Regulation of the Peripheral Body Temperature by Foods: A Temperature Decrease Induced by the Japanese Persimmon (kaki, Diospyros kaki)

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We investigated whether the ingestion of the Japanese persimmon (kaki, Diospyros kaki) could lower the human peripheral body temperature. It was found that the temperatures recorded at the foot and wrist were depressed after kaki consumption compared to after the same amount of water consumption. The effects of ingesting freeze-dried kaki and eating a cookie (as its nutritional counterpart) containing the same amount of carbohydrate, protein, fat, and water were compared. A similar temperature-reducing effect of kaki was observed. The recovery of finger temperature after soaking the finger in ice-cooled water was also studied. The temperature recovery was delayed after kaki consumption. It was thus quantitatively demonstrated that ingesting kaki indeed had the effect of lowering (or repressing the rise) of the peripheral human body temperature, as has been traditionally believed in China for many hundreds of years.

Key words: persimmon; peripheral body temperature; autonomic nerve; Chinese traditional medicine; human

The original medical system in China (Chinese traditional medicine or zhonyao) has been handed down for many hundreds of years. This system differs from Western medicine, in that there is no essential distinction between foods and medicines in Chinese traditional medicine. The difference between the two is the degree of physiological effectiveness on humans. Some foods are considered to have physiological effects to warm or to cool the human body. All foods are classified as having either of these effects or as having no effect on normal humans.1–5 This physiological effect of foods on the human body temperature is called xing or qi (nature) in Chinese traditional medicine. It is common for people to feel hot and to sweat after ingesting hot spices like red pepper.

However, the classification is based on the sense and experience of ancestors, and lacks scientific justification. For example, there is a possibility that some foods cool the human body just because they contain a lot of water. A quantitative evaluation of the physiological effect of foods is needed, together with consideration of the factors which might influence the human body temperature (e.g., the water content and nutritional composition).

We examined in this study whether the consumption of the Japanese persimmon (kaki, Diospyros kaki) could cause a fall in the human body temperature when compared with the consumption of an equivalent amount of water and a nutritionally equivalent cookie.

Subjects and Methods

Subjects. All the subjects were healthy, Japanese student volunteers who provided informed consent complying with the Helsinki Declaration for all experiments. Their body weights were within 10% of the normal Figure.4) Experiments 1 and 2 involved 8 women aged 18–22 y; Experiment 3 involved 10 women aged 18–20 y.

Diets and experimental conditions. The diets and experimental conditions are summarized in Table 1. In Exp. 2 and 3, freeze-dried kaki was consumed to investigate the effects of ingesting solid kaki while avoiding the influence of ingested water. The ingredients of the cookie (the nutritional counterpart of freeze-dried kaki) are shown in Table 2.

Variables measured. In Exp. 1, the body surface temperatures at the forehead, neck, wrist, top of the right foot and armpit were measured with a BAT-12 thermistor (Physitemp Instruments Inc., Clifton, NJ, USA). The temperature data were recorded automatically with a computer through an AM-7002 data collector (Adachi-keiki Co., Tokyo, Japan). Blood pressure was measured with a BP-88 automatic sphygmomanometer (Colin Co., Aichi, Japan), and...
Table 1. Experimental Conditions

<table>
<thead>
<tr>
<th>Room temperature</th>
<th>Exp. 1</th>
<th>Exp. 2</th>
<th>Exp. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>22 ± 0.5°C</td>
<td>22 ± 0.5°C</td>
<td>22 ± 0.5°C</td>
</tr>
<tr>
<td>Amount of diet consumed</td>
<td>raw kaki(^1) (100 g) plus water (43 g), or water alone (143 g)</td>
<td>freeze-dried kaki(^2) (0.56 g/kg of body wt)(^3) or nutritionally equivalent cookie(^4) with 30 g of water(^5)</td>
<td>freeze-dried kaki(^2) (0.56 g/kg of body wt)(^3) or nutritionally equivalent cookie(^4) with 30 g of water(^5)</td>
</tr>
<tr>
<td>Variables measured</td>
<td>body surface temperature, blood pressure, and blood flow rate in the back of the hand</td>
<td>body surface temperature, blood pressure, and blood flow rate in the wrist</td>
<td>finger temperature after soaking the finger in ice-cooled water</td>
</tr>
</tbody>
</table>

\(^1\) Fuyuh-kaki from Gifu Prefecture, Japan. The amount of water consumed was selected in relation to experiments investigating the physiological effects of other kinds of food.

