

HEALTH RISK RELATED TO URANIUM-238 INTAKE IN MAIZE

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Abstract

The regular use of phosphate fertilizer in maize crops may increase ^{238}U , the long-lived radionuclide, in agricultural soils. Maize simply accumulated ^{238}U during growth and development. In this study, ^{238}U concentrations were determined in sweet corn or yellow maize (*Zea mays saccharata*) and flour corn or white maize (*Zea mays amylocea*) using radioanalytical technique and alpha spectrometry. Samples were collected from maize fields in Mae Ramat district, Tak province in 2018-2019. Health risk of children, juvenile and adults as consumers related to radiation dose and risk of fatal and illness cancer were evaluated. Concentrations of ^{238}U in all investigated samples were found to be generally low, range from 4.98 to 7.47 Bq.kg⁻¹ ww. in sweet corn and from 6.41 to 10.29 Bq.kg⁻¹ ww. in flour corn which was below the average world value for ^{238}U in all food types of 35 Bq.kg⁻¹. Annual committed effective doses due to ^{238}U intakes as a result of sweet corn and flour corn consumption for children, juveniles, and adults were 13.91 ± 1.47 , 78.18 ± 3.48 , and 34.05 ± 2.29 $\mu\text{Sv.y}^{-1}$, respectively. These individual doses were below the UNSCEAR recommended limit of 120 $\mu\text{Sv.y}^{-1}$. The lifetime cancer risks varied from 1.05×10^{-5} to 2.18×10^{-5} for fatal cancer and 1.61×10^{-5} to 3.34×10^{-5} for illness cancer. These were relatively low compared with the ICRP recommendation risk of 2.5×10^{-3} . Results presented herein suggest no health risk effect to consumers related to the intake of ^{238}U from sweet corn and flour corn.

Keywords: Health risk; Lifetime cancer risk; Maize; Radiation dose; Uranium-238

Introduction

Maize or corn (*Zea mays* L.) is a leading food grain globally as measured by the highest yield production and ranks third after rice and wheat in terms of staple food. Maize is widely cultivated throughout the world, it was adapted to a broad range of growing conditions; from the tropics zone to the high altitudes, from lowland to upland, and from 6 weeks to 13 months of a growing period, The worldwide maize yield of 30-40% is used for

food and 60-70% for livestock feed and biofuel (ethanol). Maize is consumed as fresh i.e., boiled or roasted, beverages, and maize-based bread and snacks. At the global level, maize cultivation areas are growing due to the non-food demand for animal feed and biomass energy (Gwartz and Garcia-Casal 2014; Kinnunen *et al.*, 2020; Erenstein *et al.*, 2022).

It was documented that maize farming areas of the Thai upland currently account for a significant

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portion (approx. 33%) and will be greatly expansion further over the coming decades because of the increasing demand of maize grain yield regarding utilization as the livestock feed and bioethanol production (Supasri *et al.*, 2020). Also, the production of maize in the world has been increasing for human consumption due to its nutritive value and the growth trend of healthy food. (Blare *et al.*, 2020) Maize becomes an important role in the human diet especially for health-conscious people (Sheng *et al.*, 2018; Swapna *et al.*, 2020). Maize cultivation concerns have been growing in the context of chemical fertilizers and other agro-chemicals input. The excessive use of mineral fertilizers such as phosphate fertilizer has caused environmental impacts, potentially leading to simultaneous soil fertility degradation and human health decline thereof. Human health decline is a critical issue that affects the quality of life and eventually life expectancy of people (Fantin *et al.*, 2017; Supasri *et al.*, 2020).

