**Tea processing in major tea producing countries**

**Abstract**

In the present study, an attempt is made to highlight the research achievement observed in India and abroad in recent years. Tea is manufactured from tender shoots of plant *Camellia sinensis* (L.) O. Kuntze with diverse processing methods to produce various types of teas. major achievements are observed in the field of research on tea processing in India as well as other tea producing countries. The differentiation of green tea, black tea and oolong tea, regardless of degree of fermentation, is also depended on their contents of free amino acids, mainly L-theanine and several natural amino acids including glutamic acid, asparagine, serine, alanine, leucine, and isoleucine. Different types of tea and tea based products are now-a-days in market to cater the need of the consumers. High impact value addition can expand the export market dramatically for countries like India, Kenya, Sri Lanka etc. and it is emerging as a new research scope in this era.

Keywords: *Camellia sinensis,* fermentation, beverages, health benefits

**Introduction**

“Tea is one of the most popular and cheapest beverages of the world and is being consumed more than 65 countries across the globe. The high consumption of tea is attributed to richness in important substances that have antioxidant, stimulating, calming properties, minerals and other diverse health benefits. The various chemical constituents of tea are amino acids, carbohydrates, vitamins, lipids, minerals, alkaloids (caffeine, theobromine, theophylline) and polyphenols (catechins, flavonoids). These components attribute to the quality, richness, taste, flavor and health benefits of different types of teas” (**Adnan *et al*., 2013**).I n addition, numerous beneficial medicinal properties due to its polyphenolic content has been reported including; antibacterial, antimicrobial, anti-diabetic etc.

“Tea is manufactured from tender shoots of plant *Camellia sinensis* (L.) O. Kuntze with diverse processing methods to produce various types of teas. In the global market, tea can generally be broadly classified according to the production method as unfermented tea (green tea), semi-fermented tea (Oolong tea), fully fermented tea (black tea) and post-fermented tea (pu-erh tea)” (**Zhao *et al.*, 2006**). “The most popular types are black tea (aerated) and green tea (unaerated). There are other types of tea produced, including white, yellow and reprocessed teas, which include flower-scented tea, compressed tea, instant tea and herbal teas” (**Hara *et al.*, 1995**).

“From the data released by Tea Board, Govt. of India, it is observed that China maintains its top position in the production of tea with a percentage share of 47.45 of the total global production in 2021. According to Tea Board, Govt of India data, production of tea in India is also on an increasing trend which may be attributed to increase in share of production by the small tea growers. It may be noted that plantations of small tea growers are comparatively young than the big tea estates. India is the second largest tea producing country in the world after China having plantation area of about 6.36 lakh hectares. Highest ever production of tea was recorded in 2022with a staggering figure of 1365.23 million kg (Table 1). India ranked fourth in terms of tea exports, which reached 196.54 million Kg in 2021.Import of tea reached to 26.51 million kg which is highest in the year 2021” (www.teaboard.gov.in).

**Table 1. Production of tea in different producing countries (Figure in Million kilograms)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Country** | **2018** | **2019** | **2020** | **2021** | 2022 | **Percentage share**  **(2022)** |
| China | 2616.00 | 2799.38 | 2986.02 | 3063.15 | 3090.00 | 48.11 |
| India | 1338.63 | 1390.08 | 1257.53 | 1343.06 | 1365.23 | 21.25 |
| Kenya | 492.99 | 458.85 | 569.54 | 537.83 | 530.00 | 8.25 |
| Sri Lanka | 304.00 | 300.13 | 278.49 | 299.34 | 251.50 | 3.91 |
| Vietnam | 163.00 | 190.00 | 186.00 | 180.00 | 174.00 | 2.70 |
| Indonesia | 131.00 | 128.80 | 126.00 | 127.00 | 125.10 | 1.94 |
| Others | 904.16 | 893.91 | 875.92 | 904.81 | 886.83 | 13.80 |
| Total | 5966.19 | 6161.15 | 6279.50 | 6455.19 | 6422.66 | 100.00 |

Source: www.teaboard.gov.in

In the last couple of years, major achievements are observed in the field of research on tea processing in India as well as other tea producing countries. In the present paper an attempt is made to highlight the research achievement observed in India and abroad in recent years.

**Machineries introduced in tea processing**

Gone are days when people used to manufacture tea manually by doing steaming/roasting of the fresh tea leaves followed by hand rolling and finally drying under sun to make the storable. However this practice is still followed by some small tea growers to make their own tea which is popularly called as handmade tea. However quantity of this type of tea is very less and price of such tea is also very in national as well as international market. Several machines have been introduced to tea industry in the last couple of years which has revolutionised the tea processing sector across the tea producing countries. A detail list of machineries introduced to tea industries is mentioned below for reference.

