Continuous infrared popping: Effect on key physicochemical attributes of popcorn

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Continuous infrared popping: Effect on key physicochemical attributes of popcorn

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Abstract

The effect of continuous infrared (Co-IR) popping at different power (600, 700 and, 800 watts (W) Co-IR power) and constant distance from sample (5 cm) on the key physicochemical properties of popcorn (*Zea Mays* L. var. Everta) (popping properties, energy consumption, morphology (SEM), sensory properties, and color) was investigated. According to the popping properties results, optimum treatment for Co-IR popping of popcorn was 700 W Co-IR power. Color were significantly changed ($P < 0.05$) during Co-IR popping. L*, a*, b*, ΔE, hue, and chroma values of Co-IR popped popcorn (700 W Co-IR power) were 71.40, -2.73, 15.44, 33.13±1.92, -1.40±0.29, and 15.68±1.07, respectively. The minimal energy usage was attained at 0.013 kWh at 800 W Co-IR power. In SEM analysis, with increasing the IR lamp power, the cavities size was increased (the cavities number per unit area decreased). The largest increase in the popcorn cavities size was determined at 800W Co-IR power. The highest consumer acceptance of Co-IR popped corns was obtained 700 W Co-IR power. This is the first study on Co-IR expansion technology for popcorn popping, and the findings show that the IR expansion method is very efficient in the popcorn popping process.

Keywords: Cereal grains, Continuous infrared, Infrared expansion, Maize, Popping.

1. Introduction

Popcorn as one of the foremost popular snacks worldwide is predestined especially for human consumption. Popcorn after expansion has great nutritional and functional attributes.[1] Expansion attributes are linked to the acceptance of sensory and consumption properties. Modification of desirable functional and sensory characteristics of foods through processing results in increased demand from consumer.[2] These attributes are the most important features of popcorn.[3]

Popcorn (flower) occurs through pericarpial breakage when grain pressure reach 930.79 kPa and the internal temperature reach 177°C.[4, 5] In this situation, the popcorn starch expands and forms the popcorn flower or expanded popcorn.[6, 7, 8] Heating of popcorn leads to a state of agitation in the water found in starch granules and has increased the inner pressure of the grain.[4, 5] Grain moisture content has a direct impact on the pressure within the grain during the popping. The high humidity reduces the rigidity of pericarp and rate of expansion, and low moisture content leads to the failure to achieve the internal vapor pressure needed for grain expansion.[9]

Brown rice in iron pan containing sand[10], white popcorn in microwave heating[7], popped rice in atmospheric radio-frequency plasma[11], sorghum in fluidized bed[12], and popcorn in aluminum popcorn popper[6], have been used for puffing and popping of cereal. In a study, effect of butter (1 % to 13 %) vegetable oil (1 % to 13 %), sodium chloride (0.5 % to 2.5 %), and sodium bicarbonate (0.0 % to 0.8 %), on popcorn properties were evaluated.[13] The effect of expansion method, moisture content (8 % to 16 %) and with and without oil of white popcorn on the sensory properties were evaluated. It was reported that 11.39 % without oil and 10.21 % with oil were the optimum humidity for expansion.[7]

Infrared (IR) irradiation is eco-friendly and very energy efficient compared to traditional heating. In addition, IR ability is characterized by high heat transfer, heating homogeneity, low processing (heating) time, improved product quality, low energy consumption, and food safety.[14] The IR irradiation was utilized in much food processing unit operations, such as drying, heating, roasting, microbiological inactivation, baking, cooking, peeling, and etc.[14, 15, 16] IR between ultraviolet (UV) and microwave wavelength is an electromagnetic spectrum part. The wavelength of IR is 0.76 μm to 1000 μm.[17]

The main goal of this study was to investigate how the continuous infrared (Co-IR) popping process (Co-IR power (600, 700, and 800 W) in the constant distance (5 cm) effect on key physicochemical attributes of popcorn (popping properties, color, morphology (SEM), sensory evaluation, and energy consumption).

