

# Cocoa Flavanol Supplementation Influences Skin Conditions of Photo-Aged Women: A 24-Week Double-Blind, Randomized, Controlled Trial<sup>1–3</sup>

Hyun-Sun Yoon,<sup>4–6</sup> Jong Rhan Kim,<sup>7,9</sup> Gyeong Yul Park,<sup>5</sup> Jong-Eun Kim,<sup>7,9</sup> Dong Hun Lee,<sup>5,6</sup> Ki Won Lee,<sup>7–9</sup> and Jin Ho Chung<sup>5,6,8\*</sup>

<sup>4</sup>Department of Dermatology, Seoul National University Boramae Hospital, Seoul, Korea; <sup>5</sup>Department of Dermatology, Seoul National University College of Medicine, Seoul, Korea; <sup>6</sup>Institute of Human-Environment Interface Biology, <sup>7</sup>Center for Food and Bioconvergence, Department of Agricultural Biotechnology, and <sup>8</sup>Institute on Aging, Seoul National University, Seoul, Korea; and <sup>9</sup>Advanced Institutes of Convergence Technology, Seoul National University, Suwon, Korea

## Abstract

**Background:** The consumption of dietary antioxidants is considered to be a good strategy against photo-aging. However, the results of previous clinical trials that investigated the effects of oral consumption of high-flavanol cocoa products on skin photo-aging have been contradictory.

**Objective:** The aim of this study was to investigate whether high-flavanol cocoa supplementation would improve the moderately photo-aged facial skin of female participants, by assessing skin wrinkles and elasticity.

**Methods:** We performed a 24-wk, randomized, double-blind, placebo-controlled study to evaluate the effects of oral supplementation of cocoa flavanols on cutaneous photo-aging. All participants were moderately photo-aged Korean women with visible facial wrinkles (age range: 43–86 y). Participants were randomly assigned to receive a placebo beverage or cocoa beverage that contained 320 mg total cocoa flavanols/d. We measured wrinkles, skin elasticity, and hydration at baseline and at 12 and 24 wk. The primary endpoint was the mean percentage change in the average roughness value (Rz) at 24 wk.

**Results:** At 24 wk, the mean percentage change in Rz (primary endpoint) was significantly lower in the cocoa group than in the placebo group (–8.7 percentage points; 95% CI: –16.1, –1.3 percentage points;  $P = 0.023$ ). The mean percentage changes in gross elasticity, as determined by a cutometer, also differed between the groups at 12 wk (9.1 percentage points; 95% CI: 1.5, 16.7 percentage points;  $P = 0.020$ ) and 24 wk (8.6 percentage points; 95% CI: 1.0, 16.2 percentage points;  $P = 0.027$ ). However, there were no significant differences in skin hydration and barrier integrity between the 2 groups.

**Conclusions:** In moderately photo-aged women, regular cocoa flavanol consumption had positive effects on facial wrinkles and elasticity. Cocoa flavanol supplementation may contribute to the prevention of the progression of photo-aging. This trial was registered at [clinicaltrials.gov](http://clinicaltrials.gov) as NCT02060097. *J Nutr* 2016;146:46–50.

**Keywords:** cocoa, flavanol, photo-aging, skin, wrinkle

## Introduction

Cocoa products such as dark chocolate and cocoa beverages are known to have many health benefits. They have favorable effects on blood pressure (1, 2), insulin resistance (3), blood lipids (4), obesity (5), and cognitive performance (3, 6).

Cocoa products are derived from the dried and fermented fatty seeds from the cocoa tree, *Theobroma cacao* (7). Cocoa products

contain a number of polyphenolic antioxidants, more than most foods, and are particularly rich in flavonoids—specifically the flavanols. The main flavanols in cocoa products are epicatechin, catechin, and procyanidins (7).

An in vitro study showed that epicatechin, a monomeric flavanol, protected skin fibroblasts from UV-induced oxidative damage (8); and an in vivo study in humans found that 12 wk of oral cocoa flavanol consumption resulted in a >2-fold increase in the minimal erythema dose (MED)<sup>10</sup> of UV-B from baseline (9). Therefore, another possible health benefit from cocoa products and

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<sup>3</sup> Supplemental Figures 1 and 2 are available from the “Online Supporting Material” link in the online posting of the article and from the same link in the online table of contents at <http://jn.nutrition.org>.

\* To whom correspondence should be addressed. E-mail: [jhchung@snu.ac.kr](mailto:jhchung@snu.ac.kr).

