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Concentration of ^{210}Po in vegan diet foods commercialized in Italy and dose calculation

Maria Assunta Meli *, Carla Roselli

Biomolecular Sciences Department, Urbino University Carlo Bo, 61029, Urbino, PU, Italy

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ABSTRACT

Ingestion of food and drink is one of the main routes by which radioactive elements in the environment enter the human body, which is why it is essential to know the concentration of the most significant naturally occurring and anthropogenic radionuclides in the diet.

The radionuclide that is the subject of this work is ^{210}Po, a radionuclide whose radiotoxicity is comparable to that of ^{239}Pu and is about five times greater than that of ^{226}Ra.

To date, natural and artificial radioactivity has been measured in various foodstuffs in Italy. However, there needs to be more sufficient data concerning the vegan diet. This particular diet excludes all foods of animal origin, which is becoming increasingly popular. According to Eurispes' Italy 2021 Report, it has been estimated that 2,4 % of the Italian population follows a vegan diet.

The first objective of this work was to complete previous alpha spectrometry measurement campaigns of ^{210}Po carried out by the same research group on typical foods of the vegan diet (legumes, cereals, and their derivatives, pseudocereals, algae, and spices) to contribute to more comprehensive databases.

The second objective was calculating the committed effective dose resulting from one year of food consumption, using the concentration data obtained in the analyzed samples.

The concentration values obtained ranged from a minimum of 0,069 ± 0,051 Bq kg^{-1} in cereal and legume products to a maximum of 3,89 ± 2,79 Bq kg^{-1} in algae. The committed effective dose for the average adult related to the consumption of these foods was 67,7 μSv y^{-1}.

1. Introduction

^{210}Po is found in minute quantities in nature and is the penultimate isotope in the decay chain of the ^{238}U series, generated by beta decay from ^{210}Bi.

It has been estimated that about 18% of the average internal dose to the population is due to the ingestion of ^{210}Po with its precursor ^{210}Pb (UNSCEAR, 2000).

The internal intake of ^{210}Po through food for individuals who do not follow an omnivorous diet was extended to foods that form the basis of alternative diets, such as the vegan diet.

The vegan diet is a diet that involves the exclusion of all foods of animal origin and the exclusive intake of plant foods. (Clarys et al., 2014; Richter et al., 2016).

Often, their choice is linked to a particular environmental sustainability by requiring less use of natural resources and less environmental damage. In addition to not eating foods from animals, a vegan person does not even consume their products (milk and dairy products, eggs, and honey) to avoid engaging in any form of animal exploitation. This choice stems from a particular respect for animals (Hopwood et al., 2020).

Recent publications by the Italian Ministry of Health (Quaderni del Ministero, 2015) and the Academy of Nutrition and Dietetics (Melina et al., 2016) consider vegetarian and vegan diets to be nutritionally adequate when adequately balanced (Parker et al. 2019). However, it should be pointed out that diets devoid of meat and especially animal derivatives, if not applied correctly, can lead to nutritional deficiencies, particularly of vitamin B12 and, to a lesser extent, vitamin D, fatty acids ω-3, calcium, zinc, and other trace elements. These diets, therefore, require proper planning that is strictly respected or the introduction of necessary supplements, especially if followed during the growth phase or pregnancy (Marrone et al., 2021).

* Corresponding author. Biomolecular Sciences Department, Urbino University Carlo Bo, Campus E. Mattei Via Ca' Le Suore 2/4, 61029 Urbino, PU, Italy.
E-mail address: maria.meli@uniurb.it (M.A. Meli).

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2. Materials and methods

2.1. Materials

The samples analyzed belong to the main food classes in a vegan diet: legumes, cereals, pseudo cereals and derivatives (tofu, seitan, tempeh), algae, and spices. The analysis was performed on six varieties of legumes, seven cereals, five derivatives of cereals and legumes, four pseudo cereals, five spices, and two algae (Table 1). Samples were purchased from large and small local retailers.

