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Evaluation of Density and Freshness of Green Tea Based on "Ripples" under Periodic Perturbation

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Abstract. The formation of patterns in green tea sediment was used for evaluating the concentration and freshness of "green tea" under external perturbation of a tea cup. The spatial manner of the sediment was changed with an increase in the number of vibration and was determined after several tens of the vibration. The manners of "ripples" changed depending on the concentration and freshness of green tea were evaluated by Fourier transformation. We believe that the present system under periodic perturbation becomes a novel analytical tool based on spatio-temporal information.

1. Introduction

Studies of "simple" experimental models are important for understanding "complex" spatio-temporal rhythmic phenomena in nature. Over the past few decades, there has been considerable interest in self-oscillatory phenomena in various chemical systems [1–6] (LARTER, 1990; SAKURAI *et al.*, 1992; KRUNG *et al.*, 1994; FIELD and GYÖRGI, 1993; GROISMAN and KAPLAN, 1994; EPSTEIN *et al.*, 1996). Such rhythmic phenomena are driven by the dissipation of chemical energy, and are generated in highly nonlinear systems.

Geological ripples that spatio-temporally modify the Earth's surface are generated by the entrainment, transport, and deposition of sediment by fluid flow (MCCORMICK, 1984; PYE, 1994). The characteristics of these ripples generally depend on the flow rate and size of the sediment. Clarification of the mechanism is quite important to improve various environmental problems, e.g., erosion, flood defense, and waste disposal. The nature of ripples under periodic perturbation has been investigated (HUNTLEY, 1977; BLONDEAUX, 1990; FUNAKOSHI and INOUE, 1992). However, "tea-ripples" has not been reported as the analytical tool, yet.

In this paper, we report that the nature of "tea-ripples" is utilized for evaluating the concentration and freshness of tea. The mm-scale "tea-ripples" were observed in a tea cup which is periodically moved laterally. The spatial manner of the sediment was changed depending on the number of vibration and was determined after several tens of the vibration. Various types of patterns were observed in green tea sediment depending on the concentration and freshness of the tea and were evaluated by Fourier transformation.

2. Experimental

Figure 1 shows the experimental apparatus used here. A plastic cylinder ("tea cup"; inner diameter: 60 mm, height: 80 mm) with a flat bed was placed on a small wagon. The wagon was connected to a motor controlled by a personal computer (NEC PC-9801, Japan). After Japanese green tea (Chikiriya Co., Kyoto) was filtered with a tea ball (25 mesh), the tea was poured into the plastic cylinder (i.d.: 60 mm) of which base is flat. After the tea sediment had homogeneously accumulated on the base of the glass cell, the tea cup was vibrated. The amplitude of vibration was 10 mm. The movement of tea sediment with vibration was monitored with a digital video camera (SONY DCR-VX700, minimum time resolution: 1/30 sec) and recorded on video tape. All of the experiments were performed at room temperature. Mathematica (Wolfram Research, Inc., IL, USA) was used to perform Fourier analysis.

3. Results and Discussion

Figure 2 shows the concentration-dependence of the tea-ripples. The formation of the tea ripples depending on the oscillatory cycle was shown in Fig. 3. A homogeneous distribution of tea-sediment on the bed (no ripples) was prepared at the initial state (Fig. 3 (1)). Most patterns reached a stationary state after ca. 100 cycles of vibration (Fig. 3 (1), (2)). The period of the ripples in Fig. 2 was not sensitive to the concentration of tea (ca. 2 mm in this analyzed condition) but the thickness of the ripples increased with the concentration. The manner of sedimentation changed depending on the size and shape of the cell, the slope of its base, the volume of green tea, and the tea grain size (data not shown).

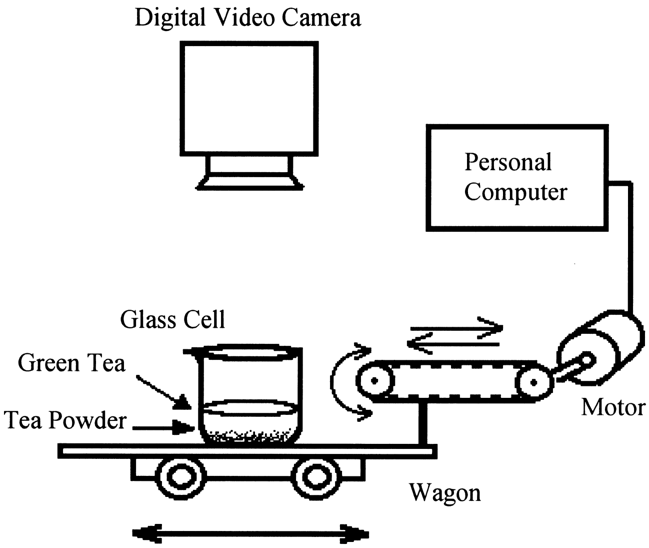

Fig. 1. Diagram of the experimental apparatus for vibration of green tea. The wagon connected to the cell with green tea was driven by the motor.