2. Materials and methods

2.1. Sample preparation

The corn (*Zea Mays* L. var. Everta) which harvested in Karaj (Alborz Province, Iran) crop year 2019-2020 was used. The corn was cleaned, sifted, and stored in polyethylene bags. The corn humidity was measured through oven method (140 ◦C, 3 h).[18] The corn's had an inner humidity of 16.25%.

The corn's moisture and oil content were adjusted to 14 % and 20 %, respectively.

2.2. Continuous infrared popping

In this study, a pilot-scale continuous infrared (Co-IR) popping was developed and designed. The Co-IR system has a chamber (stainless-steel, length 120 cm, radius 30 cm), 2 IR lamps (1000 Watt, 350 mm), electric motor, variable frequency inverter (Pentax, 1.5 KW, Italy) and a power supply (Fig. 1). The effect of Co-IR system power (600, 700 and 800 W) and constant distance (5 cm) on the popcorn (oil 20 % salt 1 %, and humidity 14 %) were evaluated.

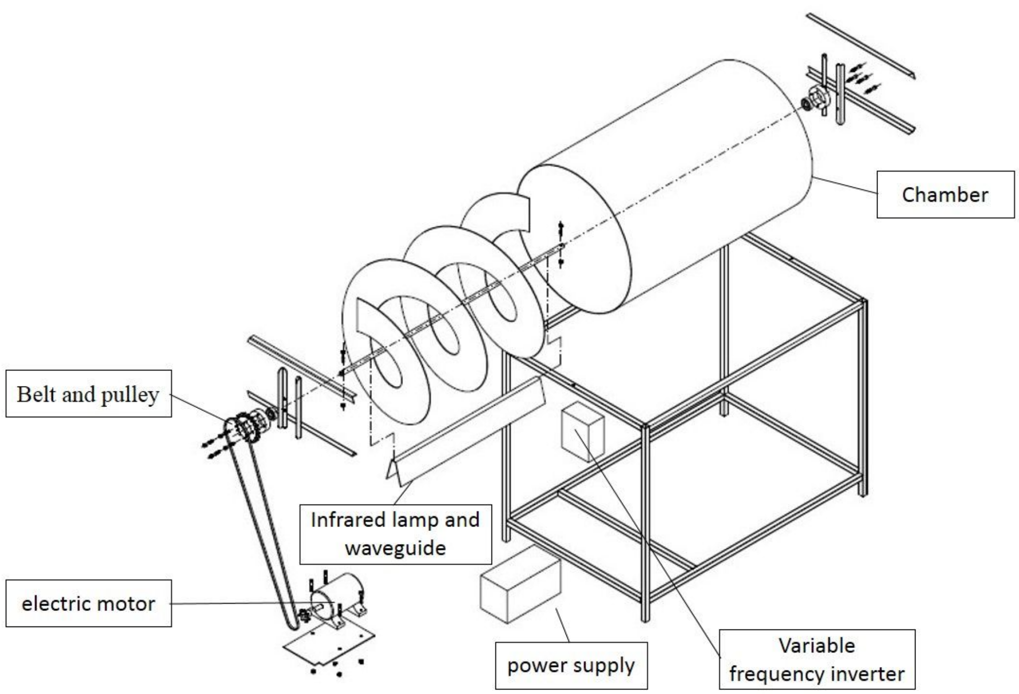

Fig. 1. Schematic diagram of pilot-scale continuous infrared (Co-IR) system.

2.3. Popping attributes

2.3.1. Popping yield

The un-popped samples were chosen after the popping process, and the total popcorn weights was recorded. The primary corn weight and the end popcorn weight were used to calculate the popping yield, which was given as a percentage Eq. (1):

$$\text{Popping yield (\%)} = \frac{(W_{fpg} + W_{spg})}{W} \quad (1)$$

Where, W_{upg} = Unpopped grains weight, W_{spg} = Semi-popped grains weight, W_{fpg} = Fully popped grains weight, and W = Grains after popping total weight = $W_{fpg} + W_{spg} + W_{upg}$.[19]

