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Enjoy Coffee without Palpitation and Insomnia—The Decaffeination Process

Coffee has become one of the most popular beverages around the globe in modern days. Its appealing fragrance and appetizing flavor make it almost irresistible. Not to mention the neural stimulation it provides, which grants people sudden bursts of energy. However, caffeine, the neural stimulant in coffee, is a two-edged sword, with proper amount of intake, it gives you a zealous spirit, when overdosing, it results in palpitation, insomnia, and even seizures. Therefore, coffee producers have been seeking different methods to filter out caffeine while preserving the original flavor of coffee so that customers can enjoy coffee without neurotic burdens. In this essay, I will briefly introduce the chemical substances in coffee, discuss various ways of decaffeination, and some related issues.

As simple as coffee might seem, it contains over thousands of distinct chemical compounds [1]. The most well-known ones are quinic acid (which tints the coffee with sour tastes), 2-ethylphenol (which generates a medicinal bitterness flavor), acetylmethylcarbinol (which gives coffee a hint of buttery texture) [2], and of course, water and caffeine. To make the matter simpler, we can break down the chemicals into six major categories: carbohydrates, nitrogenous compounds, lipids, minerals, vitamins, and acids. In every 100 grams of unroasted coffee (Coffea arabica), it comprises about 50% of carbohydrates, 10% of nitrogenous compounds, 20% of lipids, 3% of minerals, and 8% of acids [3]. The carbohydrates are mostly polysaccharides, including fiber, which does not provide any notable flavor yet gives structural integrity of coffee beans. Like other kinds of beans, the nitrogenous compounds of coffee consist mostly of protein and peptides, the difference is that in coffee, about 10% of nitrogenous compounds are caffeine [3]. Though lipids occupy only 20%, the variety of them endows coffee with rich flavor. In fact, the comprehensive aroma of coffee is greatly contributed by the diversity of lipids. Among the minerals in coffee, potassium is most abundant while traces of sodium, magnesium and manganese could also be found. Notably, it is the great amount of potassium that result in the risk of osteoporosis by coffee intake [11]. As for vitamins, riboflavin and niacin are most commonly found in coffee beans. They both belongs in the vitamin B family. Lastly, the 8% of acid presents a hint of (fruity) sourness in coffee, which layers up the complexity of the flavor. The acids are preserved more in light roast and medium roast beans than deep roast and dark roast, so light to medium roast coffee has a stronger sour taste.

With a glimpse on the constituents of coffee and you may understand how difficult decaffeination is. After all, you must filter a specific compound, caffeine, out of the abundance of other chemicals. In fact, it is practically impossible to completely drain caffeine out of coffee, but throughout history, numerous methods have been devised to minimize the percentage of caffeine in the contents of a cup of coffee. Since caffeine is water soluble, all decaffeination process requires water. Nonetheless, due to the low selectiveness of water, it is necessary to apply some decaffeinating agents to solely extract caffeine out of the coffee beans [4]. Various well-established methods will be elaborated in the following paragraphs including the Roselius Process, direct and indirect solvent-based process, carbon dioxide process, Swiss Water Process, and triglyceride process.

Back in the 1900s, a German merchant Ludwig Roselius discovered the first commercially successful decaffeination process [4]. Nowadays, it is often referred to as the Roselius Process. The main idea of the process is to utilize benzene as a solvent to remove the caffeine after heating the beans in brine solution. The Roselius Process was widely adopted in the early 20th century until researchers proved that benzene is carcinogenic. Though the Roselius Process fell into disuse finally, it opened a gateway for later successes of solvent-based decaffeination process.