<sup>10</sup> Abbreviations used: MED, minimal erythema dose; R2, gross elasticity; R5, net elasticity; R7, biological elasticity; Ra, arithmetic average roughness; Rm, maximum roughness; Rp, smoothness depth; Rt, skin roughness; Rz, average roughness.

cocoa flavanols is thought to be the protection of skin from UV radiation (7).

However, clinical trials that have investigated the effects of consuming high-flavanol cocoa products on skin photo-aging have shown conflicting results. The first trial, to our knowledge, to investigate the anti-photo-aging effects of the regular consumption of high-flavanol cocoa beverages showed significant improvements in skin hydration, transepidermal water loss, and skin thickness (10). However, a recent randomized controlled trial failed to show any protective effect of high-flavanol chocolate on UV sensitivity measured by MED and skin hydration (11).

All previous clinical studies were conducted for 12 wk (9–11). However, finding an adequate daily dose and duration of cocoa flavanol supplementation that might provide significant antioxidant photoprotection is important (12). Furthermore, improvement in skin wrinkles might require a much longer period of supplementation than 12 wk (13). Therefore, we conducted a 24-wk randomized controlled trial to investigate whether high-flavanol cocoa supplementation would improve the moderately photo-aged facial skin of female participants, by assessing skin wrinkles and elasticity.

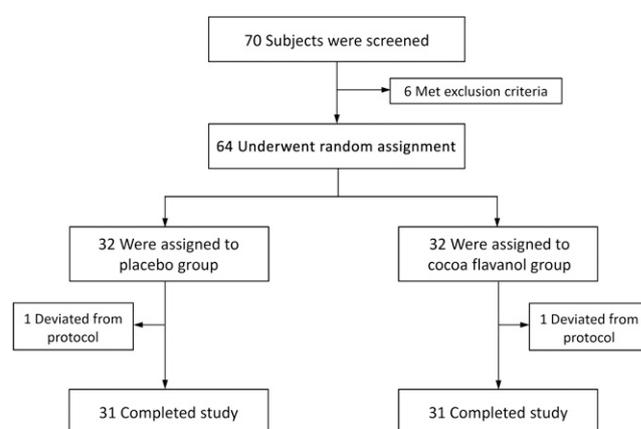
## Methods

**Study participants.** Healthy female volunteers aged  $\geq 40$  y with visible wrinkles  $\geq$  grade 2 (14) were enrolled in the study. The exclusion criteria were as follows: 1) reported consuming functional foods high in antioxidants within 1 mo of the study, 2) underwent any antiaging procedure that interferes with the general aging process within 3 mo of the study, 3) had a history of acute or chronic illness such as severe liver or kidney disease or uncontrolled diabetes, 4) had a history of allergies against any component of the trial food, or 5) had any visible skin disease that might be confused with a skin reaction to the materials used or interfere with clinical measurements.

**Study design.** We conducted a 24-wk, randomized, double-blind, placebo-controlled study to evaluate the effects of cocoa flavanol supplementation on cutaneous photo-aging between February 2014 and March 2015. This study was approved by the Institutional Review Board of Seoul National University Hospital, and written informed consent was obtained from all trial participants. The majority of participants (90.6%, 58 of 64) were enrolled from June to September and completed the study from December to February. This study was registered at clinicaltrials.gov (NCT02060097).

**Dietary supplement.** A randomization table was computer-generated by a statistician who was not involved in the study. A permuted block randomization design using a block size 4 in a 1:1 ratio was used to generate the random allocation sequence. The study participants were randomly assigned to either the cocoa group or the placebo group (Figure 1). The cocoa group daily ingested a cocoa beverage that contained fat-reduced cocoa powder that had been produced using gentle methods that preserved the naturally high amounts of cacao bean flavanols (Barry Callebaut Belgium N.V.). The beverage contained 4 g cocoa powder to yield 320 mg total cocoa flavanols and was consumed every day for 24 wk. The placebo group ingested a nutrient-matched cocoa-flavored beverage without cocoa flavanols for the same time period. Both beverages were provided in the form of dry powder and were dissolved in 150–200 mL hot water before ingestion. Details on the composition of the beverages used in the study are given in Table 1.

**Noninvasive assessment of skin features.** Facial wrinkles were measured in the crow's feet area with the use of transparency profilometry (Skin-Visiometer SV 600; Courage + Khazaka Electronic) and silicone replicas of skin. The visiometer is a computerized instrument that uses the transmission of light to produce a microrelief of skin from a blue-colored replica. It determined 5 roughness variables: skin roughness (Rt), maximum



**FIGURE 1** Screening, randomization, treatment, and follow-up of the study population.

roughness (Rm), average roughness (Rz), smoothness depth (Rp), and arithmetic average roughness (Ra). Visiometer R values decrease as the wrinkles diminish in depth (improve) (15).