2.2. Radioanalytical method for ^{210}Po determination

The radioanalytical method applied for the determination of ^{210}Po is extensively described in previous works of the research group (Desideri et al., 2007; Desideri et al., 2010; Meli et al., 2011; Meli et al., 2014; Roselli et al., 2013). The method consists of the complete consumption of the food matrix by wet mineralization to solubilize the ^{210}Po in its spontaneous deposition on silver disks, followed by counting by alpha spectrometry.

3. Results and discussion

3.1. ^{210}Po concentration

The activity of ^{210}Po was always detectable (MDA = 1.0 10^{-2} Bq kg^{-1} calculated according to Strom and Stansbury, 1992) for all samples, as shown in Table 2. An uncertainty of 10% is associated with the activity concentrations (Bq kg^{-1}) calculated by considering ^{209}Po activity (yield internal standard), statistical fluctuations of the peaks and backgrounds and mass of the analyzed sample.

Table 3 shows the mean activity concentration, standard deviation, and minimum and maximum concentration obtained for all food groups analyzed.

The concentration trend of this radionuclide is as follows:

algae ≫ spices ≫ pseudocereals > legumes > cereals ≈ derivatives

The concentration of ^{210}Po activity is highest in algae and spices.

The concentration of ^{210}Po activity found in cinnamon and ginger samples influences the average value for spices.

The higher values obtained in algae are in good agreement with what has been reported in the literature (Desideri et al., 2017). These values are justified by the activity of 'bioconcentrators' that algae perform towards the elements present in the waters in which they live, similar to filter-feeding mollusks such as mussels and clams (Kumar et al., 2023).

Table 1
List of food classes and varieties analyzed.

Legumes	*Pseudocereals*
lentils	amaranth
chickpeas	quinoa
peas	buckwheat
broad beans	hulled sorghum
beans	
yellow soybeans	
Cereals	*Spices*
pearled spelt	pumpkin seeds
pearl barley	jerusalem artichoke
corn	cinnamon
rye	ginger
hulled oats	flax seeds
brown rice	
mile	
Derivatives (legumes and cereals)	*Algae*
fresh tempeh	hijiki
dry tofu	arame
fresh smoked tofu	
fresh seitan	
instant seitan	

Table 2
Concentration (Bq·kg^{-1}) of ^{210}Po in the samples analyzed.

Sample	^{210}Po	Sample	^{210}Po
Legumes		*Pseudocereals*	
lentils	0,130 ± 0,013	amaranth	0,080 ± 0,008
chickpeas	0,056 ± 0,006	quinoa	0,224 ± 0,022
peas	0,016 ± 0,002	buckwheat	0,061 ± 0,006
broad beans	0,028 ± 0,003	hulled sorghum	0,105 ± 0,011
beans	0,023 ± 0,002		
yellow soybeans	0,240 ± 0,024		
Cereals		*Spices*	
pearled spelt	0,144 ± 0,014	pumpkin seeds	0,040 ± 0,004
pearl barley	0,036 ± 0,004	jerusalem artichoke	0,150 ± 0,015
corn	0,032 ± 0,003	cinnamon	4460 ± 0,446
rye	0,030 ± 0,003	ginger	1900 ± 0,190
hulled oats	0,040 ± 0,004	flax seeds	0,130 ± 0,013
brown rice	0,160 ± 0,016		
mile	0,050 ± 0,005		
Derivatives (legumes and cereals)		*Algae*	
fresh tempeh	0,015 ± 0,002	hijiki	5,86 ± 0,59
dry tofu	0,058 ± 0,006	arame	1,91 ± 0,19
fresh smoked tofu	0,152 ± 0,015		
fresh seitan	0,047 ± 0,005		
instant seitan	0,071 ± 0,007		

Table 3
Mean concentration (Bq kg^{-1}), standard deviation, minimum value, and maximum of ^{210}Po for the food groups (number of varieties analyzed for each group).