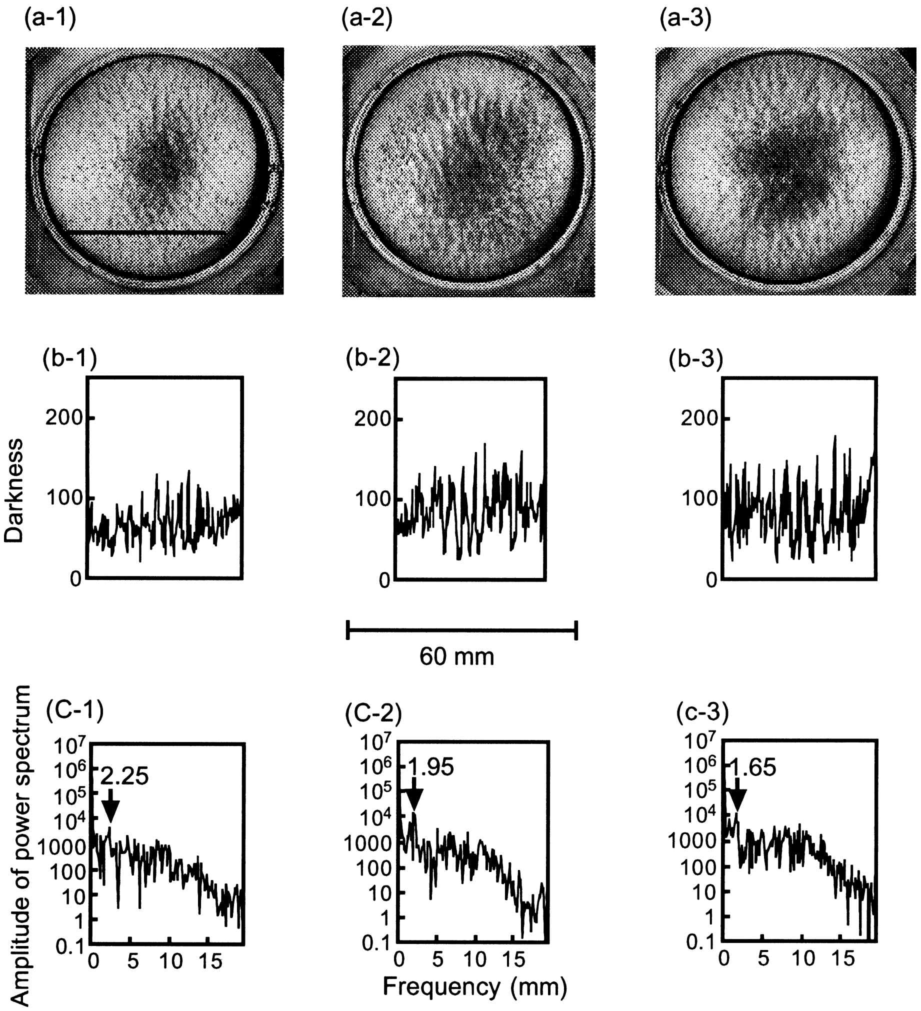

Fig. 2. Concentration-dependence of tea-ripples. (a) Snapshots of green tea sediment in the plastic cell (top view), (b) density of the green tea sediment on the line (see Fig. 2(a-1)), and (c) amplitude of the power spectrum of FFT on (b). The concentrations of green tea were (1) 0.520, (2) 0.637, and (3) 0.710 g/l, respectively. Individual images were obtained after 150 cycles of external vibration. The volume of tea was 30 ml.

Figure 4 shows the freshness-dependence of the tea-ripples. In general, a green tea in water is oxidized with time. The period and thickness of the tea-ripple’s increased with time.

Let us discuss the mechanism of pattern formation in green tea (HUNTLEY, 1977; BLONDEAUX, 1990; FUNAKOSHI, 1992). In the initial condition, green tea sediment is homogeneously distributed on the base of the cell while influenced by convection of the aqueous phase, as indicated in Fig. 3(1). With the application of lateral oscillation, the

