MOOR JOURNAL OF AGRICULTURAL RESEARCH
Journal homepage: https://iart.gov.ng/moorjournal/index.php/mjar/

Effect of Drying on the Nutritional and Microbial Quality of Tea (*Camellia sinensis)* using a Passive Solar Dryer

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Article Info

Article history:
Received: July 25, 2023
Revised: October 18, 2023
Accepted: October 24, 2023

Keywords:
Tea
Solar dryer
Quality
Nutrition
Phytochemical compounds

Abstract

Drying of food materials under direct sunlight predispose the food item to nutritional losses and microbial contamination. Drying of tea in a cabinet dryer is thus necessary to reduce nutrient losses in tea. This research studies the effect of using solar cabinet dryer on quality of dried tea. Tea from tea plant *Camellia sinensis* obtained from Cocoa Research Institute of Nigeria was dried using a passive solar dryer. Weight of tea was taken before loading into the dryer. Temperature and relative humidity were measured. Microbiological analysis was carried out on the representative samples of the dried tea leaves. Mean comparison of evaluation parameter for the variations in the temperature and relative humidity of the dryer and ambient were investigated using Analysis of Variance (ANOVA) and Least Significant Difference (LSD). Differences were considered significant at $p \leq 0.05$. The pH, crude protein percentage and total dissolved solids (TDS) of tea leaves from the cabinet dryer were within the safe range and comparable with that dried in direct sunshine. The microbiological analysis of tea samples taken from Tray 1 (Partition A) showed only *Trichoderma* spp. (100%), while *Penicillium chrysogenum* (66.67%) and *Aspergillus niger* (60%) dominated samples obtained from the second and third partitions of the tray respectively. The phytochemical compounds present in the *Camellia sinensis* extract dried at ambient temperature was more than the chemical contents associated with extract dried in the dryer. The phytochemical compounds represented in tea extract dried at room temperature was at peak, 4336.00 (35%) and 4009.00 (35%) were absent at the Fourier transform infrared (FTIR) analysis of tea extract dried with a dryer. These peaks have the highest percentage in tea. However, tea can be dried using the solar cabinet dryer as it makes it safe and suitable for human consumption rather than tea dried under the sun which can allow contamination by microorganisms and weather conditions.

Introduction

There are many different types of tea with different taste, flavor and colour. Some examples are Darjeeling and Chinese greens which have a cooling, slightly bitter, and astringent flavor, while others have vastly different profiles that include sweet, nutty, floral or grassy notes (Penelope, 2000). Tea is generally divided into categories based on how it is processed, this include white, yellow, green, oolong, black and post-fermented tea (Liu, 2005). The natural flavor of the dried tea leaves is determined by the type of cultivar of the tea, the quality of the plucked tea leaves and the manner and quality of the production processing.

Teas may be altered through additional processing such as blending, flavouring, scenting, and decaffeination before consumption. It can be consumed by adding milk, sugar and lemon. All

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tea comes from the same plant, the *Camellia sinensis* but there exist hundreds of kinds of teas, with their own individual appearance, taste, and aroma. Every harvest of tea will vary year to year due to changes in climate, rainfall, and other seasonal conditions. Thus, tea from the same plantation or garden may taste very different from one year to the next. Moreover, a particular tea gains much of its individual character from how the leaves are cultivated and processed. To make sense of all the varieties possible, teas can be placed in several categories. The most common categories used today are green tea, white tea, oolong tea, black tea and Pu-erh tea (Karori *et al*., 2007). Caffeine constitutes about 3% of tea's dry weight, translating to between 30 mg and 90 mg per 8-oz (250-ml) cup depending on type, brand, (Weinberg *et al.*, 2001). Chattejiee *et al.*, 2012 found that the caffeine content of 1 g of black tea ranged from 22 to 28 mg, while the caffeine content of 1 g of green tea ranged from 11 to 20 mg, reflecting a significant difference. The astringency in tea can be attributed to the presence of polyphenols. These are the most abundant compounds in tea leaves, making up 30-40% of their composition (Harbowy, 1997). Tea also contain small amounts of theobromine and theophylline, which are stimulants, and xanthines similar to caffeine (Graham, 2002). Black and green teas contain no essential nutrients in significant content, with the exception of the dietary mineral, manganese at 0.5 mg per cup or 26% of the value.