\(^2\) Raw kaki was cut into a comb shape about 5 mm thick and then freeze-dried for 96 h (Eyela FD-1 freeze dryer, Tokyo Rika Kikai Co., Tokyo, Japan). 33.8 g of freeze-dried kaki is equivalent to 200 g of raw kaki.

\(^3\) Equivalent to 200 g of raw kaki (60 kg of body wt).

\(^4\) Ingredients and nutritional data are shown in Table 2.

\(^5\) Water was consumed to ease swallowing of the freeze-dried kaki.

Table 2. Ingredients of the Cookie and Nutritional Data for the Cookie and Kaki

<table>
<thead>
<tr>
<th>Cookie ingredients (g per 60 kg of body wt)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>flour</td>
<td>8.0</td>
<td></td>
</tr>
<tr>
<td>corn starch</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>sugar</td>
<td>13.5</td>
<td></td>
</tr>
<tr>
<td>whole egg</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>starch sugars</td>
<td>4.0</td>
<td></td>
</tr>
</tbody>
</table>

The cookie was baked for 10 min at 200°C.

<table>
<thead>
<tr>
<th>Nutritional data (per 60 kg of body wt)</th>
<th>Cookie</th>
<th>Kaki</th>
</tr>
</thead>
<tbody>
<tr>
<td>dry matter (g)</td>
<td>22.9</td>
<td>33.8</td>
</tr>
<tr>
<td>energy (kcal)</td>
<td>124</td>
<td>120</td>
</tr>
<tr>
<td>protein (g)</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>fat (g)</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>sugar (g)</td>
<td>30</td>
<td>31</td>
</tr>
<tr>
<td>dietary fiber (g)</td>
<td>0</td>
<td>0.8</td>
</tr>
<tr>
<td>Ca (mg)</td>
<td>4</td>
<td>18</td>
</tr>
<tr>
<td>P (mg)</td>
<td>10</td>
<td>28</td>
</tr>
<tr>
<td>Fe (mg)</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Na (mg)</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>K (mg)</td>
<td>12</td>
<td>340</td>
</tr>
</tbody>
</table>

Testing protocol. All measurements were made in a quiet, stringently air-controlled room (temperature of 22 ± 0.5°C and humidity of about 50%). Each measurement involved a pair of subjects who consumed kaki or its counterpart to reduce the influence of day-to-day temperature difference and fluctuation during each measurement. In consideration of the circadian rhythm, measurements were taken at around 16:00 each day, the subjects abstaining from food, drink and exercise for the previous 3 h. To remove the influence of inter-individual differences in the subject’s clothes on the body surface temperature, the subjects wore the same personal clothes during each measurement. Each subject rested in the sitting position for more than 30 min prior to commencement of the experiments. After consuming the relevant diet, the body surface temperatures and blood flow rate were measured at intervals of 3 min, and blood pressure at intervals of about 9 min for about 1 h. The recovery of the finger temperature was also evaluated in Exp. 3. 20 min after starting to consume the diet, the subject soaked her forefinger in ice-cooled water for 20 min.\(^5\) The ice-cooled water was continually stirred to maintain the water temperature at 0°C. A thermoprobe was fixed on the forefinger tip by winding surgical tape around the forefinger three times. In order to identify extraneous influences and to improve data reliability, each subject answered a questionnaire about her current physical condition at every sitting. If a subject appeared to be in poor health, or had consumed a caffeiinated beverage before measurement, the data were not used for subsequent analyses.
Statistics. The time versus treatment effect was evaluated by repeated ANOVA. Comparisons between kaki and its counterpart of the mean temperature changes over 1 h after ingestion were evaluated by a two-tailed, unpaired t-test. Statistical values were calculated with the StatView software package (Macintosh Version J-4.5, Abacus Concepts, Berkeley, CA, USA), a rejection level of \( P<0.05 \) being used as the criterion for statistical significance.

Results

Surface temperature

At the peripheral parts of the body (wrist and foot), the surface temperature tended to fall after ingestion, regardless of the diet consumed, under the ambient temperature employed (22°C). However, the degree of fall was greater after a subject had consumed kaki. Results from the time-course experiment recording the foot surface temperature after consuming kaki or water (Exp. 1), and freeze-dried kaki or the cookie counterpart (Exp. 2) are shown in Fig. 1. In both cases, the time versus treatment effect was statistically observed (\( P<0.0001 \) in Exp. 1 and \( P<0.001 \) in Exp. 2 by ANOVA).