**Table 2. Introduction of machineries into tea processing**

|  |  |  |  |
| --- | --- | --- | --- |
| **Sl. No.** | **Name of the Machine** | **Year of Introduction** | **Introduced by** |
| 1. | Withering Trough | 1960 | M.De San |
| 2. | Tunnel Withering | 1955 | TTRI, Jorhat |
| 3. | Drum Withering | 1990 | - |
| 4. | Mobile Tat System | Early part of 20th Century | Brooke Bond Company |
| 5. | Rolling Table | 1899 | William Jackson |
| 6. | Rotorvane | 1958 | Ian McTear,TTRI, Jorhat |
| 7. | CTC Machine | 1930 | McKercher, TTRI, Jorhat |
| 8. | Trolley Fermentation | - | James William |
| 9. | Trough Fermentation | - | Williamson Magor Company |
| 10. | Tocklai Continuous Fermenting Machine | 1969 | TTRI, Jorhat |
| 11. | Venetian Dryer | 1880 | - |
| 12. | Victoria Dryer | 1885 | - |
| 13. | Paragon Dryer | 1884 | - |
| 14. | Pressure Dryer | 1907 | - |
| 15. | Tocklai Continuous Tray Dryer | 1960 | I. McTear and D.N.Borbora, TTRI, Jorhat |
| 16. | Vibro Fluid Bed Dryer |  | McNeil & Magor Group |
| 17. | Andrew’s Breaker | 1948 | H.C.Andrew |

Source : Sarma, G. (2009)

Different withering troughs with modification in the systems of withering have been introduced over the years. However, the most popular method is the trough withering which could be performed either in the open trough or in the enclosed trough. Introduction of CTC machine by Ian Mctear from Amgoorie Tea Estate in the year 1930 had revolutionised the tea industry and since then tea processing units across the world have been manufacturing the most preferable form of tea i.e. CTC black tea. In India out of total tea produced in the country in the year 2018, 90 per cent is CTC tea which is a granular form of tea found in different grades according to the size of the tea particle (Table 2). In modern day factory, fermentation is carried out in the floor or in continuous fermenting machine. Drying of tea particle is necessary after fermentation to stop the fermentation process and make the tea storable. For sorting and grading of tea particle machines like Electrostatic Fibre Extracor, Myddleton, McIntosh sorter etc. are used in CTC tea processing.

**Changing pattern of tea processing in India**

Over the last couple of years a changing pattern of tea manufacture has been observed where production of green tea has increased more than double in the year 2018 in comparison to eighties. Consumer preference towards orthodox tea has also gone down in the last three decades but CTC production has increased over four times since 1981 (Table 3).

**Table 3. Changing pattern of tea manufacture in India (Quantity in Million Kilograms)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Year** | **CTC** | **Orthodox** | **Darjeeling** | **Green** | **Total** |
| 1981 | 357.5 | 183.1 | 12.2 | 7.6 | 560.4 |
| 1991 | 603.6 | 136.9 | 13.9 | 9.8 | 754.2 |
| 2000 | 760.4 | 71.0 | 9.3 | 6.2 | 846.9 |
| 2001 | 759.4 | 79.2 | 9.8 | 5.4 | 853.9 |
| 2005 | 849.4 | 75.9 | 11.3 | 9.4 | 946.0 |
| 2006 | 893.4 | 66.3 | 10.9 | 11.2 | 981.8 |
| 2007 | 887.9 | 78.6 | 10.0 | 9.9 | 986.4 |
| 2015 | 1098.70 | 82.67 | 8.21 | 19.08 | 1208.66 |
| 2016 | 1148.50 | 92.49 | 7.74 | 18.63 | 1267.36 |
| 2017 | 1190.24 | 107.69 | 3.76 | 20.07 | 1321.76 |
| 2018 | 1208.81 | 102.34 | 7.93 | 19.55 | 1338.63 |
| 2019 | 1233.81 | 131.08 | 7.96 | 17.23 | 1390.08 |
| 2020 | 1143.07 | 89.71 | 6.70 | 18.05 | 1257.53 |
| 2021 | 1209.27 | 106.83 | 7.01 | 19.95 | 1343.06 |

Source: www.teaboard.gov.in

**Tea Processing in India**

At present India is world’s second largest tea producer after China.Tea is grown in 13 states in the country whereAssam, West Bengal, Tamil Nadu, and Kerala account for about 95 per cent of total tea production.India has acquired an exalted status on the global tea map. From the Table 3 it is observed that majority of tea produced is CTC followed by Orthodox, Green tea and rest is Darjeeling tea.

There are two forms of Black tea *viz*., CTC and Orthodox. Black tea is manufactured by so called fermentation of the processed leaves. Different cell rupturing processes are employed to expose the leaf polyphenols and the enzyme polyphenol oxidase to the atmospheric air so that the polyphenols get oxidized. Plucked green tea leaves are first withered, then rolled or crushed, torn and curled and then fermented before final drying. Processed and dried leaves are then sorted and graded to meet the market demand.

Green tea is manufactured without the process of fermentation. Here polyphenols are not allowed to get oxidized and to stop the process of fermentation, the green tea leaves are either dipped in boiling water, steamed or roasted at the beginning so as to inactivate the enzyme responsible for oxidation of the polyphenols. Steamed or roasted leaves are first dewatered and cooled down, then rolled, sifted and semi dried. Half dried leaves are first sifted and finer and coarser segments are rolled again for different periods and then sent for final drying. Manufactured leaves are then sorted and graded before packing.

Darjeeling tea is a special kind of tea that is being produced only in the high mountains of Darjeeling of West Bengal. This tea cannot be produced anywhere else in the world. This tea is famous for its unique flavor and quality which makes it a special one than the other teas. As a result it has won the patronage and recognition of discerning consumers worldwide for more than a century. Darjeeling word and a logo is given by Tea Board, India which were the first Geographical Indications to be registered in India in the name of the Tea Board. In the year 2018, 7.93 Million Kgs of Darjeeling tea was produced from 87 tea gardens located in Darjeeling, Mirik, Karseong and Kalimpong of West Bengal.