2.3.2. Volume expansion

The volume expansion was measured in a 500 mL cylinder. Eq. (2) was used to get the volume expansion ratio:

$$\text{Volume expansion ratio} = \frac{V_f}{V_i} \quad (2)$$

Where, V_i = Initial unpopped grains volume and V_f = Final popped grains volume.[19]

2.3.3. Popping percentage

Eq. (3) was used to compute the popping percentages;

$$\text{Popping percentage (\%)} = \frac{N_p}{\text{N}} \times 100 \quad (3)$$

Where, N= total number of initial grains and N_p = number of grains popped.[20]

2.3.4. Popping commencement

Using a stopwatch, the time of popping initiation from the start point was recorded as the popping commencement.[20]

2.3.5. Bulk density

In a 500 mL cylinder, the bulk density of popped corns was calculated using Eq. (4)[10]:

$$\text{Bulk density} = \frac{\text{mass (mg)}}{\text{volume (mL)}} \quad (4)$$

2.3.6. Expansion residue

The expansion residue (%) were evaluated using the Eq. (5):

$$\text{Expansion residue (\%)} = \frac{N_{up}}{\text{N}} \times 100 \quad (5)$$

Where, N_{up} = Number of grains that did not expand and N = Total number of initial grains.[7]

2.4. Color change

The popcorn color was evaluated using image J software. Each sample images were scanned and evaluated. The L* (lightness), a* (redness), and b* (yellowness) values were calculated.[21] L*, a*, and b* were used to compute the total color difference (ΔE) Eq. (6), chroma Eq. (7) and hue Eq. (8).

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad (6)$$

$$C = \sqrt{a^2 + b^2} \quad (7)$$

$$H = \tan^{-1}(b/a) \quad (8)$$

2.5. Energy consumption

Eq. (9) was used to calculate the threshold energy produced by Co-IR processing in the period between the start of process and the first popping.[20, 21]

$$\mathrm{E_{Co-IR}} = \mathrm{Co-IR} \times \mathrm{t} \quad (9)$$

Where t is the processing time (h) and Co-IR is the power consumption of Co-IR (kW).

2.6. Scanning electron microscopy

Scanning electron microscopy (SEM, Tescan Mira) was used to examine the influence of IR on the morphology of popcorn at high vacuum (10-4 Pa) and at 15 kV. Without cutting the popcorn, they were examined as whole grains. To get high-resolution pictures, samples were placed on aluminum stubs and a conductive layer of 8 nm gold was sprayed onto the samples.

2.7. Sensory evaluation

Measurement of the sensory evaluation of popcorns was performed using the modified method of Simic et al. (2018).[22] In this study, 34 trained panelists investigated the sensory properties of popcorns according to the most important sensory attributes including odor, taste, color, firmness, and general acceptance. The rate of samples from 1 the most satisfaction to 5 the lowest satisfaction were numbered.

2.8. Statistical analyses

The results were reported as mean of three independent replicates and the standard deviation. SAS software version 9.3 (SAS Institute Inc.) was used to analyze all of the data using Duncan post hoc at $P<0.05$.

3. Results and discussion

3.1. Popping attributes

The effect of Co-IR system on the popping attributes of popcorn was evaluated. The results of popping percentage, popping yield, popping commencement, expansion residue, bulk density, and volume expansion are shown in table 1. The analysis of variance showed a significant effect ($P < 0.05$) for popping percentage, popping yield, popping commencement, expansion residue, bulk density, and volume expansion.

Table 1. Popping properties of expanded popcorn through continuous infrared (Co-IR).

Power (W)	Popping yield (%)	Popping percentage (%)	Volume expansion	Popping commencement (Min)	Expansion residue (%)	Bulk density (g/cm^3)
800	88.42±1.67B	92.59±1.33A	13.66±1.31B	1.00±0.08C	7.41±1.45C	0.05±0.01A
700	89.28±1.33A	91.36±1.28B	14.15±1.33A	2.00±0.10B	8.64±1.11B	0.05±0.01A
600	76.84±2.00C	81.01±1.14C	12.00±1.04C	2.50±0.09A	18.99±1.33A	0.06±0.02A

Values are given as Mean ± SD. Different letters (a-c) within a columns indicate significant difference (*P*<0.05).

