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An Apple Plus a Brazil Nut a Day Keeps the Doctors Away: Antioxidant Capacity of Foods and their Health Benefits

Carlos Kusano Bucalen Ferrari[1,3], Sandro Percário[2,4], José Carlos Costa Baptista Silva[2] and Elizabeth Aparecida Ferraz da Silva Torres[1*]

[1]Department of Nutrition, School of Public Health, University of São Paulo (USP); [2]Centers for Disease Control and Prevention (CDC), Atlanta, USA; [3]Latin American Institute of Life and Natural Sciences (ILACVN), Federal University of Latin American Integration (UNILA). [4]Oxidative Stress Research Laboratory, Institute of Biological Sciences (LAPEO/ICB), Federal University of Pará (UFPA)

Carlos K.B. Ferrari

Abstract: Antioxidant-rich foods scavenge free radicals and other reactive species, decreasing the risk of different non-communicable chronic diseases. The objective of this study was to review the content of total antioxidant capacity of commonly foods comparing with experimental data and to explore the health benefits due to foods with moderate to high TAC. The TAC was analytically measured using the "Total Antioxidant Capacity" (NX2332) test from Randox® (UK) by spectrometry at 600 nm. Brazil nut (*Bertholletia excelsa*), "guaraná" (*Paullinia cupana* Kunth) powder, ready to drink boiled coffee (*Coffea arabica* L.), and milk chocolate (made from seeds of *Theobroma cacao*) had the highest TAC values, followed by collard greens (*Brassica oleracea* L.), beets (*Beta vulgaris* L.), apples (*Malus domestica* Borkh.), bananas (*Musa paradisiaca*), common beans (*Phaseolus vulgaris*), oranges (*Citrus sinensis* (L.) Osbeck), onions (*Allium cepa* L.), and lettuce (*Lactuca sativa* L.). Other foods also showed antioxidant capacity. The binomial antioxidant capacity of foods and health was extensively discussed according to science literature. Based on the high TAC content of Brazil nuts, guaraná, coffee, chocolate, collard greens, apples, beets, beans, oranges, onions and other foods, their regular dietary intake is strongly recommended to reduce the risk of chronic non-communicable diseases.

Keywords: Antioxidant capacity, cardiovascular diseases, cerebrovascular diseases, cancer.

INTRODUCTION

It is strongly recognized that the Mediterranean diet is inversely associated with human mortality across Europe. Nutrition experts have suggested that food phytochemicals, especially antioxidants, could be a plausible explanation for the health benefits of the Mediterranean diet [1-6]. In this respect, the traditional Brazilian diet has been suggested to offer potent cardioprotective benefits similar to those of the Mediterranean diet [7].

Free radicals and other reactive oxygen, nitrogen, and chlorine species have been implicated in many pathologies such as chronic inflammation, cancer and cardiovascular, neurological, hepatic, and other diseases [8-11]. On the other hand, dietary intake of fruits, vegetables, legumes, seeds, and grains, which contain plenty of compounds with antioxidant properties (vitamins, minerals, phenols, and others), has been associated with a decreased risk for and mortality from chronic noncommunicable diseases among people living in the Mediterranean region as well as in many other world populations [12-23].

For this reason, new bioactive compounds have been isolated from foods and herbs, including tea, chocolate, wine as well as many other food and drinking products, and their antioxidant activities have been determined [1, 2, 5, 24-32]**.**

Regular dietary intake of chocolate and drinking of coffee have been associated with a lower risk of cardiovascular diseases, stroke, and metabolic syndrome [33-37].

Since the development of total antioxidant capacity tests [38, 39], many chronic noncommunicable diseases (including diabetes) have been correlated with biomarkers of increased oxidative stress and decreased total antioxidant capacity (TAC) [40-44].

*Address correspondence to this author at the Department of Nutrition, School of Public Health, University of São Paulo (USP);
E-mail: eatorres@usp.br

Dietary consumption of foods with moderate to high antioxidant activities has been associated with many different health benefits, decreasing pathological biomarkers and the risk of heart, brain and neoplastic diseases, improving endothelial function, systolic and diastolic blood pressure and body mass index, and reducing the risk of thrombosis and atherosclerosis [45-51]. Dietary intake of food with higher TAC has been found to be inversely associated with ischemic but not hemorrhagic stroke in an Italian cohort study [52].