There are some other forms of tea are also being manufactured in India such as Phalap tea, handcrafted tea, tea bags, white tea, flavoured teas such as Elaichi tea, Masala tea, Ginger tea etc.

**BLACK TEA PROCESSING**

**Withering**

“It is the first step in black tea processing. Withering refers to the changes that occur in the green leaf from the time it is detached from the plant (plucked) to the time of maceration” **(Tomlins and Mashingaidze, 1997).** “The method and value of withering in relation to black tea quality appears to be changing in recent time. As withering progresses, the stomata of the lower leaf surface begin to close; two and a half times as much water is lost through the lower surface, which has stomata, compared to the upper surface which has no stomata” **(Kramer and Kozlowski, 1979)**. “As the degree of wither progresses, the permeability of the cell membranes in tea shoots increases. In addition to moisture loss, up to 4% of the dry matter in the leaf is lost as carbon dioxide through respiration” **(Hampton, 1992)**. “Biochemical changes during withering are reported by several workers. The partial breakdown of proteins to amino acids which acts as a precursor for aroma” **(Sanyal, 2011)**. “The decline in carotenoid concentration is most significant during physical (not chemical) wither” **(Tomlins and Mashingaidze, 1997). “**There is a conversion of carbohydrates to simple sugars during withering. During withering, the level of chlorophylls declines by 15%, forming chlorophyllides.Catechins produce theaflavin (TF) and thearubigins (TR) in the presence of PPO” (**Sanyal, 2011**). “The activity of PPO has been reported to decrease during withering” **(Robertson*,* 1992)** “as a result of moisture loss. Flavour compounds that are important to quality (linalool, geraniol, methylsalicylate) have been reported to increase during withering, while compounds (E-2-hexenal) detrimental to quality are highest in unwithered teas” **(Howard, 1978). “**The most important quality attributes viz., theaflavin, which is responsible for brightness and thickness of the liquor progressively increased with withering time” **(Ramamoorthy, 2014).**

**Rolling**

Rolling is the traditional method employed to rupture the leaf cells to initiate the fermentation process in tea. Rolling impats the desired rolling and twisting action to the tea leaves important for the appearance of orthodox tea. It is carried out in batches mostly in a machine called Table Roller. Other rolling machines like Rotorvane, Barbara Leaf Conditioner may also be used as pre-conditioners for manufacturing CTC tea. **Ramamoorthy(2014)** conducted “a comparative study between Rotorvane and Orthodox Roller for Preconditioning in CTC Tea Manufacture. He was of the view thatOrthodox rollers improve the liquoring characters like brightness, briskness, colour and flavour.However, this could be done only if the quality of green leaf is good i.e. at least 70 percent of the raw material should conform to prescribed standard”.

**Fermentation**

The leaves rolled in Table rollers or ctrushed in CTC machine are sent for fermentation. This is the stage during which the desirable properties of made tea start developing in the processed leaves in a suitable atmosphere in presence of lot of oxygen. The polyphenols on oxidation result in desired colour, strength, briskness and quality in the leaves. Proper fermentation of tea leaves determines the quality of made tea. Both over and under fermentation affects the quality of made tea. To understand the optimum fermentation time and flavour of the processed tea, CDAC Kolkata had developed a hand held electronic nose system (HEN).The results obtained by **Manigandean (2015)**through HEN were correlated with the existing chemical method. The processed teas consisting CTC and orthodox types of manufacture and different grades were evaluated through HEN and the results were compared with organoleptic evaluation of tea by national and international tea tasters. The results revealed that the Handheld Electronic Nose is a suitable instrument for determining the optimum fermentation time during tea manufacture based on aroma.

**Drying**

Fermented tea leaves are dried in drying machines to stop the fermentation process as well as to remove the moisture from the leaves which then become storable. Drying may be carried out in different kinds of drying machines like ECP Dryers, Tocklai Continuous Tray Dryer and Vibro Fluid Bed Dryer. Various fuels are burnt to heat up air to a temperature of around 100°C and this hot air is forced to pass through the wet leaves to remove their moisture.**Akhtaruzzaman *et al.* (2013)** conducted an experiment to determine the drying time, drying constant and dynamic equilibrium moisture contents of tea. Drying was performed in Vibro Fluid Bed Dryer which is considered as most popular dryer in tea industry. He was of the view that tea dried at high temperatures (130 – 140°C for a short period (20 min) can retain their quality and flavour and longtime storage without deterioration.

**GREEN TEA PROCESSING**

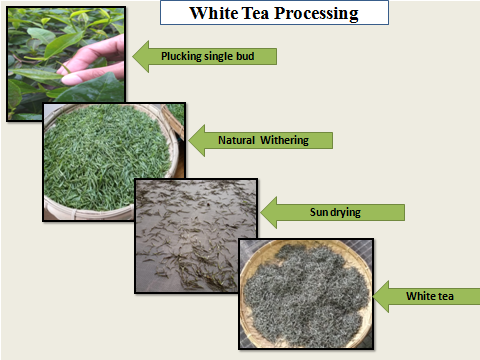
Green tea is manufactured without the process of fermentation. Here polyphenols are not allowed to get oxidized and to stop the process of fermentation, the green tea leaves are either dipped in boiling water, steamed or roasted at the beginning so as to inactivate the enzyme responsible for oxidation of the polyphenols. Steamed or roasted leaves are first dewatered and cooled down, then rolled, sifted and semi dried. Half dried leaves are first sifted and finer and coarser segments are rolled again for different periods and then sent for final drying. Manufactured leaves are then sorted and graded before packing. Green tea processed by this method is called orthodox green tea. There is another form of green tea which is called CTC green tea. The different step involved in orthodox green tea processing is mentioned below.