Sample	^{210}Po	Sample	^{210}Po
Legumes (6)		*Pseudocereals (4)*	
Mean vale	**0,082**	Mean vale	**0,118**
Standard Dev.	0,088	Standard Dev.	0,073
Minimum	0,016	Minimum	0,061
Maximum	0,240	Maximum	0,224
Cereals (7)		*Algae (2)*	
Mean vale	**0,070**	Mean vale	**3,89**
Standard Dev.	0,056	Standard Dev.	2,79
Minimum	0,030	Minimum	1,91
Maximum	0,160	Maximum	5,86
Derivatives (legumes and cereals) (5)		*Spices (5)*	
Mean vale	**0,069**	Mean vale	**1,34**
Standard Dev.	0,051	Standard Dev.	0,080
Minimum	0,015	Minimum	1912
Maximum	0,152	Maximum	4,46

The concentrations of ^{210}Po in other food categories present in the vegan diet were determined in a previous campaign. Figs. 1 and 2 show the trend of average concentrations (Meli et al., 2014; Roselli et al., 2013; Desideri et al., 2007, 2007a, 2007b).

For calculating the committed effective dose resulting from one year of food consumption, D, for an average adult individual (>10 years old) on a vegan diet, the concentration data of ^{210}Po presented in this paper were supplemented with those shown in Figs. 1 and 2.

Table 4 shows the ranges of ^{210}Po concentration values obtained in the various campaigns by this group of researchers compared with those found in the international literature.

The differences found are compatible with the different geographic origins of the food products, closely related to the different growing environments and soils and the different fertilizers used.

3.2. ^{210}Po committed effective dose

Radiation produced by radioisotopes interacts with the matter with

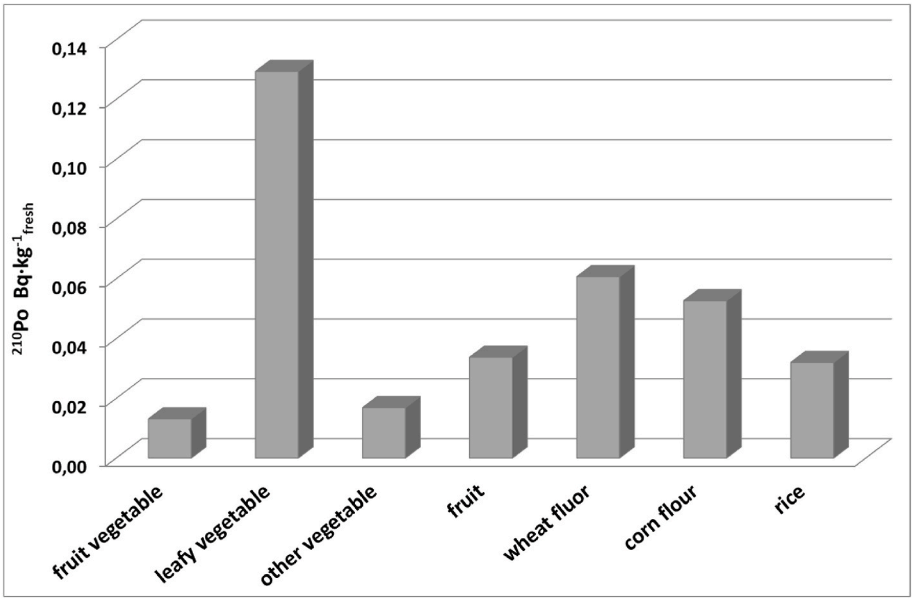

Fig. 1. Comparison of average concentrations of ^{210}Po (Bq kg^{-1}) in classes of food of plant origin.

