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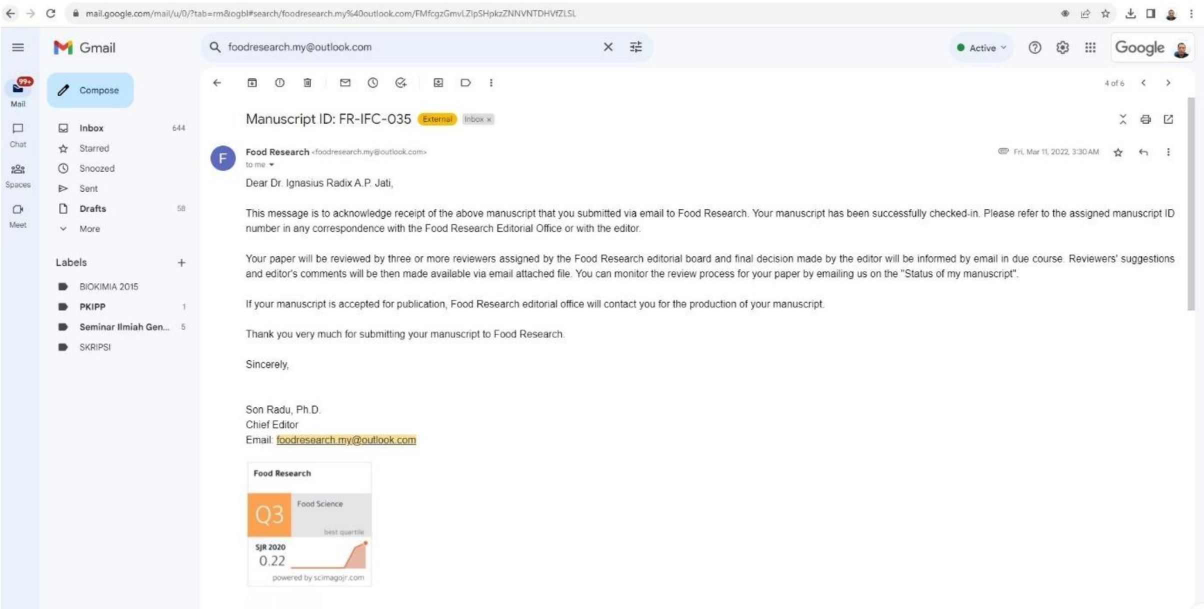
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Synergistic Effect of Kappa-carrageenan and Konjac Flour in Enhancing Physicochemical and Organoleptic Properties of Wheat-based Edible Straw

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Abstract

The food and beverage sector is one of the contributors to plastic pollution from the use of disposable tableware. The development of edible straws is an affordable solution to reduce the use of plastic tableware as well as a promising innovation to promote an eco-friendly lifestyle. This study was aimed at producing wheat-based edible straw made by combining high-protein wheat flour with kappa-carrageenan, konjac flour, salt and water. All ingredients were introduced to mixing, kneading, resting, dough rolling, dough flattening, molding, and baking. The effect of six different proportions of kappa-carrageenan and konjac flour (100:0, 80:20, 60:40, 40:60, 20:80, 0:100) on the physicochemical and organoleptic properties of wheat-based edible straw was evaluated. The water content of edible straws from all treatments ranged from 7.07-8.12%. Among the six treatments, the maximum synergy of kappa-carrageenan and konjac flour in producing high gel strength and desired edible straw characteristics was obtained from the proportion of 60:40 with the produced edible straw possessed the lowest water activity (Aw), % water absorption at tested temperatures (0-5, 25-30, and 65-70^{o} C), turbidity, and fracturability. The results of the organoleptic evaluation showed that the panelists slightly liked and could accept the aroma and color of wheat-based edible straw made with the proportion of kappa-carrageenan and konjac flour 60:40.

Keywords: edible straw, wheat flour, kappa-carrageenan, konjac flour

INTRODUCTION

The convenience and low price of plastic have brought communities to utilize plastic products in daily lives. The lack of public awareness in recycling plastic products along with poor waste management, however, has unwittingly made plastic waste a global crisis. Plastic is a polymer that takes many years to decompose and will persist in environment for hundreds of years. The accumulation of plastic waste has eventually posed detrimental effects to many aspects, including agricultural land, marine environment, animal, and human health[1].

The food and beverage sector accounts for a large proportion of plastic waste from disposable tableware, such as food wrappers, food and beverage containers, cutlery, and straw[2,3]. The reduction of aforementioned plastic usage can be endeavored through modifying the materials used to make the tableware[4]. In this study, edible straw was developed as one affordable solution to plastic waste issue in the beverage product sector. Edible straw is made from food ingredients that undergo cooking process, thus making it ready to be used and safe to be consumed. Moreover, unlike the plastic straw, edible straw is environment-friendly, completely biodegradable, and able to decompose if not needed[5].

Fracture resistance, insoluble in various beverage temperatures, and absence of distinctive aroma and taste are the ideal characteristics that have to be fulfilled by edible straw. In order to meet those criteria, high-protein wheat flour with the protein content of 12-13% was chosen as the basic ingredient to produce the edible straw. Besides having plain flavor and aroma, high-protein wheat flour contains complex protein called gluten. Each component of gluten, namely glutenin and gliadin, offers different unique characteristics that can provide a rigid structure to the edible straw. The continuous network of glutenin proteins through the polymerization disulfide bonds is responsible for creating an elastic and strong dough, whereas gliadin provides plasticity toward the glutenin polymeric network and preserves the whole protein structure. Glutenin and gliadin, after being added with water and introduced to kneading process, form a strong three-dimensional gluten matrix that generate a strong, stretchy dough and allows the dough to be shaped as desired[6].

In addition to high-protein wheat flour, a mixture of hydrocolloid consisting of kapaa-carrageenan and konjac was also incorporated in the present edible straw formulation. Hydrocolloids possess an important role as gelling agents targeted to strengthen the structure and lower the water absorption rate of the wheat-based edible straw[7]. The gelation of kappa-carrageenan is initiated by heating which changes the random coil structure into a helix structure. A decrease in the temperature favors the helices to associate with each other to form a hard, brittle thermo-irreversible gel. Compared to other types of carrageenan, kappa-carrageenan is less soluble in water due to the presence of hydrophobic 3,6-anhydrous-D-galactose group with lesser amount of hydrophilic sulfate ester group[8]. On the other hand, konjac is a high molecular weight, water-soluble polysaccharide containing glucomannan with a very high water absorptivity (up to 50 times its weight in water). Glucomannan comprises of the main chain of β-1,4-linkages that connect D-glucose and D-mannose backbones, and slightly branched through β-1, 6-glucosyl units. Gels of konjac can be both thermo-reversible and thermo-irreversible[9].

The combined use of kappa-carrageenan and konjac flour was based on the ability of konjac flour to enhance the properties of kappa-carrageenan gel, allowing the produced gel to be stronger, more elastic, and more stable. The synergistic interaction between these hydrocolloids is the result of association and lining up of the mannan molecules into the junction zones of helices[10]. However, researches also indicated that the improvement of gel quality was influenced by the optimal proportion of kappa-carrageenan and konjac. Tunieva *et al*.[11] found out the ratio of 1:1 was the optimal ratio of kappa-carrageenan and konjac gum to generate strong and plastic gels. The same conclusion was also reported by Kaya *et al.*[12] Another study by Wei *et al.*[13] reported the largest strength of gels was produced from combining kappa-carrageenan and konjac gum with the ratio of 5.5:4:5. Therefore, the aim of this study was to investigate the effect of various proportions of kappa-carrageenan and konjac flour in producing wheat-based edible straw with ideal physicochemical characteristics. Furthermore, the selected treatment was proceeded to the organoleptic test to evaluate consumer acceptance of the wheat-based edible straw.

MATERIALS AND METHODS

Materials

Commercial high-protein wheat flour containing 13% protein, table salt, and drinking water were purchased from the local market in Surabaya, Indonesia. Kappa-carrageenan and konjac flour were obtained from PT. Algalindo Perdana, Indonesia.