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**Fig. 1. Flow chart of orthodox green tea processing**

**White tea processing**

White tea is known to be one of the most delicate tea varieties because it is so minimally processed. For processing this unique tea, only the bud is plucked before the tea plant’s leaves open fully, when the young buds are still covered by fine white hairs, hence the name “white” tea. These buds and unfurled leaves from the newest growth on the tea plant are handpicked and then quickly and meticulously dried, so that polyphenols present in the bud are prevented to go for oxidation to the maximum extent possible. This minimal processing and low oxidation results in some of the most delicate and unique tea that has lot of medicinal properties too.

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**Fig. 2. Flow chart of white tea processing**

**Phalap/Phanap – A Heritage Assam Tea**

It is a traditional tea of Singpho tribe residing in upper Assam, India. Tangsha Naga community residing in upper Assam, India are also involved in processing of this unique form of this tea. The leaves of tea are said to grow in tall trees and are collected around elephant backs to brew the native beverage for the guests. The tea leaves are fried and dried under the sun and then smoked in cylinders of bamboo to induce piquancy in the tea. This process helps in the long shelf life of tea which can last up to years and only gets better with time. This makes Phalap more flavourful than regular organic tea.

**Handcrafted tea**

A number of small tea growers have been producing variety of handcrafted tea which have a niche segment of the market. No sophisticated machineries are used in processing of this tea. Such tea is also mostly organic in nature. This handmade tea is categorised as Assam orthodox black tea, Assam orthodox green tea etc. These teas have huge marketing potential.

**Tea Processing in China**

Tea was originally discovered some 3,000 years ago in China. It was used for medicinal purposes, but eventually it became a recreational and social drink for people in all walks of life not only in China but all over the world. There are a number of distinct varieties, different ways it can be processed before use, a whole range of activities and ceremonies associated with its consumption, and an assortment of beliefs about its spiritual and health benefits. The different processes involved in processing of tea are discussed below.

1. **Withering:** Plucked green tea leaves wilt or wither, and moisture content is reduced, allowing flavour compounds to develop. There are various methods of withering, some outside and some indoors. If the process is short the leaves retain a greenish appearance and grassy flavour, but a longer process produces a darker, more intense tea.
2. **Oxidation:** Here the leaves are browned and the flavour compounds are intensified, with specific intensities being selected by controlled oxidation of polyphenolic compounds with steady humidity and temperature. At the appropriate time for the particular type of tea, oxidised leaves are moved to a place where they are heated and dried.
3. **Fixing:** It is sometime called "kill-green" and during this process the enzymatic browning of the wilted leaves is controlled through the application of heat by steaming, pan-firing, baking, or with heated tumblers. A slower fixing produces a more aromatic tea.
4. **Rolling:** The leaves are gently rolled and shaped, depending on the required style, to look wiry, kneaded, or as tightly rolled pellets. The leaf juice comes out and the taste intensifies.
5. **Drying:** This keeps the tea moisture free, enhances flavours, and improves shelf-life. The process needs to be carefully controlled so as not to make the tea taste harsh.
6. **Aging:** Some special tea types are aged and fermented, sometimes for years.

**Different types of traditional tea in China**

Pu-erh tea,

Yellow tea.

Chinese Dark Tea (CDT)s

**Pu-erh tea: “**It is one of the most exotic teas, is green tea fermented with several microbes. It is produced mainly in Yunnan Province. Pu’er is pleasantly aromatic beverage that promoters claim reduces cholesterol and cures hangovers. It can be categorized into several types according to several standards” **(Wang *et al.,* 2016).**

**Yellow tea: “**Yellow tea, also known as *huángchá* in Chinese, is a lightly fermented tea unique to China. As a rare and precious variety of tea, it has gained increasing popularity in recent years Yellow tea is similar to green tea in many ways. But the production of yellow tea requires additional steps” **(Xu *et al.,* 2018).**

**Chinese Dark Tea (CDT)s: “**Chinese dark teas (CDTs) are post-fermented tea products, which are mainly produced in Southwestern China. Deactivated leaves of *Camellia sinensis* and *Camellia assamica* are post-fermented under controlled conditions to make CDTs. Its quality is dependent on the microorganisms like *Aspergillus, Penicillium* and *Eurotium* species in post fermentation process. The health benefits and chemistry of CDTs are increasing trends in the research field of teas. CDTs possess antimicrobial, antioxidative and antimutagenic activities. Post fermentation structurally changes the original compounds of raw CDTs, significantly decreases the contents of catechins and forms some novel catechins derivatives” **(Zhang *et al.*, 2013).**

