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Studies on dielectric properties of Gorgon nut (*Euryale ferox* Salisb.)

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ABSTRACT

In the present investigation the dielectric properties such as dielectric constant (ε′), dielectric loss (ε″), and dissipation factor (tan δ) of different Gorgon nut samples were measured. Significant variations observed in dielectric parameters of Gorgon nut could be attributed to its porosity, heterogeneity, inorganic composition and water content. The study reveals that the dielectric behavior of Gorgon nut could be attributed to macrostructure polarization.

Keywords: *Euryale ferox Salisb, Dielectric constant (ε′), Dielectric loss (ε″), Dissipation factor (tan δ), Water content mineral content Makhana.*

INTRODUCTION

Euryale ferox Salisb is a rooted floating maerophyte that is grown as a crop in Mithila area of northern Bihar. Its wild populations are available is different parts of north and northeastern India, Japan, Korea, China *etc*. It is an 8 month crop that is frequently grown in shallow water bodies of lentic types. Seeds collected from the pond bottom are roasted to yield white pops that are generally mistaken to be the product of lotus (*Nelumbo nucifera*). Makhana is widely associated with Mithila culture. It is held sacred and is used in Hindu rituals all over India. It is widely known for its spermatogenic properties and is intimately linked with a marital ritual called Kojagara. Jha, *et al*. (1991a, b) made nutritional evaluation of Makhana and found it having a high EAAI. Nath and Chakraborty (1985a,b) also investigated the properties of its starch and protein. Its pops face a loss of quality during storage, on account of attack of pests. Mechanized system of popping and decortication of its seeds as well as a formulation for Instant Makhana Kheer Mix has also been developed (Jha and Verma, 2008 and Jha, 2014).

Work done by Choo, *et al*.(2009) refer to cosmeceutical properties in *E.ferox*. Jan, *et al*. (2012) developed a nutri-bar with Makhana as a component. Negi, *et al.* (2011) developed a non-effervescent floating matrix tablet from its seed powder while Weimin, *et al.* (2012) investigated the mechanical properties of gorgon nuts at different maturities. Photochemical ingredients in *E. ferox* were been investigated by Zhao, *et al*, (1989), Zhao and Zhao (1994) *etc*.

Other bio-physical aspects of this plant have been investigated with reference to friction characteristics of its nuts in mechanical shelling (Zhang, *et al*, 2013) while Kumar, *et al*, (2013) investigated the influence of moisture content and grade on its engineering properties. Arjun, *et al.* (2016) studied the physico-fracture characteristics of *E. ferox* seeds.

MATERIALS AND METHODS

The popped Makhana samples were brought to laboratory within 24 hours of popping. Care was taken while collection of specific Makhana samples from different farmers and kept them separately in plastic boxes.

Preparation of specimens:

After the collection of popped Makhana samples, specimens (pellets or discs, bars, cylinders, and torroids) were cut from mid region of the Makhana samples for electrical and dielectric measurements. The Makhana surface at the site of electrode attachment was polished with progressively finer grades of sand paper. The above test pieces used in the different experiments were cut at the desired orientation and to the shape required using a diamond-slitting wheel. This permitted very light loading of the sample during the cutting operation and by means of a low speed of rotation. (Figure 1) Test pieces were stored in vacuo for two days prior to experimentation. Study was confined to estimate amount of water content and mineral content present in Makhana samples. The other remaining samples were stored in plastic boxes for the long period. After that the Makhana Smples were crushed into fine particles of 10 to 50 μm size Makhana powder by using ball mill (Model: Retsch PM 200, Germany). Specimens (pellets/discs) were prepared by applying the pressure (20kN to 30kN) by hydraulic machine (Model: AIMIL Ltd., Cat No. AIM 315 RAM DIA 86 mm, Bangalore) for dielectric measurements.

Fig. 1: Instruments used to prepare desired shape and size of required Makhana sample

Measurement of adsorbed water:

Percent water content of Makhana was determined by taking masses before and after oven drying and using the formula-

$W\% = [(m_1 - m_3)/m_1] \times 100$ where m_1 = mass of normal Makhana,
m_3 = mass of oven dried Makhana.