The highest popping yield (89.28 %) of Co-IR popped popcorn at 700 W Co-IR power was obtained. The highest popping percentage (92.59 %) of Co-IR expanded popcorn was obtained at 800 W Co-IR power. The highest volume expansion (14.15±1.33) of Co-IR expanded popcorn at 700 W Co-IR power was evaluated. The lowest popping commencement (1.08±0.08 min) of Co-IR expanded popcorn at 800 W Co-IR power were evaluated. The lowest expansion residue (7.41±1.45 %) of Co-IR expanded popcorn at 800 W Co-IR power was obtained. The lowest bulk density (0.05±0.01 g/cm3) of Co-IR expanded popcorn at 700 W Co-IR power and 800 W Co-IR power were obtained.

According to the results, the optimum treatment for Co-IR popping of popcorn was 700 W Co-IR power.

In pilot batch IR popping system, the optimum treatment for IR expansion of popcorn was 10 cm distance and 550 W IR power.[23]

The expansion volume can be related to the method of expansion, humidity, grain's physical characteristic (dimensions and density), and genotype.[24, 25] It was reported that the maximum expansion volume happened in the range of humidity from 15.5 % to 11.0 %.[24, 25, 26] The cereal bulk density after expansion severely decreased.[27]

3.2. Color changes

Color is one of the significant parameters in the food industry and affecting consumers' approval. Acceptability, preference, perception, saltiness, sweetness, and flavor are all influenced by color. As a result, color preservation during thermal processing is critical.[21, 28]

Table 2 indicates ΔE, hue, and chroma values and Fig. 2 shows color index (L*, a*, and b*) of Co-IR popped and control corn. Color index, ΔE, chroma, and hue were significantly changed in Co-IR popped popcorn ($P<0.05$).

Table 2. The effect of IR on ΔE, chroma, and hue in expanded popcorn.

Power (W)	ΔE	Chroma	Hue
Control (raw corn grains)		46.61±1.67a	1.45±0.48a
800	29.11±2.48c	18.22±0.99b	-1.52±0.15c
700	33.13±1.92a	15.68±1.07d	-1.40±0.29b
600	30.34±2.24b	17.96±1.11c	-1.41±0.27b

Values are given as Mean ± SD. Different letters (a-d) within a columns indicate significant difference ($P<0.05$).

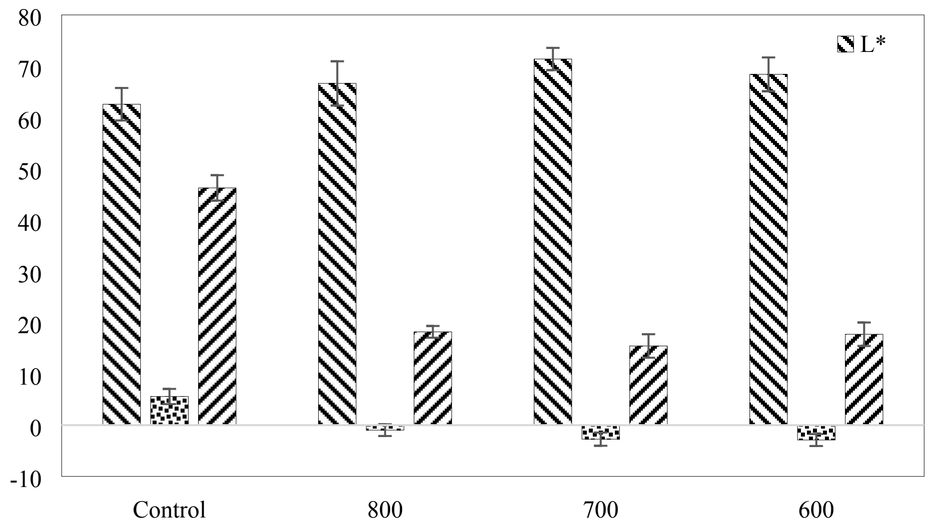

Fig. 2. Effect of continuous infrared (Co-IR) system on color index in expanded popcorns.