**Table 4 : Some other types of Chinese green tea**

| **Types of Green Tea** | **Production Characteristics** | **Appearance** |
| --- | --- | --- |
| Biluochun | * Originally produced in Jiangsu Province * Floral aroma and fruity taste * Tightly rolled to resemble tiny snails | C:\Users\Admin\Desktop\Biluochun.jpg |
| Gunpowder (Pearl tea) | * Grown primarily in Zhejian province * Tightly rolled in pellet form | C:\Users\HP\Desktop\Gunpowder.jpg |
| Hou Kui | * Famous for its two straight leaves clasping the enormous bud with white hairs. * The oven-made leaves are deep green in color with red veins underneath. * The tea shoots can be as long as 15 centimetres (5.9 in). * Found only in Anhui Province. | C:\Users\HP\Desktop\Fresh_Hou_Kui_Green_Tea_Leaves.jpg |
| Long Jing | * Tea leaves are roasted early in processing followed by firing. * Tea leaves experience minimal oxidation. * The tea contains vitamin C, amino acids and like most finer Chinese green teas, has one of the highest concentrations of catechins among teas. | C:\Users\HP\Desktop\Longjing_tea.jpg |
| Xin Yang Mao Jian | * Chinese high-altitude tea grown porimarily in Henan province, famous for its fragrant aroma. * Tippy pointy leaves with fine hairs. * This tea has significant amounts of acids and esters such as the Hexaecanoic and Phtalic acids, which collectively give off a strong floral smell. | C:\Users\HP\Desktop\Maojian_(high_grade,_spring_2007).jpg |

**Tea processing in Japan**

“Japan is a major tea producing and consuming country, especially of green tea.In Japanese culture, tea is usually synonymous with green tea. *Sencha* is the country’s mainstay teas.

The basic Japanese green tea is called bancha. Some Japanese green teas resemble varieties of green tea produced in other countries such as China.The country produced 81.50 Million Kgs of tea in the year 2018” **(Tea Statistics, 2019)**.

**Table 5 : Important Japanese Tea**

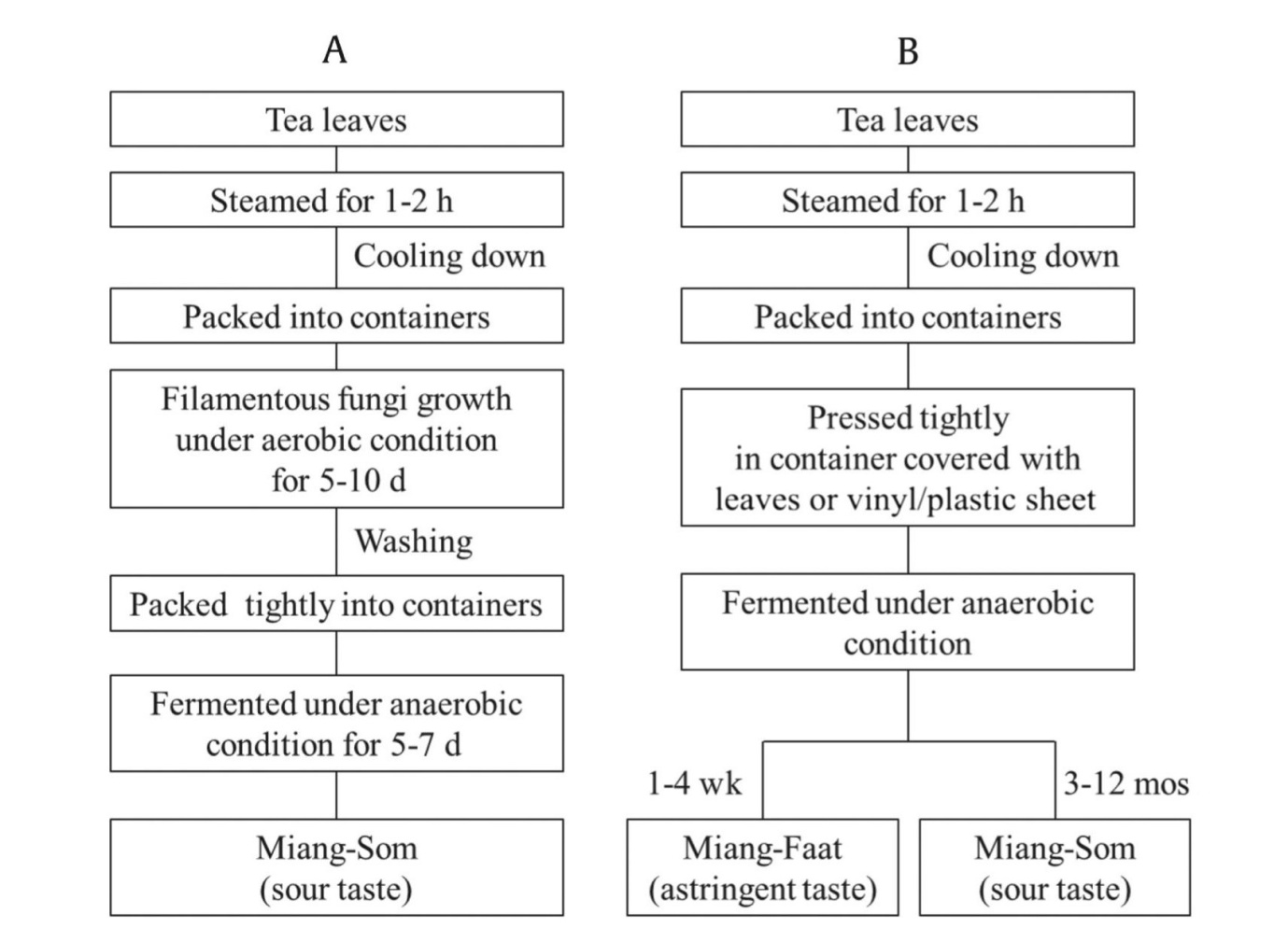
|  |  |  |
| --- | --- | --- |
| Bancha | * It is plucked later than *sencha* giving it a lower market grade. * It is considered to be one of the lowest grades of Japanese green teas. * Its flavour is unique and varies depending on the type. * It can be found in a number of forms such as roasted, unroasted, smoked, matured or fermented for three years and even post-fermented. | Batcha |
| Tamaryokucha | * It is a coiled Japanese green tea also commonly known as ***guricha*** (curly tea). * It can be processed in one of two ways to destroy the enzymes * Pan fried (rarely used in Japan, it is the Chinese process), or steamed (as most Japanese teas). * Many believe that steaming preserves the vitamins and antioxidants better than pan-frying. * The taste varies between the two as well. * The pan-fried version has more of an aroma of cooked vegetables. * In both cases, the leaves are then rolled into "comma" shapes (instead of being kneaded into "needle" shapes, like *sencha* teas). | Tamaryokucha |
| Kabusecha | * It is a tea where tea plant is covered for a period ranging from 2–25 days. * Kabusecha tea is almost exclusively a first flush tea. * Though kabusecha tea is usually processed into a green tea, freshly plucked leaf can be used to produce any kind of tea. | Kabusecha |
| Tencha | * It is a shaded Japanese green tea that is mostly used to make matcha. * That means the tea leaves are shaded for about three weeks. * Plucked leaves are briefly steamed and dried but in contrast to most other Japanese teas it is not rolled. * Finally all stems are removed so that only the pure leaves are left. | Tencha |
| Gyokuro | * It is another type of shaded green tea. * Gyokuro is shaded longer than kabusecha tea. * It is shaded for approximately three to four weeks. * This causes both the amino acid theanine and the alkaloid caffeine in the tea leaves to increase which yields a sweet flavour. | Gyokuro |