The objective of the present study was to review and discuss the role of food antioxidant capacity for health promotion and disease prevention. In order to achieve the goals two methods were done: a bibliographic review using three databases (MEDLINE, LILACS, and Food Science and Technology Abstracts) and presentation of experimental data of TAC (using a trolox-equivalent antioxidant assay) from 20 common foods or drinks was assessed in order to determine which foods could have protective effects.

MATERIALS AND METHODS

Sample Preparation

Between 0.5 and 1.0 g of the food samples (Table **1**) were weighed with an analytical scale (Mettler-Toledo, mod. AB204-S) and each sample was diluted with 1.15% KCl to give a 1:10 (w/w) solution. Liquid samples (grape juice and ready-to-drink boiled coffee) were ready for centrifugation.

Solid samples were homogenized in an ultrasonicator (Thornston/Unique) at maximal potency until fibrous non-dissociated material was left. Most of the foods were submitted to this procedure for five minutes, with the exception of bananas, which required just two to three minutes.

After homogenization, the samples were centrifuged (CELM centrifuge) for 10 minutes at 2500 rpm to release the antioxidants from the solid phase into the liquid phase.

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Table 1. Total antioxidant capacity per 100 g or 100 mL (µmol TE/100 g or µmol TE/100 mL) and per food portion of 20 common foods.

Food	N	TAC (µmol TE/100 g or by 100 mL)	Food portion	TAC (µmol TE/ portion)
Apple	6	400.68 ± 67.88	139 g	556.95
Banana	5	312.71 ± 71.19	109 g	340.85
Brazil nuts	5	2536.24 ± 1481.27	28 g	710.15
Carrots	3	231.81 ± 10.22	65 g	150.67
Chocolate	5	1004.42 ± 175.19	41 g**	411.81
Coffee*	6	1025.84 ± 10.55	50 mL 200 mL	512.92 2051.67
Cooked beans	5	312.17 ± 55.64	78 g	243.49
Eggplant	6	200.77 ± 66.32	80 g	160.62
Grape juice*	6	146.19 ± 39.50	250 mL	365.48
Green collards	5	411.33 ± 171.16	48 g	197.44
Guaraná	3	1053.27 ± 19.22	_	_
Lemon	4	311.14 ± 56.98	_	_
Onion	5	284.93 ± 45.05	33 g	94.03
Orange	4	284.08 ± 56.02	123 g	349.42
Lettuce	4	239.16 ± 92.14	43 g	102.84
Papaya	3	221.99 ± 12.97	158 g	350.74
Pepper	3	151.91 ± 60.64	_	_
Red beet	4	404.65 ± 120.26	45 g	182.09
Tomato	3	235.48 ± 8.93	115 g	270.80
Watermelon	3	232.17 ± 2.56	190 g	441.12

*Cardoso MA, Kida AA, Tomita LY, Stocco PR. Reproducibility and validity of a food frequency questionnaire among women of Japanese ancestry living in Brazil. Nutr Res 2001; 21: 725-33.
**Dreosti (2000). ⁻ No food portion.
TE = Trolox-equivalent;

Evaluation of Total Antioxidant Capacity (TAC)

TAC was measured analytically using the Total Antioxidant Status test (TAS - NX2332) from Randox Laboratories Ltd (UK), originally described by Miller *et al.* [53]. The formation of the cation radical $ABTS^+$ (2,2'-azino-di-[3-ethylbenzthiazoline sulphonate]) with stable blue green color was measured by spectrophotometry. The presence of antioxidants in the food sample reduces color intensity in a manner proportional to the antioxidant concentration of the sample [38].

After sample preparation, a blank (20 µL of twice distilled water plus 1 mL of chromogen), the standard (20 µL of standard plus 1 mL of chromogen), and the food samples (20 µL of food sample plus 1 mL of chromogen) were prepared and absorbance was measured at 600 nm (CELM 225-D), at 37ºC. Next, 200 µl of substrate (hydrogen peroxide) was added to each tube (blank, standard and samples). The tubes were mixed simultaneously and the timer was triggered. After exactly three minutes, absorbance was measured at 600 nm (37ºC). TAC values were calculated as the difference between initial and final absorbance values multiplied by the concentration factor of the standard.