Tea leaves contain diverse polyphenols, including flavonoids, epigallocatechin gallate (commonly noted as EGCG) and other catechins (Ferruzzi, 2010; Willamson *et al.*, 2011). It has been suggested that green and black tea may protect against cancer or other diseases such as obesity or Alzheimer's disease (Darvesh, 2010) but the compounds found in green tea have not been conclusively demonstrated to have any effect on human diseases. One human study demonstrated that regular consumption of black tea over four weeks had no beneficial effect in lowering blood cholesterol levels (Troup *et al.*, 2015). Chemical composition of green tea leaves includes Polyphenols 37%, Carbohydrates 25%, Caffeine 3.5%, Protein 15%, Amino acids 4%, Lignin 6.5%, Organic acids 1.5%, Lipids 2%, Ash 5% a**n**d Chlorophyll 0.5% of dried leaf (Sinija, and Mishra, 2008). Tea reduced risk of heart disease and stroke (Larsson *et al.*, 2013; Peters *et al.*, 2001). White, green, oolong or black tea, and tea compounds such as epigallocatechin gallate (EGCG), may play role in cancers amelioration. Tea compounds have may mechanisms by which they provide chemo-protection: reducing free radical and DNA damage; inhibiting uncontrolled cell growth (cell proliferation) by promoting programmed cell death (apoptosis) and boosting the immune system to help fed off the development and promotion of cancer cells (Hakim *et al.*, 2008; Roy *et al.*, 2003). Preliminary investigation also suggests that tea may provide protection against various types of cancer including digestive, skin, oral, lung, prostate, breast, and ovarian cancers (Zheng *et al.*, 2013; Dora *et al.*, 2003; Su and Arab, 2002; Sun *et al.* 2002).

Tea research indicates recommendations to improve heart and cardiovascular function are also neuroprotective (Scarmeas *et al.*, 2009). The bioactive compounds found in tea may promote neurological health through various actions (Mandel *et al.*, 2008; Rezai-Zadeh *et al.*, 2005). Tea processing is the method in which the leaves from the tea plant *Camillia sinensis* are transformed into the dried leaves for brewing. The most important steps involve in green tea production are as follows: plucking, cooling, roasting or pan frying, re-cooling, drying, pre-sieving and final sieving (Ahmed and Steppy, 2012). However, the drying rate depends on the type of drying methods and the drying materials. Nutrients are also lost during drying depending on the type of drying method. This research studies the effect of using solar cabinet dryer on quality of dried tea.

Materials and Methods

The tea (*Camellia Sinensis*) (Fig. 1) used for this research was sourced from the Cocoa Research Institute of Nigeria (CRIN) Idi-Ayunre, Ibadan, Nigeria. The solar cabinet dryer (Fig. 2) was designed and constructed at the Department of

Agricultural and Bioenvironmental Engineering, Federal College of Agriculture, Ibadan. Other materials include frying pan, cooking stove, digital thermometer and hygrometer obtained from the processing laboratory of the above department.

Fig. 1: Tea Leaves

Fig. 2: Solar Cabinet Dryer

Description and operation of the cabinet dryer compartment

The cabinet dryer was made with metal. It comprises two compartments- the cabinet and the solar heat collector. The cabinet contains three set of perforated trays arranged vertically, one on top of the other. The hot air collector was made of a square bin which contains granite stones painted black and covered with a plain glass. The black stones absorb heat during the day and release it in the night. The bin has two openings- one to the atmosphere for air to enter the bin and the other for air to exit into the cabinet to aid the drying process.

Preparation of the tea for drying

Tea was plucked at the tea plot of Cocoa Research Institute of Nigeria. It was done by picking the tender apical shoots which includes the terminal bud along with 2/3 adjacent leaves. The tea shoot was nipped off with the thumb and forefinger in order to ensure the quality and taste of tea. The weight of the tea was taken and allowed to wither slightly under the ambient temperature to reduce moisture and for better distribution of moisture to improve the taste. Panfrying of the leaves inside empty frying pan was carried out for about 20 minutes to prevent mould and colour change. The hot fried leaves were allowed to cool before being transferred to the solar cabinet dryer.

The drying process

The roasted leaves were weighed and divided into seven parts. Two tea leaf samples were placed in each tray inside the solar cabinet dryer while the seventh tray was put on an open floor to have direct contact with solar radiation as a control. The temperature and relative humidity above each tray were measured using digital thermometer and hygrometer, respectively. The drying process was properly monitored and the parameters where measured thrice daily. The experimentation took four days to be completed.