Skin elasticity on the cheek at a point 3 cm below the outer corner of the eye was measured by using a Cutometer MPA580 (Courage + Khazaka Electronic). The measuring principle of the cutometer is based on the suction method. In particular, the following variables assessed by the cutometer are known to be important indicators of skin elasticity: gross elasticity (R2), net elasticity (R5), and biological elasticity (R7) (16)—the closer each value is to 1, the more elastic the skin. Hydration of facial skin was evaluated on the cheek at a point 5 cm below the outer corner of the eye by a corneometer and a tewameter (both, Courage + Khazaka Electronic).

The facial skin of each participant was evaluated at baseline, 12 wk, and 24 wk. Before measurements, all participants rested for 30 min in a temperature- and humidity-controlled room (temperature: 20–22°C; humidity: 45–55%) to become acclimatized to the ambient environment at the Clinical Research Institute, Seoul National University Hospital.

**UV irradiation and MED.** The MEDs for participants who agreed to undergo UV-B irradiation ( $n = 10$ /group) were assessed at baseline and after 24 wk of supplementation. A UV-irradiation device that used TL20W/12RS UV lamps (Philips) with an emission spectrum between 275 and 380 nm (peak: 310–315 nm) served as the UV source. A Kodacel filter (TA401/407; Eastman Kodak) was mounted 2 cm in front of the UV lamp to remove wavelengths of  $<290$  nm (UV-C) (17).

Twelve  $1 \times 1$ -cm squares of skin on the buttock were irradiated in  $10\text{-mJ/cm}^2$  increments of UV doses, and the MED was determined 24 h later. The MED was defined as the minimal UV dose that caused recognizable erythema on all 4 edges of the square (18).

**Safety and adherence.** Adverse events related to the supplements and the clinical protocol were evaluated at 12 and 24 wk of treatment. Blood samples were drawn at baseline and 24 wk after the start of supplementation; and aspartate aminotransferase, alanine transaminase, glucose, blood urea nitrogen, creatinine (autoanalyzer, 200FR-1; Toshiba), and hemoglobin concentrations and hematocrits (autoanalyzer,

**TABLE 1** Composition of cocoa powder used for the test

Component	Placebo, unit/12 g	Cocoa, unit/12 g
Energy, kcal	30.8	31.7
Total fat, g	0.0	0.3
Sodium, mg	29.1	17.2
Total carbohydrates, g	9.8	8.9
Sugar, g	4.0	5.1
Protein, g	1.3	1.9
Cholesterol, mg	0.8	1.2
Total cocoa flavanols, mg	0.0	320.0

Sysmex XN Series; Sysmex) were measured. Body weight was measured at baseline and at 24 wk. Adherence to the intervention was monitored by counting the remaining supplement packages at 12 and 24 wk.

**Statistical analysis.** Because Rz is less affected by artifacts than the other visiometer variables, it is considered to be the most useful variable for describing the depth of skin wrinkles (15). Therefore, our primary endpoint was percentage change in skin wrinkle depth from baseline, as reflected by the visiometer Rz value at 24 wk.

The sample size required for a power of 80% at a 2-tailed  $\alpha$  level of 0.05 was determined by assuming a difference in the primary endpoint (percentage change in Rz) between the 2 study groups of 11% and an estimated SD of 15%. On the basis of a drop-out rate of 8%, we calculated a sample size of 32 per group.

In addition, the following were analyzed as secondary endpoints: 1) the percentage change from baseline in Rt-Ra visiometer values at 12 wk (wrinkle depth); 2) the percentage change from baseline in Rt, Rm, Rp, and Ra by visiometer values at 24 wk (wrinkle depth); 3) the percentage change from baseline in R2, R5, and R7 cutometer values at 12 and 24 wk (skin elasticity); 4) the percentage change from baseline in epidermal hydration measured by the corneometer and tewameter at 12 and 24 wk; and 5) the change in MED from baseline at 24 wk.

An independent *t* test was used to compare the baseline values and the percentage changes in values from baseline between the 2 study groups. The Mann-Whitney *U* test was used to identify differences in change from baseline in MED at 24 wk between the 2 study groups, and Wilcoxon's Signed Rank test was used to compare 24-wk MED values with respective baseline MED values. SPSS version 20.0 was used for analysis. A *P* value <0.05 was considered significant. Values in text are means  $\pm$  SDs unless otherwise indicated.