**Tea processing in Thailand**

In Thailand, Chiang Mai and Chiang Rai provinces are the largest area planted with tea occupying over 80 percent of the total tea growing area. Tea has been cultivated in many places as beverage, chewing matter, food and drug for a long time. Two famous traditional tea of Thailand are Miang tea and Oolong tea.

**Miang tea:** Miang is an ethnic fermented tea leaf (*Camellia sinensis* var. *assamica*) from northern Thailand. It is a unique product that is known as chewing tea or eating tea.In addition, it is also a specific food for traditional religious ceremonies and funerals. The chemical constituents in Miang are of interest and the scientific advances to understand and develop this ethnic tea product are rapidly emerging.

**Chart 1: Fermentation Process of Miang**

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Source: **Khanongnuch *et al*. (2017)**

“Recent studies indicated that the astringent Miang possessed higher phenolic metabolites especially epigallocatechin gallate than the sour Miang and fresh tea leaf used for making miang in general. Miang has many potential benefits and is proposed to be used for many applications such as foods, pharmaceuticals, and nutraceuticals”. **(Bouphun *et al.,* 2018).**

**Green tea processing and its effect on biochemical constituents**

“Several researchers reported green tea processing with some modifications in the conventional orthodox processing method, and their effect on biochemical constituents.In orthodox processing of green tea, first deactivation of endogenous enzymes, mainly polyphenol oxidase and peroxidase is carried out. This deactivation of fresh leaf enzymes is the key step in green tea processing which prevents the oxidation of catechins. This could be achieved either by steaming or pan frying of green leaves”**(Baba and Kumazawa, 2014)**. “However, these enzyme deactivation processes drastically affect the quality of green tea, particularly the aroma and physical appearance”. **Han *et al.* (2016)** reported that, “in the steaming process, freshly plucked leaves are subjected to hot steam of water at around 102°C for a certain amount of time (1–2 min). On the other hand, in the pan frying process, freshly plucked leaves undergo withering for 2–3 h, where endogenous enzymes affect the chemical composition of the leaves” **(Baba and Kumazawa, 2014)**followed by panfrying at 220°C for 5 minutes **(Wang *et al.*, 2019).** The steamed or panfried leaves are then rolled for 30–60 minutes for rupture of the leaf tissues as well as to have the desired shape and finally dried at 90–110°C for 5–15 minutes.

“Green tea processed from fresh leaves picked at an early stage is considered to possess a high quality that consequently reduces with time” **(Chen *et al.*, 2008).** “The amount of pubescence on leaf epidermis is an important morphological marker for the quality of green tea, as the tender tea was also found to have more pubescence than old one” (**Chen *et al*., 2005).** “Tea with plenty of pubescence has a better taste depending on the profiling of tea leaf pubescence metabolites. Moreover, tea leaves should not be stored for more than two months at room temperature, since they become oxidized. Bioactive-ingredients extraction from green tea through ultrahigh pressure extraction (UPE) technique is characterized by being less time-consuming, producing higher extraction yields, consuming less solvent, and possessing higher purity with minimal heat generation, which may lead to thermal degradation of bioactive components. Its micromechanism is the disruption of cellular organelle which enhances the diffusion and mass transfer”. **(Zhu *et al.,* 2017)**.