Quality analysis

Caffeine composition was determined by placing 5 g of grounded tea leaves (Kubmarawa *et al.*, 2011) in a separating funnel 150 ml of water added and shook together. 40 ml of Dichloromethane was added to the funnel content and shook again for good mixing. The lower Dichloromethane layer was drained into a flask after proper layer separation. This process was repeated 3 times to obtain maximum caffeine content in the leaves. 2 g of anhydrous Sodium Sulphurate was added to flask content to remove possible water content. Caffeine composition was recovered using distillation method as reported by Okoli *et al.* (2012). Percentage caffeine content of the tea leaves was calculated using the equation:

$$\%\ of\ Caffeine\ = \frac{Weight\ of\ Caffeine}{Weight\ of\ tea} x100$$

The grounded samples were infused in distilled water and allowed for 30 minutes to reach equilibrium. pH meter was calibrated using Buffer solutions of 4.0 and 7.0. The meter was used to determine the pH and Total Dissolved Solids (TDS) of the tea leaf samples by switching to the appropriate modes of the parameters. Crude protein contents of the tea leaves were determined through Kjeldahl method by digesting 0.5 g of each sample. Crude protein content was obtained by multiplying the Nitrogen percentage by 6.25 conversion factor.

Microbiological analysis

Representative samples of the dried tea leaves (in trays 1, 2, 3 and the control) were plated into freshly prepared potato dextrose agar plates using direct plating technique. The inoculated plates were incubated at 30±2ºC for five days. The fungi isolates observed on the plates were characterized with the aid of fungi identification book Watanabe (2002). Percent occurrence of each of the isolated fungi was calculated per sample using the following formula:

$$\text{Percent occurrence of fungus isolate} = \frac{Number\ of\ specific\ fungus\ isolate\ colonies}{Total\ number\ of\ fungi\ colonies} \text{ x } 100 \quad (2)$$

Statistical analysis

Data obtained were subjected to Descriptive and inferential statistics (ANOVA) using Statistical Package for Social Sciences (SPSS). Data were presented in histograms; mean values, standard deviation (SD). Means were separated

using Least Significant Difference (LSD). Differences were considered significant at $p \leq 0.05$.

Results and Discussion

Changes in weight of tea leaf samples with time of the day and number of days

Figure 3 below show reduction in weight of the tea leaves stored in both the cabinet solar dryer and at direct sun drying, with increase in temperature and time of the day. The weight reduced from morning till afternoon but the weight loss at afternoon was maintained in the evening in the first and second day of drying. Weight loss (reduced moisture) was more pronounced in samples stored in the solar cabinet dryer than that stored under direct sun on days 3 and 4. Day 4 illustrated that there was much loss of moisture content in tea leaves dried using a solar dryer than that placed in the open floor with direct contact with solar radiation as it accumulates moisture from the environment during the night.

Temperature and relative humidity during the drying of the tea leaves

Table 1 shows the average relative humidity and temperature for morning, afternoon and evening for four consecutive days while Table 2 shows the analysis of variance of the relative humidity and temperature. Table 3 present the least significant difference between the two methods; it enables us to make direct comparisons between the two methods. The highest relative humidity (77%) was recorded in the morning inside the cabinet (CRH) while the least (60%) was obtained for the ambient (ARH) in both afternoon and evening. Temperature was highest (38^{o}C) in the afternoon for both the cabinet (CT) and the ambient (AT) while the least (32.5^{o}C) temperature was obtained in the morning from the ambient (AT). It was found that the RH value was inversely proportional to the drying temperature. Mulianda *et al*. (2022) obtained an average drying temperature of 55^{o}C and average RH value of 20% in the drying chamber of the system that utilize firewood as source of heat. The analysis of variance showed that all the parameters, CRH, ARH, CT and AT were significant at $p<0.05$. The LSD also shows that there were significant differences among all the parameters for the three trays except between trays 2 and 3 for CHR and ARH, and trays 1 and 3 for AH.

