints" is accompanied by lipid hydrolysis and auto-oxidative reactions. These reactions result in losses of theaflavins, amino acids, sugars, photosynthetic pigments and volatile aliphatic constituents and increases of non-dialysable pigments and some volatile phenolic components (5). Moisture and heat play important roles for accelerating these reactions. Although lipid oxidation is insignificant except under hot dry conditions, it is postulated that oxidation of free fatty acids released during storage occurres during brewing, and has a profound influence on the quality of the tea liquor. Stagg indicated that the characteristics of deteriorated black teas are the tea liquor having stewy, coarse and tainted with a dull, muddy even purple appearance. The tea value is inversely proportional to its moisture content.

Jayaratnam and Kirtisinghe (8) also investigated the effect of relative humidity (RH) on the shelf-life of made black tea. Deterioration on storage is found accelerated with RH. At a low RH of 32.3%, tea may be stored for 300 days without loss of tea characters whereas under 100% RH, the deterioration of tea takes place after only 15 days . A significant decrease in evaluation is observed in tea stored at 12 to 100% RH as storage time increases. But no significant change in evaluation is observed in samples stored at 12 to 32.3% RH for 4 months. This shows the shelf-life of black tea stored in low RH may be as lony as 4 months without quality or price drop. After investigating the moisture sorption isotherm patterns of black tea, Jayaratnam and Kirtising0he (15) found that the concept that is widely held that tea would neither lose nor gain moisture when stored at 60-65% RH is shown to be invalid. The best condition for the storage of tea is in the range of 10-45% RH. The optimum moisture content of black tea should not be over 6%.

Dougan et al (16) investigated the effects of storage temperature and humidity on the flavor strength of black tea and infused leaf and value. The decline in the tea value during storage is due to the effect of moisture and, to a smaller extent, to temperature, while about half of the loss in value is due to the decrease in theaflavins. The rate of loss of theaflavins is however affected about equally by moisture and temperature. The results further indicate that the value of black tea packed in polyethylene bags and stored at 25 ℃ and 75% RH decreases about 20% after six months.

Stagg (5), Dougan et al (16) and Wickremasinghe and Perera (4) all confirmed that the contents of theaflavins in black tea decrease significantly after storage. Dougan et al pointed out that the decrease of theaflavins in black tea is the major reason for the value drop of black tea after storage. Its content is highly related to the brightness and briskness of infusion and the value of black tea. It is well proved that theaflavins is a good indicator of black tea quality (17-21).

Dougan et al (16) and Wickremasinghe and Perera (4) did not explain the reasons for theaflavins decrease in black tea after storage. But Stagg (5) suspected that the theaflavins decline and increasing in non-dialysable pigments may be caused by peroixidase(POD)-catalysed destructive oxidation of the phloroglucinol rings in theaflavins and other polyphenols. However, there is no evidence to suggest that peroxidase survives the drying stage of black tea manufacture. An alternative explanation is that theaflavins undergo non-enzymatic oxidation with cleavage of the tropolone ring.

Till 1981, Cloughley (6) has proved that there are some residual activities of polyphenol oxidase (PPO) and peroxidase (POD) existed in black tea during storage. Both enzymes get activated when the black tea absorbes the moisture. POD activity increases with degree of moisture absorption increases while PPO activity increases first then decreases. POD and PPO activities may reach to about 22% and 14%, respectively, of the original activity in the unprocessed shoot tissue. The regeneration of POD activity is found related to the decrease of theaflavins. During storage the levels of thearubigins (TR), the high-molecular-weight SII TR fraction, and caffeine increase, while flavanols and soluble solids decrease. The loss of of theaflavins content in black tea during storage is the major factor responsible for the deterioration in quality and the reduction in valuation of black tea. There is a strong linear relationship between theaflavin loss and quality deterioration of black tea ($r=0.86$, $p<0.001$). The storage time also is highly related to the theaflavins content of black tea. The relationship can be expressed by the following equation:

$$TF = a + bt \qquad (r = 0.90,\ p<0.001)$$

where TF = percentage of theaflavins content

t = time of storage (in week)