Density of Makhana:

The specific gravity and there by the density of Makhana with reference to its implication in drug delivery has been a subject of interest in recent years. The chemical analysis of Makhana specimens with their agricultural uses for practical purposes must be based on their density. The reason is that chemical analyses are usually associated with weight percent.

In general the density of wet and oven dried specimen, was measured by taking their masses in air (m_1) and when immersed in water (m_2), the density (d) is calculated as

$$d = m_1/(m_1 – m_2) \text{ gm/cm}^3$$

But, in our investigation density of Makhana in different physiological conditions was calculated by taking their masses in air (M) and calculating the volume of the sample to get accurate density values (to avoid absorption of water when Makhana samples were immersed in water). Then density was calculated as

$$d = \text{Mass/volume} = M/V \text{ gm/cm}^3$$

Fractional change (F_d) in the density of oven dried Makhana was determined by using the formula

$F_d = (d_1 – d_{2)}/d_1$ where d_1 = density of normal Makhana sample.
d_2=density of oven dried Makhana sample.

The mean values along with SD for different Makhana samples are tabulated in Table.1

Estimation of trace elements by atomic absorption spectroscopy:

For the estimation of trace elements by atomic emission spectroscopy, smooth powder of the Makhana sample was prepared by grinding. The powder was collected in clean polythene bags.

Fig. 2: Makhana / Gorgon nut powder in clean polythene bags

To analyze the Makhana samples by atomic emission spectroscopy Jerrel Ash 1.5 M plane grating spectrograph (Model no. 19-300 USA) was used. The electrodes were drilled with a fine drill bid. One of them was filled with the R.U (Raise Ultima) powder while the other was filled with sample under investigation (Makhana powder). The electrode containing the given sample was placed in the arc stand and the arc was struck between the electrodes and spectrum was recorded. During the exposure the current strength was varied so as to make the requisite excitation potential for various elements present in the sample. The R.U powder spectrum was recorded in juxtaposition. Similarly, iron spectrum was recorded in juxta position (upper) of the sample, so that spectrum of the sample was in between R.U powder and iron spectrum as shown in Figure 3.

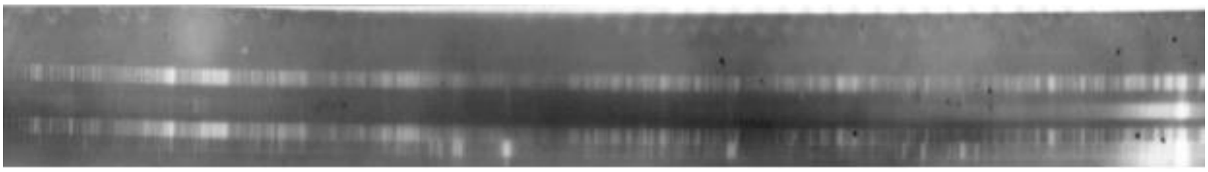

Fig. 3: Grating spectrograph of Makhana sample

The wavelength of a line in the sample spectrum was found out, by comparing the iron spectrum with R.U powder spectrum. The intensity variation helped to determine the presence of major and minor components of the elements and tabulated in Table 3.

Measurement of dielectric parameters:

For the study of dielectric properties, fresh pop was taken in the pellet form. After that compressed Makhana powder in the form of pellets or discs were taken to measure dielectric parameters.

For the dielectric measurements, (Shoaib, 2008) a two terminal cell was constructed in the laboratory. The cell consists of two parallel circular plates made up of copper. The diameter and thickness of the plates were 1.2 cm and 0.5 cm respectively. The lower circular plate electrode was plugged directly into the live terminal of the capacitance measuring bridge while the upper one, at earth potential was moved by means of a micrometer having least count 0.001 cm. This served two purposes. One was to apply a slight pressure on the specimen placed between them and the other was to measure the separation of the plates or the thickness of the sample.

