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# Encapsulation of curcumin through spherification: A novel nutraceutical approach

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**Abstract**
The curcumin sodium alginate balls were developed using pectin to standardize the process technology for encapsulation of curcumin by spherification technique. The primary objective was to enhance the stability and bioavailability of curcumin. Curcumin balls were prepared with different concentrations of sodium alginate 1%, 1.5%, 2% and 2.5% and pectin 0.25%, 0.50% and 0.75% along with 0.4% curcumin and spherified in a 0.4 M calcium chloride solution. These formulations were evaluated for the number of balls per gram, diameter, color parameters (L, *a*, b* values), curcumin content and total soluble solids (TSS). Sensory attributes such as color, flavor, texture, and overall acceptability were also assessed. Among the curcumin balls made with 0.75% sodium alginate and 0.75% pectin was found to be best with least number of balls per gram (11.747 g) and colour a* (2.415) and maximum value for Diameter (4.757 mm), colour L* (7.620), b* (35.492), curcumin content (0.4%) and TSS (15.156$^0$B) and maximum sensory score for colour (8.213), flavour (7.863), texture (8.063) and overall acceptability (7.833). The 0.4% Curcumin encapsulated by spherification with 2.5% sodium alginate and 0.75% pectin are recommended for consumption due to their superior physical, chemical and sensory qualities.

**Keywords:** Curcumin encapsulation, sodium alginate, spherification technique, pectin, calcium chloride, hydrocolloids

## Introduction

Turmeric is considered the soul of Indian spices. The rhizomatous herbaceous perennial plant *Curcuma longa* L, a member of the ginger family *Zingiberaceae* and native to tropical South Asia, is the source of turmeric. Temperatures between 20 °C and 30 °C and a significant amount of rainfall throughout the year are necessary for the turmeric plant to thrive. Each plant can reach a height of one meter and has long, oblong leaves. India leads the world in turmeric production, consumption, and exports. The country produced 11.16 lakh tons of turmeric from 2.90 lakh hectares during 2024-2025, accounting for more than 75% of the world's total production. Turmeric is grown in over 20 Indian states with more than 30 different varieties. Maharashtra, Telangana, Karnataka, and Tamil Nadu are the major turmeric-producing states (Anon., 2024-25) [5]. India consumes 80% of the turmeric produced worldwide due to its natural properties and high content of the crucial bioactive component curcumin (Prasad and Agarwal, 2011) [19].

Turmeric's primary clinical targets are the gastrointestinal system. It can be used to treat colon cancer, inflammatory bowel disease, and intestinal familial adenomatous polyposis (Hanai and Sugimoto, 2009) [12]. Turmeric has been used for ages as an antibiotic, blood purifier, dermatological treatment, liver illness remedy, conjunctivitis medication, antioxidant, diabetic retinopathy treatment, and cholesterol-lowering agent (Rathaur *et al.*, 2012) [21]. Antioxidants including vitamins C and E present in turmeric help to alleviate the signs of common chronic illnesses such as rheumatoid arthritis, cancer, atherosclerosis, liver disease, heart disease, and cataracts. Turmeric is also a great natural food colouring because of its natural ingredients, which has contributed to its growing popularity as a food additive (Pari *et al.*, 2008) [18].

Turmeric oleoresin is used to make curcumin, the yellow component that gives turmeric its colour. Turmeric is a widely used spice with well-established therapeutic benefits in Chinese and Indian medicine. It has frequently been utilized to treat a number of illnesses. An in-depth review of research on turmeric indicates that it is widely considered a valuable herb in traditional medicine with a broad range of potential health benefits (Nasri *et al*., 2014) [16].