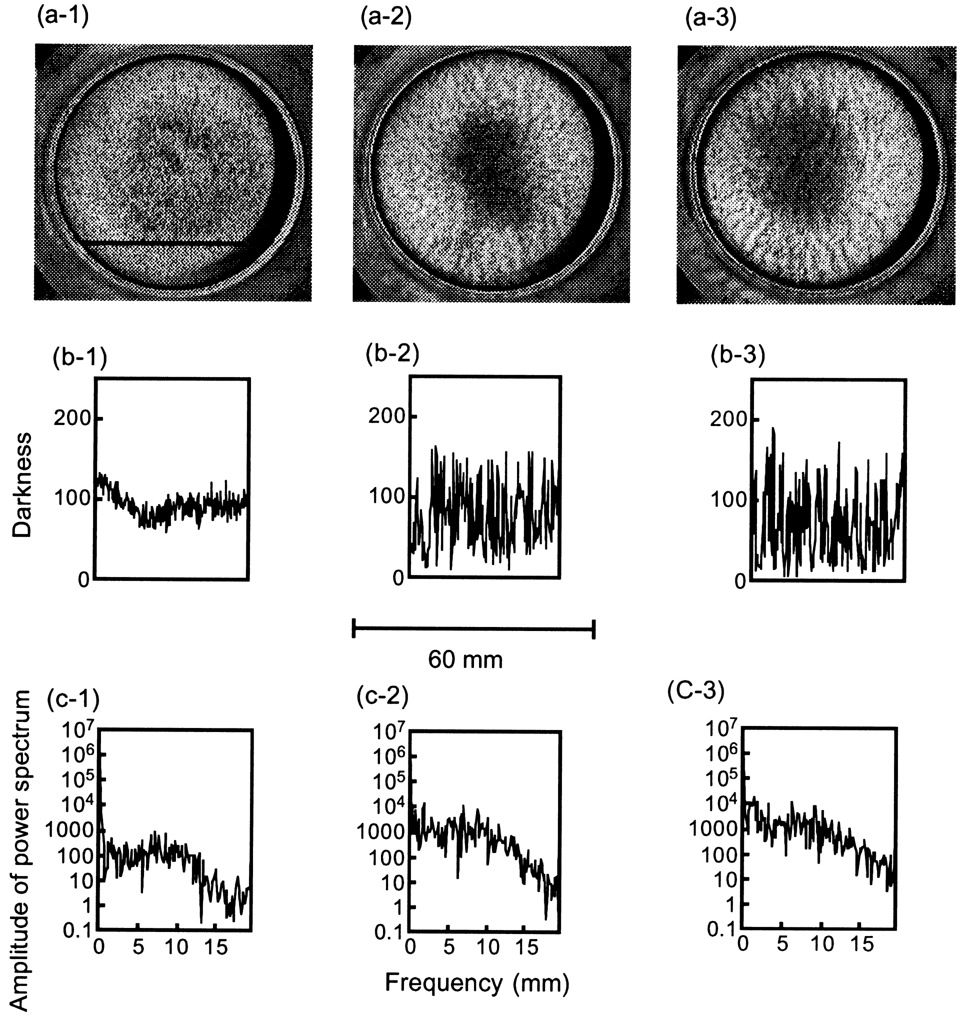

Fig. 3. Oscillatory cycle-dependence of tea-ripples. (a) Snapshots of green tea sediment in the plastic cell (top view), (b) density of the green tea sediment on the line (see Fig. 3(b-1)), and (c) amplitude of the power spectrum of FFT on (b). The images were obtained after (1) 0, (2) 75, and (3) 150 cycles of oscillations. The concentration of green tea was 0.730 g/l. The volume of tea was 30 ml.

small sediment particles vibrate in the same direction as the external vibration; the small particles are readily moved by the external force. These small particles may attach to each other to form larger sediment particles with a greater mass (HUNTLEY, 1977; BLONDEAUX, 1990; FUNAKOSHI, 1992). The ripples grow with the number of vibrations, and a stable pattern is achieved with heavy aggregations, as seen in Fig. 3. At a higher concentration, the density of patterns increased, i.e., entrainment among aggregates with a higher density may be occurred. Thus, longitudinal ripples may be generated by lateral vibration. The