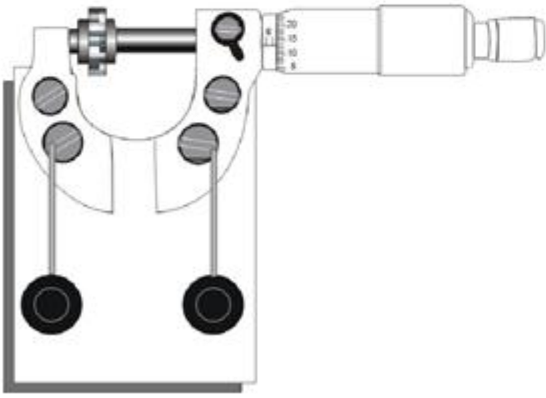

Fig. 4: Dielectric Cell for the measurement of dielectric properties

To eliminate capacitance due to leads, the capacitance (Ca) of the cell for different inter-electrode spacing (d) was measured. A plot was drawn between air capacitance on y – axis and 1/d value on x-axis. The plot was linear and the capacitance C_a at infinite distance of the plates (i.e. 1/d = 0) gave the value of lead capacitance (C_L) of the cell. This value was subtracted from the measured value of capacitance with the sample $C'_s$and with air C'_a to have an exact value of the capacitance with sample (C_s) and with air (C_a).

$$\text{i.e } Cs = C'_s - C_L \text{ and } C_a = C'_a - C_L$$

A commercial digital LCR meter (Pacific, PLCR 8C) was used to measure the capacitance and dissipation factor (tanδ). To have a comparative study of dielectric behavior of fresh pop sample and compressed powder in form of pellets in the applied alternating field of frequency 1 kHz. Capacitance and dissipation factor were measured with and without the sample in the cell. All the measurements were taken at room temperature. The dielectric constant (ε′) of the sample is given by

$$\varepsilon' = C_S / C_a = C'_S - C_L / C'_a - C_L$$

Where C_s = actual capacitance of the cell with the sample.
C_a = actual capacitance of the cell with air
C'_s = measured capacitance of the cell with sample
C'_a = measured capacitance of the cell with air.
C_L = lead capacitance.

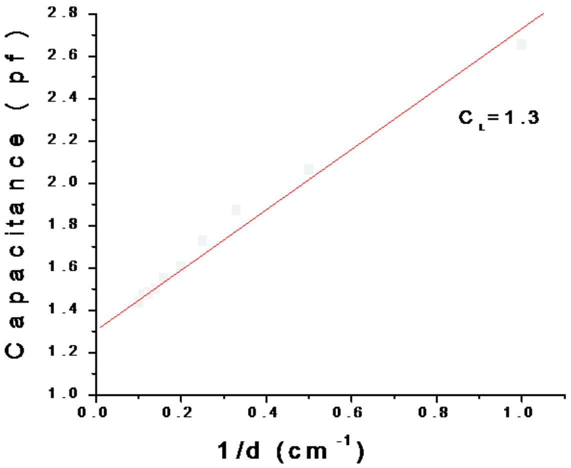

Fig. 5: Graph between 1/d vs Capacitance

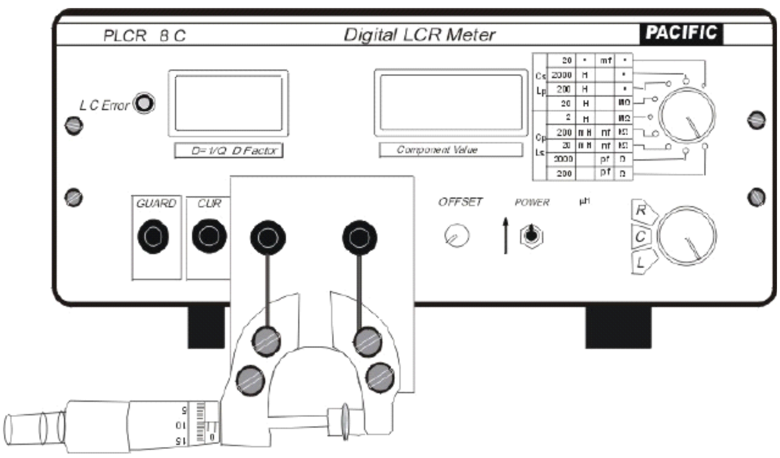

Fig. 6: Experimental set-up for the determination of dielectric properties of Makhana pops.