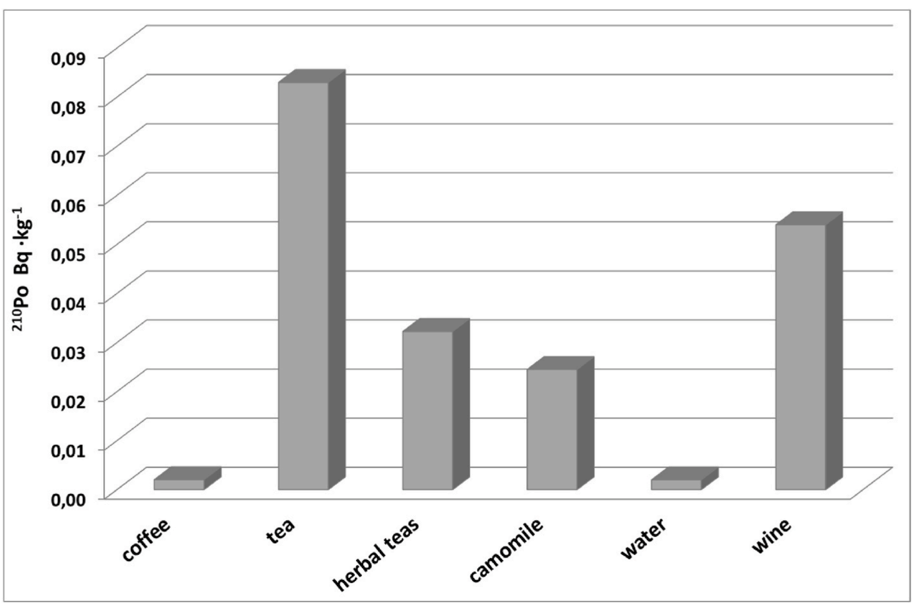

Fig. 2. Average concentration of ^{210}Po (Bq kg^{-1}) in water and various beverages.

which it comes into contact, transferring energy to it. This energy transfer produces an ionization of molecules in living organisms, hence the term ionizing radiation.

The committed effective dose calculation for an average adult individual (>10 years old) was performed using the following formula:

$$^{210}\text{Po D} = {}^{210}\text{Po C} \cdot \text{I} \cdot \text{Q}$$

Where.

^{210}Po D = committed effective dose for ^{210}Po resulting from one year of food consumption (μSv·y^{-1})
^{210}Po C = average concentration of ^{210}Po (Bq·kg^{-1})
I = ingestion rate (kg·y^{-1})
Q = committed effective dose coefficient (Sv·Bq^{-1})

The committed effective dose coefficient used for adults, recommended by UNSCEAR (UNSCEAR, 2000) for ^{210}Po, is 1,2 μSv·Bq^{-1}.

Daily consumption data (g·d^{-1}) reported by Waldmann et al., 2003 were used to calculate the annual ingestion rate.

Table 5 shows the ingestion rate (kg·y^{-1}), the average concentration of ^{210}Po (Bq·kg^{-1}), the intake of ^{210}Po (Bq·y^{-1}), and the resulting D (μSv·y^{-1}) for each of the main food groups in the vegan diet.

The D value from ingestion of ^{210}Po in an adult average member of a vegan population was 67,7 μSv·y^{-1} and constitutes 22,6% of internal natural radiation exposure (0,3 mSv·y^{-1}, UNSCEAR, 2000), a lower dose than that provided by a non-vegan diet (Table 6). This result can be explained by the absence of consumption of fish products, a food group responsible for a significant intake of ^{210}Po (Alam & Mohamed, 2011; Piñero-García et al., 2023).

The most significant contribution to D of ^{210}Po is mainly from vegetables and beverages (Carvalho et al., 2017; Din, 2011).

Table 4
Comparison between the concentration of ^{210}Po (Bq kg^{-1}) obtained by the same team of researchers and those reported in the international literature.