## Results

**Study population.** This study enrolled 64 Korean women between the ages of 43 and 86 y ( $61.7 \pm 13.1$  y) who had visible facial wrinkles. There were no significant differences between the study groups in the baseline characteristics (Table 2).

**Wrinkle severity as measured by visiometer.** At 12 wk, there was no significant difference between the 2 study groups in any of the visiometer variables (Table 3). However, at 24 wk (Table 4), the mean percentage changes in Rz (primary outcome)

**TABLE 2** Demographic characteristics and baseline values of key variables related to skin aging in moderately photo-aged women<sup>1</sup>

	Placebo (n = 31)	Cocoa (n = 31)
Age, y	60.0 $\pm$ 12.6	63.3 $\pm$ 13.9
Weight, kg	57.3 $\pm$ 7.9	58.2 $\pm$ 7.0
Wrinkles		
Rt	1.07 $\pm$ 0.15	1.17 $\pm$ 0.41
Rm	0.83 $\pm$ 0.15	0.96 $\pm$ 0.35
Rz	0.47 $\pm$ 0.11	0.53 $\pm$ 0.14
Rp	0.33 $\pm$ 0.10	0.33 $\pm$ 0.09
Ra	0.17 $\pm$ 0.06	0.17 $\pm$ 0.07
Elasticity		
R2	0.60 $\pm$ 0.08	0.58 $\pm$ 0.08
R5	0.58 $\pm$ 0.12	0.53 $\pm$ 0.11
R7	0.32 $\pm$ 0.05	0.31 $\pm$ 0.06
Hydration		
Epidermal hydration	52.4 $\pm$ 9.6	53.4 $\pm$ 10.2
TEWL, g/(h $\cdot$ m <sup>2</sup> )	14.2 $\pm$ 4.1	13.8 $\pm$ 4.1

<sup>1</sup> Values are means  $\pm$  SDs. R2, gross elasticity; R5, net elasticity; R7, biological elasticity; Ra, arithmetic average roughness; Rm, maximum roughness; Rp, smoothness depth; Rt, skin roughness; Rz, average roughness; TEWL, transepidermal water loss.

values were significantly lower in the cocoa group than in the placebo group (*P* = 0.023). Similarly, the mean percentage changes in Rm values were also significantly lower in the cocoa group than in the placebo group (*P* = 0.030). Because visiometer values decrease as wrinkles diminish, these results suggest that the cocoa group showed improvement in wrinkle severity compared with the placebo group. However, the mean percentage changes in the other visiometer variables (Rt, *P* = 0.10; Rp, *P* = 0.07; Ra, *P* = 0.24) were not significant at 24 wk (Table 4, Supplemental Figure 1).

**Skin elasticity as measured by cutometer.** The mean percentage change in R2 from baseline was significantly larger in the cocoa group than in the placebo group at 12 wk (*P* = 0.020). The mean percentage changes in R5 (*P* = 0.06) and R7 (*P* = 0.10) from baseline tended to be larger in the cocoa group compared with the placebo group at 12 wk, but the differences were not significant (Table 3, Supplemental Figure 2). At 24 wk, the mean percentage changes in R2 from baseline were still greater for the cocoa group than for the placebo group (*P* = 0.027). Mean percentage changes both in R5 (*P* = 0.027) and R7 (*P* = 0.032) from baseline were also significantly greater for the cocoa group than for the placebo group at 24 wk (Table 4, Supplemental Figure 2).

**Epidermal hydration assessed by corneometer and transepidermal water loss (barrier integrity) assessed by tewameter.** There were no significant differences in percentage changes in epidermal hydration variables from baseline between the 2 groups after either 12 or 24 wk of supplementation (Tables 3 and 4).

**Safety and adherence.** Supplementation was well tolerated, and no subjective adverse events were reported during the 24-wk trial period. Laboratory evaluations did not reveal any significant abnormality after 24 wk of treatment (data not shown).