L*, a*, b*, ΔE, hue, and chroma values of Co-IR popped popcorn (700 W Co-IR power) were 71.40, -2.73, 15.44, 33.13±1.92, -1.40±0.29, and 15.68±1.07, respectively.

The color of expanded popcorn has something to do with the expansion peroperties.[29]

It was reported that in pilot batch IR popping system, L*, a*, b*, hue, and chroma values of IR popped corns (10 cm distance and 550 W IR power) were 76.297, -2.566, 9.502, -1.34, and 10.36, respectively.[23]

The effects of feed humidity and temperature of barrel zone on whole grain in extruded whole grain products were explored. The color look is improved by the reduced moisture levels and greater temperature.[30] The impact of the iron pan puffing method on the brown rice color was studied. The puffing procedure was shown to have a considerable impact on the brown rice color.[10] The color of cardamom seeds may be changed by IR irradiation, according to reports.[21]

3.3. Energy consumption

Table 3 shows the threshold energy for Co-IR treatments on expanded popcorn. The minimal energy usage was attained at 0.013 kWh at 800 W Co-IR power. The effect of several Co-IR treatments on expanded popcorn energy consumption was substantial (P< 0.05). The energy usage was reduced by lowering the Co-IR power and treatment time.

Table 3. The effect of different IR treatments on the threshold energy in expanded popcorn.

Power (W)	Time (min)	Threshold energy (kWh)
800	1	0.013c
700	2	0.023b
600	2.5	0.025a

Values are given as Mean ± SD. Different letters (a-c) within a columns indicate significant difference (P<0.05).

In pilot batch IR popping system, the minimum energy consumption in 0.0159 kWh at 10 cm distance and 450 W IR power was measured.[23]

The *B. cereus* in cardamom seeds was studied using IR power (100, 200, and 300 W), sample distance (5, 10, and 15 cm), and process time (0–11 min). The energy consumption was claimed to have dropped due to a reduction in treatment power and treatment duration, which was connected to our findings.[21] Devi and Das (2018) found that when grain thickness rose, the threshold energy increased as well.[20]

3.4. Surface morphology

Scanning electron microscopy (SEM_ was utilized to analyze change of structure in popped popcorn using Co-IR. The surface changes in popped popcorn at various Co-IR popping treatments, as illustrated in Fig. 3.

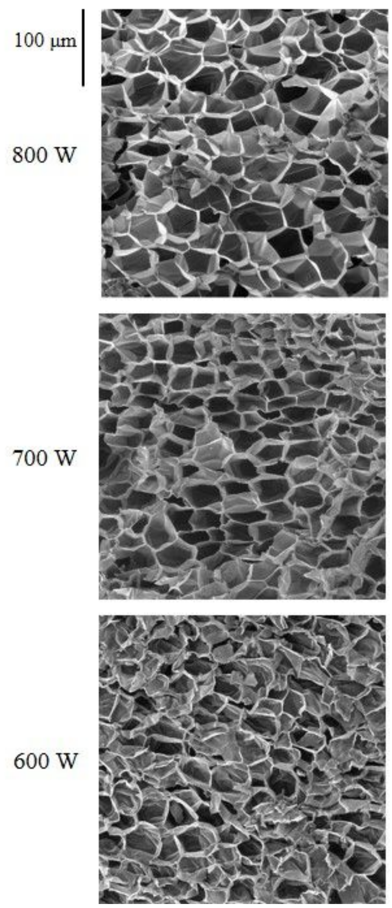

Fig. 3. Scanning electron microscopy of expanded popcorns at different stages of puffing through continuous infrared (Co-IR) system.

Many cavities were found in the samples, as seen in Fig. 3.

By increasing the IR lamp power, the cavities size was increased (the cavities number per unit area decreased). At 800W Co-IR power, the largest increase in the cavities size of popcorn was seen.

The effectiveness of the expansion process in popcorn is demonstrated by an increase in the cavities size, which results in an increase in the samples volume.