Turmeric contains 390 Kcal of energy, 10 g of total fat, 3 g of saturated fat, is cholesterol-free, and provides 0.2 g of calcium, 0.26 g of phosphorus, 10 mg of sodium, 2500 mg of potassium, 47.5 mg of iron, 0.9 mg of thiamine, 4.8 mg of riboflavin, 4.8 mg of niacin, 50 mg of ascorbic acid, 21 g of dietary fiber, 3 g of sugars, and 8 g of protein. Other components identified in turmeric include 2-5% curcumin, 55-70% antioxidants, 0.5-0.8% flavonoids, 0.3-0.7% alkaloids, 0.4-0.5% phenols, 0.6-1.12% tannin, 0.2-0.5% saponins, 0.6-1.5% terpenoids, 2-6% essential oils, and 8-15% oleoresins (Jadhav *et al*., 2023). The flavonoid curcuminoids consisting of monodesmethoxycurcumin, bisdesmethoxycurcumin, and curcumin (diferuloylmethane) are the active ingredients in turmeric. About 90% of the curcuminoid content in turmeric is curcumin. Additional components consist of proteins, carbohydrates, and resins. Curcumin is the most thoroughly studied active ingredient, making up 0.3-5.4% of raw turmeric (Tanmay *et al*., 2006) [25].

Spherification, an innovative technique within the field of molecular gastronomy, was initially developed through laboratory research and has now been successfully integrated into the food industry. Through the process of spherification, liquids are encapsulated into small, spherical jellies using a combination of calcium chloride and sodium alginate. Spherification transforms liquids into edible spheres with a thin, gel-like outer layer and a liquid centre. These spheres burst with flavour when eaten. This technique allows for customization, creating spheres in various sizes, flavours, and textures, resembling edible caviar (Gaikwad *et al*., 2019) [10].

Spherification techniques can be classified according to preparation methods viz. Basic spherification, which involves injecting sodium alginate (SA) solution into a calcium solution, causing calcium ions to permeate into the SA droplet and form calcium alginate from the surface to the inside of the sphere (Tsai *et al*., 2017) [26]; and Reverse spherification (RVS), in which the calcium solution is injected into the SA solution, causing diffusion of calcium ions into the surrounding SA and forming calcium alginate in the outer layer (Lee and Rogers, 2012) [14].

Polysaccharides such as cellulose, starch derivatives, pectins, gums, and seaweed extracts are utilized in edible coatings. However, these substances are typically highly hydrophilic, which means that in moist environments they have poor gas and water barrier qualities. Research has shown that the majority of polysaccharides have good barrier properties at low relative humidity levels (less than 25%) (Baldwin *et al*., 2011) [6].

Alginates are an attractive component since they are obtained from marine brown algae (Mabeau and Fleurence, 1993) [15], which are non-toxic, biodegradable, and naturally occurring (Silva *et al*., 2006) [24]. According to Vilgis (2012) [27], they are categorized as hydrocolloids large, water-soluble molecules that increase viscosity and are often used as texturizers. The spherification process has potential for creating edible curcumin balls. The possible advantages of curcumin encapsulation include increased stability and bioavailability. It is feasible to produce these curcumin balls for use in supplements or food items. These curcumin balls have consumer acceptability and potential applications in the food industry.

## Material and Methodology

The experiment was conducted at Department of Post-Harvest Management of Medicinal, Aromatic, Plantation, Spices and Forest Crops (MAPSF), Post Graduate Institute of Post-Harvest Technology and Management Killa-Roha, Dist.-Raigad, Maharashtra, India (18° 42’5947” N, 73°17’9361” E) during the year 2024-2025. The experimental data were statistically evaluated using a factorial completely randomized design (FCRD).

**Plant material collection:** The fresh turmeric rhizomes was obtained from the local farmers at Sutarwadi Tal. Roha. Dist. Raigad of Maharashtra of variety Salem. Turmeric powder was made from the fresh turmeric rhizomes. The curcumin was extracted using Soxhlet method using Acetone as solvent from the turmeric powder.

### Preparation of Curcumin-Sodium Alginate-Pectin Beads Using Calcium Chloride Solution

**Preparation of Calcium Chloride Solution:** A clean beaker was used to measure 100 ml of distilled water. To this, 0.4 M calcium chloride ($CaCl_2$) was added and mixed thoroughly using a magnetic stirrer to ensure complete dissolution. The prepared calcium chloride solution was then refrigerated to chill. This chilled solution was later used for the formation of curcumin-sodium alginate beads through ionic gelation.

**Preparation of Sodium Alginate-Pectin-Curcumin Solution:** In a separate beaker, 100 ml of distilled water was measured, and 2.5 g of sodium alginate along with 0.4 g of curcumin powder were gradually added. The mixture was stirred using a magnetic stirrer until the sodium alginate was fully dissolved. The solution was then gently heated using a heating mantle. After heating, 0.75 g of pectin was slowly added to the sodium alginate solution while continuously stirring with a glass rod to ensure uniform mixing and prevent clumping.