Changes in body weight from baseline were minimal. The placebo group had gained  $1.5 \pm 2.7$  kg at 24 wk. In contrast, the

**TABLE 3** Percentage changes from baseline in wrinkle depth, elasticity, epidermal hydration, and TEWL after 12-wk consumption of cocoa flavanols or placebo in moderately photo-aged women<sup>1</sup>

	Percentage change from baseline		Difference in percentage change <sup>2</sup> (95% CI)
	Placebo (n = 31)	Cocoa (n = 31)	
Wrinkles			
Rt	4.5 $\pm$ 14.1	2.9 $\pm$ 8.4	-1.6 (-7.5, 4.4)
Rm	2.8 $\pm$ 18.8	0.44 $\pm$ 15.5	-2.3 (-11.1, 6.4)
Rz	5.2 $\pm$ 17.6	3.8 $\pm$ 20.6	-1.3 (-11.1, 8.4)
Rp	10.8 $\pm$ 29.8	9.5 $\pm$ 32.0	-1.3 (-17.0, 14.4)
Ra	0.37 $\pm$ 27.9	1.7 $\pm$ 32.9	1.3 (-14.2, 16.8)
Elasticity			
R2	-0.77 $\pm$ 12.5	8.3 $\pm$ 17.0	9.1 (1.5, 16.7)*
R5	-6.3 $\pm$ 21.5	3.7 $\pm$ 20.4	10.0 (-0.59, 20.7)
R7	-3.0 $\pm$ 19.3	5.3 $\pm$ 19.1	8.3 (-1.5, 18.0)
Hydration			
Epidermal hydration	3.2 $\pm$ 17.8	0.31 $\pm$ 22.2	-2.9 (-13.1, 7.3)
TEWL	5.1 $\pm$ 25.0	6.1 $\pm$ 28.0	1.0 (-12.5, 14.5)

<sup>1</sup> Values are means  $\pm$  SDs. All variables in this table were secondary endpoints. \*Percentage changes differed between groups, *P* < 0.05. R2, gross elasticity; R5, net elasticity; R7, biological elasticity; Ra, arithmetic average roughness; Rm, maximum roughness; Rp, smoothness depth; Rt, skin roughness; Rz, average roughness; TEWL, transepidermal water loss.

<sup>2</sup> Values were calculated by subtracting the values in the placebo group from the values in the cocoa group (Cocoa - Placebo).

**TABLE 4** Percentage changes from baseline in wrinkle depth, elasticity, epidermal hydration, and TEWL after 24-wk consumption of cocoa flavanols or placebo in moderately photo-aged women<sup>1</sup>

	Percentage change from baseline		Difference in percentage change <sup>2</sup> (95% CI)
	Placebo (n = 31)	Cocoa (n = 31)	
<b>Wrinkles</b>			
Rt	4.4 ± 13.2	0.24 ± 4.9	-4.2 (-9.3, 0.93)
Rm	1.6 ± 16.0	-6.4 ± 12.2	-8.0 (-15.3, -0.83)*
Rz (primary endpoint)	8.0 ± 12.6	-0.69 ± 16.3	-8.7 (-16.1, -1.3)*
Rp	18.0 ± 24.4	5.8 ± 26.9	-12.2 (-25.2, 0.86)
Ra	7.9 ± 31.8	-1.0 ± 27.2	-9.0 (-24.0, 6.1)
<b>Elasticity</b>			
R2	0.14 ± 13.1	8.7 ± 16.7	8.6 (1.0, 16.2)*
R5	-7.7 ± 16.9	2.9 ± 19.7	10.6 (1.3, 19.9)*
R7	-4.1 ± 13.5	5.9 ± 21.3	10.0 (0.92, 19.1)*
<b>Hydration</b>			
Epidermal hydration	-4.1 ± 21.7	-3.3 ± 26.5	0.85 (-11.5, 13.2)
TEWL	0.07 ± 30.4	-0.95 ± 22.5	-1.0 (-14.6, 12.6)

<sup>1</sup> Values are means ± SDs. \*Percentage changes differed between groups,  $P < 0.05$ . R2, gross elasticity; R5, net elasticity; R7, biological elasticity; Rt, skin roughness; Rm, maximum roughness; Rz, average roughness; Rp, smoothness depth; Ra, arithmetic average roughness; TEWL, transepidermal water loss.

<sup>2</sup> Values were calculated by subtracting the values in the placebo group from the values in the cocoa group (Cocoa - Placebo).

cocoa group had gained only  $0.04 \pm 2.3$  kg from baseline at 24 wk. The change in body weight from baseline was minimal but was greater in the cocoa group than in the placebo group after 24 wk ( $-1.5$  kg; 95% CI:  $-2.8, -0.23$  kg;  $P = 0.021$ ).