Knowing the value of ε′ and tanδ, the dielectric loss was calculated by using the formula ε″= tanδ. ε′. The specific alternating current conductance K was calculated from the relation $\varepsilon'' = 1.8 \times 10^{12}$ K/ν where ν is the frequency of the applied electric field in Hertzs. Results were tabulated in Table.3 and Table.4

RESULTS

Table 1 shows density of Makhana samples in different conditions such as fresh pop and its compressed powder. The data represents mean values along with S.D., taking 10 samples. The data reveals significant variation with respect to the type of Makhana and also its condition. Compressed Makhana powder in the form of pellets has more density than fresh normal pop. The average density values were tabulated for the above conditions. Table 2 shows elements present in Makhana samples in traces, which were estimated by atomic emission technique. Table 3 presents dielectric parameters of Makhana samples. The mean and S.D. were calculated for ten samples.

Table 1
Data on density of Makhana samples in different conditions

Makhana Samples	Density (Average value for 10 samples) gm/cm^3	
	Fresh normal pop	Compressed powder
M1	0.469 ± 0.10	0.997 ± 0.0
M2	0.482 ± 0.10	0.997 ± 0.0
M3	0.497 ± 0.13	0.997 ± 0.0
M4	0.484 ± 0.13	0.997 ± 0.0
M5	0.492 ±0.04	0.997 ± 0.0
M6	0.499 ±0.08	0.997 ± 0.0
M7	0.401 ± 0.09	0.997 ± 0.0
M8	0.469 ± 0.27	0.997 ± 0.0
M9	0.482 ± 0.15	0.997 ± 0.0
M10	0.497 ± 0.17	0.997 ± 0.0
Mean ± S.D.	**0.477 ± 0.12**	**0.997 ± 0.0**

Table 2
Major and Minor trace elements present in Makhana / Gorgon nut

Major elements	Minor elements
Copper (Cu), Sodium (Na), Calcium (Ca), Iron (Fe),Magnesium (Mg), Phosphorus (P) Potassium (K),Barium (Ba), Aluminium (Al), Antimony (Sb),Cadmium (Cd), Zinc (Zn)	Manganese (Mn),Chromium (Cr),Nickel(Ni), Lead (Pb), Tungsten (W),Vanadium (V),Titanium (Ti),Thallium (Tl),Rhodium (Rh), Molybdenum (Mo), Cobalt (Co), Tin (Sn), Beryllium (Be), Bismuth (Bi), Silver (Ag)

Table 3
Data on dielectric parameters of fresh pop Makhana measured at 1 kHz in room temperature

Fresh Popped Makhana Sample	Average Value for 10 samples each				
	Tan δ	Dielectric Constant ε′	Dielectric Loss ε″	Conductivity K (mho.cm^{-1}) x 10^{-9}	Resistivity ρ (ohm-cm) x10^9
M1	0.427 ± 0.14	23.83 ± 7.57	13.29 ± 2.68	7.3886±1.49x10^{-9}	0.1709±0.03 x10^9
M2	0.558 ± 0.04	27.12 ± 4.31	15.15 ± 2.68	11.1245±0.84 x10^{-9}	0.1302±0.02 x10^9
M3	0.514 ± 0.03	30.21 ± 1.19	17.20 ± 5.50	14.89202±4.68x10^{-9}	0.1019±0.03 x10^9
M4	0.396 ± 0.06	25.89 ± 5.55	13.91 ± 1.86	9.5568±3.33 x10^{-9}	0.1567±0.07 x10^9
M5	0.556 ± 0.06	29.12 ± 2.45	16.31 ± 1.86	13.3952±2.35 x10^{-9}	0.1191±0.06 x10^9
M6	0.346 ± 0.09	24.32 ± 6.14	16.13 ± 2.35	8.77295±1.03x10^{-9}	0.1667±0.07 x10^9
M7	0.562 ± 0.25	26.66 ± 3.95	13.60 ± 2.22	10.5568±3.33 x10^{-9}	0.1485±0.05x10^9
M8	0.269 ± 0.13	28.89 ± 3.14	14.94 ± 3.65	12.9460±1.25 x10^{-9}	0.1267±0.07 x10^9
M9	0.332 ± 0.18	27.75 ± 4.55	16.50 ± 2.26	11.8995±0.29 x10^{-9}	0.1392±0.01 x10^9
M10	0.696 ± 0.21	29.96± 3.11	16.89 ± 5.14	13.89202±4.68x10^{-9}	0.1144±0.04 x10^9
Mean ± S.D	**0.465 ± 0.11**	**27.37 ± 4.19**	**15.39 ± 3.02**	**11.4424 ± 2.32x10^{-9}**	**0.1374 ±0.045x10^9**