Methods

Preparation of wheat-based edible straw

Wheat-based edible straws were prepared by mixing high-protein wheat flour (150 g), kappa-carrageenan (0-7.5 g), konjac flour (0-7.5 g), and table salt (1.5 g) with water (100 ml). The amount of kappa-carrageenan and konjac flour was adjusted in such a way that their proportion came to 100:0 (P1), 80:20 (P2), 60:40 (P3), 40:60 (P4), 20:80 (P5), and 0:100 (P6) with the total amount of 7.5 g. The mixture was thoroughly kneaded until uniform and rested for 30 min. The dough was rolled using rolling pin and further flattened using dough flattener to a thickness of ± 0.08 cm. The thin dough was cut into a rectangular shape (15 cm x 2 cm) and molded around the surface of stainless-steel straw covered with baking paper to form a cylindrical shape. The dough was baked at 100 ^{o}C for 1 h, cooled at room temperature for 1 h, and packed inside a PP plastic added with pouched silica gel.

Moisture content and water activity

Moisture content of wheat-based edible straw was measured thermogravimetrically according to Association of Official Analytical Chemists method[14]. Water activity was measured using Aw meter (Rotronic, Switzerland).

Texture analysis

The fracturability evaluation of wheat-based edible straw was performed using a texture analyzer (TA-XT2 Texture Analyzer, Stable Micro System, England) according to Carsanba and Schleining[15] with some modification. The sample was laid on two supports and subjected to a shear test using a 3-point bending rig until the sample snapped into two. The pre-test speed was 3 mm/s, test speed was 3 mm/s, and post-test speed was 10 mm/s. The fracturability was determined based on the maximum peak force (N) which indicated the cutting force of wheat-based edible straw.

Water absorption test

Water absorption test was performed according to the method proposed by Harouna *et al*.[16] with some modification. The samples from all treatments were prepared with all were of the same weight. The prepared samples were immediately immersed in cool (5-10 ^{o}C), room (25-30 ^{o}C), and warm (65-70 ^{o}C) water. The samples were taken out from the water, drained, weighed, and re-immersed in water every 5 min for 20 min. The percentage of water absorptivity was calculated using the formula below:

$$\text{Water absorptivity (\%)} = \frac{wt.\ of\ sample\ after\ immersion - wt.\ of\ sample\ before\ immersion}{wt.\ of\ sample\ before\ immersion} \times 100\%$$

Solubility evaluation using turbidity test

The level of turbidity represents the amount of wheat-based edible straw's solids leached out into the beverage product. The turbidity test was performed by immersing the wheat-based edible straws into warm water (65-70 ^{o}C) for 10 min. The turbidity of the water was analyzed using a turbidimeter (Velp Scientifica, Italy) and the results were expressed in Nephelometic Turbidity Units (NTU).

Organoleptic evaluation

Wheat-based edible straw that possessed the lowest Aw, water absorptivity, turbidity, and the highest fracture resistance was proceeded to the organoleptic evaluation. The evaluation was conducted by 100 untrained panelists with the parameters of wheat-based edible straw tested were color and aroma. The samples were evaluated using a five-point hedonic test with line scales (1 = strongly dislike, 5 = strongly like).

Statistical analysis

All the analyses were done four times and the results were expressed as mean values ± standard deviation (SD). Analysis of variance (ANOVA) was performed to analyze differences between treatments. If significant difference was found, the treatments were compared by using Duncan's Multiple Range Test ($p \leq 0.05$).

Result and Discussion

Edible straw is one form of cutlery in the form of straw. The aims of this innovation is to reduce the amount of plastic-based straw. The preliminary research revealed that wheat can be used to create the edible straw, however, it had limitation on its susceptibility to fracture. Thus, the edible straw will be difficult to produced, transported and stored, and also used. Hydrocolloids can be used in the formulation of edible straw to improve its physical, chemical, and sensory properties. According to……….. hydrocolloids have the ability as gelling agent through bonding and networking with water, starch, and gluten, then could improve the quality of edible straw. Hydrocolloids such as kappa carrageenan and konjac can potentially be used to produce edible straw

Edible straw merupakan salah satu inovasi dari edible cutlery yang berbentuk sedotan. Tujuan dari inovasi ini adalah untuk meminimalkan penggunaan limbah sedotan plastik sekali pakai. Berdasarkan penelitian pendahuluan, edible straw berbahan dasar terigu memiliki sifat yang mudah patah. Oleh karena itu, diperlukan bahan tambahan untuk menghasilkan edible straw yang tidak mudah patah yaitu bahan hidrokoloid kappa karagenan dan tepung konjak secara kombinasi. Bahan hidrokoloid digunakan karena memiliki kemampuan dalam membentuk gel (sebagai gelling agent) dengan membentuk ikatan dengan air, pati, dan gluten sehingga dapat meningkatkan kekuatan edible straw yang dihasilkan (Devi dkk, 2019). Kappa karagenan menghasilkan gel yang kuat namun rapuh (Siregar dkk, 2016), sedangkan tepung konjak menghasilkan gel yang elastis (Sudjarwo dkk, 2019). Kombinasi kappa karagenan dan tepung konjak dengan proporsi tertentu menghasilkan kekuatan gel yang tinggi karena tepung konjak dapat menurunkan kerapuhan gel kappa karagenan sehingga diharapkan dapat menghasilkan edible straw yang tidak mudah patah. Proporsi kappa karagenan dan tepung konjak yang digunakan pada penelitian ini yaitu 100:0; 80:20; 60:40; 40:60; 20:80; dan 0:100. Parameter yang diuji dalam penelitian ini diantaranya yaitu kadar air, water activity (aw), tekstur, daya serap air, turbiditas, dan organoleptik (warna dan aroma) edible straw.

Kadar Air Pengujian kadar air bertujuan untuk mengetahui jumlah air bebas ataupun terikat lemah yang terkandung dalam edible straw berbahan dasar terigu dengan proporsi kappa karagenan dan tepung konjak yang berbeda. Kadar air berkaitan dengan umur simpan (self life) suatu produk pangan, termasuk edible straw. Semakin tinggi kadar air yang terdapat pada suatu produk pangan, maka umur simpan akan semakin rendah. Hal ini terjadi karena kadar air yang tinggi dapat dimanfaatkan untuk pertumbuhan mikroorganisme seperti bakteri, kapang, dan khamir yang menyebabkan penurunan mutu (Jay dkk, 2005). Selain itu, parameter kadar air juga mempengaruhi parameter lainnya seperti tekstur daya patah, daya serap air, turbiditas, dll. Pengujian kadar air edible straw dilaksanakan dengan metode thermogravimetri. Prinsip dari metode ini adalah menguapkan air bebas dan air terikat lemah yang ada dalam sampel dengan pengovenan pada suhu 105oC hingga berat konstan. Jumlah air yang terdapat dalam sampel dihitung dari selisih berat sampel sebelum dan sesudah pemanasan (Sudarmadji dkk, 2010). Pengaruh proporsi kappa karagenan dan tepung konjak terhadap kadar air edible straw berbahan dasar terigu dapat dilihat pada Gambar 4.1. Berdasarkan hasil pengujian, kadar air edible straw dengan penambahan proporsi kappa karagenan dan tepung konjak yang berbeda berkisar antara 7,07-8,12%. Hasil pengujian kadar air edible straw dianalisa menggunakan uji ANOVA dengan α=5% (Lampiran D.1.1.) dan menunjukkan hasil bahwa ada pengaruh proporsi kappa karagenan dan tepung konjak terhadap kadar air edible straw berbahan dasar terigu. Hasil pengujian ANOVA ini dilanjutkan dengan uji DMRT (Duncan Multiple Range Test) pada α=5% (Lampiran D.1.2.).

Berdasarkan Gambar 4.1, kadar air edible straw terendah ada pada perlakuan proporsi kappa karagenan dan tepung konjak 100:0 (P1) dan 0:100 (P6) yang tidak berbeda nyata, sedangkan kadar air tertinggi ada pada proporsi kappa karagenan dan tepung konjak 60:40 (P3). Proporsi kappa karagenan dan tepung konjak 80:20 (P2) dan 60:40 (P3) menghasilkan peningkatan kadar air edible straw, sedangkan proporsi 40:60 (P4) dan 20:80 (P55) menghasilkan penurunan nilai kadar air edible straw. Edible straw dengan kappa karagenan 100% (P1) dan tepung konjak 100% (P6) menghasilkan nilai kadar air yang tidak berbeda nyata karena kappa karagenan dan tepung konjak yang ditambahkan adalah dalam presentase yang sama yaitu 5%, dimana kedua jenis hidrokoloid ini memiliki kemampuan mengikat air yang baik karena adanya gugus hidroksil (Adriaprana dkk, 2016). Secara umum, air yang terperangkap dalam hidrokoloid adalah air yang terikat lemah, sehingga masih dapat terlepas ketika proses pengovenan (Supriyati dkk, 2016).