The solvent-based decaffeination process can be divided into two, the direct method and the indirect method. In both methods, the poisonous benzene is replaced with other equally effective organic yet harmless solvents such as dichloromethane and ethyl acetate [5], but the core mechanics are similar to the Roselius Process. For the direct method of solvent-based decaffeination, the unroasted beans are steamed and washed with organic solvents (such as the previously mentioned ethyl acetate) repeatedly until up to 97% to 99% of caffeine is rinsed away [6]. Just like the Roselius Process, since caffeine is highly soluble in the organic solvents, it could be extracted while leaving most of the other compounds intact, preserving the original flavor of coffee. The indirect method, on the other hand, is slightly more complex. We divide the unroasted coffee beans into different batches and pour the first batch of beans in hot water. They are soaked for several hours, basically brewing a pot of highly concentrated coffee. The first batch of beans is then taken out of the water before we apply solvents to extract the caffeine from the hot water. The previous process will be performed over and over again for later batches of beans until an equilibrium is reached—except for caffeine. That is, the beans and hot water now have similar composition aside from caffeine. After all the preparation work, the actual decaffeination process will finally be achieved on the remaining batches of beans. They are also poured into the hot water, but this time, only the caffeine dissolves into the water. By simply collecting the beans out of the hot water, we essentially produce a batch of decaffeinated coffee beans [4].

After perceiving the full process of solvent-based decaffeination process, some may be concerned about the health impacts due to the organic solvents. Fortunately, according to U.S. Food and Drug Administration, the organic solvent dichloromethane is "non-carcinogenic and causes no noticeable health risk to human below 350 ppm" [7]. On top of that, since dichloromethane is highly volatile and vaporizes around 40 degree Celsius, it is very unlikely that it remains in the coffee beans after roasting. As for ethyl acetate, because it occurs naturally in fruits [8], it is extremely unlikely that it does harm to human beings. However, as ethyl acetate is more difficult to obtain compared to dichloromethane, most decaffeinated coffee producers prefer using dichloromethane as the extracting solvent [5].

Apart from solvent-based decaffeination processes, numerous non-solvent-based decaffeination processes has been developed in the recent decades, including the carbon dioxide process and the Swiss Water Process. To begin the carbon dioxide process, unroasted beans should first be placed inside a high-pressure container. Then a fusion of water and supercritical carbon dioxide is circulated through the beans at around 300 standard atmosphere and 65 degree Celsius. When contacting the liquid fusion, the caffeine in the beans dissolves into the supercritical carbon dioxide while the other composition of the beans remains unaffected (since they are largely insoluble in carbon dioxide). At last, the carbon dioxide is stripped of caffeine using clean water and recirculated to the container for the decaffeination process of later batches of coffee beans [6]. Although this approach consumes more energy and requires special facilities, it guarantees that no residual organic solvents will be left in the final coffee beans.

Swiss Water Process is another way of non-solvent-based decaffeination process. It was developed in the 1930s in Switzerland and became available in the market in the 1980s [9]. The full process is proprietary and inaccessible to the public, but the core idea is identical to the indirect solvent-based process. Batches of beans are poured into a container full of hot water so that a highly concentrated coffee solution is produced. The difference from the indirect solvent-based process is that instead of washing away the caffeine by organic solvents, Swiss Water Process utilizes a special designed carbon filter, which captures large caffeine molecules while letting small lipid and acid compounds pass through freely. This process is repeated until the water reaches equilibrium (except for caffeine, of course). Now we throw out the previous batches and introduce new batches of caffeine into the solution, and only caffeine can dissolve out of the beans [4] [9]. The Swiss Water Process seems to be an eco-friendlier way of producing decaffeinated coffee, so most decaffeinated coffee labelled "organic" in the market utilizes this approach. Nonetheless, the detailed process is patented and inaccessible to the wide public.

Another less popular way to prepare decaffeinated coffee is the triglyceride process. This is also referred to as the direct-contact method. The process begins with submerging the unroasted beans into a container full of hot water, aiming to move caffeine to the surface of the beans. Then the beans are taken out and drenched in used coffee grounds at high temperature. After several hours, the triglycerides in the lipids of the coffee grounds extract the caffeine of the beans while not affecting other fragrant compounds of the beans.