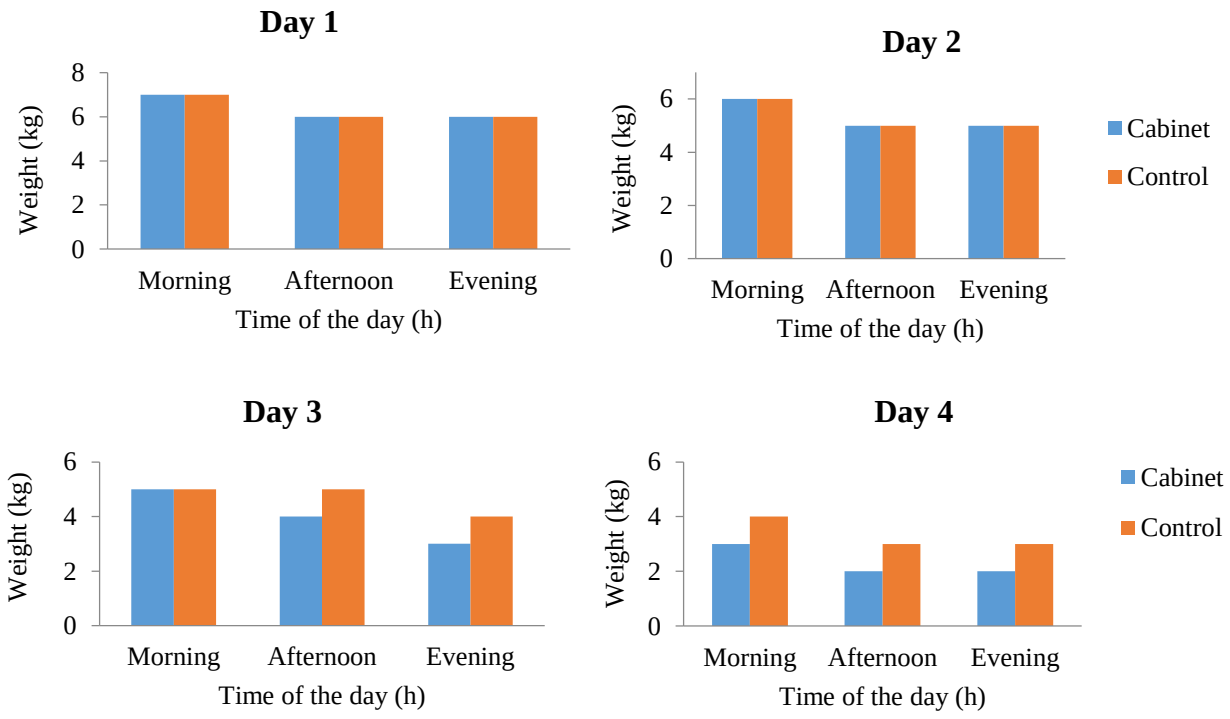

Fig. 3: Changes in weight of tea leaf samples with time of the day and number of days

Table 1: Summary result of the relative humidity and temperature

		NOD	Mean	Std. Deviation	Minimum	Maximum
CRH	Morning	4	75.0750	2.32863	72.30	77.00
	Afternoon	4	59.8250	3.57619	57.00	65.00
	Evening	4	61.7500	4.27200	56.00	65.00
	Total	12	65.5500	7.75271	56.00	77.00
ARH	Morning	4	71.2500	4.34933	67.00	75.00
	Afternoon	4	55.0000	3.91578	51.00	60.00
	Evening	4	55.0000	3.91578	51.00	60.00
	Total	12	60.4167	8.80556	51.00	75.00
CT	Morning	4	31.9500	1.10303	31.00	33.30
	Afternoon	4	37.6500	1.39642	35.30	38.00
	Evening	4	34.6250	1.16154	33.00	35.60
	Total	12	34.4083	2.29642	31.00	38.00
AT	Morning	4	30.8250	1.12064	30.20	32.50
	Afternoon	4	35.0750	1.43149	35.60	38.40
	Evening	4	33.0750	2.33435	30.40	36.00
	Total	12	33.6583	3.11053	30.20	38.40

NOD-Number of Day, CRH-Relative Humidity Inside Cabinet, ARH- Ambient Relative Humidity, CT-Temperature Inside Cabinet, AT-Ambient Temperature

Table 2: The analysis of variance of the relative humidity and temperature

		Sum of Squares	df	Mean Square	F	Sig.
CRH	Between Groups	551.765	2	275.883	22.699	.000
	Within Groups	109.385	9	12.154		
	Total	661.150	11			
RRH	Between Groups	704.167	2	352.083	21.303	.000
	Within Groups	148.750	9	16.528		
	Total	852.917	11			
CT	Between Groups	44.462	2	22.231	14.769	.001
	Within Groups	13.547	9	1.505		
	Total	58.009	11			
AT	Between Groups	80.167	2	40.083	13.736	.002
	Within Groups	26.263	9	2.918		
	Total	106.429	11			

Table 3: The least significant difference of the relative humidity and temperature.