Trolox, a synthetic water-soluble vitamin E analogue, was used as a standard and the results are expressed as µmol of Trolox-equivalents (TE)/100 g (food) or µmol of TE/100 mL (drink).

The Bibliographic Survey

In order to find science articles regarding TAC in foods and health three databases were used (MEDLINE, LILACS, and Food Science and Technology Abstracts). The search words or phrases were: "total antioxidant capacity" and "name of food" (each of the 20 foods); "total antioxidant capacity" and "health"; "total antioxidant capacity" and "name of food" and "health".

RESULTS AND DISCUSSION

The TAC values of twenty foods are summarized in Table **1**. The normal TAC ranges have not been established for human fluids and tissues. However, in order to trigger a minimal effective antioxidant activity, it should be remembered that the TAC of human plasma ranges from 132 to 160 µmol TE/100 ml [38]. This suggests that all twenty foods evaluated in this study can exert antioxidant activities in the human body, although the highest values were found for Brazil nuts, Amazonian guaraná, ready-to-drink boiled coffee, dark chocolate, collard greens, red apples, and beets.

The mean TAC value of Brazil nuts obtained here (2,536 µmol TE/100 g) was lower than that of walnuts (20,970 µmol TE/100 g), whereas it was 5.17-, 8.45- and 11-fold higher than that of hazelnuts (490 µmol TE/100 g), almonds (300 µmol TE/100 g) and cashew nuts (230 µmol TE/100 g), respectively, evaluated in Norway [27].

To illustrate the therapeutic potential of antioxidant-rich vegetable extracts, it should be emphasized that the TAC of Brazil nuts obtained in the present study (2536 µmol TE/100 g) was 51% higher than the TAC of *Hypericum perforatum* (St. John's herb) (1677 µmol TE/100 g), used for the treatment of depression, 91% higher than the TAC of *Salvia officinalis* (1328 µmol TE/100 g), an anti-inflammatory herb, 92% higher than the TAC of *Ginkgo biloba* (1318 µmol TE/100 g), an antioxidant which improves brain circulation, and 13.49-fold higher than the TAC of *Aloe vera* (188 µmol TE/100 g), which is added to cosmetics for skin protection [28].

Another study showed that the dietary intake of Brazil nuts increased plasma selenium levels, improved antioxidant status, and reduced oxidized LDL levels in hypertensive dyslipidemic patients [54]. The dietary intake of Brazil nuts also enhanced plasma and erythrocyte selenium levels and improved the cognitive function of elderly adults [55]. Recent epidemiological studies have reported that regular dietary intake of nuts was associated with lower total mortality as well as lower respiratory, neurodegenerative, and cardiovascular mortality [56, 57]. Those studies confirmed the report of Hu *et al*. [16] who observed a lower risk of non-fatal myocardial infarction and a reduced risk of fatal coronary heart disease among women who regularly ate more than five nuts a week.

The Amazonian fruit guaraná has potent antioxidant capacity and no toxicological effect [58-60], and has been associated with health benefits such as enhanced cognitive performance, improved memory, as well as anxiolytic and antidepressant effects [61-64]. These cerebral effects may be due to the potent antioxidant capacity of the fruit as seen in the present study. In this respect, the potent antioxidant capacity of guaraná has been associated with DNA protection against free radicals and carcinogens, cytoprotection, and antineoplastic effects in many different carcinogenesis models [65-67]. Furthermore, regular dietary intake of guaraná produced higher physiological antioxidant capacity, which was associated with diminished levels of total cholesterol and c-LDL, and a lower prevalence of hypertension, obesity and metabolic syndrome [68]. Portella *et al*. [69] reported that guaraná inhibited LDL oxidation, an effect that could protect against atherosclerosis.