The results of the Co-IR popping attributes in table 1 correspond to the results of SEM analysis (surface morphology) in Fig. 3. As a result, the size of cavities has increase in tandem with the increase in volume expansion, popping yield, and popping percentage.

In our previous study in pilot batch IR popping system, the similar results was evaluated.[23]

The texture of popcorn is influenced by its expansion properties.[29] Higher expansion volumes may be linked to the softness and palatability of popcorn.[31] Gun puffing's effect on common wheat, emmer wheat, buckwheat, rice, barley, and rye was evaluated in a study. Puffing generates considerable changes in physical attributes and the structure of materials, according to SEM analysis, which was connected to our findings.[27]

3.5. Sensory evaluation

The effect of Co-IR popping on sensory evaluation of popcorns shown in Fig. 4. The effect of Co-IR popping on sensory evaluation such as odor, taste, color, firmness, and general acceptance in popcorns was significant ($P< 0.05$). The highest consumer acceptance of Co-IR popped corns was evaluated 700 W Co-IR power.

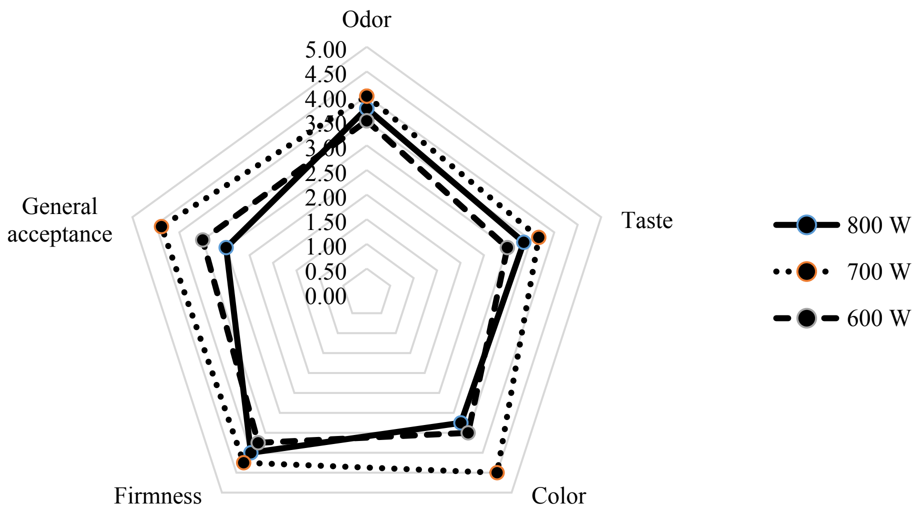

Fig. 4. The effect of continuous infrared (Co-IR) system on sensory evaluation of popcorns by panel test.

4. Conclusion

In this study, effect of continuous infrared (Co-IR) popping, Co-IR power (600, 700 and, 800 watts (W)) in the constant distance (5 cm) on key physicochemical attributes of popcorn (*Zea Mays* L. var. Everta) (popping properties, energy consumption, morphology (SEM), sensory evaluation, and color) was investigated. Popcorns physicochemical qualities were significantly affected by the popping process. According to results, the optimum treatment for Co-IR popcorn was 700 W Co-IR power. Color were significantly changed ($P < 0.05$) during Co-IR popping. L*, a*, b*, ΔE, hue, and chroma values of Co-IR popped popcorn (700 W Co-IR power) were 71.40, -2.73, 15.44, 33.13±1.92, -1.40±0.29, and 15.68±1.07, respectively. The energy usage was reduced by lowering the treatment time and

Co-IR power. The effectiveness of the expansion process in popcorn is demonstrated by an increase in the cavities size, which results in an increase in the samples volume. The cavities size has increase in tandem with the increase in volume expansion, popping yield, and popping percentage. The effect of Co-IR popping on sensory evaluation such as odor, taste, color, firmness, and general acceptance in popcorns was significant ($P < 0.05$). According to the findings, Co-IR popping is a high-efficiency popping process approach. Finally, it's possible that Co-IR popping technology might be researched for cereal grains enlargement.