To see how effective kaki was on each part of the body, a comparison was made of the mean temperature changes over 1 h after the subject had consumed kaki with those after the subject had consumed the counterpart. The effect of ingestion was also evaluated by using the mean area under the temperature curve divided by the unit of time as shown in Fig. 2. In comparison with either water or the cookie, kaki was shown to keep the body surface temperature lower (to repress the temperature rise or to enhance the temperature fall). This was especially the case in peripheral parts of the body like the wrist (\( P<0.1 \) in Exp. 1 and \( P<0.05 \) in Exp. 2 by the unpaired \( t \)-test) and foot (\( P<0.005 \) in Exp. 1 and \( P<0.05 \) in Exp. 2). The change in temperature after kaki consumption at other surface parts like the forehead and neck

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Fig. 1. Time-course Change in the Foot Surface Temperature after Consuming Kaki or Water (Exp. 1) and after Consuming Freeze-dried Kaki or Cookie (Exp. 2).
Each value is expressed in terms of the difference from the mean temperature before consumption as the mean ± SEM. Time versus treatment effect, \( P<0.0001 \) in Exp. 1 and \( P<0.001 \) in Exp. 2.

Fig. 2. Change in the Body Surface Temperature after Consuming Kaki, Water, Freeze-dried Kaki or Cookie.
Each value is the mean difference over 1 h after consuming kaki, water or cookie from that before consumption expressed as the mean ± SEM, ** \( P<0.005 \), * \( P<0.05 \), (*) \( P<0.1 \).
showed no significant difference from the counterpart (water or cookie). The armpit or tympanic temperature measured as an index of the body core temperature also showed no significant difference between kaki and counterpart consumption.

**Blood pressure and blood flow-rate**

In Exp. 2, the mean rise in the diastolic blood pressure (DBP) after freeze-dried kaki consumption was greater than that after cookie consumption (Fig. 3(A), mean blood pressure change divided by the unit of time; \( P < 0.1 \) by the unpaired \( t \)-test). No difference was apparent when the effect of kaki was compared with that of water ingestion (Exp. 1). No difference was apparent either in the systolic blood pressure (SBP) in both experiments.

In respect of the blood flow on the back of the hand (Exp. 1), the decrease was greater after the subject had ingested kaki than after the subject had consumed water (\( P < 0.1 \), data not shown). The blood flow measured at the wrist (Exp. 2) after freeze-dried kaki consumption was also lower than that after counterpart cookie consumption (Fig. 3(B), \( P < 0.05 \)).

**Cold-exposure test**

In Exp. 3, the temperature of the forefinger fell to nearly 0°C, and a hunting reaction, which shows that the subject’s sympathetic nerve (cutaneous vasomotor nerve) is normal, was observed 15–20 min after finger immersion. The temperature subsequently rose to around 10°C when in the ice-cooled water, and then rapidly returned to nearly normal body temperature when the finger was removed from the ice-cooled water (Fig. 4). Recovery of the forefinger temperature was delayed after freeze-dried kaki consumption compared with cookie consumption in a comparison between the mean of the three time-points before soaking the finger and the three time-points 10 min after removing the finger from the ice-cooled water (30 min after soaking; time versus treatment effect; \( P < 0.05 \) by ANOVA).

**Discussion**

The amount of kaki ingested and the kind of counterpart were selected for a number of reasons. If the body temperature is influenced by the ingestion of some foods, then a range of factors may vary the effect. Possible examples of these factors are the amount of the food ingested, the nutritional ingredients, the water content and physical state of the food (toughness, viscosity, density, etc.), the place and season of the harvest and the taste of the subject.

In the present study, the effect of kaki consumption was studied. To allow a meaningful comparison, the kaki consumed in Exp. 1 was matched with an equivalent volume of water (counterpart) as described in the Subjects and Methods section. This use of water as counterpart provides a simple basis for subsequent experiments with other foods. However, the influence of the nutritional composition, and particularly the energy content, cannot be ignored because the level of thermogenesis differs according on the amount of carbohydrate, protein and fat ingested. At the second stage, the experimental method used a counterpart that matched the amount of carbohydrate, protein and fat with the food being tested. In Exp. 2 and 3, a nutritionally equivalent cookie
was used as the counterpart for kaki. The present study did not use the blind method simply because we could not find a way to apply it and also because we thought that the subjects and the observers could not guess and expect the results.