The third food with the highest TAC was coffee. The present study evaluated ready-to-drink boiled coffee prepared according to Latin American tradition, resulting in a higher TAC value (≈1026 µmol TE/100 mL). This result agrees with data from the antioxidant food database, which shows that boiled coffee at least 1240 µmol TE/100 mL [70]. A study with espresso coffee reported a TAC ranging from 1500 to 1770/100 mL [71]. Since espresso coffee is more concentrated, this difference in TAC is understandable. Nevertheless, regular coffee intake reduces the risk of metabolic syndrome and the prevalence of coronary atherosclerosis [35, 36]. A Japanese cohort study reported an inverse association between coffee drinking and prostate cancer risk [72]. A systematic review showed an inverse association between coffee drinking and stroke risk [73]. A meta-analysis of studies regarding coffee and cancer also pointed out an inverse association between coffee drinking and prostate cancer risk [74]. Both caffeinated and decaffeinated coffee consumption was associated with a slight but significant decrease of total mortality [75].

In the current study, the other foods with the highest TAC were chocolate, collard greens, and red beets. A higher TAC was observed here for milk chocolate (1004.42 µmol TE/100 g) sold in supermarkets. A United States study with commercially available chocolate found a TAC of 800 µmol TE/100 g [76]. In an Italian survey, dark and milk chocolates had TAC levels of 147.4 and 78.3 µmol Fe^{2+}/100 g, respectively [77]. In the same study, intake of dark chocolate, but not milk chocolate, enhanced the TAC of plasma of healthy volunteers. Another study with milk chocolate reported a mean TAC value of 6740 µmol TE/100 g [78]. According to the Antioxidant Food Database, a world compilation of the TAC of foods, the mean TAC value is 4930 µmol TE/100 g [70].

Due to its antioxidant activities, chocolate intake can protect LDL and DNA from oxidation as well as decrease the risk of cataract and atherosclerosis [79]. In fact, according to various studies [34, 80-82], dietary intake of cocoa and chocolate improves antioxidant capacity and endothelial function, preserves pancreatic beta cells, lowers systolic and diastolic blood pressure and triglycerides, and enhances cognitive function.

A study evaluating TAC reported that collard greens, tomatoes, potatoes, cauliflower, green cabbage, spinach, and lettuce had the highest antioxidant capacity values, followed by onions, cucumbers and carrots [83]. Another study corroborated the high TAC of collard greens that was influenced by different cooking methods [84]. Źitńanová *et al* [85] reported that red beets and onions had highest TAC values, whereas carrots had TAC values lower than 100 µmol TE/100 g. In the same study, the order of TAC was as follows: banana > apple > orange > lemon, and, lemon TAC levels (150 µmol TE/100 g) were half those found in the present study (311.14 µmol TE/100 g). Other studies reported that red beets had also considerable antioxidant capacity against free radicals and reactive species [86]. The intermediate TAC level of red beets is due to many polyphenols, especially betanin and betalain [87, 88].

The current TAC value for apples was 400.68 µmol TE/100 g, which was higher than those found in some other studies (159, 290, and 343 µmol TE/100 g) [2, 27, 89]. Although apples had lower TAC levels (400 µmol TE/100 g) compared to Brazil nuts (400 µmol TE/100 g), the chemopreventive properties of these fruits have been reported in the literature. Eberhardt *et al*. [90] demonstrated that apple extracts (50mg/mL), with or without skin, inhibited the proliferation of gut cancer cells by 43% and 29%, respectively, rates that reached 40% (apple without skin) to 57% (apple with skin) regarding suppression of proliferation of liver tumor cells. Apple intake can inhibit carcinogenesis via both antioxidant activity and cell cycle control [91]. Apple extracts had potent cellular antioxidant activities and protected DNA from oxidative damage [92, 93]. This could explain the material evidence for the relationship between apple intake and reduced risk of colon cancer [93].

Apple intake releases antioxidants which protect LDL cholesterol from oxidation, decrease lipid peroxidation and total blood cholesterol, protect the endothelium against free radicals, and reduce proliferation and enhance apoptosis of cancer cells [94, 95]. Another empirical approach to apple juice drinking also improved blood phenol levels and TAC of plasma in healthy volunteers [96].

Many studies have analyzed the TAC of foods worldwide. In decreasing order of TAC, the highest values were found for strawberries, followed by plums, oranges, red grapes, kiwi, pink grapefruit, white grapes, bananas, apples, tomatoes, pears, and honeydew melons [97]. According to Cao *et al*. [25], beets, onions and eggplants had intermediate TAC values, whereas potatoes, lettuce and carrots had lower TAC. In contrast, another study reported that potatoes, carrots, tomatoes and lettuce were the major foods providing effective intracellular scavenging of free radicals [98], diverging from other literature data.