Dependent Variable	Tray (I)	Tray (J)	Mean Difference (I-J)	Std. Error	Sig.
CRH	1	2	15.25000*	2.46515	.000
		3	13.32500*	2.46515	.000
	2	1	-15.25000*	2.46515	.000
		3	-1.92500	2.46515	.455
ARH	1	2	16.25000*	2.87470	.000
		3	16.25000*	2.87470	.000
	2	1	-16.25000*	2.87470	.000
		3	.00000	2.87470	1.000
CT	1	2	-4.70000*	.86755	.000
		3	-2.67500*	.86755	.013
	2	1	4.70000*	.86755	.000
		3	2.02500*	.86755	.044
AT	1	2	-6.25000*	1.20790	.001
		3	-2.25000	1.20790	.095
	2	1	6.25000*	1.20790	.001
		3	4.00000*	1.20790	.009

*The mean difference is significant at the 0.05 level.

The pH, proximate composition, total solids and caffeine content of the tea leaf samples

The pH, crude protein percentage and total dissolved solids (TDS) of the tea leaves are presented in Table 4. The pH, crude protein and total dissolved solids (TDS) of tea leaves from the cabinet dryer were within the same range (18.25-19.69% for crude protein) and comparable with the direct sunshine, 19.12% (control). Values of crude protein were higher than that presented by Sinija, and Mishra (2008) for green tea leaves (Protein 15%). The values were also higher than11.63% and 8.23 for *Cassia tora* and *Celtis integrifolia* respectively, but lower than 27.4% for *Chochorus olitoris* as reported by Kubmarawa *et al*. (2011). The differences could be as a result of the variety used for this work. Report of Unilever (2019) indicated that green tea differs substantially based on varieties of *camellia sinensis*, growing conditions and methods, processing methods and time of harvest. The percentage caffeine content of the samples is shown in Table 5. Caffeine content ranges from 0.5 to 0.7 g (3.3-4.6%) were obtained. Caffeine is a vital compound of tea because of its stimulating property. These values are comparable with caffeine of 3.5-5.1% for instant tea and 3.89% for black tea reported by Anonymous (2020) and Teshome, (2019) respectively. Chattejiee *et al.*, 2012 found that the caffeine content of 1 g of green tea ranged from 11 to 20 mg. Weinberg *et al.*, 2001 also, reported that caffeine constitutes about 3% of tea's dry weight, translating to between 30 mg and 90 mg per 250-ml cup depending on types. There was not much difference in the caffeine content of the samples (Table 4). An indication that the type of drying and the drying environment did not have a much influence on the properties of dried tea leaves. Total Dissolved Solids (TDS) which ranges from 548-1600ml/g (≈0.1-0.2%) were lower than 0.3-0.45% non-volatile extractable solids reported by Anonymous (2020). The difference may be due to tea types, harvesting method and quality of brewing water. According to Desai (2020), pH ranges of green tea, herbal tea and black tea were 7-10, 6-7 and 4.9-5.5 respectively which can be affected by tea types and

water quality. It was added that pH values lower This implies that values obtained in this work are

Table 4: The pH and Crude protein of the tea after drying.

S/code	pH	Crude protein (%)	Total dissolved solids (Mol)
1	5.58	18.81	1540
2	5.32	19.69	548
3	5.30	18.25	1280
Control	5.66	19.12	1600

Table 5: Caffeine of the tea after drying.

S/code	Empty beaker(g)	beaker caffeine crystal (g)	Amount of caffeine (g)	% of caffeine
Tray 1	154.7	155.3	0.6	4
Tray 2	163.7	164.3	0.6	4
Tray 3	154.7	155.2	0.5	3.33
Control	154.7	155.4	0.7	4.6