CTC is widely used in black tea manufacturing process. In the CTC step, the rolled leaves are subjected to crushing, tearing and curling in a CTC machine. The advantages of CTC black tea manufacturing are lower fermentation time and higher extraction efficiency. Very limited literatures are available where CTC step has been introduced for green tea processing. **Barbora and Saha (1995)** introduced “CTC after the initial step of steaming or pan frying for green tea processing.The authors reported more cuppage (also known as number of cups) and shorter processing period for CTC green tea over the orthodox. However, no biochemical data was reported by the authors”. **Kilel *et al*. (2013)** also introduced “the CTC step in green tea processed from purple colored tea clones of Kenya. To the best of our knowledge report on the comparative study of orthodox and CTC green tea processing is very limited in terms of biochemical constituents and their subsequent transfer into the infusion. Moreover, this aspect in the scenario of Assam's geographical and climatic condition has never been addressed”. Organoleptic evaluation (also known as sensory evaluation) of both types of tea and the risk assessment of the daily intake level of caffeine and EGCG were also carried out in the experiment conducted by **Deka *et al.* (2020).**

**White tea processing and its effect on biochemical constituents**

“Amino acids, polyphenols and methylxanthines are the main biochemicalcompounds present inwhite tea” **(Dias *et al.,* 2014).** “The most common amino acid in white tea is L-theanine which is responsible for pleasant and relaxing effects of the tea” **(Sun *et al.,* 2014).** “Among the polyphenols, the catechin represents more than 20%–30% of leaf dry weight” **(Dias *et al.*, 2014).** “These are the compounds that makes white tea a superior health drink because of its antioxidant properties. The main catechin derivatives present in white tea are epicatechin (EC), epigallocatechin (EGC), epicatechin gallate (ECG) and epigallocatechin gallate (EGCG). Dias *et al.*(2014) reported that epigallocatechin gallate is the most important bioactive component present in white tea which accounts for about 50% of all the catechins” **(Dias *et al.,* 2014).** “The antioxidant potential of catechins is measured by their free radical–scavenging ability and metal-chelating properties” **(Frei and Higdon, 2003).** “The most effective radical scavengers in white tea are EGCG and EGC due to their characteristic structure. The catechin content is often mistakenly used as a differentiation parameter between WT and GT, but it is not a reasonable approach to take. There are some WT types that contain a higher catechin content than GT” **(Koech *et al.,* 2013),** but the opposite also occurs **(Dias *et al.,* 2014).** “This is due to the fact that tea chemical composition is influenced not only by differences in the processing techniques, but also by the geographical origin of growth, climate, soil, botanical variety, harvest time, horticultural practices, and even brewing conditions” **(Damiani *et al.,* 2014).** “Thus, there is a high variance not only in catechin content, but also in other components, such as methylxanthines. On the other hand, it does seem feasible to use catechin content as a differentiating parameter when comparing either white tea or green tea with oolong and black tea” **(Koech *et al.,* 2013)**. “Indeed, most of the components of black tea are thearubigins (60%–70%), with only 3%–10% catechins” **(Kuhnert *et al.*, 2010).**

Similarly to green tea, most of white tea’s health-promoting effects are due to its high phenolic contentsand antioxidant activity **(Dias *et al.,* 2013)**. “Although the human body possesses efficient defense systems to control naturally produced free radicals, unhealthy lifestyle habits, aging, and physiological disorders may reduce their efficiency. This may lead to the impairment of redox homeostasis, resulting in the overproduction of free radicals, such as reactive oxygen and nitrogen species (RONS)” **(Willet, 1994).** “Chronic exposure to RONS can lead to DNA damage, alterations in membrane lipids, and changes in functional and structural proteins” **(Halliwell *et al.,* 1997).** “Subsequently, this oxidative damage may trigger the development of numerous human dysfunctions, such as cardiovascular diseases” **(Dhalla *et al.,* 2000)**, diabetes mellitus **(Rochette *et al.,* 2014)**, obesity **(Marseglia *et al.,* 2014)**, neurodegenerative disorders **(Dasuri *et al.,* 2013)**, subfertility/infertility **(Agarwal *et al.,* 2008),** and certain types of cancer **(Sosa *et al.,* 2013)**. “This highlights the importance of using exogenous antioxidants as a preventive measure or even to avoid the progression of oxidative stress–related diseases” **(Dias *et al.,* 2017)**.