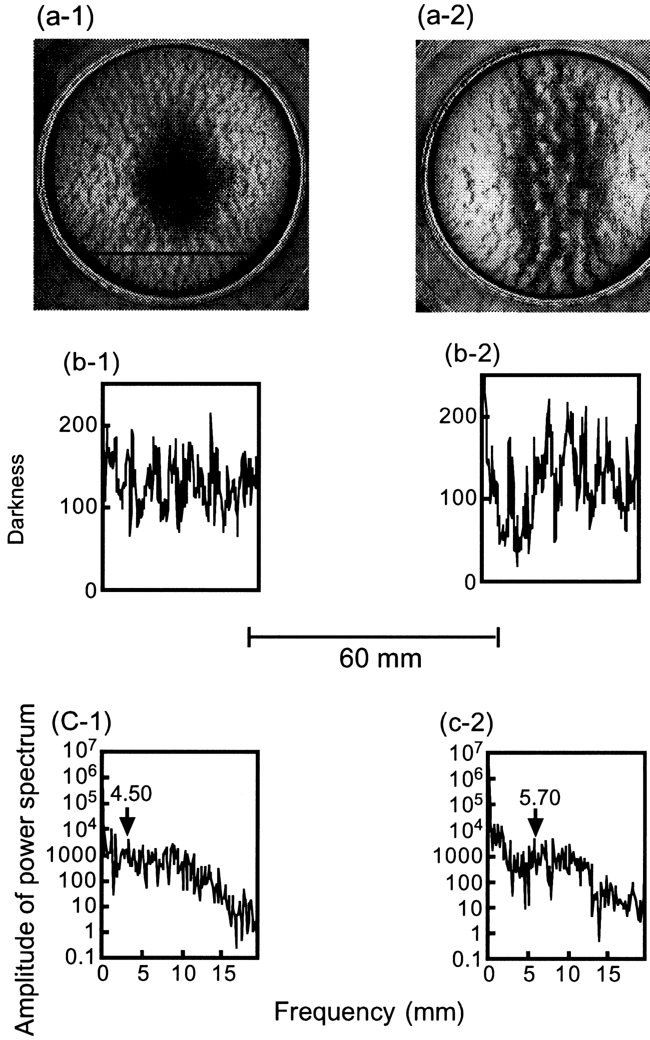

Fig. 4. Freshness-dependence of tea-ripples. (a) Snapshots of green tea sediment in the glass cell (top view), (b) density of the green tea sediment on the line (see Fig. 4(b-1)), and (c) amplitude of the power spectrum of FFT on (b). The images were obtained after (1) 1 and (2) 2 day. The sample corresponds to Fig. 2(a-3). The volume of green tea was 30 ml.

results of freshness-dependence of the tea-ripples suggest that the nature of tea particles are changed by the oxidation and then the manner of the tea ripples is changed (Fig. 4).

Our results and experimental system are only preliminary; for example, the spatial patterns are certainly influenced by the edge of the cell as a boundary condition. In addition, it is not clear why the various types of ripples are generated under vibration. To clarify the mechanism of pattern formation, we should measure the direction of liquid flow in the cell.

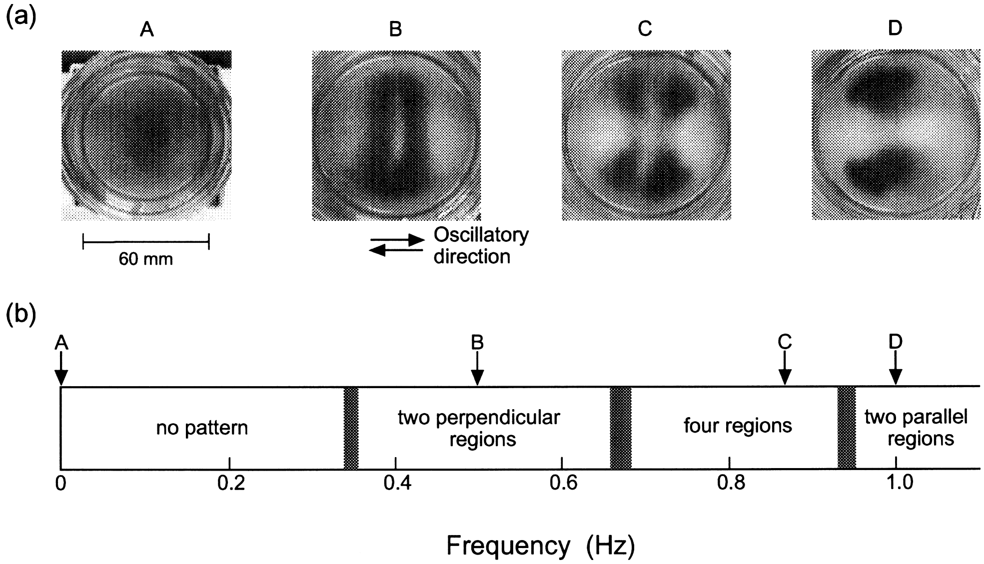

Fig. 5. (a) Snapshots of green tea sediment in the glass cell (top view) and (b) the manner of the deposition of green tea sediment depending on the frequency of vibration. Individual images were obtained after 80 cycles of external vibration. The volume of green tea was 25 ml.

However, it is apparent that several types of patterns can be created even with the present simple system. We found that the nature of the tea-ripples changed depending on the volume of green tea owing to the convection under the periodic perturbation (HUNTLEY, 1977; BLONDEAUX, 1990; FUNAKOSHI, 1992), as shown in Fig. 5. This result suggests that various types of patterns can be created by external vibration. In addition, we believe that the present system may help to not only utilize as the analytical tool but also control spatial pattern formation in self-assembly.

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