b = regression coefficient

a = a constant

From this result, the author named the regression coefficient (b) as the coefficient of TF deterioration (CTFD). It is a quantitative measure for storage deterioration and allows the direct comparison of different storage experiments. CTFD value is negative value. The bigger the absolute CTFD value the faster the TF deterioration per unit of time during storage. For example, the CTFD are - 0.46 and - 1.30 for black tea samples stored at low temperature and low RH with nitrogen-pack and at room temperature, respectively. After 20 weeks, the former TF reduces 9.2% while the later one reduces 26%. Both differes about 3 folds. Therefore, Cloughley's CTFD may say is one of good indicators for predicting the shelf-life of black tea. However, the content of theaflavins in black tea varies with different variety, production technique, and production season (20,21). The CTFD can not be a sole indicator to justice the shelf-life of black tea from different batches or sources unless the original theaflavins content in black tea is known.

The infusion of black tea becomes bitter after prolonged storage. Cloughley believed that it may be because of the degradation of caffeine-theaflavin complex during storage. Caffeine is released and becomes available for extraction. The color of infusion changes from bright orange-brown in fresh black tea to a dull brown in stored tea. It is mainly due to changes in the chemical complex and heterogeneous group of thearubigins pigments. The increase in the high-molecular-weight SII TR fraction in black tea after storage causes the overall flavor of black tea become flat and soft and the appearance become dull. Mahanta and Hazarika (22) pointed out that the chlorophyll a and b of black tea decrease with increasing storage time, whereas pheophytin increases first then decreases and pheophorbide continuously increases. The author believed that auto-oxidation and a hydrolase-type activity are responsible for the deterioration of pigments in black tea during storage. The increase of pheophorbide content in black tea is the reason for the color of tea infusion turning brown after the tea stored for a period of time.

Furuya (23) examined the changes in volatile components of black tea during storage. For the tea samples with moisture content of either 8 or 4% and stored at either 5 or 25 ℃, the contents of propanal and n-hexanal increase significantly in the samples packed with air while not so much changes in those packed with nitrogen. Therefore, Furuya suggested that nitrogen gas packaging can be used for preventing the tea components from oxidation completely. Saijo (24) further compared the volatile components of black tea having off-flavor after 4-year storage with those of freshly-made black tea. The result indicated that aged old tea contains plenty of n-hexanal, β-myrcene, Z-β-ocimene, E-β-ocimene, acetic acid and benzaldehyde while freshly-made black tea contains mainly 1-penten-3-ol, E-2-hexenal, Z-2-pentenol, Z-3-hexenol, E-2-hexenol, linalool and linalool oxides, phenylacetaldehyde, methylsalicylate, geraniol and β-phenylethanol. The off-flavor of black tea is related to these mentioned components. Stagg (5) also pointed out that the volatile fraction shows an overall decline which is accelerated by the uptake of moisture and, to some extent, by storage at elevated temperature. The decrease occurres principally among aliphatic aldehydes and alcohols, while fatty acids lactones and certain high boiling aromatic compounds increase. He also pointed out that the changes in fatty acids are due to the enzymatic lipolysis of phospholipids. The increase in fatty acids is the reason for black tea become "soapy" and slightly "bitter", "acrid", "oily" and "earthy".

Yamanishi et al (25) investigated the effect of temperature on the changes in aroma composition of black tea during storage at 5 and 20 ℃. The proportions of E-2-hexenal, benzaldehyde, pentanol, hexanol and Z-3-hexen-1-ol (these compounds give the fresh green note to the aroma of black tea) decrease while those of E, E-2.4-heptadienal, 2,4-decadienal, β-ionone and 5,6-epoxy-β-ionone increase by storage. All the above mentioned variations, either decrease or increase, are more remarkable at 20 ℃ than at 5 ℃. Changes in some compounds, however, are greater at lower temperature than at high temperature. It seems that the changes in the aroma components of black tea are more complicated than that of green tea and Pouchong tea.

Based on the results from all the above mentioned reports dealing with changes in volatile components of black tea during storage, these volatile components can not be used as the indicator for predicting the shelf-life of black tea due to their complexity. The changes in theaflavins contents of black tea are not only highly related to the storage time, but also to the quality including the color and taste of tea infusion. Cloughley's CTFD value may be a good indicator of shelf-life for black tea, if the tea is in the same batch.