Berdasarkan Gambar 4.1, Edible straw dengan kombinasi kappa karagenan dan tepung konjak memiliki kadar air yang lebih tinggi dibandingkan edible straw dengan kappa karagenan 100% (P1) atau tepung konjak 100% (P6). Hal ini terjadi karena sinergitas antara kappa karagenan dan tepung konjak dalam menghasilkan struktur gel yang memiliki kemampuan mengikat air lebih baik dibandingkan kappa karagenan atau tepung konjak saja (Adiaprana dkk, 2016). Senyawa glukomannan yang ada pada tepung konjak akan masuk ke junction zone stuktur gel kappa karagenan sehingga menghasilkan ikatan dengan air yang kuat (Aldin dkk, 2020). Ikatan air yang kuat menyebabkan sedikitnya jumlah air yang teruapkan saat pengovenan suhu 100oC selama 1 jam sehingga air yang tersisa dalam edible straw akan semakin banyak. Proporsi kappa karagenan dan tepung konjak 80:20 (P2) dan 60:40 (P3) menunjukkan kenaikan nilai kadar air karena struktur gel dan daya ikat air yang semakin kuat pula, dimana gel konjak akan masuk ke struktur double helux gel kappa karagenan yang dominan menghasilkan ikatan yang kuat dengan air. Dengana adanya hal ini maka air dari adonan edible straw akan sulit terlepas saat pengovenan pada suhu 100oC selama 1 jam sehingga kadar air akhir edible straw yang dihasilkan semakin meningkat. Hasil yang berbeda terjadi pada proporsi kappa karagenan dan tepung konjak 40:60 (P4) dan 20:80 (P5) menunjukkan penurunan nilai kadar air. Hal ini terjadi karena struktur double helix dari kappa karagenan lebih sedikit dibandingkan tepung konjak sehingga banyak gel konjak yang berada diluar struktur double helix gel kappa karagenan sehingga ikatan dengan air menurun. Oleh karena itu, air dalam adonan edible straw semakin mudah lepas ketika pengovenan pada suhu 100oC selama 1 jam sehingga kadar air akhir edible straw yang dihasilkan semakin menurun.

Proporsi kappa karagenan dan tepung konjak yang menghasilkan nilai kadar air edible straw tertinggi adalah 60:40 (P3). Hal ini terjadi karena sinergitas dari kappa karagenan dan tepung konjak terbaik dimana gel konjak masuk struktur double helix gel kappa karagenan serta pembentukkan gluten dari terigu secara maksimal sehingga menghasilkan daya ikat air yang maksimal pula. Oleh karena itu, air yang terlepas saat pengovenan suhu 100oC selama 1 jam paling rendah diantara perlakuan yang lain. Hasil penelitian ini sejalan dengan hasil penelitian yang dilakukan oleh Adlin dkk (2020) yang menyatakan bahwa penggunaan kombinasi kappa karagenan dan tepung konjak menghasilkan kadar air edible film yang lebih tinggi dibandingkan penggunaan kappa karagenan ataupun tepung konjak saja. Karakteristik yang diharapkan pada edible straw adalah kadar air yang rendah untuk memperpanjang masa simpannya. Secara keseluruhan, nilai kadar air edible straw berbahan dasar terigu pada penelitian lebih tinggi dibandingkan kadar air edible plate berbahan dasar tepung sorghum yaitu 2,57% (Sood and Deepshika, 2018). Meskipun kadar air yang dihasilkan produk edible straw (7,07-8,12%) lebih tinggi, namun kadar air ini masih tergolong rendah sehingga memiliki umur simpan yang panjang.

Water Activity (aw) Water activity (aw) merupakan salah satu parameter yang menentukkan umur simpan produk pangan (Syamaladevi dkk, 2016). Water activity adalah banyaknya kandungan air bebas yang terkandung dan produk pangan. Air bebas dapat dimanfaatkan untuk pertumbuhan mikroba yang mengakibatkan penurunan mutu, sehingga semakin tinggi kandungan air bebas dalam suatu produk maka umur simpannya akan semakin rendah (Sakti dkk, 2016). Nilai water activity berkisar antara 0-1 dimana semakin mendekati 1 maka kandungan air bebas dalam produk semakin tinggi, dan sebaliknya. 30 Pengukuran water activity dilakukan dengan alat aw meter dengan cara memasukkan sampel kedalam tabung hingga setengah tinggi tabung kemudian dimasukkan kedalam chamber dan didiamkan selama 5 menit, lalu angka yang terbaca pada layar alat merupakan water activity produk (Ariani dkk, 2016). Pengaruh konsentrasi kappa karagenan dan tepung konjak terhadap water activity edible straw berbahan dasar terigu dapat dilihat pada Gambar 4.2. Berdasarkan hasil pengujian water activity edible straw dengan penambahan proporsi kappa karagenan dan tepung konjak yang berbeda berkisar antara 0,360-0,464. Hasil pengujian water activity edible straw dianalisa menggunakan uji ANOVA dengan α=5% (Lampiran D.2.1.) dan menunjukkan hasil bahwa ada pengaruh proporsi kappa karagenan dan tepung konjak terhadap water activity edible straw berbahan dasar terigu.

Berdasarkan hasil pengujian pada Gambar 4.2, nilai water activity tertinggi terdapat pada perlakuan proporsi kappa karagenan dan tepung konjak 100:0 (P1) dan 0:100 (P6) yang tidak berbeda nyata, sedangkan nilai aw terendah terdapat pada perlakuan proporsi kappa karagenan dan tepung konjak 60:40 (P3). Pada Gambar 4.2 dapat dilihat bahwa aktivitas air edible straw dengan kombinasi kappa karagenan dan tepung konjak lebih rendah dibandingkan penggunaan kappa karagenan 100% (P1) ataupun tepung konjak 100% (P6). Hal ini sejalan dengan pernyataan oleh Adriaprana dkk (2016) yang menyatakan bahwa sinergitas antara kappa karagenan dan tepung konjak menghasilkan aktivitas air produk yang lebih rendah dibandingkan penggunaan penggunaan kappa karagenan atau tepung konjak saja (Adiaprana dkk, 2016). Dari hasil pengujian ini, dapat dilihat bahwa perlakuan kombinasi kappa karagenan dan tepung konjak 80:20 (P2) dan 60:40 (P3) menghasilkan penurunan nilai water activity edible straw sedangkan pada proporsi 40:60 (P4) dan 20:80 (P5) menghasilkan peningkatan water activity edible straw. Penurunan water activity pada proporsi kappa karagenan dan tepung konjak 80:20 (P2) dan 60:40 (P3) disebabkan karena adanya sinergisme antara kappa karagenan dan tepung konjak dimana gel konjak akan masuk ke junction zone sturktur gel kappa karagenan yang dominan yang menghasilkan daya ikat air yang kuat sehingga aktivitas air nya akan menurun (Aldin dkk, 2020). Hal yang berbeda terjadi pada proporsi kappa karagenan dan tepung konjak 40:60 (P4) dan 20:80 (P5). Hal ini terjadi karena jumlah tepung konjak yang lebih banyak dibandingkan kappa karagenan sehingga pada edible straw yang dihasilkan, banyak gel konjak yang berada diluar struktur double helix gel kappa karagenan sehingga daya ikat air menurun dan water activity edible straw meningkat. Edible straw dengan aktivitas air terenterendah ada pada perlakuan proporsi kappa karagenan dan tepung konjak 60:40 (P3). Hal ini terjadi karena sinergitas dari kappa karagenan dan tepung konjak terbaik dimana gel konjak masuk ke dalam struktur double helix gel kappa karagenan serta pembentukkan gluten dari terigu dengan maksimal sehingga menghasilkan daya ikat air yang maksimal pula. Dari hasil pengujian juga dapat dilihat bahwa aktivitas air dari edible straw dengan tepung konjak 100% (P6) lebih rendah dibandingkan kappa karaganen 100% (P1). Hal ini disebabkan karena kappa karagenan yang digunakan murni, sedangkan tepung konjak yang digunakan tidak murni yaitu selain mengandung senyawa glukomanan juga mengandung senyawa lein seperti pati, protein, dan serat yang memiliki kemampuan dalam mengikat air (Supriyati, 2016).