In this study, lemons, cooked common beans and bananas had TAC levels of 311-312 µmol TE/100 g. Compared to data from other studies, lemons, crude beans (green or common beans), and bananas had the following TAC values, respectively [27, 45]: 1020 and 253.33 µmol TE/100 g (lemons), 200 and 1140 µmol TE/100 g (beans), and 200 µmol TE/100 g (bananas). Another study reported lower TAC values for bananas (64 to 181μmol TE/100 g) [1, 2, 89] compared to the present investigation.

After the initiation of lipid peroxidation, peroxyl radicals are formed. According to a Spanish study, bananas were the most effective scavengers of peroxyl radicals, whereas lemons had the highest capacity for removing hypochlorous acid ($HOCl^-$), which can damage proteins and lipids [5].

In the present study, onions and oranges had a TAC of 284 μmol TE/100 g. Cao *et al*. [25] and Halvorsen *et al*. [27], reported higher TAC values for onions (450 and 670 μmol TE/100 g) and oranges (750 and 1140 μmol TE/100 g). Another study reported mean TAC levels of 579 μmol TE/100 g, ranging from 349 to 696 μmol TE/100 g [100]. Different TAC values were also reported in other investigations. Orange TAC values ranged from 849 to 874 μmol TE/100 g and onion TAC values ranged from 182, to 532 and 580 μmol TE/100 g [1, 2, 89].

The TAC of carrots, tomatoes and watermelons observed here ranged from 232 to 235 μmol TE/100 g. Compared to the present study, others have reported lower TAC values for carrots (40 and 210 μmol TE/100 g) [25, 26, 27]. Halvorsen *et al*. [27] reported 40 μmol TE/100 g and 60 μmol TE/100 g for carrots and watermelons, respectively, which were only 17% and 25.5% of the values reported in the present study. The TAC of watermelons found in the current study is responsible in part for the health benefits of its consumption. Watermelon intake increased blood TAC and decreased inflammation and triglycerides, total cholesterol, and c-LDL [99].

Although Halvorsen *et al*. [27] found a mean TAC of 310 μmol TE/100 g for tomatoes, other authors reported lower or similar TAC values for tomatoes (160 to 255 μmol TE/100 g) [1, 2, 89]. Because of their richness in many carotenoids, especially lycopene, tomatoes have important antioxidant capacity and have been associated with DNA protection against damage, enhancement of blood pressure in hypertensive and diabetic patients, as well as with a reduced risk of carcinogenesis and prostate cancer [33, 100-102].

In the present study, lettuce showed a mean TAC of 239.16 μmol TE/100 g, which was lower than that reported by Halvorsen *et al*. [27] (340 μmol TE/100 g), but higher than that observed in other studies (133 to 171μmol TE/100 g) [1, 2, 89]. In an experimental rat model, regular intake of a diet with high amounts of lettuce (20%) strongly increased TAC values and improved cholesterol excretion in feces [103].

The TAC value observed here for eggplant (200.77 μmol TE/100 g) was higher than that reported in another study (170 μmol TE/100 g) [27].

Considered one the major health benefits of grape juices and wines, antioxidant capacity was first recognized 20 years ago [104-109]. The mean TAC of grape juice observed here (146.20 μmol TE/100 g) was lower than the values reported in other studies (212.2 and 271 μmol TE/100 g) [110, 111]. According to the type of lettuce and part of the leaf, TAC ranged from 40 to 563 μmol TE/100 g, with a mean of 100 to 330 μmol TE/100 g [112].

Since the classic studies by Cao *et al*. [45, 46], many other studies have observed that dietary intake of foods with high TAC increased plasma antioxidant capacity [43, 52, 54, 68, 97, 104, 113]. In addition, dietary intake of these foods also enhanced antioxidant defenses, helping to decrease cell, tissue or organ damage and consequently the risk of diseases.