Uranium-238 (^{238}U) is a long-lived naturally occurring radioactive heavy metal, present in rocks, soils, and sediments. ^{238}U level can be enhanced by human activities including the use of phosphate fertilizers in agriculture contribute to an increasing ^{238}U concentration in soils. Phosphate rocks, raw material of phosphate fertilizers are source of ^{238}U and its decay products. It has been reported that an annual crop rarely takes up more than about 25% of the phosphate applied to it as fertilizer. Thus, residue of phosphate fertilizer accumulates in soil. Uptake of ^{238}U by plants and subsequent accumulation along the food chain is a potential threat to animal and human health. ^{238}U has a very long physical half live of 4.47×10^9 y which is recognized as a persistent environmental contaminant. ^{238}U exposure causes health risks because of its chemotoxicity and radiotoxicity associated with the deposition in various human organs. The health risks include atherosclerosis, cardiovascular disease, kidney, lung, and liver damage, neurological disorders (Parkinson's and Alzheimer's disease), immune dysfunction, cancer, and increase in mortality rate (Van *et al.*, 2019; Vu *et al.*, 2022; Yang *et al.*, 2022).

Several studies and reviews have been performed on ecological effects and human health risk assessment focused on the application of mineral fertilizers (Fantin *et al.*, 2017; Cui *et al.*, 2023 and references therein). Fantin *et al.* (2017) evaluated the effects on soil fertility from wheat and maize cultivation in Italy. The key problem was owing to excessive use of mineral fertilizer and pesticide. The residual concentrations of ^{238}U in soil continued to increase due to repeated application. Food crops can absorb some ^{238}U from soil which

eventually will end up in plant-based food. Studies documented that human health hazards are closely linked to the intake of ^{238}U -contaminated food crops (Cui *et al.*, 2023).

The present study determined ^{238}U concentrations in yellow maize and white maize kernels cultivated in Mae Ramah district, Tak province for 2 years (2018-2019). The annual effective dose rates and lifetime cancer risk of different ages (children, juveniles, and adults) were also evaluated.

Materials and Methods

Study Area

The study site was carried out at Mae Pasa subdistrict, Mae Ramah district (169 07' N, 986 15' E), an upland area of 195 meters elevation in Tak province, Thailand (Figure 1).



Figure 1. Location of the study site

The site has a tropical monsoon climate with an average annual precipitation of 1540 mm, an average annual temperature of 16°C to 36°C, atmosphere humidity of 36% to 75% and a mean annual sunshine hour of 11.38 h (Report of Thai Meteorological Department, 2020). The soil of the study site was classified as Calcaric Phaeozems which is being calcareous between 20 and 50 cm from the surface (LDD, Soil Resources Survey and Research Division http://oss101.ldd.go.th/web_thaisoilinf/north/Tak/tk_prov.html).

Sample Collection and Preparation

In the study area of Mae Pasa subdistrict, Mae Ramah district (169 07' N, 986 15' E), the first and second crop of maize was usually grown in May and October, respectively. The overall plantation period of both yellow and white maize was 100 - 110 days. Grain samples were taken during the harvest. Thus, the samples collections were carried out on two

occasions per year in July and December during 2018 and 2019 as a representative of first and second crop harvesting, respectively. Four farming fields (MF1, MF2, MF3, and MF4) each of 0.8 hectare were selected for sampling as specified by each farm was planting both yellow and white maize. Other considerations such as cultivation practices, plant cultivars, soil types, and slope complex location were considered on their alike.

Maize sampling in July and December 2018-2019 were carried out according to the randomization completely block design (Alesso *et al.*, 2019). The sampling cells divided by grid were 20 blocks as shown in Figure 2. Twenty samples each (30 ears of each yellow and white maize per sample) were randomly collected from four farming fields.

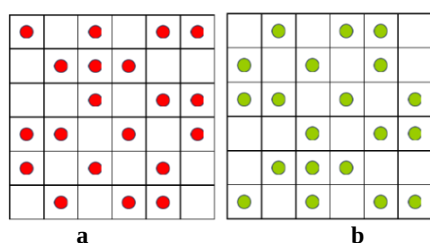


Figure 2. Spot shows the 20 sampling cells (A) sampling in July and (B) in December

Totally 320 samples were analyzed. All the collected samples were taken to the laboratory for further processing. Briefly, the maize was first removed from their husks and skin, washed off, and then maize kernels were separated from the corncobs. The vegetables were taken from the edible part only or 100% edible for food.