For using nitrogen gas packaging or low temperature to store the black tea, Stagg suggested that nitrogen-pack or vacuum is unlikely to be of value in reducing deterioration of black tea. An increase of moisture content is found to be the most important parameter operative in those all deterioration reactions during storage while the temperature effect is the second. He suggested that controlling the moisture content within 3-5% is the most important for preserving the black tea. But on the other hand, Saijo and Kuwabara (26) reported for the samples with moisture contents of 4 and 8%, it is temperature not the moisture content highly related to the sensory quality of black tea during storage.

3.2. Changes in chemical components and quality of green tea during storage

Next to black tea, the world production of green tea is around 600 thousand tons per year and about 25% of total world production of tea (14). Since green tea belongs to nonfermented kind of tea, the quality emphasizes on the natural freshness with bright green appearance. The contents of flavor components not only are less in green tea than in other kinds of tea but also they get oxidized easily. Therefore, the loss of freshness and decoloration ocuurred so easily are possibly the mean reasons for the short storage time of green tea (12,27,28).

Chlorophyll is the major component of green tea for its bright green appearance. Tanaka and Hara (27) reported that chlorophyll in green tea gradually decreases with increasing storage time while pheophytin increases. Under the high temperature and moisture content conditions, the rate of degradation of chlorophyll greatly increases and causes the decoloration of green tea. They also pointed out that the color of green tea is very unstable. Chlorophyll a may be reduced to about 25% of the original within one month storage at 40 ℃ while pheophytin increases about 80%. From the results of correlation analysis between the sensory data and changes in pheophytin, a high negative correlation is shown. When the content of pheophytin reaches to 70% or higher, the appearance of green tea becomes very bad. It indicated that under improper storage condition the qualtiy deterioration of green tea may occur within one month. On the other hand, under low temperature storage at 5 ℃ for three months, the pheophytin in green tea is less than 10%. It is concluded that low temperature storage is a good way to keep the good quality of green tea.

Furuya (23) has investigated the effects of storage temperature, residual oxygen and moisture content on the sensory quality of green tea during storage. The results show that the changes in four sensory attributes, color of made tea, aroma, taste and color of infusion, and the content of ascorbic acid of green tea are affected by storage temperature and moisture content significantly. The oxygen content also significantly affects the aroma, taste and color of infusion and the content of ascorbic acid of green tea except the color of made tea. Under low oxygen content (less than 1% oxygen) condition, the quality of green tea with moisture content of 3.2 - 6.7% can be well kept as stored at 5-25 ℃. However, when the oxygen content reaches to 5% or above, the quality of green tea would change significantly. It is concluded that the good quality of green tea can be well kept, if the moisture content of green tea is kept low and stored at low temperature with the oxygen content less than 10%.

For studying the effects of water activity (Aw) and storage temperature on the shelf-life of green tea, Simplified kinetic models are used by Kim (28) et al to obtain various kinetic parameters for browning development in green tea subjected to accelerated shelf-life tests. The green tea is maintained at Aw of 0.33, 0.44, 0.52, and 0.62 using saturated salt solutions and stored at 35, 45, and 55 ℃. The browning reaction is zero order. The activation energies are found 1.5-2.4 Kcal/mol and Q_{10} values are between 1.07 and 1.12. These kinetic parameters are used to predict the browning development under various storage conditions. The calculated shelf-life at 25 ℃ (the time to reach 1.02 absorbance/g solid), which severe brown color change can be detected, ranges 57-113 days and decreases with increasing Aw. However, the predicted shelf-livies at different Aw are a little higher than the actual values.

Fukatsu (29) investigated the effects of different packaging materials on the shelf-life of green tea. The report provided a source of information about the shelf-life of green tea. Several kinds of packaging materials with different degree of air and water vapor permeability are used to pack green tea and stored at 25 ℃ and 80% RH which is a simulated storage condition for green tea in Japan for a period of time. The results are concluded as follows:

1. The quality preservation for green tea is best with multi-layer film laminated with aluminum, followed by polypropylene film coated densely with polyvinylidene chloride. Cellophane-polyethylene laminated film is least effective which the quality of green tea deteriorates after about 1 month, and some samples become not suitable for drinking after 3 months. The shelf-life of green tea packed in various plastic films under 25 ℃ and 80% RH condition is shown in Table 3.