Tekstur Pengujian tekstur yaitu daya patah bertujuan untuk mengetahui tingkat kekuatan atau kekokohan edible straw saat transportasi, distribusi, bahkan saat digunakan untuk meminum. Pengujian daya patah dilakukan dengan menggunakan alat texture profile analyzer dan probe three point bend rig. Daya patah adalah gaya maksimum dalam satuan Newton (N) yang diperlukan untuk mematahkan produk (Andarwulan dkk, 2011). Dalam penelitian ini, produk yang diteliti adalah edible straw berbahan dasar terigu. Semakin besar daya patah dari edible straw menandakan bahwa edible straw semakin kuat dan kokoh, dan sebaliknya. Pengaruh konsentrasi kappa karagenan dan tepung konjak terhadap daya patah edible straw berbahan dasar terigu dapat dilihat pada Gambar 4.3. Hasil pengujian daya patah edible straw berbahan dasar terigu dengan proporsi kappa karagenan dan tepung konjak yang berbeda berkisar antara 14,995-29,954 N. Hasil pengujian daya patah edible straw dianalisa menggunakan uji ANOVA dengan α=5% (Lampiran D.3.1.) dan menunjukkan hasil bahwa ada pengaruh proporsi kappa karagenan dan tepung konjak terhadap daya patah edible straw berbahan dasar terigu. Hasil pengujian ANOVA ini dilanjutkan dengan uji DMRT (Duncan Multiple Range Test) pada α=5% (Lampiran D.3.2.). Hasil nilai daya patah edible straw berbahan dasar terigu terendah terdapat pada perlakuan proporsi kappa karagenan dan tepung konjak yaitu 0:100 (P6), sedangkan nilai daya patah tertinggi terdapat pada perlakuan proporsi kappa karagenan dan tepung konjak yaitu 60:40 (P3). Berdasarkan histogram yang tercantum dalam Gambar 4.3, dapat dilihat bahwa nilai daya patah edible straw dengan penggunaan kombinasi kappa karagenan dan tepung konjak lebih tinggi dibandingkan penggunaan kappa karagenan 100% (P1) ataupun tepung konjak 100% (P6). Hal ini dikarenakan terjadinya sinergisme antara kappa karagenan dan tepung konjak yang menghasilkan kekuatan gel yang tinggi. Kappa karagenan menghasilkan gel yang kuat namun rapuh atau brittle sedangkan tepung konjak menghasilkan gel yang elastis. Penambahan tepung konjak dalam gel kappa karagenan akan menurunkan kerapuhan dari gel kappa karagenan sehingga menghasilkan gel yang kokoh dan elastis (Kaya dkk, 2014). Dengan terbentuknya gel yang kokoh dan elastis dari kombinasi kappa karagenan dan tepung konjak maka akan menghasilkan edible straw yang tidak mudah patah. Senyawa glukomannan dalam tepung konjak akan terabsorpsi kedalam junction zone struktur double helix kappa karagenan sehingga menurunkan kerapuhan dari gel kappa karagenan serta menghasilkan gel yang kuat dan elastis (Kaya dkk, 2014). Pada Gambar 3.4. juga dapat dilihat bahwa nilai daya patah kombinasi kappa karagenan dan tepung konjak 80:20 (P2) dan 60:40 (P3) meningkat, sedangkan pada proporsi 40:60 (P4) dan 20:80 (P5) menurun. Peningkatan pada proporsi 80:20 (P2) dan 60:40 (P3) disebabkan karena peranan tepung konjak dalam menurunkan kerapuhan gel dari kappa karagenan sehingga edible straw menjadi kuat dan elastis. Penurunan pada proporsi 40:60 (P4) dan 20:80 (P5) disebabkan karena proporsi tepung konjak yang banyak mengganggu pembentukkan matriks double helix kappa karagenan dalam membentuk gel sehingga edible straw yang dihasilkan lebih lunak (Akesowan, 2014). Hasil penelitian ini sejalan dengan hasil penelitian yang dilakukan oleh Akesowan dan Choonhahirum (2014) mengenai penggunaan kappa karagenan dan tepung konjak pada orange jelly. Pada penelitian tersebut disebutkanbahwa proporsi kappa karagenan dan tepung konjak yang menghasilkan kekuatan gel tertinggi pada orange jelly adalah 55-60 : 40-45. Kekuatan gel yang dihasilkan kappa karagenan dan tepung konjak pada proporsi ini juga dapat diterapkan untuk menghasilkan edible straw yang tidak mudah patah. 4.4. Daya Serap Air Daya serap air merupakan salah satu parameter yang perlu diuji karena menggambarkan kelunakan dari edible straw berbahan dasar terigu dengan proporsi kappa karagenan dan tepung konjak yang berbeda. Semakin tinggi daya serap air, edible straw akan semakin lunak. Edible sraw yang baik adalah dengan nilai daya serap air yang rendah sehingga dapat bertahan lama dalam air ketika digunakan untuk menghisap minuman. Pengujian daya serap air dilakukan dengan merendam edible straw pada 3 suhu yang berbeda yaitu 0-5 oC yang merupakan suhu minuman dingin, 25- 30oC yang merupakan suhu minuman di suhu ruang, dam 65-70oC yang merupakan suhu minuman hangat. Selain itu, pengujian juga dilakukan pada waktu 0-20 menit dengan interval waktu pengujian 5 menit. Pengaruh proporsi kappa karagenan dan tepung konjak terhadap daya serap air edible straw pada suhu 0-5 oC dapat dilihat pada Gambar 4.4, pengaruh proporsi kappa karagenan dan tepung konjak terhadap daya serap air edible straw pada suhu 25-30oC dapat dilihat pada Gambar 4.5, dan pengaruh proporsi kappa karagenan dan tepung konjak terhadap daya serap air edible straw pada suhu 65-70oC dapat dilihat pada Gambar 4.4, sedangkan keseluruhan data rerata daya serap air edible straw dapat dilihat pada Tabel 4.1.