Before performing ash analysis, samples were completely dried in the oven to resist spattering at the time of ashing. Placed the crucible containing samples inside the muffle furnace and heated to 450°C for overnight. Let the furnace cooled and took out the crucibles containing ash which was white in color. If traces of carbon remained, cooled the crucible, and broke up the ash with a glass rod. Repeated the ashing process until obtained white ash, then stored in sealed plastic bag prior to analysis.

²³⁸U isotope analysis

Determination of ²³⁸U in maize was carried out based on radiochemical technique described in Nochit *et al.* (2021). The procedure steps include sample dissolution, purification, and electrodeposition followed by alpha counting.

In brief, ²³⁶U (yield tracer) radioactivity of 23.427 mBq was added to the ~ 5 g sample. The sample was wet digested to remove organic

matter using HNO₃, HClO₄, HF, and HCl. The purification of ²³⁸U was using 3 columns of AG1×8 anion resins, 200 mesh. After that, the solution containing ²³⁶U and ²³⁸U isotopes were electrodeposited onto a stainless-steel disc for counting. Measurement was conducted by using alpha spectrometry equipped with high-resolution ion-implanted silicon Charged-Particle detectors (ORTEC: Octete Plus). Blanks were conducted in each batch of the samples analysis. Quality control was performed using IAEA reference material (IAEA-330 Spinach).

Computing activity concentration of ²³⁸U

The assumption of the computing is that the chemical reactions of ²³⁶U and ²³⁸U are exactly the same. The known activity of ²³⁶U added in the analysis procedure is related to its area peak. Thus, the radioactivity of the ²³⁸U is obtained by comparing ²³⁸U net peak area in the spectrum with that of the ²³⁶U tracer peak.

The Age-dependent Annual Effective Dose (AED)

The dose received by three different age groups (children, juvenile, and adult) due to maize consumption was calculated using the measured concentrations of ²³⁸U in maize samples, the age-dependent effective dose coefficients (IAEA 1996; ICRP, 1996), and the annual maize consumption rate for the eater of three different age groups (children, juvenile and adult) (Food consumption data of Thailand, 2016). The calculation of the annual effective dose (AED) is given by (UNSCEAR, 2000).

$$AED = DCF \times MF \times A_i \times C_i \times F_i$$

where, AED is the annual committed effective dose (μSv.y⁻¹); DCF is the committed effective dose conversion factor; MF is the modifying factor (0.6) due to the decay of ²³⁸U between maize collection and consumption (UNSCEAR, 2000). A_i is the ²³⁸U concentration (Bq.kg⁻¹ wet weight); C_i is the maize consumption rate of three age groups (Kg.y⁻¹) (NCFS, 2016) and F_i is the real fraction consumed (100% edible part). Shown in Table 1.

Table 1. Dose conversion factors (DCF) (IAEA 1996; ICRP 1996) and annual maize consumption rate for different age groups (NCFS 2016)

Age group (y)	DCF (μSv.Bq ⁻¹)	Maize consumption rate (Kg.y ⁻¹)
Children (2-7)	0.8	5
Juvenile (7-17)	1.5	28
Adult (>17)	0.28	35

Evaluation of the Lifetime Cancer Risk

The equation for computing excess lifetime cancer risk, LTCR is;

$$\text{LTCR} = \text{Ai} \times \text{Ci} \times \text{Le} \times \text{C}_{\text{coe}}$$

where LTCR is the lifetime cancer risk, Ai is the ^{238}U concentration, Ci is the annual maize consumption rate depending on age group (Kg. y^{-1}), Le is the exposure duration; 70 years for children, 60 for juvenile, and 50 for adult while the average life expectancy at birth for Thai people is 75 years (Central Intelligent Agency, 2020) and C_{coe} is the ^{238}U cancer risk coefficients of $1.13 \times 10^{-9} \text{ Risk.Bq}^{-1}$ for mortality and $1.73 \times 10^{-9} \text{ Risk.Bq}^{-1}$ for morbidity (UNSCEAR, 2000; USEPA, 1999).