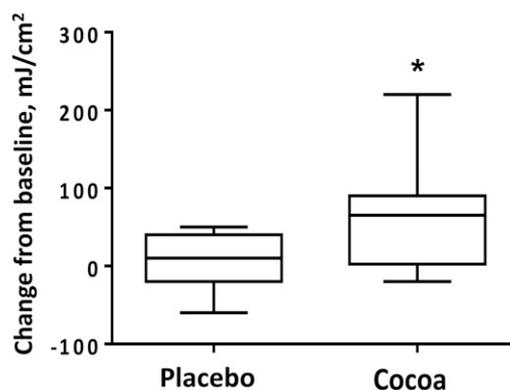
The overall adherence rates to the 2 assigned interventions were 97.6% at 12 wk and 98.4% at 24 wk. The adherence rates of the cocoa group were 98.6% at 12 wk and 99.0% at 24 wk. Similarly, the adherence rates of the placebo group were 96.6% at 12 wk and 97.8% at 24 wk. The adherence to supplementation was excellent in our study population.

**UV irradiation and MED.** The median baseline MED value for all of the study participants volunteering to undergo UV irradiation was  $160$  mJ/cm<sup>2</sup> (range:  $100$ – $310$  mJ/cm<sup>2</sup>;  $n = 19$ ). The MED of the placebo group did not change significantly during the 24 wk of the study period ( $P = 0.55$ ;  $n = 9$ ). In contrast, the cocoa group showed a significantly increased MED at 24 wk ( $P = 0.022$ ;  $n = 10$ ). The change in MED at 24 wk from baseline was  $50$  mJ/cm<sup>2</sup> higher in the cocoa group (median:  $65$  mJ/cm<sup>2</sup>; range:  $-20$  to  $220$  mJ/cm<sup>2</sup>) than in the placebo group (median:  $10$  mJ/cm<sup>2</sup>; range:  $-60$  to  $50$  mJ/cm<sup>2</sup>;  $P = 0.035$ ) (Figure 2). Participants consuming a daily flavanol-containing cocoa beverage for 24 wk showed a higher increase in MED from baseline than did participants consuming the placebo beverage.

## Discussion

We found that 24 wk of daily cocoa flavanol consumption improved the primary endpoint of Rz (wrinkle depth) in moderately photo-aged women. In addition, there were significant beneficial effects for secondary endpoints of skin elasticity and MED. However, we did not find beneficial effects of cocoa flavanol supplementation on skin hydration and barrier integrity.

The present study has a few advantages compared with previous trials that investigated the anti-photo-aging effects of cocoa

**FIGURE 2** Change in minimal UV-B erythema dose after 24-wk consumption of cocoa flavanols or placebo in moderately photo-aged women. Whiskers on box plots represent the minimum and maximum values,  $n = 9$ – $10$ . The Mann-Whitney  $U$  test was used to identify differences between the 2 study groups. \*Different from placebo,  $P < 0.05$ .

flavanols. To our knowledge, the 24-wk trial period was the longest time period used by clinical trials evaluating the anti-photo-aging effects of cocoa flavanols. All of the previous trial periods lasted 12 wk (9–11). In addition, we enrolled only moderately photo-aged participants, who already manifested visible wrinkles on their faces. Although the present study showed that cocoa flavanols can improve facial wrinkles and elasticity assessed by noninvasive objective measurements, the sizes of effects were smaller than other direct curative strategies such as topical tretinoin, laser resurfacing, and chemical peeling (19). Therefore, the main effect of cocoa flavanols on photo-aging might be preventive rather than curative. Previous trials, however, included young adults without visible wrinkles and decreased skin elasticity (9–11), so they were unable to show changes in aging-related phenotypes such as wrinkles.

The findings of changes in wrinkle severity and skin elasticity were consistent with those of previous trials (10, 11). In the present study, we found that wrinkle severity was unchanged at 12 wk but improved at 24 wk. These results are similar to those of an earlier study that reported that there was no change in wrinkle severity at 6 and 12 wk (10). In contrast, skin elasticity started to improve earlier than did skin wrinkles, and we found that skin elasticity was already improved at 12 wk. Another recent trial also showed that net skin elasticity improved after 12 wk of high-flavanol chocolate consumption (11).

However, there remain conflicting results on changes in MED after cocoa flavanol consumption. One study report showed that after 12 wk of high-flavanol (600 mg/d) chocolate consumption, the mean MED doubled (9); but another recent study did not find an increased MED (11). In the present study, we found that the median MED was  $50$  mJ/cm<sup>2</sup> higher in the cocoa flavanol group than in the placebo group. Our findings thus support the study findings that cocoa consumption can increase the UV-B MED in human skin.