Table 4
Data on dielectric parameters of Makhana powder measured at 1 kHz, at room temperature

Makhana Powder Sample	Average Value for 10 samples each				
	Tan δ	Dielectric Constant ε′	Dielectric Loss ε″	Conductivity K (mho.cm^{-1}) x 10^{-9}	Resistivity ρ (ohm-cm) x10^{9}
M1	0.734 ± 0.01	119.84 ±2.44	67.56 ± 2.56	55. 568 ± 7.2 x10^{-9}	0.0254±0.03 x10^{9}
M2	0.703 ± 0.01	111.0 ± 8.20	66.00 ± 9.04	47.598 ± 1.16x10^{-9}	0.0327±0.01 x10^{9}
M3	0.766 ± 0.01	115.56 ± 2.56	59.76 ± 1.46	51.784 ± 5.0 x10^{-9}	0.0325±0.02 x10^{9}
M4	0.666 ± 0.01	106.64 ± 1.58	54.40 ± 8.88	42.227 ± 1.33 x10^{-9}	0.0399±0.05 x10^{9}
M5	0.715 ± 0.01	97.28 ± 2.45	64.52 ± 3.41	35. 091 ± 4.12x10^{-9}	0.0427±0.04 x10^{9}
M6	0.733 ± 0.01	116.48 ± 9.8	65.24 ± 4.42	53. 580 ± 4.9x10^{-9}	0.0297±0.06 x10^{9}
M7	0.696 ± 0.01	103.56 ± 2.22	55.64 ± 7.44	38. 227 ± 3.32 x10^{-9}	0.0416±0.07x10^{9}
M8	0.889 ± 0.01	120. 84± 4.76	68.80 ± 2.20	59. 568 ± 8.72 x10^{-9}	0.0231±0.03 x10^{9}
M9	0.947 ± 0.01	108.48 ± 1.72	60.60 ± 2.21	44.498± 3.36x10^{-9}	0.0391±0.07 x10^{9}
M10	0.844 ± 0.01	95.36 ± 3.02	53.16 ± 1.72	29.554 ±5.96x10^{-9}	0.0431±0.03 x10^{9}
Mean ± S.D	**0.770 ± 0.01**	**109.50 ± 3.87**	**61.56 ± 4.33**	**45. 769 ± 4.50x10^{-9}**	**0.0349 ± 0.04x10^{9}**

DISCUSSION

The relationship between electrical properties as a function of temperature and frequency with composition of Makhana/ Gorgon nut and density is poorly known. Three factors must be taken into account in Makhana density analysis: (1) the overall mass per unit volume or density of the whole specimen, (2) the density of its constituents and (3) the fact that the relative amounts of each of its constituents may vary simultaneously.

It can be noted that water content of the specimens, having lower specific gravity or density when hydrated is greater in proportion to the solids in the specimen than in the case of those Makhana specimens having a higher specific gravity or density when hydrated.

In the present study, electrical, dielectric and density measurements were conducted for the Makhana samples. By studying density in two different conditions it can be concluded that the density of fresh popped Makhana is less when compared to compressed Makhana powder. One possible explanation could be that the organization of the microstructure, as reflected by increased density, results in an increase in the area of carbohydrate in all directions. Although this may be true for normal popped Makhana, such relations may vary under different conditions. The Makhana sample displays a highly anisotropic and frequency dependent electrical and dielectric properties. Results on dielectric parameters of Makhana samples as a function of temperature and frequency in different conditions reveals that these parameters *i.e.*, dielectric constant (ε') dielectric loss (ε″) and dissipation factor (tanδ) of Makhana samples do not vary significantly with respect to the plant, but differ considerably with respect to the Makhana sample. This may be attributed to the similar chemical composition and structure of the Makhana substances with which the product like Makhana, is made up of. The slight variation in the values of dielectric constant (ε') and dissipation factor (tanδ) either among different samples of the same plant or different plants may be due to the highly porous nature of pops.

The value of dielectric constant of normal popped Makhana ranged from 23.83 ± 7.57 (Table 3). The dielectric parameters are very low compared to other dry fruits. In fact, plant seeds are considered as lossy dielectrics. They are partly polarisable and partly conductive. The high values of dielectric constant in biological seeds and fluids are because of free water they contain and due to this reason ion transfer process occurs. But here, Makhana possesses low values of dielectric constant due to the presence of very small quantity of free water.