Statistical analysis

A one-way analysis of variance (ANOVA) was carried out to investigate the differences in ^{238}U concentrations between yellow and white maize samples at the confidence level of 95%. Statistical analysis of data was performed using GraphPad Prism V.8 (GraphPad Software, Inc., La Jolla, California, USA). The null hypothesis of no differences in ^{238}U concentrations between two types of maize was determined by the p-value of 0.05.

Results and Discussion

The average ^{238}U concentration of a total of 160 yellow maize (sweet corn) samples and 160 white maize (flour corn) samples collected from the four maize farms at Mae Ramah district of Tak province are given in Table 2. It was found that the lowest concentration of ^{238}U in maize samples was in the sweetcorn sample measured in MF1, while the highest concentration of ^{238}U was in the white maize sample with a value of $10.29 \pm 1.14 \text{ Bq.kg}^{-1}$ (MF2).

Table 2. Average ^{238}U concentrations in yellow and white maize samples

Maize Field	^{238}U Concentration (Bq.kg^{-1})	
	Yellow maize (Sweet corn)	White maize (Flour corn)
MF 1	4.98 ± 0.38	6.41 ± 0.77
MF 2	6.22 ± 0.74	10.29 ± 1.14
MF 3	5.02 ± 0.31	10.11 ± 1.05
MF 4	7.47 ± 0.85	9.06 ± 1.03

In this present study, ^{238}U concentrations were examined in the same locations with identical cultivation practices; however, the results showed that ^{238}U levels of yellow and white maize samples were differences. This may be due to the differences in the starch and sugar contents in the kernels. The absorption and storage of ^{238}U by plants depend

on plant types (Sarić *et al.*, 1995). Günther *et al.*, (2003) have observed that uranium was taken up into the lupine plants and had greater binding affinity to phosphate groups (Günther *et al.*, 2003). Although, the precise conditions of absorbed, stored, and removed uranium inside the plants have not been adequately understood. Most of the studies revealed that ^{238}U contents of the various plant species were differences. The results were in agreement with the observational study in Iraq that ^{238}U concentrations of tomato and onion were 6.99 ± 0.20 and $3.63 \pm 0.20 \text{ Bq.kg}^{-1}$, respectively (Abojassim *et al.*, 2016).

Yellow maize or sweet corn has a unique yellow color while white maize or flour corn has a distinct off-white or cream color. The sweetness of sweet corn kernels is resulting from sugary genes that prevent the sucrose from changing to starch in biosynthesis pathway. Thus, sweet corn has a higher sugar level due to sugar accumulation in kernels; however, it has a lower starch content compares with flour corn. (Farsiani *et al.*, 2011; Singh *et al.*, 2014). Oktem and Oktem, (2005) reported that sweet corn has only 10 - 11% starch content though contains 29.9% sucrose at its optimum market maturity. It found that sucrose levels in sweet corn was eight-fold higher than flour corn. Results from this study suggested that ^{238}U accumulated higher in starchy than sugary maize. The observation of ^{238}U contents in both maize types were comparable and in the same range with the research performed in Nigeria (Oluyide *et al* 2019). The present study of yellow and white maize samples revealed relatively low ^{238}U concentrations according to the world average values of 35 Bq kg^{-1} (UNSCEAR, 2000).

The obtained data of ^{238}U activities were assisted to determine the age-dependent annual effective dose and to evaluate the lifetime cancer risk. The AEDs from yellow and white maize samples for three groups of children, juveniles and adults were shown in Table 3.