Hasil pengujian daya serap air dari penggunaan edible straw berbahan dasar terigu dengan proporsi kappa karagenan dan tepung konjak, suhu, dan waktu yang berbeda berkisar antara 0 - 63,53%. Hasil pengujian daya serap air edible straw dianalisa menggunakan uji ANOVA dengan α=5% (Lampiran D.4.1.) dan menunjukkan hasil bahwa ada pengaruh proporsi kappa karagenan dan tepung konjak terhadap daya serap air edible straw berbahan dasar terigu. Hasil pengujian ANOVA ini dilanjutkan dengan uji DMRT (Duncan Multiple Range Test) pada α=5% (Lampiran D.4.2.). Pada Gambar 4.4, 4.5, dan 4,6, dapat dilihat bahwa semakin lama waktu perendaman edible straw dalam air dan semakin tinggi suhu air maka semakin tinggi daya serap air edible straw yang dihasilkan. Semakin lama waktu perendaman edible straw dalam air menyebabkan semakin banyak waktu penetrasi air ke edible straw menghasilkan nilai daya serap air yang meningkat. Selain itu, semakin tinggi suhu air maka nilai daya serap air meningkat karena semakin tinggi suhu air maka kemampuan penetrasi air ke edible straw akan semakin tinggi karena adanya gerakan mekanik molekul air yang semakin besar (Nasir, 2010). Hasil penelitian ini sejalan dengan pernyataan oleh Nasir (2010) yang menyatakan bahwa semakin tinggi suhu larutan maka akan semakin tinggi penetrasi air ke produk. Pada 3 suhu yang berbeda juga dapat dilihat bahwa peningkatan nilai daya serap air paling signifikan terjadi pada menit ke-5. Hal ini disebabkan karena kadar air awal edible straw (menit ke-0) yang rendah sehingga ketika direndam dalam air, terjadi perpindahan air dari air ke edible straw dalam jumlah banyak. Hal ini terjadi hingga terjadi keseimbangan kelembapan antara edible straw dan air. Oleh karena itu, peningkatan nilai daya serap air pada menit ke-10, 15, dan 20 tidak sebesar pada menit ke-5 karena sebagian air sudah terserap dalam edible straw sehingga penetrasi air akan menurun. Hasil pengujian ini sejalan dengan hasil penelitian yang dilakukan oleh Safriani dkk (2013) bahwa semakin tinggi suhu air dan lama pemasakan maka penetrasi air ke produk mi kering akan semakin tinggi sehingga daya serap airnya akan meningkat. Selain itu, hasil pengujian ini juga sejalan dengan hasil penelitian yang dilakukan oleh Nasir (2010) yaitu penetrasi air pada produk kering akan meningkat secara signifikan pada 10 menit pertama, kemudian akan stabil hingga satu titik keseimbangan kelembapan antara produk dan lingkungan. Pada Gambar 4.4, 4.5, dan 4.6 juga dapat dilihat bahwa nilai daya serap air edible straw berbahan dasar terigu tertinggi ada pada perlakuan proporsi kappa karagenan dan tepung konjak 0:100 (P6), dan nilai terendah ada pada proporsi 60:40 (P3). Pada perlakuan proporsi kappa karagenan dan tepung konjak 80:20 (P2) dan 60:40 (P3) terjadi penurunan nilai daya serap air, sedangkan pada proporsi 40:60 (P4) dan 20:80 (P5) terjadi peningkatan nilai daya serap air. Hasil pengujian juga menunjukkan bahwa nilai daya serap air edible straw pada suhu dan waktu yang berbeda pada perlakuan kombinasi kappa karagenan dan tepung konjak lebih rendah dibandingkan perlakuan kappa karagenan 100% (P1) atau tepung konjak 100% (P6). Hasil pengujian ini terjadi karena sinergisme antara kappa karagenan dan tepung konjak dimana gel konjak akan masuk ke struktur double helix gel kappa karagenan sehingga menghasilkan daya ikat air yang kuat (Aldin dkk, 2020) dalam adonan dan struktur edible straw yang rapat sehingga penetrasi air saat perendaman akan lebih rendah. Perlakuan dengan daya serap air terendah adalah proporsi kappa karagenan dan tepung konjak 60:40 (P3) karena sinergisme antara kappa karagenan dan tepung konjak dalam membentuk gel serta pembentukkan gluten dari terigu yang maksimal sehingga menghasilkan struktur gel yang rapat dan daya serap air yang rendah. Penurunan nilai daya serap air terjadi pada perlakuan proporsi kappa karagenan dan tepung konjak 80:20 (P2) dan 60:40 (P3) karena adanya sinergisme gel konjak yang masuk dalam sturktur double helix gel kappa karagenan sehingga struktur gel semakin rapat dan daya serap air menurun. Hal yang berbeda terjadi pada perlakuan proporsi kappa karagenan dan tepung konjak 40:60 (P4) dan 20:80 (P5) dimana terjadi peningkatan nilai daya serap air. Hal ini terjadi karena jumlah tepung konjak yang lebih banyak dibandingkan kappa karagenan, sehingga banyak gel konjak dalam edible straw yang berada diluar struktur double helix kappa karagenan dimana gel konjak mengandung senyawa glukomannan yang memiliki banyak gugus hidroksil yang dapat menyerap air hingga 200x berat asalnya (Supriyati, 2014) sehingga daya serap air meningkat. Selain itu, dalam tepung konjak juga terkandung senyawa yang memiliki kemampuan dalam menyerap air diantaranya yaitu pati, protein, dan serat (Supriyati, 2016).

4.5. Turbidimetri Pengujian turbiditas dilakukan pada air dari penggunaan edible straw berbahan dasar terigu dengan proporsi kappa karagenan dan tepung konjak yang berbeda. Pengujian ini perlu dilakukan untuk mengetahui kelarutan edible straw dalam minuman sehingga dapat mengetahui kemungkinan terjadinya kekeruhan dan perubahan organoleptik minuman yang dikonsumsi. Kekeruhan terjadi karena lepasnya padatan dari edible straw ke air. Karakteristik edible straw yang diharapkan adalah dengan kelarutan yang rendah sehingga tidak mengubah sifat organoleptik minuman yang dikonsumsi ketika digunakan sebagai pengganti sedotan plastik. Pengujian turbiditas ini diawali dengan perendaman edible straw dalam air suhu 65-70oC kemudian air dimasukkan dalam tabung hingga garis batas. Tabung yang telah terisi kemudian dimasukkan dalam alat turbidimeter yang sudah terkalibrasi kemudian dibaca dengan alat. Standar kalibrasi yang digunakan adalah 800, 100, 20, dan 0,02 NTU. Satuan NTU merupakan singkatan dari Nett Turbidity Unit. Semakin besar nilai turbiditas menandakan air semakin keruh karena banyaknya suspense padatan dari edible straw yang larut ke air, dan sebaliknya. Hasil pengujian pengaruh konsentrasi kappa karagenan dan tepung konjak terhadap turbiditas air dari penggunaan edible straw berbahan dasar terigu dapat dilihat pada Gambar 4.7 Hasil pengujian turbiditas air dari penggunaan edible straw berbahan dasar terigu dengan proporsi kappa karagenan dan tepung konjak yang berbeda berkisar antara 77,1-100,1 NTU. Hasil pengujian turbiditas air dari penggunaan edible straw dianalisa menggunakan uji ANOVA dengan α=5% (Lampiran D.5.1.) dan menunjukkan hasil bahwa ada pengaruh proporsi kappa karagenan dan tepung konjak terhadap turbiditas air dari penggunaan edible straw berbahan dasar terigu. Hasil pengujian ANOVA ini dilanjutkan dengan uji DMRT (Duncan Multiple Range Test) pada α=5% (Lampiran D.5.2.). Pada Gambar 4.7, dapat dilihat bahwa turbiditas air dari penggunaan edible straw berbahan dasar terigu terendah adalah proporsi kappa karagenan dan tepung konjak 60:40 (P3) sedangkan turbiditas tertinggi ada pada perlakuan proporsi 100:0 (P1). Dari histogram yang tercantum dalam Gambar 4.7, juga dapat dilihat bahwa turbiditas air dari penggunaan edible straw dengan kombinasi kappa karagenan dan tepung konjak lebih rendah dibandingkan penggunaan kappa karagenan 100% (P1) ataupun tepung konjak 100% (P6). Hal ini terjadi karena adanya sinergisme antara kappa karagenan dan tepung konjak yang menghasilkan ikatan yang kuat dengan air (Aldin dkk, 2020) sehingga kemungkinan memiliki kemampuan mempertahankan keseluruhan sistem edible straw yang lebih baik dibandingkan kappa karagenan atau tepung konjak saja. Hasil pengujian menunjukkan bahwa proporsi kappa karagenan dan tepung konjak 80:20 (P2) dan 60:40 (P3) menghasilkan penurunan turbiditas air dari penggunaan edible straw, sedangkan pada proporsi 40:60 (P4) dan 20:80 (P5) menunjukkan peningkatan turbiditas air dari penggunaan edible straw. Penurunan turbiditas air dari penggunaan edible straw pada proporsi kappa karagenan dan tepung konjak 80:20 (P2) dan 60:40 (P3) karena sinergitas antara kappa karagenan dan tepung konjak dimana gel konjak akan masuk ke junction zone gel kappa karagenan menghasilkan daya ikat sistem adonan edible straw yang kuat. Ikatan yang terjadi dalam edible straw diantaranya adalah air-pati, air-hidrokoloid, air-protein, protein-hidrokoloid, dan proteinpati. Hal yang berbeda terjadi pada proporsi 40:60 (P4) dan 20:80 (P5) dimana menunjukkan peningkatan turbiditas air dari penggunaan edible straw. Hal ini karena banyaknya proporsi tepung konjak dibandingkan kappa karagenan sehingga mengakibatkan banyaknya gel konjak yang berada diluar struktur double helix gel kappa karagenan sehingga menghasilkan edible straw dengan daya ikat sistem yang rendah.