**Methodology:** Four different concentrations of sodium alginate (1%, 1.5%, 2%, and 2.5%) were combined with three concentrations of pectin (0.25%, 0.50%, and 0.75%) along with 0.4% curcumin powder to standardize the formulation of curcumin-encapsulated sodium alginate-pectin beads. The best treatment will be selected for further experimentation based on physical, chemical, and sensory attributes.

### Characterization of the physicochemical properties of the curcumin

**No. of balls per g:** The no. of balls per gram was measured by using digital weighing balance.

**Diameter (mm):** The diameter of curcumin balls was measured using Vernier caliper and expressed in millimeter.

**ColourL*,a*and b*value:** The colour of curcumin balls was measured using colorimeter and expressed as L* (light to dark), a* (red to green), b* (yellow to blue) values.

**Curcumin content (%):** About 1g of the sample was refluxed with 75 ml acetone for 1 hr after which it was filtered, and volume made up to 200 ml. From this further 1ml was taken and volume made up to 100 ml in a standard flask. The UV spectral reading for this solution was recorded at 420nm. A UV spectrum was recorded for standard curcumin. Percentage curcumin in samples was calculatedusing the following formula: (Geethanjali *et al*., 2016) [11].

Curcumin (%) = [Ds ×As/100×Ws×1650] × 100

Where, Ds-dilution volume of the sample; Ws-weight of the sample taken in grams; As-absorbance of the sample; 1650-calculated standard value.

**TSS ($^0$Brix):** The total soluble solids were determined by using Hand Refractometer (Atago Japan, 0 to 32 ˚B) and the values were corrected at $20^0$ with the help of temperature correction chart (A.O.A.C. 2020) [1].

**Sensory evaluation:** The sensory quality of curcumin balls in terms of colour, flavour, texture and overall acceptability was studied during the filler trials of curcumin encapsulated sodium alginate pectin beads by the semi-trained panel of 9-10 judges on a 9-point Hedonic scale (Amerine *et al*. 1965) [4]. The overall acceptability rating was obtained by averaging the score for colour, flavour and texture. The samples with score of 5.5 and above was rated as acceptable.

**Statistical analysis:** The experiment was laid out in a Factorial Completely Randomized Design (FCRD) with four main treatments (sodium alginate concentrations 1%, 1.5%, 2% and 2.5%) and sub-treatments (0.25%, 0.50% and 0.75% pectin concentrations). Observations were recorded in triplicates, and critical differences were calculated to compare the effects of various treatments using mean values and ANOVA. Data were analyzed and interpreted based on the factorial completely randomized design, and valid conclusions were drawn only when significant differences ($p \leq 0.05$) were observed between treatment means. The statistical procedures followed the methods described by Panse and Sukhatme (1985) [17] and Amdekar (2014) [3].

## Results and Discussion

### Physical parameters of curcumin encapsulated sodium alginate pectin balls

**No. of balls per gram:** It is evident from Table 1 that 2.5% sodium alginate recorded the significantly lowest number of balls per gram (11.983), while 0.75% pectin also resulted in a significantly lower number of balls per gram (13.609). The interaction between different concentrations of sodium alginate and pectin on number of balls per gram was found to be significant. Among the combinations, T4P3 (2.5% sodium alginate and 0.75% pectin) recorded the lowest mean number of balls per gram (11.747). This reduction may be attributed to the higher concentration of sodium alginate, which increases the amount of alginate required to form each microsphere. Consequently, the particle size of the microspheres increases, resulting in fewer balls per gram. Similar findings were reported by Purwanti *et al*. (2020) [20], who observed a comparable trend while studying the effect of different sodium alginate-gelatin ratios on microsphere characteristics.