Age, skin phototype, and race of participants varied in different trials and the conflicting results may reflect these differences. However, the treatment period may also be a factor as important as the daily dose of flavanols. Another phytochemical,  $\beta$ -carotene, showed a time-dependent protective effect against UV-induced sunburn of the skin (12). This time dependence may partially explain why we found an increased MED, even though the flavanol dose (320 mg/d) was relatively lower than the dose used in previous trials (600 mg/d) (9, 11).

Interestingly, we found a small but significantly greater weight reduction for the cocoa group than for the placebo group. Cocoa

products and cocoa flavanols have been known to have beneficial effects on obesity (5, 20). The participants' diet and physical activities were not controlled in our study, so our finding can only be interpreted as indirect evidence and was an unintended outcome.

The avoidance of excessive sun exposure and the regular use of sunscreen are the most well-known preventive strategies against photo-aging. However, sunscreen or protective clothing can sometimes be used incorrectly, and there are some occasions when those methods are not practical (21).

The dietary consumption of antioxidants as well as the application of topical antioxidants can increase the amount of antioxidant in the skin. Increased amounts of antioxidant in the skin can protect skin from UV-induced damage (22). Therefore, the consumption of dietary antioxidants has been considered to be a good strategy against photo-aging (23). Most antioxidants are derived from plants because oxidation protection is necessary in the UV-rich outdoor environment. Flavanoids are representative plant antioxidants, and important sources of flavonoids other than vegetables and fruit are cocoa, tea, and red wine (24).

This study had some limitations. First, we recruited only female participants; whether cocoa flavanols also protect against the photo-aging process in men remains uncertain. Second, 24 wk may be too long a period for assessing the effects of flavanols on skin hydration and barrier integrity. Korea has 4 distinct seasons and the majority of the participants completed the study in winter, with unfavorable conditions for hydration and barrier integrity. Furthermore, epidermal hydration and transepidermal water loss were secondary endpoints in the present study. Therefore, this study could not conclusively ascertain the effects of flavanols on skin hydration and barrier integrity.

In addition, previous clinical trials have provided conflicting results for the effects of consuming cocoa flavanols on skin hydration (10, 11). Even though the first trial to our knowledge to investigate the anti-photo-aging effects of the consumption of high-flavanol cocoa products reported the beneficial effects of cocoa flavanols on skin hydration and barrier integrity (10), the recent trial did not reproduce the results (11). Further investigation is needed to confirm whether flavanols have beneficial effects on skin hydration and barrier integrity. These future studies should have a shorter trial period and be completed within one season.

Despite the limitations, the present study showed that 24 wk of daily consumption of cocoa flavanols improved skin wrinkles and elasticity in human skin. Skin elasticity began to improve after 12 wk of supplementation, and the effect was maintained while supplementation continued, for a total of 24 wk. In conclusion, regular cocoa flavanol consumption may be a good strategy for prevention of the progression of skin photo-aging.

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H-SY, JRK, and JHC designed the research; GYP and DHL conducted the research; J-EK and KWL provided essential materials; H-SY analyzed the data; H-SY and JHC wrote the manuscript; JHC had primary responsibility for final content. All authors read and approved the final manuscript.