Table 3. Annual effective dose (AED) in yellow and white maize samples

Age group	AED ($\mu\text{Sv.y}^{-1}$)	
	Yellow Maize	White maize
Children	13.91 ± 1.47	19.25 ± 1.63
Juvenile	78.18 ± 3.48	108.26 ± 3.86
Adult	34.05 ± 2.29	47.15 ± 2.55

Results revealed that the AEDs from ingestion of maize samples under this study by juvenile was higher than the dose from ingestion by children and adults. It was found that in this study area, the average AEDs in all age groups were lower than the world average AEDs of $120 \mu\text{Sv.y}^{-1}$ recommended by UNSCEAR (2000) and hence do not pose any health risk.

Comparing to a study by Islam *et al.*, (2014), the mean ^{238}U concentration in papaya samples from Tulatoli village, Bangladesh was $64.77 \pm 38.47 \text{ Bq.kg}^{-1}$ and the AED resulting from the ingestion of papaya was $349.76 \mu\text{Sv. y}^{-1}$ which was found times higher than the world safe value. In addition, the results in this study appeared to be below than those values found in fruits and vegetables grown in Turkey (Küçükönder *et al.*, 2023).

The lifetime cancer risks varied from 1.05×10^{-5} to 2.18×10^{-5} for fatal cancer and 1.61×10^{-5} to 3.34×10^{-5} for illness cancer. These are relatively low compared with the ICRP acceptable cancer risk of 2.5×10^{-3} (ICRP 1996). Results presented herein suggest no health risk effect to consumers related to the intake of ^{238}U from yellow maize (sweet corn) and white maize (flour corn).

Conclusions

Uranium-238 is a common metal found in phosphate rocks; the raw material for phosphate fertilizer. Agricultural fertilization by phosphate has been increased the ^{238}U concentrations in soil. ^{238}U persists and retains in soil for a long period of time and the binding capacity of ^{238}U to soil inorganic and organic matters has enhanced the soil toxicity. Its long half-life and the strong adsorption capacity are the most important factors for ^{238}U retention in the agricultural soil. ^{238}U does not have any nutritional functions for plants, yet it finds its way into plant tissues. Plants uptake ^{238}U directly through the roots, translocate from roots to shoots and eventually accumulate in them by biosorption and bioaccumulation mechanisms. The concentrated ^{238}U in plants can lead to ultimately human which is a potential threat to human health (Cui *et al* 2023). The finding results revealed that:

1. The activity concentrations of ^{238}U , measured in yellow maize (sweetcorn) and white maize (flour corn) in this study are lower than 35 Bq kg^{-1} which is given as world limit.
2. The ranged of age-dependent AED due to ^{238}U consumption of maize for children, juveniles and adults were 13.91 to 19.25, 78.18 to 108.26 and 47.15 to 34.05 μSv , respectively. The estimated average value in the study area was lower than the world average AED of ^{238}U consumption of $120 \mu\text{Sv.y}^{-1}$ by UNSCEAR (2000) and hence does not pose any health risk.
3. The calculated excess lifetime cancer risk (ELCR) values were lower than the world safe limit value of 2.5×10^{-3}

4. The results indicate that ingestion of maize grown in the study maize fields did not pose any risk to the public.
5. Data from this present study will assist in producing a baseline of ^{238}U exposure to the public due to the dietary intake of food crops.

Limitations of the study

Maize samples in this study were considerably low to result in negligible harmful effects. However, it is some limitations. The authors recognize that the vegetable type of yellow and white maize was rather limited. The low dose was merely due to the consumption of a single diet. Therefore, further studies on other types of plants and plant-based foods including drinking water, as well as the dose contributions from ^{228}Th and its daughters are recommended since both ^{238}U and ^{228}Th are naturally occurring radionuclides present in earth crust and phosphate fertilizer.