**Diameter (mm):** It is clear from the Table 1 that the maximum diameter of curcumin balls was recorded in 2.5% sodium alginate (4.598 mm) and 0.75% pectin (4.194 mm), both of which showed significant effects. The interaction between different concentrations of sodium alginate and pectin on diameter was also found to be significant. Among the interactions, T4P3 (2.5% sodium alginate and 0.75% pectin) exhibited the highest mean diameter (4.757 mm). This increase in diameter may be attributed to the higher concentration of sodium alginate, which results in a greater amount of alginate forming each microsphere. Consequently, the particle size of the microspheres increases. Similar findings were reported by Purwanti *et al*. (2020) [20], who observed a comparable trend while studying the effect of varying sodium alginate-gelatin ratios on microsphere characteristics.

**Colour L* value:** The L* colour value of curcumin-encapsulated sodium alginate balls increased with higher concentrations of both sodium alginate and pectin. The significantly highest L* value was recorded in 2.5% sodium alginate (7.517) and 0.75% pectin (7.063). The interaction between different concentrations of sodium alginate and pectin on the L* value was also found to be significant. Among the treatment combinations, T4P3 (2.5% sodium alginate and 0.75% pectin) exhibited the highest L* value (7.620), as shown in Table 1. This may be attributed to the fact that alginate/pectin gels exhibit higher hardness and an opaque, lighter appearance compared to pectin-only gels, as reported by De Avelar and Efraim (2020) [9].

**Colour a* value:** It is noticed from Table 1 that the lowest a* value was recorded in 2.5% sodium alginate (2.491) and 0.75% pectin (2.880), both showing significant effects. The interaction between different concentrations of sodium alginate and pectin on the a* value was also found to be significant. Among the treatment combinations, T4P3 (2.5% sodium alginate and 0.75% pectin) exhibited the lowest a* value (2.415). The decrease in the a* value may be attributed to surface darkening and the development of a reddish-brown hue. These findings are consistent with those reported by Alharaty and Ramaswamy (2020) [2], who observed a similar decreasing trend in the a* value due to the effect of sodium alginate-calcium chloride treatment on strawberries.

**Colour b* value:** It is clear from the Table 1, the significantly highest b* value was recorded in 2.5% sodium alginate (35.299) and 0.75% pectin (33.477). The interaction between different concentrations of sodium alginate and pectin among all the treatments the treatment $T_4P_3$ (sodium alginate 2.5% and pectin 0.75%) had the highest colour b* value (35.492). Indicating a notable increase in yellowness directly attributable to curcumin. This substantial difference in b* values suggests that curcumin is the primary determinant of the yellow coloration in these beads.

### Chemical parameters of curcumin encapsulated sodium alginate pectin balls

**Curcumin content (%):** According to Table 2, curcumin-encapsulated sodium alginate beads prepared with 0.4% curcumin exhibited the highest curcumin content in 2.5% sodium alginate (0.383%) and 0.75% pectin (0.354%), both showing significant effects. However, the interaction between different concentrations of sodium alginate and pectin on curcumin content was found to be non-significant. Among all treatments, T4P3 (2.5% sodium alginate and 0.75% pectin) recorded the highest curcumin content (0.395%). This may be attributed to the fact that increasing the concentration of alginate polymer generally improves encapsulation efficiency. Similar observations were reported by Danarto (2020) in the microencapsulation of riboflavin (vitamin B2) using alginate and chitosan, where higher concentrations of both polymers led to increased encapsulation efficiency.

**TSS ($^0$Brix):** It is evident from Table 2 that the maximum TSS was recorded in 2.5% sodium alginate (15.03°B) and 0.75% pectin (14.66°B), both of which showed significant effects. The interaction between different concentrations of sodium alginate and pectin on TSS was also found to be significant. Among the interactions, T4P3 (2.5% sodium alginate and 0.75% pectin) recorded the highest total soluble solids content (15.15°B). The increase in TSS may be attributed to the conversion of insoluble constituents into soluble ones. Similar observations were reported by Shoaei *et al*. (2022) [23], who studied the survivability of microencapsulated *Lactobacillus plantarum* in rose petal jam, and by Chauhan *et al*. (2013) [7], who observed a comparable trend in tender coconut pulp during jam manufacturing.