Although a variety of different commercially viable decaffeination processes have been introduced throughout the 20th century, in reality, there are still many issues regarding decaffeinated coffee. First of all, decaffeinated coffee has never been popular among consumers [10]. Only the United States and some European countries have a higher decaffeinated coffee consumption rate, yet they are all below 20%. I argue that this is due to the reduced flavor of decaffeinated coffee. Although decaffeinated producers claim to fully preserve the flavor of coffee, from my personally experience, the taste and odor of decaffeinated coffee still seems slightly duller than ordinary coffee. Furthermore, I suggest that a majority of people drink coffee mainly for the "spiritual lift" provided by caffeine, since coffee is the cheapest and most available neural stimulant out in the market. As a result, decaffeinated coffee may never top the chart of bestselling coffee, and in turn, less companies are willing to invest money in discovering new methods of decaffeination. Aside from the commercial issue, a more practical problem is the difficulty in roasting decaffeinated coffee beans. You may question how decaffeination affect roasting, since all beans are decaffeinated before roasting, but in fact, roasting decaffeinated beans require more experience and practice from the coffee roaster due to its color and inconsistent reaction under heat. Ordinary unroasted coffee beans are green, but decaffeinated beans usually start as brown even before roasting due to the decaffeination process [4]. This makes it extremely challenging for the coffee roasters to distinguish the different states of coffee roasting. To make the matter worst, since all decaffeinated coffee beans are processed with water or other solvent, the arrangement of the structure as well as the chemical composition may differ from ordinary coffee beans. This result in the chaotic reaction of decaffeinated beans when roasting because the parameters of temperature and time are certainly different from ordinary coffee roasting.

As unpopular and problematic as decaffeinated coffee might seem, I consider that it is still a viable choice for coffee drinkers. It prevents people from over excitement, palpitation, insomnia, seizures and other neurotic symptoms while still provides the overall satisfactory flavor of coffee. On top of that, contrary to general belief, decaffeinated coffee beans produced by modern decaffeination process are harmless to human body. Therefore, people can enjoy a cup of decaffeinated coffee without any concerns even before sleep.

In conclusion, there is a variety of methods to produce decaffeinated coffee, including direct and indirect solvent-based process, carbon dioxide process, Swiss Water Process, and triglyceride process. Most of them involve the dissolution of caffeine into different substances and the preservation of aromatic compounds. Although the decaffeination processes are well-established, decaffeinated coffee still faces problems such as bad market reaction and the difficulty of roasting. Nonetheless, decaffeinated coffee still serves as a valid alternative to ordinary coffee because it does not stimulate our neural system or damage our health.

References:

[1] R.J. Clarke, *Coffee Volume 1 Chemistry*, 2013.

[2] P.D Justo, *Here's everything that's hiding in your cup of coffee*, 2015. (https://www.businessinsider.com/chemicals-in-coffee-2015-3)

[3] A. Farah, *Coffee Constituents*, 2012.

[4] E. Lorenzo, *Decaffeination 101: Four ways to decaffeinate coffee*, 2014. (https://coffeeconfidential.org/health/decaffeination/)

[5] R. Clarke and O.O. Vizthum, *Coffee: Recent Developments*, 2001.

[6] K. Ramalakshmi and B. Raghavan, *Caffeine in Coffee: Its Removal. Why and How?*, 1999.

[7] U.S. Food and Drug Administration, *Toxicological data for class 2 solvents*,1985.

[8] T. Gale, *Ethyl Acetate, Encyclopedia.com*, 2006. (https://www.encyclopedia.com/science/academic-and-educational-journals/ethyl-acetate)

[9] The Swiss Water Process. (https://www.swisswater.com/)

[10] The Coffee Guide, *Demand—Decaffeinated Coffee*, 2010. (http://www.thecoffeeguide.org/coffee-guide/the-markets-for-coffee/demand---decaffeinated-coffee/)

[11] S. Y. Kim, *Coffee Consumption and Risk of Osteoporosis*, 2014. (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3912260/)