Sample	^{210}Po	References
Cereals		
	0,03-0,16	**The same team of researchers**
	0,04-0,11	Alboloushi et al. (2024)
	0,29	Arunachalam et al. (2014)
	0,01-0,40	Din (2011)
	0,28-9,55	Barescut et al., (2009)
	0,14-0,21	Chang et al. (2009)
	0,8-2,6	Al-Masri et al. (2004b)
	0,30	Cunha et al. (2001)
	0,04-0,49	Kannan et al. (2001)
	0,01-0,63	McDonald et al. (1999)
Leafy vegetable		
	0,01-0,65	**The same team of researchers**
	0,02-0,29	Alboloushi et al. (2024)
	0,015–0,152	Piñero-García et al. (2022)
	2,18	Arunachalam et al. (2014)
	0,05-3,0	Din (2011)
	0,32	Chang et al. (2009)
	0,18-9,4	Ekdal et al. (2006)
	0,09-0,34	Kannan et al. (2001)
	0,004-0,14	McDonald et al. (1999)
	1,48-4,83	Pietrzak et al. (1995)
	0,20-0,90	Othman and Yassine (1995)
	1,55-13,08	Santos et al., (1990)
Fruit vegetable		
	0,005-0,04	**The same team of researchers**
	0,01-0,08	Alboloushi et al. (2024)
	0,003–0,055	Piñero-García et al. (2022)
	2,18	Arunachalam et al. (2014)
	0,14-0,46-	Din (2011)
	0,04	Chang et al. (2009)
	0,07-0,31	Cunha et al. (2001)
	0,013-0,12	Kannan et al. (2001)
	0,06	Othman and Yassine (1995)
Other vegetable		
	0,005-0,03	**The same team of researchers**
	0,075–1721	Piñero-García et al. (2022)
	<0,01-0,23	Din (2011)
	0,16	Chang et al. (2009)
	0,15-1,18	Ekdal et al. (2006)
	0,013-0,12	Kannan et al. (2001)
	0,001–0,013	McDonald et al. (1999)
	0,03-2,55	Pietrzak et al. (1995)
	0,06	Othman and Yassine (1995)
	1,27-7,77	Santos et al., (1990)
Fruits		
	0,01-0,07	**The same team of researchers**
	0,02-0,11	Alboloushi et al. (2024)
	0,011–0,289	Piñero-García et al. (2022)
	0,065	Arunachalam et al. (2014)
	0,14-0,53	Din (2011)
	0,08	Chang et al. (2009)
	0,3–9,3	Al-Masri et al., (2004)
	0,05-0,07	Cunha et al. (2001)
	0,016-0,43	McDonald et al. (1999)
Beverage		
	0,001-0,20	**The same team of researchers**
	0,009–14,6	Alboloushi et al. (2024)
	0,0005–7,6	Carvalho et al., (2017)
	0,7-4,1	Al-Masri et al. (2004b)
	<0,01–18,6	Din (2011)
	0,23-1,62	Cunha et al. (2001)

Fig. 3 shows the percentage contribution of each food group to D for a vegan average subject (Fig. 3a) and a non-vegan average subject (Fig. 3b).

4. Conclusions

The ^{210}Po concentration data obtained in this work on the main foods of the vegan diet contribute to the integration of previous research on other foods such as vegetables, fruit, and beverages, enriching the databases on natural radioactivity in foods consumed in Italy. The calculated committed effective dose received by the vegan average adult was 0,0677 mSv·y^{-1}, representing 22,6% of internal natural radiation exposure.

37,2% of committed effective dose was due to ingesting vegetables (both fruit and leafy vegetables) and potatoes, 26,6% to beverages (mainly tea, herbal teas, and wine), and 15,3% to fruit.

Although algae presented higher average concentration values of ^{210}Po than other food classes, their percentage contribution to committed effective dose is still moderate, given the low annual ingestion rate.

By significantly altering the composition and quantity of food ingested, the vegan diet produces a lower dose to the average adult consumer than an omnivorous diet. The cause may lie in the non-introduction of fishery products.

Table 5
Ingestion rate (kg·y^{-1}), average concentration of ^{210}Po (Bq·kg^{-1}), intake (Bq·y^{-1}), D (μSv·y^{-1}), and the percentage contribution of each food group to D for the average adult of a vegan population.

Samples	Ingestion rate	^{210}Po	^{210}Po Intake	D
Cereals and dairy products	103	0,058	6	7,2 (10,6)
Vegetables and patatos	288	0,073	21	25,2 (37,2)
Legumes and dairy products	37	0,082	3	3,6 (5,3)
Spices	0,04	1336	0,1	0,1 (0,1)
Fruit	257	0,034	8,7	10,4 (15,3)
Algae	0,7	3,89	2,7	3,2 (4,7)
Drinks	500	0,03	15	18 (26,6)
TOTALE			56,5	**67,7**

Table 6
Intake (Bq·y^{-1}) and D (μSv·y^{-1}) to the average adult of each typical food group of a medium non-vegan diet.