Organoleptik Edible straw merupakan salah satu inovasi produk edible cutlery dengan tujuan untuk menggantikan penggunaan sedotan plastik pakai sehingga dapat menekan jumlah limbah plastik di dunia. Sebagai produk inovasi, edible straw akan digunakan oleh masyarakat sehingga diperlukan adanya pengujian organoleptik kesukaan atau hedonik. Tujuan dari pengujian organoleptik ini adalah untuk mengetahui respon kesukaan masyarakat terhadap produk edible straw berbahan dasar terigu. Parameter organoleptik yang diuji adalah warna dan aroma. Menurut Laskmi dkk (2012), parameter warna dan aroma dari suatu produk mempengaruhi kesukaan panelis terhadap inovasi produk baru. Parameter rasa tidak dilakukan karena sedotan yang dibuat pada penelitian ini adalah “edible” dan bukan “eatable”. Sedotan yang “edible” merupakan sedotan yang dapat dimakan namun masih belum memiliki rasa yang enak, sedangkan sedotan yang “eatable” merupakan sedotan yang dapat dimakan dan memiliki rasa yang enak. Pengujian organoleptik yang dilakukan pada penelitian ini adalah parameter warna dan aroma pada edible straw berbahan dasar terigu perlakuan P3 yaitu proporsi kappa karagenan dan tepung konjak 60:40. Perlakuan ini dipilih berdasarkan hasil nilai pengujian parameter aktivitas air terendah, tekstur daya patah tertinggi, daya serap air terendah, dan turbiditas terendah sesuai dengan karakteristik edible straw yang diharapkan. Pengujian organoleptik dilakukan dengan panelis tidak terlatih yaitu sebanyak 100 panelis masyarakat awam dengan media pengumpulan data berupa kuisioner yang dapat dilihat pada Lampiran C.

Warna Warna adalah sesuatu yang dilihat konsumen dengan indera mata pertama kali ketika ingin menggunakan ataupun mengkonsumsi suatu produk pangan sehingga sangat mempengaruhi derajat penerimaannya. Produk pangan yang memiliki rasa yang enak dan tekstur yang baik tidak akan dikonsumsi apabila memiliki warna yang menyimpang ataupun kurang baik secara visual (Noviyanti dkk, 2016). Data hasil kuisioner organoleptik warna edible straw berbahan dasar terigu dapat dilihat pada Gambar 4.8. Hasil pengujian hedonik organoleptik warna menghasilkan rerata nilai 3,52 (Lampiran D.6) dengan predikat agak suka. Dari data ini dapat diambil kesimpulan bahwa warna edible straw berbahan dasar terigu masih dapat diterima oleh masyarakat awam. Berdasarkan Gambar 4.8, dapat dilihat bahwa tidak ada panelis yang memberikan nilai sangat tidak suka (nilai Nilai rerata dari pengujian kesukaan warna edible straw hanya 3,52 dengan predikat agak suka disebabkan edible straw yang dihasilkan pada penelitian ini memiliki warna putih pucat kekuningan khas terigu seperti adonan roti berbeda dengan sedotan pada umumnya yang bewarna putih. Selain itu, edible straw ini masih merupakan inovasi baru sehingga masyarakat masih tidak terbiasa dengan sedotan yang bewarna putih pucat kekuningan. Warna putih pucat kekuningan ini berasal dari warna bahan dasar terigu yang memiliki karotenoid dan xantofil dalam jumlah yang kecil, serta adanya reaksi maillard atau pencoklatan yang terjadi saat pengovenan (Bhat dan McMaster, 1976). 4.6.2. Aroma Aroma produk pangan adalah parameter organoleptik yang diperhatikan konsumen setelah warna. Aroma adalah bau yang ditimbulkan oleh rangsangan kimia yang tercium dan terdeteksi oleh syaraf olfaktori yang berada dalam rongga hidung sebagai indera penciuman ketika mencium atau memasukkan makanan kedalam mulut (Winarno, 2004). Aroma memiliki peranan yang sangat penting terhadap derajat penerimaan suatu inovasi produk pangan (Noviyanti dkk, 2016). Data hasil kuisioner organoleptik aroma edible straw berbahan dasar terigu dapat dilihat pada Gambar 4.9 Hasil pengujian hedonik organoleptik aroma menghasilkan rerata nilai 3,47 (Lampiran D.6) dengan predikat agak suka. Dari data ini dapat diambil kesimpulan bahwa aroma edible straw berbahan dasar terigu masih dapat diterima oleh masyarakat awam. Berdasarkan Gambar 4.9, dapat dilihat bahwa tidak ada panelis yang memberikan nilai sangat tidak suka (nilai <2) dan sangat suka (nilai 5). Berdasarkan hasil ini juga dapat dilihat bahwa 41% panelis memberikan nilai tidak suka, 30% memberikan nilai agak suka, dan 29% memberikan nilai suka terhadap aroma edible straw. Banyaknya panelis yang memberikan nilai tidak suka dikarenakan panelis mendeteksi adanya bau tepung dari sampel edible straw. Bau tepung ini tidak diinginkan karena pada umumnya sedotan tidak berbau. Aroma ini berasal dari bahan dasar yang digunakan yaitu terigu. Selain itu, sebagian panelis tidak mendeteksi adanya bau dari edible straw.

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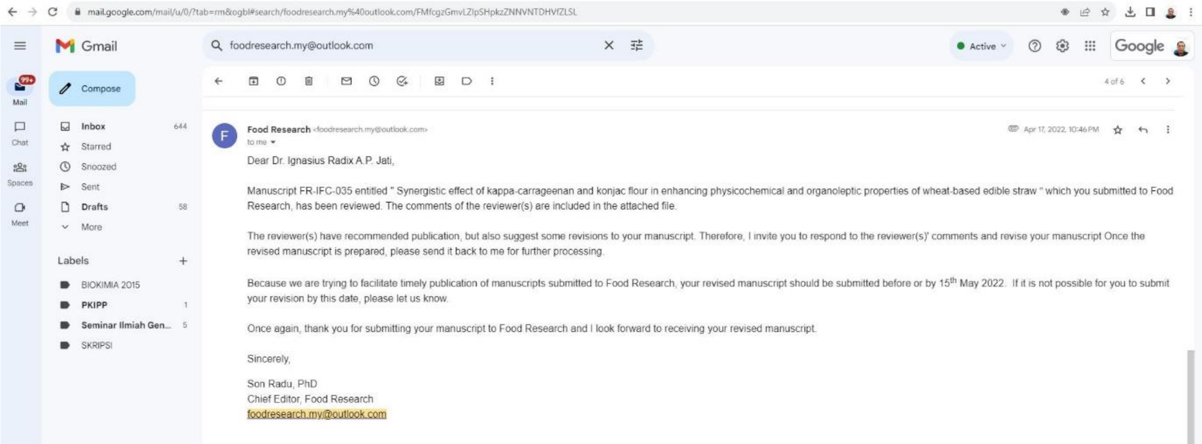
2. Bukti konfirmasi review dan hasil review
   17 April 2022



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Dear Dr. Ignasius Radix A.P. Jati,

Manuscript FR-IFC-035 entitled " Synergistic effect of kappa-carrageenan and konjac flour in enhancing physicochemical and organoleptic properties of wheat-based edible straw " which you submitted to Food Research, has been reviewed. The comments of the reviewer(s) are included in the attached file.

The reviewer(s) have recommended publication, but also suggest some revisions to your manuscript. Therefore, I invite you to respond to the reviewer(s)' comments and revise your manuscript Once the revised manuscript is prepared, please send it back to me for further processing.

Because we are trying to facilitate timely publication of manuscripts submitted to Food Research, your revised manuscript should be submitted before or by 15th May 2022. If it is not possible for you to submit your revision by this date, please let us know.

Once again, thank you for submitting your manuscript to Food Research and I look forward to receiving your revised manuscript.