Microbial properties

Table 6 shows the percentage occurrences of fungi isolates associated with the tea leaf samples placed in the fabricated solar cabinet dryer. Tea samples taken from Tray 1 (Partition A) showed only *Trichoderma* spp. (100%), while *Penicillium chrysogenum* (66.67%) and *Aspergillus niger* (60%) dominated partitions B and C of the first tray respectively. *Trichoderma* spp. (66.67%), followed by *Pythium* spp. (33.33%) also dominated the first partition of the third tray. Equal proportion (33.33%) of each of *Pestalotia, Rhizoctonia* and *Fusarium* spp. were found in the third partition of the third tray. Only second partition (partition B) of Tray 2 showed fungi growth. *Bipolaris* sp. was the only fungus noticed in the tea samples placed in Tray 2. The control samples however showed the growth of equal proportions of colonies of *Botrytis, Pestalotia* and *Fusarium* spp. (Table 6). Variations in the fungi colonies in the dried tea samples may be due to variation in the environmental conditions (for the trays) to favour or inhibit the proliferation/survival of fungi isolates in the samples. The presence of members of the *Aspergillus* and *Penicillium* spp. on some of the tea leaf samples agrees with the discoveries of Elshafie *et al.* (1999) and Carraturo *et al.* (2018) who worked on dried and processed tea leaves respectively.

Table 6: Percentages of occurrence of fungi isolates associated with tea leaves

Partition	A	B	C
CONTROL	Botrytis (33.33%),	Pestalotia sp. (33.33%)	Fusarium (33.33%)
Tray 1	Trichoderma sp. (100%)	Fusarium sp. (33.33%), Penicillium chrysogenum (66.67%)	Pythium sp. (20%), A. niger (60%), Botrytis sp. (20%)
Tray 2	No growth	Bipolaris sp. (100%)	No growth
Tray 3	Trichoderma spp. (66.67%), Pythium sp. (33.33%).	Rhizopus sp. (100%)	Pestalotia sp. (33.33%), Rhizoctonia (33.33%), Fusarium sp. (33.33%).

The phytochemical compounds present in the dried tea

Figures 4a and 4b shows the phytochemical properties of the tea leaves dried on floor with direct contact with solar radiation and cabinet dryer respectively. The abundance of each chemical component is represented as percentage transmittance (%T). The phytochemical compounds present in the *Camellia sinensis* extract dried on floor with direct contact with solar radiation was more than the chemical contents associated with extract dried in the dryer (Figure 4). The phytochemical compounds represented in tea extract dried on floor with direct contact with solar radiation was at peak, 4336.00 (35%) and 4009.00 (35%) were absent at the Fourier transform infrared (FTIR) analysis of tea extract dried with a dryer. These peaks have the highest percentage in tea. The phytochemical compounds represented in tea extract dried in ambient temperature at peak 3386.00 (3%) which is tetra carboxillic acid was present in the tea dried in chamber but with a difference in percentage of 5 %. Also, the phytochemical represented in the tea extract dried at room temperature at peak 2975.41 (10%) and 2901.29(13%) which is 2-aminoethyltrimethul ammonium chloride were absent in the tea extract dried in the dryer. The phytochemical represented in tea extract dried at room temperature at peak 2139.00 (32%) was also present in the extract dried in a chamber at peak 2101.00 (2%). Also, the phytochemical represented in tea extract at room temperature at peak 1923.00 (335) which is myrtanylami was absent in the extract dried in a dryer. The phytochemical represented in tea extract at peak 1648.81, 1442.97 of -3-propyloxirane methanol,1390.05 and 1050.02 were also present in the extract dried in the dryer but the range of percentage are different. The component in tea extract dried in the chamber at peak 1234.81of 2,2-Dimethl,3-dioxolane -4-methanol and 1149.50 were absent in the extract dried at ambient temperature. Finally, the phytochemical represented in tea extract dried at room temperature at peak 421.00 of pentane diol and 384.26 were also present in the extract dried in the dryer. It was observed from the varieties of peaks indicated in Fig. 4 (a and b) below that more phytochemical compounds were retained in aqueous extract of tea dried at ambient temperature than extract of tea dried using the solar dryer. Sagar *et al*. (2022) reported that tea contains almost 4000 phytochemicals of which polyphenols contribute to 33%. These phytochemicals have beneficial role in defense mechanism in human health.