2. Samples, which are assessed that no quality change occurres by the sensory test, show their water contents less than 5.5% (5.0% after 1 month) and residual vitamin C contents more than 70%. On the other hand, samples assessed to be deteriorated in quality, show their water contents more than 6.0% and residual vitamin C contents less than 70%.

3. There is a high correlation between residual vitamin C and quality change in tea samples, suggesting that the residual

Table 3. The Shelf-life of green tea packed in various plastic films

Shelf-life	Main component of film
Less than 10 days	PVDC/CPVDC/PE; C/PE.
Less than 30 days	OPP/PE/NY/PE; PVC/C/PVC/P/PE; PVDC/C/PVDC/P/PE.
Less than 60 days	C/PE/OPP/PE; PET/PE; OPP/PVDC/PE.
Less than 90 days	OPP/C; OPP/PE/P/PE; C/PE/CPP; OPP/PE/AL/PE/P/PE; OPP/PE/CPP/

AL: Aluminum foil; C: Cellophane; CPP: Casted polypropylene; OPP:Biaxially oriented polypropylene; PE: Polyethylene; P: Kraft paper; PVDC: Polyvinylidene chloride; NY: Nylon; PVC: Polyvinyl chloride.
* adapted from Fukatsu (29).

vitamin C content can be used as a quantitative criterion for expressing quality deterioration. A high correlation is also observed between residual vitamin C and water content of tea.

For the relationship between the quality deterioration of green tea and its free sugar contents, Anan et al (30) analyzed the changes in free sugar contents of green tea after storage at 25℃ for 9 months, the free sugar contents in green tea decrease a little, though the quality of tea decreases considerably. The effect of storage temperature on the decrease of the free sugar contents is not recognized if the temperature is below 25 ℃.

Stagg (5) reported that the contents of lipids and C 16:0, among the fatty acids in black tea increase during storage. The change in lipid content of green tea stored at 25 ℃ for 0, 3, 6 and 18 months is investigated by Anan (31). The results show that the total lipid content decreases by 10% after 3-

month storage, and by 20% after 6 months, but only a little by further storage. Of the lipid groups, glycolipids show the greatest amount decreased to 15% after 3 months and 30% after 6 months, while both neutral lipids and phospholipids decrease by 10% and 15% after 3 and 6 months of storage, respectively. The total fatty acid contents also decrease by 10% and 15% after 3 and 6 months of storage, respectively. It shows that the change in lipids of green tea during storage is quite different from black tea. Anan further investigated the effect of the storage condition on the quality of green tea. The flavor quality of green tea stored at - 70 ℃ for 18 months is almost the same as the freshly made tea while those stored at 25 ℃ for 6 months become undrinkable. It clearly shows that the shelf-life of green tea stored at room temperature can not be so long as 6 months.

In addition, the report by Huo and Jiang (32) has shown that staling of green tea occurred during storage is associated with lower levels of total lipids, glycolipid, gllycerides, phospholipids, fatty acids and free amino acids, and higher levels of methyl sulfide, n-nonaldehyde, Z-3-hexenyl acetate, 1-penten-3-ol, Z-2-penten-1-ol and 3,5-octadien-2-one. The oxidation of vitamin C, the dissociation of magnesium from chlorophylls, and the oxidation of polyphenols are also observed in the green tea during storage.