**Oolong tea**

“Production and consumption of oolong tea across the world have increased over the past decades. Processing of this type of tea involves oxidation of catechins in the range of 10–80% during processing depending on the demand of customers. The taste quality of oolong tea depends on several properties, such as smell of volatile fragrance, taste sensation of sweetness, umami, and intensity of astringency. The differentiation of green tea, black tea and oolong tea, regardless of degree of fermentation, is also depended on their contents of free amino acids, mainly L-theanine and several natural amino acids including glutamic acid, asparagine, serine, alanine, leucine, and isoleucine” **(Barbora and Saha, 1995).**

**Processing of Oolong Tea**

“Oolong tea is a semi-fermented tea where polyphenolic compounds are partially oxidized. This tea is mostly popular in South China (mainly in Fujian and Guangdong provinces), Taiwan, Taipei, Darjeeling in India, Parts of Nepal, Thailand, Vietnam and Indonesia. OT is also being cultivated in central African countries” **(Kuo *et al.*, 2005)**, as well as on the North Island of New Zealand **(Fraser *et al.*, 2014).**

“For processing of Oolong tea, the freshly plucked tea leaves are withered in direct sunlight and then shaken gently in bamboo baskets to lightly bruise the edges of the leaves. Next the leaves are air-dried in the shade until the surface of the leaf turns slightly yellow. The process of shaking and drying the leaves is repeated several times. The oxidation period for oolong teas is less than that for black teas and depends on the type of oolong. This can vary from about 20% for a green oolong to 60% for a classic Formosa oolong. After the desired oxidation level is reached, the leaves are pan-fired at high temperatures to prevent further oxidation. Due to the higher firing temperatures, oolong teas contain less moisture and have a longer shelf life than green teas.  Being a slightly oxidised tea, Oolong has a taste and aroma that sits somewhere between green teas and black teas. Individual types of Oolong tea can range from almost like a green tea to almost like a black tea, depending on the degree of oxidation during processing” **(https://teaworld.kkhsou.in)**.

The concentration of chlorophyll in Oolong tea is correlated strongly with the appearance of the infused leaf. Besides, the concentration of total free amino acids and theanine positively correlated with perceived taste. The major biochemical constituents include glutamic acid and catechins in most Oolong teas. Researchers have found that the principal components, including glutamic acid, epicatechin and total catechins, could be used to characterize the quality of Oolong tea. However, for interpretation of quality, opinion differs among the researchers. In order to have a more conclusive judgments, sophisticated instrument may be used such as colorimeter to characterize tea color, electronic nose, electronic tongue and lipid membrane taste sensors, could be designed to assess the quality of tea.

There are several types of Oolong tea produced in China and Taiwan. The most famous Chinese Oolong teas include Tieguanyin, Dahongpao, Phoenix Narcissus, White Crest, Phoenix Bush and Iron Lohan, while the most well known of Taiwanese Oolong's include Dongding, Wenshan Pouchong and Oriental Beauty.  Taiwanese Oriental Beauty is also well known as Formosa Tea, or – because of the abundance of white pekoe – White Tipped Oolong Tea.

**Oolong tea processing and its effect on biochemical constituents**

**Sasaki *et al.* (2004)** and **Yoo *et al.* (2011)**, have observed that “Oolong tea has antibacterial effect on oral streptococci, including Streptococcus mutans and Streptococcus sobrinus. Their study showed significant antibacterial activity against Streptococcus mutans, and advocated that the antibacterial activity of Oolong tea extract is caused by a synergistic effect of Epigallocatechin Gallate and Gallocatechin Galate”.

“Research on Oolong tea indicates that different tea types have different in vitro antioxidant functional power, and this power strongly depends on the total phenolics content in the tea” (**Hou *et al.*, 2006**). “Moreover, epigallocatechin and epigallocatechin gallate account for about 70% of OT total catechins. Because of this Oolong tea has effective antioxidant function” (**Yang *et al.*, 1998**).

“A variety of polyphenols are present in Oolong tea. These different polyphenolic compounds are categorized into four subgroups, namely catechins, tannins, flavonols, and flavonol glycosides. The catechins in Oolong tea includes epigallocatechine , epicatechine, epigallocatechin gallate epicatechin gallate , gallocatachine, catechine, gallocatechin gallate, catechin gallate” (**Theppakorn *et al.*, 2014**).

**Laphet - Myanmar’s traditional fermented tea**

“It has been developed as an ethnic food. It has a very long history in Myanmar. In ancient times fermented tea leaves were used as a peace symbol or peace offering between warring kingdoms. Nowadays, the laphet tea is a main expression of hospitality offering to houseguests. Laphet tea contains several compounds that are also in green tea. The total polyphenols is higher in green tea than in laphet. Laphet contains all catechins, and it has the maximum rate of caffeine, and lowest rate of EGCG” (**Anug, 2012)**. “Total polyphenols and EGCG in the pickled tea leaf, the astringent miang which is produced by a very similar process as laphet teas higher in total polyphenols (both EGCG and EGC), compared to non-steamed samples” (**Sumalee *et al.*, 2010)**.

**Conclusion**

Tea is the most popular beverage across the world. Production of tea has been on an increasing trend in recent years. However,safety of the produce and hygiene has become the prime objective of tea processing units. Automation in tea industry may be helpful in maintaining quality in tea processing which is a common feature in major tea producing countries including China and India. Energy consumption measures are important issues for future and efforts will be made to undertake research on alternate fuel for factory. There is a strong need to develop or modify the existing processing methods, for the better retention of the phytochemicals as well as tea-based products. Our research agenda needs a special focus on packaging to enhance the shelf life.Upscaling of diversification efforts supported by research outcome is the future of tea business. Different types of tea and tea based products are now-a-days in market to cater the need of the consumers. High impact value addition can expand the export market dramatically for countries like India, Kenya, Sri Lanka etc. and it is emerging as a new research scope in this era.

**Disclaimer (Artificial intelligence)**

**Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.**

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