Sincerely,

Son Radu, PhD
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Synergistic effect of kappa-carrageenan and konjac flour in enhancing physicochemical and organoleptic properties of wheat-based edible straw

Abstract

The development of edible straws is an affordable solution to reduce the use of plastic tableware as well as a promising innovation to promote an eco-friendly lifestyle. This study was aimed at producing wheat-based edible straw made by combining high-protein wheat flour with kappa-carrageenan, konjac flour, salt and water. All ingredients were introduced to mixing, kneading, resting, dough rolling, dough flattening, molding, and baking. The effect of six different proportions of kappa-carrageenan and konjac flour (100:0, 80:20, 60:40, 40:60, 20:80, 0:100) on the physicochemical and organoleptic properties of wheat-based edible straw was evaluated. The water content of edible straws from all treatments ranged from 7.07-8.12%. Among the six treatments, the maximum synergy of kappa-carrageenan and konjac flour in producing high gel strength and desired edible straw characteristics was obtained from the proportion of 60:40 with the produced edible straw possessed the lowest water activity (*aw*), % water absorption at tested temperatures (0-5, 25-30, and 65-70^{o}C), turbidity, and fracturability. The results of the organoleptic evaluation showed that the panelists slightly liked and could accept the aroma and color of wheat-based edible straw made with the proportion of kappa-carrageenan and konjac flour 60:40.

Keywords: edible straw, wheat flour, kappa-carrageenan, konjac flour

1. Introduction

The convenience and low price of plastic have brought communities to utilize plastic products in daily lives. The lack of public awareness in recycling plastic products along with poor waste management, however, has unwittingly made plastic waste a global crisis. Plastic is a polymer that takes many years to decompose and will persist in environment for hundreds of years. The accumulation of plastic waste has eventually posed detrimental effects to many aspects, including agricultural land, marine environment, animal, and human health (Thompson *et al.*, 2009).

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The food and beverage sector accounts for a large proportion of plastic waste from disposable tableware, such as food wrappers, food and beverage containers, cutlery, and straw (Hussain, Husnain and Shah, 2020; Ncube *et al.*, 2021). The reduction of aforementioned plastic usage can be endeavored through modifying the materials used to make the tableware (Gautam and Caetano, 2017). In this study, edible straw was developed as one affordable solution to plastic waste issue in the beverage product sector. Edible straw is made from food ingredients that undergo cooking process, thus making it ready to be used and safe to be consumed. Moreover, unlike the plastic straw, edible straw is environment-friendly, completely biodegradable, and able to decompose (Natarajan *et al.*, 2019).

Fracture resistance, insoluble in various beverage temperatures, and absence of distinctive aroma and taste are the ideal characteristics that have to be fulfilled by edible straw. In order to meet those criteria, high-protein wheat flour with the protein content of 12-13% was chosen as the basic ingredient to produce the edible straw. Besides having plain flavor and aroma, high-protein wheat flour contains complex protein called gluten. Each component of gluten, namely glutenin and gliadin, offers different unique characteristics that can provide a rigid structure to the edible straw. The continuous network of glutenin proteins through the polymerization disulfide bonds is responsible for creating an elastic and strong dough, whereas gliadin provides plasticity toward the glutenin polymeric network and preserves the whole protein structure. Glutenin and gliadin, after being added with water and introduced to kneading process, form a strong three-dimensional gluten matrix that generate a strong, stretchy dough and allows the dough to be shaped as desired (Barak, Mudgil and Khatkar, 2014).

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In addition to high-protein wheat flour, a mixture of hydrocolloid consisting of kappa-carrageenan and konjac was also incorporated in the present edible straw formulation. Hydrocolloids possess an important role as gelling agents targeted to strengthen the structure and lower the water absorption rate of the wheat-based edible straw (Rohmah, Windarwati and Luketsi, 2019). The gelation of kappa-carrageenan is initiated by heating which changes the random coil structure into a helix structure. A decrease in temperature favors the helices to associate with each other to form a hard, brittle thermo-irreversible gel. Compared to other types of carrageenan, kappa-carrageenan is less soluble in water due to the presence of hydrophobic 3,6-anhydrous-D-galactose group with lesser amount of hydrophilic sulfate ester group (Geonzon, Bacabac and Matsukawa, 2019). On the other hand, konjac is a high molecular weight, water-soluble polysaccharide containing glucomannan with a very high water absorptivity (up to 50 times its weight in water). Glucomannan comprises of the main chain of β-1,4-linkages that connect D-glucose and D-mannose backbones, and slightly branched through β-1, 6-glucosyl units. Gels of konjac can be both thermo-reversible and thermo-irreversible (Ji *et al.*, 2017).

The combined use of kappa-carrageenan and konjac flour was based on the ability of konjac flour to enhance the properties of kappa-carrageenan gel, allowing the produced gel to be stronger, more elastic, and more stable. The synergistic interaction between these hydrocolloids is the result of association and lining up of the mannan molecules into the junction zones of helices (He *et al.*, 2012). However, researches also indicated that the improvement of gel quality was influenced by the optimal proportion of kappa-carrageenan and konjac. Tunieva, Spiridonov and Nasonova (2021) found out the ratio of 1:1 was the optimal ratio of kappa-carrageenan and konjac gum to generate strong and plastic gels. The same conclusion was also reported by Kaya et al. (2015). Another study by Wei, Wang and He (2012) reported the largest strength of gels was produced from combining kappa-carrageenan and konjac gum with the ratio of 5.5:4.5. Therefore, the aim of this study was to investigate the effect of various proportions of kappa-carrageenan and konjac flour in producing wheat-based edible straw with ideal physicochemical characteristics. Furthermore, the selected treatment was proceeded to the organoleptic test to evaluate consumer acceptance of the wheat-based edible straw.

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Please revise it!

2. Materials and methods

2.1 Materials

Commercial high-protein wheat flour containing 13% protein, table salt, and drinking water were purchased from local market in Surabaya, Indonesia. Kappa-carrageenan and konjac flour were obtained from PT. Algalindo Perdana, Indonesia.

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2.2 Methods

2.2.1 Preparation of wheat-based edible straw

Wheat-based edible straws were prepared by mixing high-protein wheat flour (150 g), kappa-carrageenan (0-7.5 g), konjac flour (0-7.5 g), and table salt (1.5 g) with water (100 ml). The amount of kappa-carrageenan and konjac flour was adjusted in such a way that their proportion came to 100:0 (P1), 80:20 (P2), 60:40 (P3), 40:60 (P4), 20:80 (P5), and 0:100 (P6) with the total amount of 7.5 g. The mixture was thoroughly kneaded until uniform and rested for 30 min. The dough was rolled using rolling pin and further flattened using dough flattener to a thickness of ± 0.08 cm. The thin dough was cut into a rectangular shape (15 cm x 2 cm) and molded around the surface of stainless-steel straw covered with baking paper to form a cylindrical shape. The dough was baked at 100 ^{o}C for 1 h, cooled at room temperature for 1 h, and packed inside a PP plastic added with pouched silica gel.

2.2.2 Moisture content and water activity

Moisture content of wheat-based edible straw was measured thermogravimetrically according to Association of Official Analytical Chemists method (AOAC International, 2005). Water activity was measured using *aw* meter (Rotronic, Switzerland).

2.2.3 Texture analysis

The fracturability evaluation of wheat-based edible straw was performed using a texture analyzer (TA-XT2 Texture Analyzer, Stable Micro System, England) according to Carsanba and

Schleining (2018) with some modification. The sample was laid on two supports and subjected to a shear test using a 3-point bending rig until the sample snapped into two. The pre-test speed was 3 mm/s, test speed was 3 mm/s, and post-test speed was 10 mm/s. The fracturability was determined based on the maximum peak force (N) which indicated the cutting force of wheat-based edible straw.

2.2.4 Water absorption test

Water absorption test was performed according to the method proposed by Harouna et al. (2019) with some modification. The samples from all treatments were prepared with all were of the same weight. The prepared samples were immediately immersed in cool (5-10°C), room (25-30°C), and warm (65-70°C) water. The samples were taken out from the water, drained, weighed, and re-immersed in the water every 5 min for 20 min. The percentage of water absorptivity was calculated using the equation below:

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$$\text{Water absorptivity (\%)} = \frac{wt.\ after\ immersion - wt.\ before\ immersion}{wt.\ before\ immersion} \times 100\%$$

2.2.5 Solubility evaluation using turbidity test

The level of turbidity represents the amount of wheat-based edible straw’s solids leached out into the beverage product. The turbidity test was performed by immersing the wheat-based edible straws into warm water (65-70°C) for 10 min. The turbidity of the water was analyzed using a turbidimeter (Velp Scientifica, Italy) and the results were expressed in Nephelometic Turbidity Units (NTU).