Samples	^{210}Po Intake	D
Milk and dairy products	2,1	2,5 (1,7)
Meat and dairy products	4,5	5,4 (3,6)
Cereals and dairy products	7	8,4 (5,5)
Leafy vegetables	7,8	9,4 (6,2)
Fruit and roots	3,4	4,1 (2,7)
Fish and dairy products	86,4	103,7 (68,5)
Water and drinks	15	18 (11,9)
TOTAL	126,2	**151,4**

CRediT authorship contribution statement

Maria Assunta Meli: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Carla Roselli:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Founding sources

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence

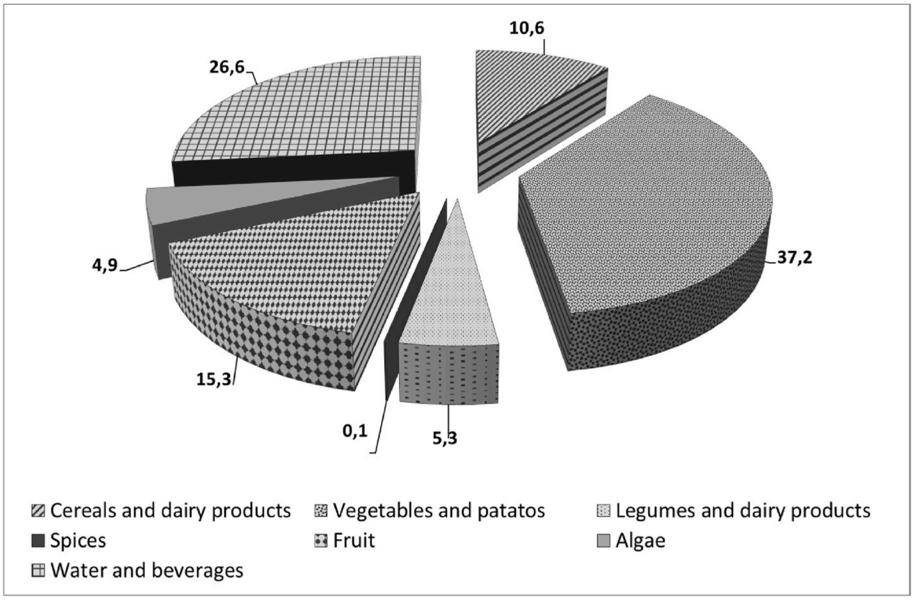

Fig. 3a. Percentage contribution of each food group to D for a vegan average subject.

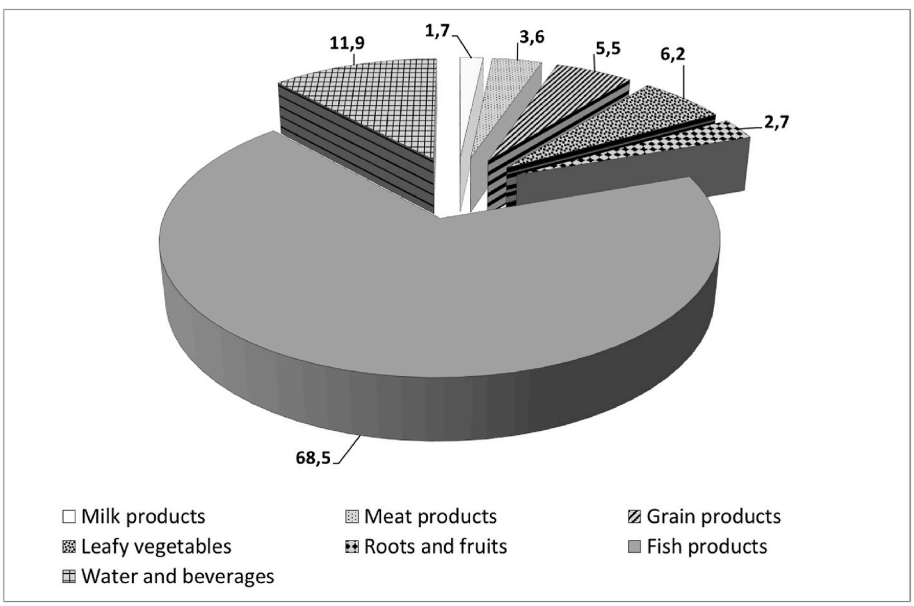

Fig. 3b. Percentage contribution of each food group to D for a non-vegan average subject.

the work reported in this paper.

Data availability

All data has been entered into the paper

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