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Conflict of Interest

All authors have no conflict of interest to report.

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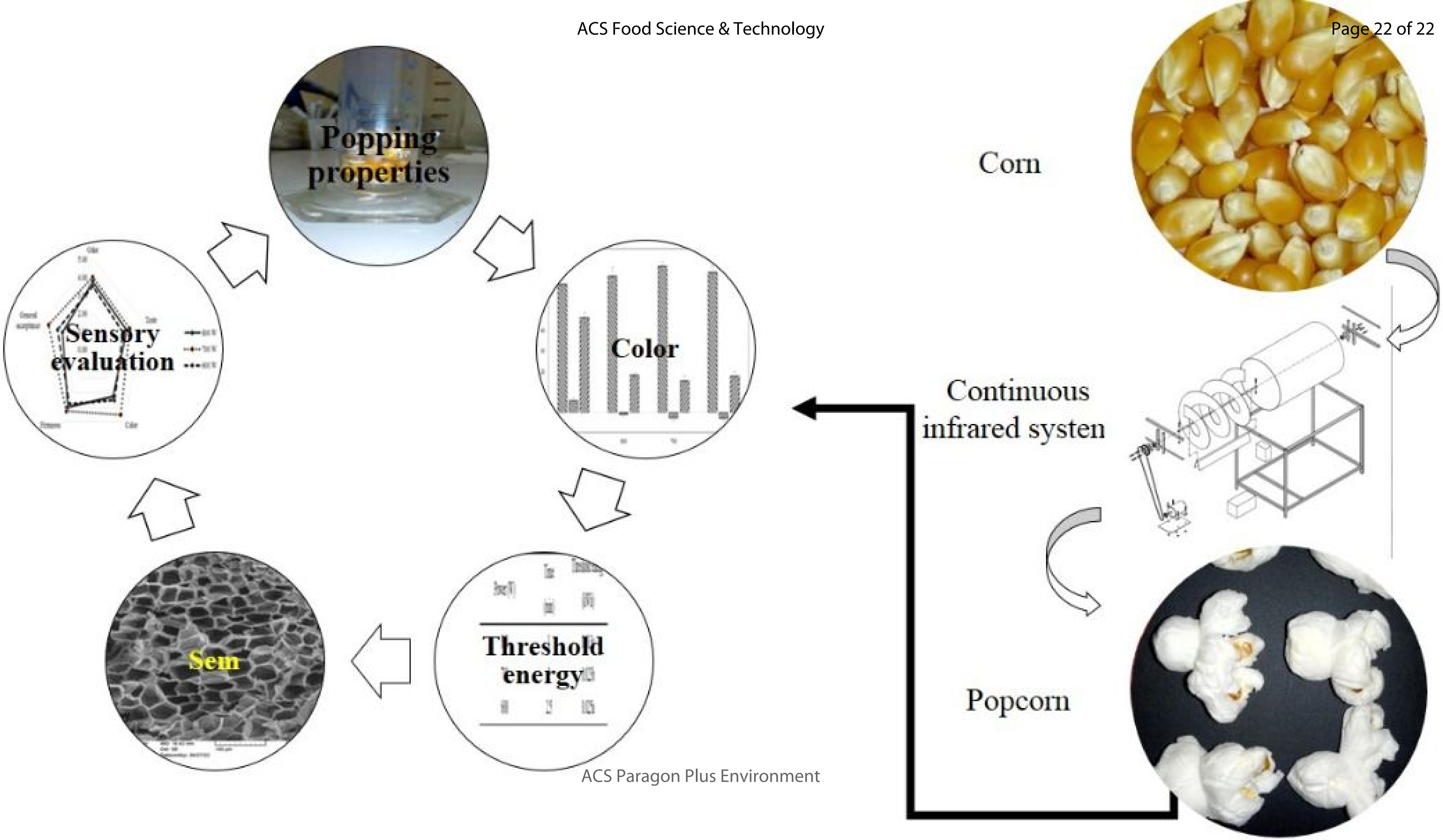
Corn
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