### References

- Hooper L, Kay C, Abdelhamid A, Kroon PA, Cohn JS, Rimm EB, Cassidy A. Effects of chocolate, cocoa, and flavan-3-ols on cardiovascular health: a systematic review and meta-analysis of randomized trials. *Am J Clin Nutr* 2012;95:740–51.
- Desch S, Schmidt J, Kobler D, Sonnabend M, Eitel I, Sareban M, Rahimi K, Schuler G, Thiele H. Effect of cocoa products on blood pressure: systematic review and meta-analysis. *Am J Hypertens* 2010;23:97–103.
- Desideri G, Kwik-Urbe C, Grassi D, Necozione S, Ghiadoni L, Mastroiacovo D, Raffaele A, Ferri L, Bocale R, Lechiara MC, et al. Benefits in cognitive function, blood pressure, and insulin resistance through cocoa flavanol consumption in elderly subjects with mild cognitive impairment: the Cocoa, Cognition, and Aging (CoCoA) Study. *Hypertension* 2012;60:794–801.
- Tokede OA, Gaziano JM, Djousse L. Effects of cocoa products/dark chocolate on serum lipids: a meta-analysis. *Eur J Clin Nutr* 2011;65:879–86.
- Farhat G, Drummond S, Fyfe L, Al-Dujaili EA. Dark chocolate: an obesity paradox or a culprit for weight gain? *Phytother Res* 2014;28:791–7.
- Field DT, Williams CM, Butler LT. Consumption of cocoa flavanols results in an acute improvement in visual and cognitive functions. *Physiol Behav* 2011;103:255–60.
- Katz DL, Doughty K, Ali A. Cocoa and chocolate in human health and disease. *Antioxid Redox Signal* 2011;15:2779–811.
- Basu-Modak S, Gordon MJ, Dobson LH, Spencer JP, Rice-Evans C, Tyrrell RM. Epicatechin and its methylated metabolite attenuate UVA-induced oxidative damage to human skin fibroblasts. *Free Radic Biol Med* 2003;35:910–21.
- Williams S, Tamburic S, Lally C. Eating chocolate can significantly protect the skin from UV light. *J Cosmet Dermatol* 2009;8:169–73.
- Heinrich U, Neukam K, Tronnier H, Sies H, Stahl W. Long-term ingestion of high flavanol cocoa provides photoprotection against UV-induced erythema and improves skin condition in women. *J Nutr* 2006;136:1565–9.
- Mogollon JA, Boivin C, Lemieux S, Blanchet C, Claveau J, Dodin S. Chocolate flavanols and skin photoprotection: a parallel, double-blind, randomized clinical trial. *Nutr J* 2014;13:66.
- Köpcke W, Krutmann J. Protection from sunburn with beta-Carotene—a meta-analysis. *Photochem Photobiol* 2008;84:284–8.
- Baldwin HE, Nighland M, Kendall C, Mays DA, Grossman R, Newburger J. 40 Years of topical tretinoin use in review. *J Drugs Dermatol* 2013;12:638–42.
- Chung JH, Lee SH, Youn CS, Park BJ, Kim KH, Park KC, Cho KH, Eun HC. Cutaneous photodamage in Koreans: influence of sex, sun exposure, smoking, and skin color. *Arch Dermatol* 2001;137:1043–51.
- De Paepe K, Lagarde JM, Gall Y, Roseeuw D, Rogiers V. Microrelief of the skin using a light transmission method. *Arch Dermatol Res* 2000;292:500–10.
- Yoon HS, Cho HH, Cho S, Lee SR, Shin MH, Chung JH. Supplementing with dietary astaxanthin combined with collagen hydrolysate improves facial elasticity and decreases matrix metalloproteinase-1 and -12 expression: a comparative study with placebo. *J Med Food* 2014;17:810–6.
- Seo JY, Lee SH, Youn CS, Choi HR, Rhie GE, Cho KH, Kim KH, Park KC, Eun HC, Chung JH. Ultraviolet radiation increases tropoelastin mRNA expression in the epidermis of human skin in vivo. *J Invest Dermatol* 2001;116:915–9.
- Cho S, Lee DH, Won CH, Kim SM, Lee S, Lee MJ, Chung JH. Differential effects of low-dose and high-dose beta-carotene supplementation on the signs of photoaging and type I procollagen gene expression in human skin in vivo. *Dermatology* 2010;221:160–71.
- Rabe JH, Mamelak AJ, McElgunn PJ, Morison WL, Sauder DN. Photoaging: mechanisms and repair. *J Am Acad Dermatol* 2006;55:1–19.
- Min SY, Yang H, Seo SG, Shin SH, Chung MY, Kim J, Lee SJ, Lee HJ, Lee KW. Cocoa polyphenols suppress adipogenesis in vitro and obesity in vivo by targeting insulin receptor. *Int J Obes (Lond)* 2013;37:584–92.
- Mukhtar H. Eat plenty of green leafy vegetables for photoprotection: emerging evidence. *J Invest Dermatol* 2003;121:viii.
- Darvin ME, Fluhr JW, Schanzer S, Richter H, Patzelt A, Meinke MC, Zastrow L, Golz K, Doucet O, Sterry W, et al. Dermal carotenoid level and kinetics after topical and systemic administration of antioxidants: enrichment strategies in a controlled in vivo study. *J Dermatol Sci* 2011;64:53–8.
- Draeos ZD. Nutrition and enhancing youthful-appearing skin. *Clin Dermatol* 2010;28:400–8.
- Hammerstone JF, Lazarus SA, Schmitz HH. Procyanidin content and variation in some commonly consumed foods. *J Nutr* 2000;130 (Suppl):2086S–92S.