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References

- Abojassim, A., Hady, H., and Mohammed, Z. (2016). Natural radioactivity levels in some vegetables and fruits commonly used in Najaf Governorate, Iraq. *Journal of Bioenergy and Food Science*, 3(3):113-123. <https://doi.org/10.18067/jbfs.v3i3.108>
- Alesso, C.A., Cipriotti, P.A., Bollero, G., and Martin, N.F. (2019). Experimental designs and estimation methods for on-farm research: A simulation study of corn yields at field scale. *Agronomy Journal*, 111(6):2724-2735. <https://doi.org/10.2134/agronj2019.03.0142>
- Blare, T., Donovan, J., and Garcia-Medina, M. (2020). The right tortilla for the right occasion: Variation in consumers' willingness to pay for blue maize tortillas based on utilization. *Journal of Food Products Marketing*, 26(6):564-579. <https://doi.org/10.1080/10454446.2020.1832637>
- Central Intelligence Agency. (2020). The CIA World Factbook 2020-2021. Retrieved from: <https://www.cia.gov/the-world-factbook/field/life-expectancy-at-birth/country-comparison/>
- Cui, Q., Zhang, Z., Beiyuan, J., Cui, Y., Chen, L., Chen, H., and Fang, L. (2023). A critical review of uranium in the soil-plant system: Distribution, bioavailability, toxicity, and bioremediation strategies. *Critical Reviews in*