Conclusion

The pH, crude protein percentage and total dissolved solids (TDS) of tea leaves from the cabinet dryer were within the same range and comparable with dried tea in direct sunshine (control). Also, the percentage caffeine content of all the tea samples in the cabinets was very close. There were variations in the fungi colonies in the dried tea samples. The phytochemical represented in tea extract dried at room temperature at peak 421.00 of pentane diol and 384.26 were also present in the extract dried in the dryer. More

phytochemical compounds were retained in aqueous extract of tea dried at room temperature than extract of tea dried using the solar dryer. Tea (*Camellia sinensis*) should be dried using the solar cabinet dryer as it makes it safe and suitable for human consumption rather than tea dried under the sun which can allow contamination by microorganisms and weather conditions. The solar cabinet was also found to retain nutritional quality of the tea leaves

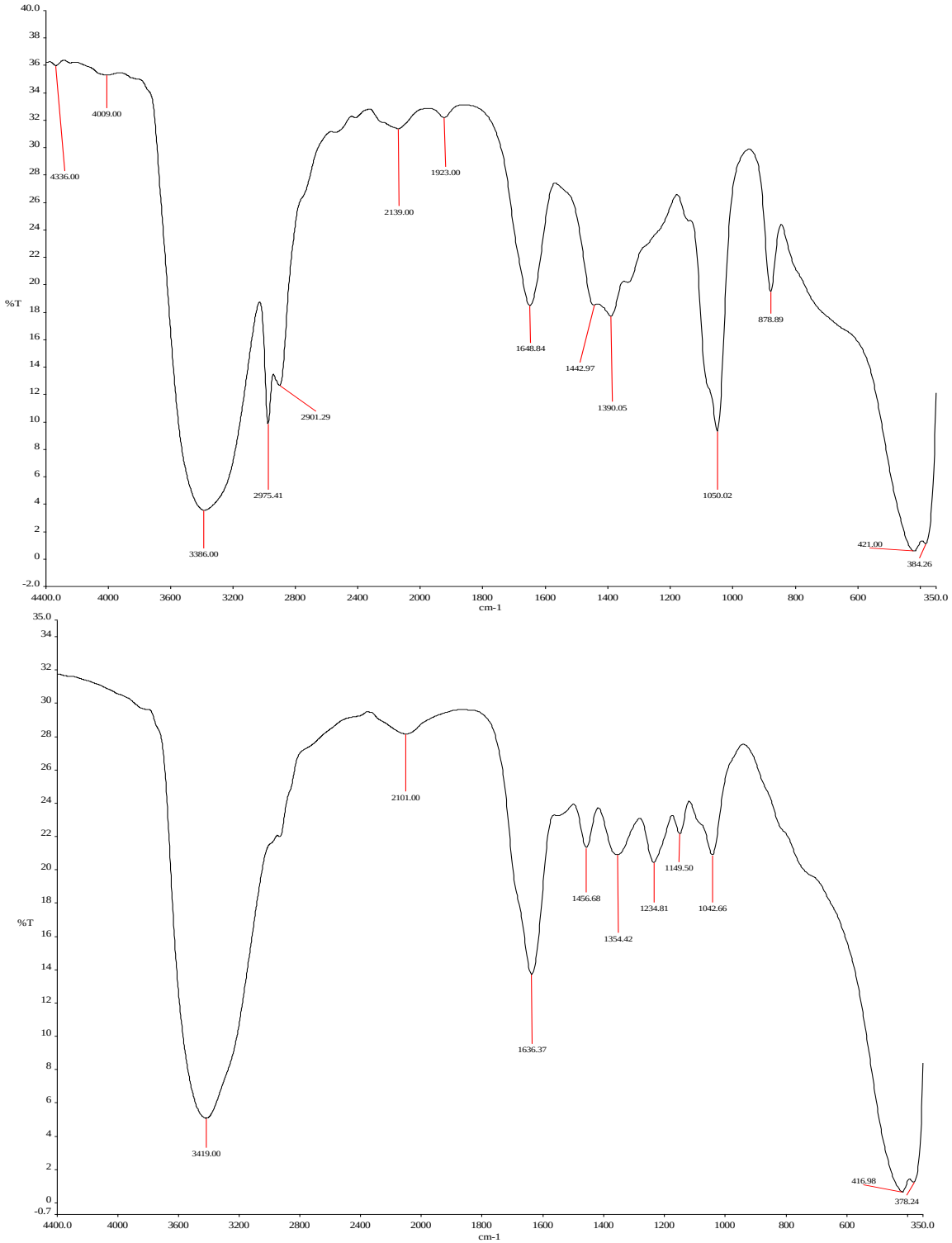

Fig. 4: The quality assurance of tea dried (a) at ambient conditions and (b) solar cabinet dryer

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