It is possible to infer from the results shown in Figs. 2 and 4 that kaki contains a principle that repressed the rise or enhanced the fall in human body surface temperature, especially in the peripheral parts of the body. Exp. 2 was repeated several times with similar results, in that the skin temperature at the wrist and foot after a subject had consumed kaki became lower than that after cookie consumption.

The environmental or ambient temperature can also influence the body surface temperature. It is known that vasoconstriction and vasodilation of the skin blood vessels regulate body heat radiation when the environmental temperature is neutral, as was the case for these experiments. Therefore, the rise and fall in the skin temperature regulated heat radiation from the subjects in these experiments. The resistance of the peripheral arterial blood vessels mainly decides the DBP. Although the increase in DBP after a subject had consumed kaki was not significant in comparison to the counterpart consumption in the present experiments (Fig. 3(A)), the fall in skin temperature and peripheral blood flow observed in this case could be thought to have been the result of vasoconstriction. The reason why the significant difference in the skin temperature and peripheral blood flow rate was not reflected by DBP remains unclear. The former measurements may have been more sensitive than the latter.

The result that kaki consumption reduced the peripheral blood flow or increased the blood pressure is not consistent with past reports. There are some reports on the effect of kaki on the blood pressure. Kaki juice or leaves have been found effective against hypertension.7,8) The tannins contained in kaki are composed of such principles as (-)-epicatechin9) which inhibits the angiotensin-converting enzyme.10) Although it is not kaki tannin, it has been reported that tea catechin had a depresor effect on both SBP and DBP in humans after long-term administration.11) Most reports on tannin mention its depressor effects, but there is one report describing the opposite effects. Although it is not clear whether this kind of tannin is contained in kaki, intravenous acetylglyceraniin, a hydrolyzable tannin contained in Euphoria longaga Lam. (Sapindaceae), elevated the plasma noradrenaline and mean blood pressure in spontaneously hypertensive rats.12) Potassium, which is contained in kaki in abundance as shown in Table 2, also had a modest blood pressure-lowering effect in normotensive persons with a low dietary intake.13)

The results of this experiment are interpreted differently from those of the past, and the subsequent discussion is based on the supposition that the decrease in blood flow observed in this present study was due to blood vessel contraction. The vasoconstriction caused by the ingestion of kaki may have been a thermoregulatory response, so it is possible to infer that some principle contained in kaki influenced the thermoregulatory system in some manner, perhaps via a signal that influenced the surface or core thermoreceptors. However, the fact that the body core temperature (armpit or tympanic temperature) was scarcely affected by kaki intake seems to negate this possibility.

It seems more likely that vasoconstriction and the subsequent decrease in blood flow did not occur via the thermoregulatory system. The delayed temperature change (Fig. 4, 20 min) observed in the forefinger might have occurred via this mechanism as it approximates the time required for kaki to be digested. In this case, the effective principle contained in kaki might have acted directly as a vasoconstrictor on the vascular smooth muscle after its absorption into the blood. Neutral endopeptidase is one kind of endopeptidase which degrades angiotensin II, etc., and by inhibiting this enzyme, vasoconstriction occurs.14) Many other compounds are known to be concerned with regulating the blood pressure,15) although the relationship with the present results is unclear. Serotonin, angiotensin II and vasopressin are known vasoconstrictors, and these three substances are also known to depress the body temperature.16) Although opposite to those three substances in its effect on the body temperature, it is hypothesized that a substance contained in kaki has both the effect of raising the body temperature and of vasoconstriction. Kaki has traditionally been considered to have the effect of cooling the human body. However, the human body somehow maintained its core temperature (the armpit and tympanic temperature did not change as shown in Fig. 2) even after kaki consumption, and repressed heat radiation from the skin. The subjective result is that the subject feels as if the body has been cooled by kaki consumption. This effect of kaki to repress heat radiation implies raising the body temperature. We could not find evidence or clarify the mechanism by which DBP was increased after kaki consumption, so the possibility that the metabolic rate and/or autonomic nervous system may affect blood flow via cardiovascular control still remains.

The results of the present study quantitatively demonstrate that ingesting kaki had the effect of keeping the peripheral human body surface temperature low. The ingestion of certain foods can produce physiological effects and can therefore be used to assist the maintenance of health.
References

6) Lewis, T., Observations upon the reactions of the vessels of the human skin to cold. Heart, 15, 177–208 (1930).