- Environmental Science and Technology, 53(3):340-365. <https://doi.org/10.1080/10643389.2022.2054246>
- Erenstein, O., Jaleta, M., Sonder, K., Mottaleb, K.A., and Prasanna, B.M. (2022). Global maize production, consumption and trade: Trends and R&D implications. *Food Security*, 14:1295-1319. <https://doi.org/10.1007/s12571-022-01288-7>
- Fantin, V., Righi, S., Rondini, I., and Masoni, P. (2017). Environmental assessment of wheat and maize production in an Italian farmers' cooperative. *Journal of Cleaner Production*, 140:631-643. <https://doi.org/10.1016/j.jclepro.2016.06.136>
- Farsiani, A., Ghobadi, M.E., and Jalali Honarmand, S. (2011). The effect of water deficit and sowing date on yield components and seed sugar contents of sweet corn (*Zea mays* L.). *African Journal of Agricultural Research*, 6(26):5769-5774. <https://doi.org/10.5897/AJAR11.1242>
- Günther, A., Bernhard, G., Geipel, G., Reich, T.Y., Roßberg, A., and Nitsche, H. (2003). Uranium speciation in plants. *Radiochimica Acta*, 91(5):319-328. <https://doi.org/10.1524/ract.91.6.319.20022>
- Gwirtz, J.A., and Garcia-Casal, M.N. (2014). Processing maize flour and corn meal food products. *Annals of the New York Academy of Sciences*, 1312(1):66-75. <https://doi.org/10.1111/nyas.12299>
- International Atomic Energy Agency [IAEA]. (1996). International basic safety standards for protection against ionizing radiation and for the safety of radiation sources. Vienna.
- International Commission on Radiological Protection [ICRP]. (1996). Age-dependent doses to members of the public from intake of radionuclides: Part 5, Compilation of ingestion and inhalation dose coefficients. ICRP Publication 72.
- Islam, A., Begum, A., Yeasmin, S., and Sultana, M.S. (2014). Assessment of dose due to natural radionuclides in vegetables of high background radiation area in south-eastern part of Bangladesh. *International Journal of Radiation Research*, 12(3):271-275.
- Kinnunen, P., Guillaume, J.H.A., Taka, M., D'Odorico, P., Siebert, S., Puma, M.J., Jalava, M., and Kumm, M. (2020). Local food crop production can fulfil demand for less than one-third of the population. *Nature Food*, 1:229-237. <https://doi.org/10.1038/s43016-020-0060-7>
- Küçükönder, E., Gümbür, S., Söğüt, Ö., and Doğru, M. (2023). Radioactivity amounts, annual effective dose rate, and lifetime cancer risk estimation of some vegetable and fruit samples cultivated in Kahramanmaraş, Turkey. *Environmental Monitoring and Assessment*, 195(4):475. <https://doi.org/10.1007/s10661-023-11098-9>
- Land Development Department [LDD]. (n.d.). Soil and resources survey of Tak Province. <http://oss101.ddd.go.th/>
- National Bureau of Agricultural Commodity and Food Standards [NCFSS]. (2016). Food consumption data of Thailand (in Thai).
- Nochit, P., Kulsawat, W., and Khunsamut, J. (2021). Concentrations of ²³⁸U in selected Thai spices and the related dose assessment. *Journal of Physics: Conference Series*, 1719(1):012077. <https://doi.org/10.1088/1742-6596/1719/1/012077>
- Oktem, A.G., and Oktem, A. (2005). Effect of nitrogen and intra-row spaces on sweet corn (*Zea mays saccharata* Sturt) ear characteristics. *Asian Journal of Plant Science*, 4(4):361-364. <https://doi.org/10.3923/ajps.2005.361.364>
- Oluyide, S., Tchokossa, P., Orosun, M., Akinyose, F.C., Louis, H., and Ige, S. (2019). Natural radioactivity and radiological impact assessment of soil, food and water around iron and steel smelting area in Fashina village, Ife, Osun state, Nigeria. *Journal of Applied Science and Environmental Management*, 23(1):135-143. <https://doi.org/10.4314/jasem.v23i1.20>
- Report of Thai Meteorological Department. (2020). The Annual Rainfall, Rainy-days and Relative Humidity: Selected Location by Regions for 2018 and 2019. Retrieved from: <http://www.climate.tmd.go.th/>
- Sarić, M.R., Stojanović, M., and Babic, M. (1995). Uranium in plant species grown on natural barren soil. *Journal of Plant Nutrition*, 18(7):1509-1518. <https://doi.org/10.1080/01904169509364999>
- Sheng, S., Li, T., and Liu, R. (2018). Corn phytochemicals and their health benefits. *Food Science and Human Wellness*, 7(3):185-195. <https://doi.org/10.1016/j.fshw.2018.09.003>
- Singh, I., Langyan, S., and Yadava, P. (2014). Sweet corn and corn-based sweeteners. *Sugar Tech*, 16(2):144-149. <https://doi.org/10.1007/s12355-014-0305-6>
- Supasri, T., Itsubo, N., Gheewala, S.H., and Sampattagul, S. (2020). Life cycle assessment of maize cultivation and biomass utilization in northern Thailand. *Scientific Reports*, 10:3516. <https://doi.org/10.1038/s41598-020-60532-2>
- Swapna, G., Jadesha, G., and Mahadevu, P. (2020). Sweet corn - A future healthy human nutrition food. *International Journal of Current Microbiology and Applied Sciences*, 9(7):3859-3865. <https://doi.org/10.20546/ijcmas.2020.907.452>
- United Nations Scientific Committee on the Effects of Atomic Radiation [UNSCEAR]. (2000). Sources and effects of ionizing radiation. United Nations.
- United States Environmental Protection Agency [USEPA]. (1999). Cancer risk coefficients for environmental exposure to radionuclides (EPA. 402 R-99-001). United States Environmental Protection Agency.
- Van, T.T., Bat, L.T., Nhan, D.D., Quang, N.H., Cam, B.D., and Hung, L.V. (2019). Estimation of radionuclide concentrations and average annual committed effective dose due to ingestion for the population in the Red river delta, Vietnam. *Environmental management*, 63(4):444-454. <https://doi.org/10.1007/s00267-018-1007-8>
- Vu, N.B., Bui, N.T., Huynh, T.P., Vo, H.H., and Truong Thi Hong Loan. (2022). Total annual effective dose and health risk due to intake of natural radionuclides of some vegetables cultivated in suburban Ho Chi Minh City, Vietnam. *Journal of Radioanalytical and Nuclear Chemistry*, 331(6):2359-2367. <https://doi.org/10.1007/s10967-022-08290-5>
- Yang, B., Tuo, F., Zhou, Q., Zhang, J., Li, Z., and Pang, C. (2022). Dietary exposure of radionuclides and heavy metals in adult residents in a high background natural radiation area using duplicate diet method. *Scientific reports*, 12. <https://doi.org/10.1038/s41598-022-19979-8>