**Sensory quality evaluation of curcumin encapsulated sodium alginate pectin balls**

Table 3 clearly shows that curcumin-encapsulated beads prepared with different concentrations of sodium alginate and pectin received significantly higher sensory scores for colour, flavour, texture, and overall acceptability. The highest mean scores were recorded in 2.5% sodium alginate (8.083, 7.793, 7.974, and 7.777, respectively) and 0.75% pectin (7.953, 7.617, 7.504, and 7.623, respectively). Among the treatment combinations, T4P3 (2.5% sodium alginate and 0.75% pectin) achieved the highest sensory ratings for colour (8.213), flavour (7.863), texture (8.063), and overall acceptability (7.833). This improvement may be attributed to encapsulation, which masks the inherent bitterness of curcumin, enhances its solubility, and increases its bioavailability under gastrointestinal conditions. Similar results were reported by Sharma *et al*. (2022) [22] during the development of curcumin hydrogel beads for functional *kulfi* formulation.

**Table 1:** Effect of different concentration of Sodium Alginate and pectin on Physical parameters of curcumin balls

| Treatment | No. of balls per gram | | | | Diameter (mm) | | | | Colour L* value | | | | Colour a* value | | | | Colour b* value | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P1 | P2 | P3 | Mean | P1 | P2 | P3 | Mean | P1 | P2 | P3 | Mean | P1 | P2 | P3 | Mean | P1 | P2 | P3 | Mean |
| $T_1$ | 15.551 | 15.340 | 15.250 | 15.380 | 3.394 | 3.478 | 3.612 | 3.495 | 6.273 | 6.396 | 6.436 | 6.369 | 3.725 | 3.566 | 3.487 | 3.593 | 31.457 | 31.509 | 31.668 | 31.545 |
| $T_2$ | 15.120 | 14.817 | 14.687 | 14.874 | 3.720 | 3.860 | 4.054 | 3.878 | 6.610 | 6.788 | 6.905 | 6.768 | 3.264 | 3.075 | 2.971 | 3.103 | 32.462 | 32.553 | 32.753 | 32.589 |
| $T_3$ | 13.047 | 12.823 | 12.753 | 12.874 | 4.159 | 4.298 | 4.355 | 4.271 | 7.055 | 7.194 | 7.291 | 7.179 | 2.849 | 2.711 | 2.647 | 2.735 | 33.888 | 33.988 | 33.996 | 33.958 |
| $T_4$ | 12.263 | 11.940 | 11.747 | 11.983 | 4.444 | 4.592 | 4.757 | 4.598 | 7.403 | 7.530 | 7.620 | 7.517 | 2.588 | 2.468 | 2.415 | 2.491 | 35.161 | 35.243 | 35.492 | 35.299 |
| Mean | 13.995 | 13.73 | 13.609 | | 3.929 | 4.057 | 4.194 | | 6.835 | 6.977 | 7.063 | | 3.106 | 2.955 | 2.88 | | 33.242 | 33.323 | 33.477 | |
| | C.D. | | SE(m) | | C.D. | | SE(m) | | C.D. | | SE(m) | | C.D. | | SE(m) | | C.D. | | SE(m) | |
| Factor (A) | 0.034 | | 0.012 | | 0.030 | | 0.010 | | 0.029 | | 0.010 | | 0.027 | | 0.009 | | 0.048 | | 0.016 | |
| Factor (B) | 0.029 | | 0.010 | | 0.026 | | 0.009 | | 0.025 | | 0.009 | | 0.024 | | 0.008 | | 0.042 | | 0.014 | |
| Factor (A x B) | 0.059 | | 0.020 | | 0.052 | | 0.018 | | 0.050 | | 0.017 | | 0.047 | | 0.016 | | 0.084 | | 0.029 | |

| | | | | | |
|---|---|---|---|---|---|
| $T_1$ | : | Sodium alginate 1% | P1 | : | Pectin 0.25% |
| $T_2$ | : | Sodium alginate 1.5% | P2 | : | Pectin 0.50% |
| $T_3$ | : | Sodium alginate 2% | P3 | : | Pectin 0.75% |
| $T_4$ | : | Sodium alginate 2.5% | | | |