Hara with his coworkers has investigated the changes in volatile components of green tea during storage. They have made the comparison of headspace volatiles between newly made green tea and aged green tea (33), the results show that the propanal and 1-penten-3-ol increase significantly in aged old green tea stored at 25 ℃ for 3 to 6 months while dimethyl sulfide, one of fresh flavor characteristics of early spring green tea, decreases. The authors reported that propanal and 1-penten-3-ol are not detectable in early spring green tea, but produce during storage, which might be used as a discriminating index for stored green tea. From the results of their another paper on the analysis of aroma components extracted by vacuum distillation with ether extraction (34), 1-penten-3-ol, 1-pentanol, Z-2-penten-1-ol, Z-3-hexen-1-ol, and 2,4-heptadienals significantly increase when green tea is stored at 25 ℃ and 75% RH for 2 - 4 months. They proposed that these increased compounds are mainly the products from the oxidative degradation of fatty acids. It is reported that tea contains a rich amount of fatty acids, such as linolenic (18:3), linoleic (18:2), palmitic (16:0), stearic (18:0) acids, etc.(31,35,36). These fatty acids are the precursers of aroma components produced during tea making. For instance: linolenic acid oxdizes and degrades to form unsaturated 6C aldehydes and alcohols, such as Z-3-hexenal, Z-3-hexenol, E-2-hexenal, E-2-hexenol, etc.; linoleic acid to form hexanal and hexanol (36). These compounds further oxidize and degrade to form even smaller compounds during storage. It causes the volatile compounds increase greatly during storage. These results are consistent with that of Anan's (31). Besides, the contents of oxidative degradation products of carotenoids such as 2,6,6-trimethyl-2-hydroxycyclohexanone, β-cyclocitral, α-ionone, β-ionone and dihydroactinidiolide also increase significantly. The contents of 1-penten-3-ol, Z-2-penten-1-ol, E,Z-2,4-heptadienal and E,E-2,4-heptadienal increase the most in green tea during storage. These four components increase more in green tea stored at high temperature than at low temperature and more in low grade green tea than in high grade green tea. The properties are very close to typical off-flavor, especially the oily green note, produced in green tea after storage (12).

Hara with his coworkers reported that a slightly reversion flavor is found in green tea stored at 25 ℃ for 2 months but a significant off-flavor is found after storage of 3 months (33, 34). Comparing with black tea, it is not only hard to keep the appearance and color of the fresh green tea, but also its aroma components. Under same storage condition, the shelf-life of green tea is much shorter than that of black tea. They further investigated the effects of packaging materials on the changes in the sensory quality and aroma components of green tea during storage. The results show that green tea in the moisture-proof pounches produces a typical lipid oxidized off-flavor after 4-month storage. The results of volatile analysis show that 1-penten-3-ol, Z-2-penten-ol and 2,4-heptadienals increase significantly. On the other hand, green tea in the non-moisture-proof pounches produces acid flavor and the amount of acetic acid increases five times of the original content. It show that green teas in moisture-proof and non-moisture-proof pounches produce the off-flavor through different pathways.

Under light, Off-flavor may be easily produced in the food. For examples, under light, beer formed "skunkiness" and dairy product formed "burnt feathers" and "metallic off-flavor" (37). Tea also produces "sunlight-flavor" after exposing to the light and the shelf-life shortened greatly. Wickremasinghe and Perera (4) first reported that black tea stored in moisture-proof bags and under light had a faster deterioration rate than that with non-moisture-proof but no light condition. It indicates that light has a significant effect on the shelf-life of teas. Masuzawa (38) reported that the content of chlorophyll in green tea decreases significantly under light and results in the decoloration of green tea.

Horita and Hara (39) investigated the the effect of light on the sensory quality and aroma components of green tea, the results concluded a few important points as follows:

1. Light causes a fast rate of quality deterioration in made tea. It is the most significant one among all the influencing factors including improper storage and packaging conditions. For example, the green tea produces off-flavor significantly after storage under light only one day and a very strong off-flavor is produced after four days while the off-flavor is produced, due to other affecting fators such as improper storage or packaging condition, at a much slower rate which is usually counted by "month" instead of by "day".

2. Exposing to the light causes the changes in chemical components of tea, including chlorophyll decreases significantly and decoloration rate and the contents of volatile components increase greatly. The dimethyl sulfide, which is one of fresh aroma representatives, decreases and pentanal increases significantly in green tea stored under light only one day. Pentanal increases 5 - 6 times under light after 6 days. The oxidative degradation products, such as alkanals, alkenals, ketones and ionone derivatives from fatty acids and carotenoids, are found in green tea after storage under light.

3. Bovolide can be formed in green tea under light even the strength of light is as weak as 50 lux. Therefore, it may be used as an indicator for the tea samples exposed to light.