It should be noted that TAC is associated with endocrine and metabolic disorders. In a study comparing healthy adults to patients with type 2 diabetes mellitus, the patients showed increased pro-oxidant markers and lower TAC levels [114]. As is well known, diabetic patients have an increased risk of cardiac events. A study demonstrated that coronary atherosclerosis was associated with lower levels of TAC in diabetic patients [42]. Another study confirmed that TAC was inversely associated with blood glucose, triglycerides, total cholesterol, and oxidized LDL, and was positively associated with c-HDL particles [115]. Higher body TAC levels were negatively correlated with both body weight and abdominal fat, and the risk of metabolic syndrome, obesity and hypertension [116]. The same study reported that dietary TAC higher than 1080 μmol TE/100 g was related to a 38% decrease in the risk of central obesity. In a clinical trial with two hypocaloric regimes there were inverse associations between TAC and body weight, body mass index, fat mass, and waist circumference [117].

TAC also appeared to be associated with a decreased risk of cancer. Ching *et al*. [41] revealed a 50% reduction in breast cancer risk among individuals with high plasma TAC compared to a group

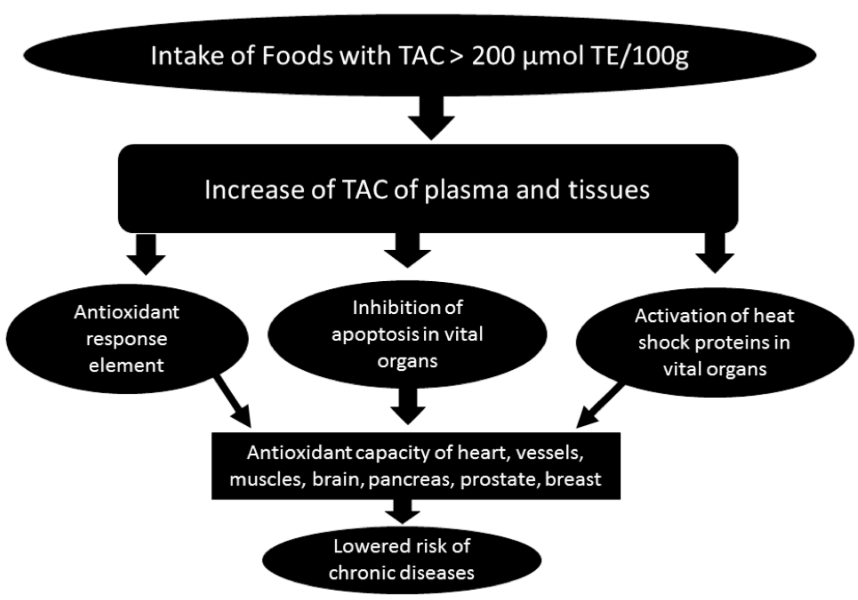

Fig. (1). Putative model of the role of TAC on chronic diseases risk.

with lower TAC levels. In other studies, TAC was inversely associated with risk of colorectal cancer and gastric cancer [43, 118]. These studies confirmed previous work regarding antioxidant dietary intake from fruits and vegetables and risk of lung, colon, rectum, breast, and other cancers [14, 17, 31].

Habitual dietary intake of foods containing many antioxidants, e.g. with a higher TAC, was associated with lower systemic inflammation and lower hepatic damage markers [112]. Antioxidant intake preserved beta-adrenergic function and decreased cerebellar inflammation [119], whereas lower plasma TAC was associated with a poor prognosis and severe damage in stroke patients [40, 44]. The protective role of TAC was recently confirmed since the dietary intake of foods with higher TAC values was associated with lower cognitive decline among middle-aged people from a Dutch cohort [120].

The regular practice of physical activity and exercise has been proposed to have an effect on TAC through many cell signaling and protective pathways against chronic noncommunicable diseases [121]. Based on this concept, regular dietary intake of foods with a minimum physiological TAC [38] (200 µmol TE/100 g) should also trigger many cell signaling and protective pathways against chronic noncommunicable diseases (Fig. **1**), but the exact pieces of this puzzle still need to be investigated.

CONCLUSION

Based on the highest TAC of Brazil nuts, guaraná, coffee, chocolate, collard greens, apples, beets, beans, oranges, onions and other foods, their regular dietary intake is strongly recommend to reduce the risk of chronic noncommunicable diseases.

LIST OF ABBREVIATIONS

$ABTS^+$	=	(2,2'-azino-di-[3-ethylbenzthiazoline sulphonate])
TAC	=	total antioxidant capacity
TE	=	Trolox-equivalent

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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Declared none.

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