**Table 2:** Effect of different concentration of Sodium Alginate and pectin on chemical parameters of curcumin balls

| Treatment | Curcumin content (%) | | | | TSS ($^0$B) | | | |
|---|---|---|---|---|---|---|---|---|
| | P1 | P2 | P3 | Mean | P1 | P2 | P3 | Mean |
| $T_1$ | 0.285 | 0.304 | 0.316 | 0.302 | 14.035 | 14.194 | 14.280 | 14.170 |
| $T_2$ | 0.322 | 0.332 | 0.339 | 0.331 | 14.358 | 14.495 | 14.410 | 14.421 |
| $T_3$ | 0.342 | 0.354 | 0.365 | 0.353 | 14.572 | 14.701 | 14.815 | 14.696 |
| $T_4$ | 0.372 | 0.383 | 0.395 | 0.383 | 14.894 | 15.042 | 15.156 | 15.031 |
| Mean | 0.330 | 0.343 | 0.354 | | 14.465 | 14.608 | 14.665 | |
| | C.D. | | SE(m) | | C.D. | | SE(m) | |
| Factor(A) | 0.019 | | 0.007 | | 0.035 | | 0.012 | |
| Factor(B) | 0.017 | | 0.006 | | 0.030 | | 0.010 | |
| Factor(A x B) | NS | | 0.011 | | 0.061 | | 0.021 | |

**Table 3:** Effect of different concentration of Sodium Alginate and pectin on Sensory parameters of curcumin balls

| Treatment | Colour | | | | Flavour | | | | Texture | | | | Overall Acceptability | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P1 | P2 | P3 | Mean | P1 | P2 | P3 | Mean | P1 | P2 | P3 | Mean | P1 | P2 | P3 | Mean |
| $T_1$ | 7.507 | 7.567 | 7.707 | 7.593 | 7.180 | 7.290 | 7.453 | 7.308 | 6.737 | 6.787 | 6.927 | 6.817 | 7.06 | 7.187 | 7.313 | 7.187 |
| $T_2$ | 7.753 | 7.647 | 7.807 | 7.736 | 7.257 | 7.367 | 7.433 | 7.352 | 7.117 | 7.180 | 7.307 | 7.201 | 7.273 | 7.363 | 7.437 | 7.358 |
| $T_3$ | 7.863 | 7.950 | 8.087 | 7.967 | 7.557 | 7.610 | 7.717 | 7.628 | 7.653 | 7.683 | 7.72 | 7.686 | 7.533 | 7.863 | 7.907 | 7.768 |
| $T_4$ | 7.993 | 8.043 | 8.213 | 8.083 | 7.710 | 7.807 | 7.863 | 7.793 | 7.890 | 7.970 | 8.063 | 7.974 | 7.707 | 7.790 | 7.833 | 7.777 |
| Mean | 7.779 | 7.802 | 7.953 | | 7.426 | 7.518 | 7.617 | | 7.349 | 7.405 | 7.504 | | 7.393 | 7.551 | 7.623 | |
| | C.D. | | SE(m) | | C.D. | | SE(m) | | C.D. | | SE(m) | | C.D. | | SE(m) | |
| Factor (A) | 0.033 | | 0.011 | | 0.028 | | 0.01 | | 0.032 | | 0.011 | | 0.026 | | 0.009 | |
| Factor (B) | 0.029 | | 0.01 | | 0.024 | | 0.008 | | 0.028 | | 0.01 | | 0.023 | | 0.008 | |
| Factor (A x B) | 0.058 | | 0.02 | | 0.049 | | 0.017 | | 0.056 | | 0.019 | | 0.046 | | 0.016 | |

## Conclusion

The curcumin balls prepared by using 2.5% sodium alginate and 0.75% pectin with 0.4% curcumin had the highest retention rate in terms of number of balls per gram (11.747 g), colour a* value (2.415) and maximum value for Diameter (4.757 mm), colour L* value (7.620), colour b* value (35.492), curcumin content (2.135%) and TSS ($^0$B) (15.1560B). The diameter, colour L* value, colour b* value, curcumin content and TSS increased with increased in the concentration of sodium alginate and pectin. For the sensory evaluation the same combination exhibited the maximum sensory score for colour (8.213), flavour (7.863), texture (8.063) and overall acceptability (7.833). Thus curcumin encapsulated beads were suggested to prepare with 2.5% sodium alginate and 0.75% pectin. Thus curcumin beads with 0.4% curcumin encapsulated with 2.5 g sodium alginate and 0.75 g pectin were found to be the most acceptable formulation, maintaining desirable physical, chemical, and sensory properties under ambient conditions.

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