Apart from water content, carbohydrate present plays a vital role in influencing the electrical behavior of Makhana seeds. When particle size of the sample is decreased by grinding for 24 -36 hours, the values of dielectic constant and dielectric loss and conductivity increase by nearly four times and resistivity decreases drastically. The large variation in dielectric parameters of Makhana samples, irrespective of the plant source, may be attributed to particle size, water content and the amount of mineral content present in them. Due to lack of free water, electrical resistance (R_s) of Makhana is very high of the order of 10^9 as compared to seeds of other plants. However Ahmad, *et al.* (1989) studied the dielectric parameters of biological tissues by using this technique. Hence these Makhana samples exhibit anisotropy in their electrical parameters. In general, dielectric parameters such as dielectric constant (ε'), dielectric loss (ε″), conductivity (K) and resistivity (ρ) depend on particular material involved, its particle size, concentration as well as environmental influences such as humidity, pressure, temperature and frequency of applied electric field. The dielectric parameters for Makhana samples in different conditions are as follows.

Dielectric Constant (ε'):

Compressed Makhana powder samples > Fresh popped Makhana samples

Dissipation factor (tanδ):

Compressed Makhana powder samples > Fresh popped Makhana samples

Dielectric loss (ε'):

Compressed Makhana powder samples > Fresh popped Makhana samples

Conductivity (K):

Compressed Makhana powder samples > Fresh popped Makhana samples

Resistivity (ρ):

Fresh popped Makhana samples > Compressed Makhana powder samples

From the present investigation the following conclusions could be drawn:

CONCLUSION AND RECOMMENDATIONS

1. The *Euryale ferox* powder (ESFP) floats on water surface. So this property very much utilized in the development of non-effervescent floating matrix tablets in pharmaceuticals.
2. From the present investigation it is observed that the density of Makhana sample is in the range 0.497 ± 0.02. By studying density in two different conditions it can be concluded that the density of fresh pop samples is less when compared to compressed powder samples.
3. The major trace elements present in Makhana samples are Cu, Na, Ca, Fe, Mg, P, K, Ba, Al, Sb, Cd, Zn, etc. The minor trace elements present in the present Makhana samples are Mn, Cr, Ni, Pb, W, V, Ti, Tl, Rh, Mo, Co, Sn, Be, Bi and Ag.
4. Dielectric parameters of Makhana samples are slightly low when compared with other seed samples.
5. Dielectric parameters such as dielectric constant (ε'), dielectric loss (ε″), conductivity (K) for fresh popped Makhana samples are low when compared to compressed Makhana

powder samples whereas resistivity (R) is very high for fresh popped Makhana samples as compared to compressed powder samples. Results of the present investigation show that when size of the Makhana particle decreases to microns, dielectric constant (ε'), dielectric loss (ε'') and conductivity (K) increase nearly four times and resistivity (ρ) drastically decreases. This significant variation may be attributed to the particle size of the chemical composition (carbohydrate, protein, calcium, phosphorus and iron) and water content of Makhana samples. Three parameters namely water content, particle size of the chemical composition and porosity with respect to applied electric field play an important role in influencing the electrical and dielectric properties of Makhana samples.

6. Post-harvest technology of gorgon nut could be possible through the dielectric studies. The results suggest that electrical dielectric spectroscopy could be used in the evaluation of Makhana/gorgon nut nature.
7. The five parameters namely water content, chemical composition (carbohydrate, proteins, calcium, phosphorus and iron), orientation of porous Makhana sample with respect to applied electric field, particle size and trace elements present in gorgon nut play an important role in influencing the dielectric and electrical properties of Makhana sample, when measured at bulk level.
8. The present investigation constitutes a step towards the application of dielectric and electrical measurements for medicinal plants for future needs.
9. The electrical and dielectric properties of Makhana are complex because Makhana/gorgon nut is an inhomogeneous composite sample containing chemical composition highly porous in nature and being structurally mechanically anisotropic.
10. A better understanding of dielectric and electrical properties of Makhana in different physical conditions may help one to develop/improve its new low cost Post-harvest technology.

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