2.2.6 Organoleptic evaluation

Wheat-based edible straw that possessed the lowest Aw, water absorptivity, turbidity, and the highest fracture resistance was proceeded to the organoleptic evaluation. The evaluation was conducted by 100 untrained panelists with the parameters of wheat-based edible straw tested were color and aroma. The samples were evaluated using a five-point hedonic test with line scales (1 = strongly dislike, 5 = strongly like).

2.2.7 Statistical analysis

All the analyses were done four times and the results were expressed as mean values ± standard deviation (SD). Analysis of variance (ANOVA) was performed to analyze differences between treatments. If significant difference was found, the treatments were compared by using Duncan's Multiple Range Test ($p \leq 0.05$).

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3. Results and discussion

Innovation in providing environmental-friendly utensils has been gaining particular interest in recent years. The development of products such as shopping bag and plate have been reported (Patil and Sinhal, 2018; Rajendran *et al.*, 2020; Ghosh and Katiyar, 2021). This research focuses on creating edible straw as one form of cutlery to reduce the use of plastic straw. The preliminary research revealed that wheat could be used to create edible straw. However, it is susceptible to fracture. Thus, wheat-based edible straw is difficult to be made, transported, stored, and also utilized. Hydrocolloids can be introduced in the formulation of edible straw to improve its physical, chemical, and sensory properties.

Hydrocolloids can act as a gelling agent through bonding and networking with water, starch, and gluten, thus could improve the quality of edible straw (Mahmood *et al.*, 2017; Li *et al.*, 2019). Hydrocolloids such as kappa-carrageenan and konjac can potentially be used in the formulation of edible straw. Kappa-carrageenan produces a strong but brittle gel (Adam, Hamdan and Bakar, 2020), while konjac flour creates an elastic gel (Hu *et al.*, 2019). The combination of kappa-carrageenan and konjac flour in suitable proportions produces a high gel strength due to the contribution of konjac flour that can improve the brittleness of kappa-carrageenan gel. Therefore, the combination is expected to produce firm and strong edible straws. The proportions of kappa-carrageenan and konjac flour used in this study were

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100:0; 80:20; 60:40; 40:60; 20:80; and 0:100. Parameters evaulated were edible straw's moisture content, water activity (*aw*), texture, water absorption capacity, turbidity, and organoleptic (color and aroma).

3.1 Moisture content and water activity

The determination of moisture content was performed to investigate the amount of free or weakly bound water contained in edible straws made from wheat flour formulated with different proportions of kappa-carrageenan and konjac flour. Information on the moisture content is closely related to the shelf life of the edible straw since the moisture content available in food can be used by microorganisms such as bacteria, molds, and yeasts to grow, thus can affect the quality of food product (Gichau, Okoth and Makokha, 2020). In addition, other quality parameters such as texture, fracture strength, water absorption, and turbidity effect are also influenced by moisture content. In this research, the moisture content was measured using thermogravimetric method. The effect of the proportion of kappa-carrageenan and konjac flour on the moisture content of wheat-based edible straws can be seen in Figure 1. The results showed that the moisture content ranged from 7.07-8.12%. Based on the statistical analysis, there was a significant difference in the proportion of kappa-carrageenan and konjac flour on the moisture content of wheat-based edible straws. As presented in Figure 1, the lowest moisture content of edible straws was observed in the proportions of kappa-carrageenan and konjac flour of 100:0 (P1) and 0:100 (P6), while the highest moisture content was found in the proportion of 60: 40 (P3). The decrease of kappa-carrageenan resulted in the rise of the moisture content of edible straw until the proportion of 60:40. However, further decrease of kappa-carrageenan proportion led to an increase or a decrease of moisture content. Both hydrocolloids can create a network and bind with water due to the hydroxyl group (Chen *et al.*, 2019). Thus for 100% of kappa-carrageenan and 100% of konjac flour added in the formulation of edible straw did not show a significant difference in the moisture content. Although hydrocolloids have a high water-binding

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capacity, the water trapped is mainly in a weakly bound state and can still be released during the heating process (Zhou *et al.*, 2021).

Figure 1 also revealed that edible straw with a combination of kappa-carrageenan and konjac flour had a higher moisture content than an edible straw with only kappa-carrageenan (P1) or konjac flour (P6) due to the synergistic effects between kappa-carrageenan and konjac flour in creating the gel network with a better water binding capacity than kappa-carrageenan or konjac flour individually (Yang *et al.*, 2019; Wu *et al.*, 2021). The glucomannan compounds present in konjac flour will enter the junction zone of the kappa-carrageenan gel structure and are responsible for producing stronger bonds with water (Wang *et al.*, 2021). This bond plays a significant role in retaining the water inside the edible straw structure and avoiding evaporation in the processing stage of heating; thus, the moisture content is higher. However, further increase of konjac flour proportions which were 40:60 (P4) and 20:80 (P5) resulted in a decrease of moisture content due to the saturated condition of the double helix structure kappa-carrageenan, which then could not accommodate the increase of konjac flour. As a result, the konjac flour will form a gel outside the double helix structure of kappa-carrageenan. In this condition, the dough could absorb the water. However, the water will be easily removed during the baking process of edible straws.

The proportion of kappa-carrageenan and konjac flour that produced the highest moisture content of edible straw was 60:40 (P3), which could be due to the optimum synergy between kappa-carrageenan and the konjac flour at P3 proportion. The complex was formed when the konjac gel entered the double helix structure of kappa-carrageenan gel together with the gluten formation, making the complex produced the maximum water holding capacity. The edible straw dough could bind the water, thus minimizing its release during the baking step (Farbo *et al.*, 2020). The results of this study are in line with the previous research (Rhim and Wang, 2013), which stated that the use of a combination of kappa-carrageenan and konjac flour resulted in a higher moisture content of hydrogel film due to the water barrier properties. The common characteristic of edible straw is having a low moisture content concerning the shelf-life capability. Overall, the moisture content of flour-based edible straws in this study was higher than that of sorghum flour-based edible plates (2.57%) (Sood and Deppshikha, 2018).

Water activity (*aw*) is one parameter that determines the shelf life of food products (Moschopoulou *et al.*, 2019). *Aw* is defined as the amount of free or unattached water contained in food and food products. Free water can be used for microbial growth. Therefore, the higher the free water available, the higher susceptibility of food to microbial contamination and leads to the shortening of the shelf life (Barbosa-Cánovas *et al.*, 2020).

Different proportions of kappa-carrageenan and konjac flour affected the *aw* of wheat-based edible straws (α = 5%) (Figure 2). The *aw* of edible straw was ranging from 0.360-0.464. As described in Figure 2, the highest *aw* value was found in the kappa-carrageenan and konjac flour proportions of 100:0 (P1) and 0:100 (P6) with no significant difference between the treatments. Meanwhile, the lowest *aw* value was observed in the proportion of 60:40 (P3). Thus, the combination of kappa-carrageenan and konjac flour could yield a lower *aw* value than the single-use of kappa-carrageenan or konjac flour. This result agrees with the previous work conducted (Chen *et al.*, 2021), which suggested that the synergy between kappa-carrageenan and konjac glucomannan is responsible for lowering the *aw* of the product. The optimum proportion in lowering *aw* of edible straw was 60:40 (P3), which is believed to be the interaction effect between kappa-carrageenan and konjac flour. Konjac gel formed during dough formation will penetrate the junction zone of the kappa-carrageenan gel structure, creating a solid network in entrapping available water leads to the lower *aw* value.

On the other hand, the increase of konjac flour proportion could increase the *aw* of edible straw because the double helix structure of kappa-carrageenan could not accommodate the excess of konjac gel. Thus, the network created failed to entrap the free water and increase the *aw* (Dai *et al.*, 2018). Additionally, the konjac flour used to produce edible straw also contains starch, protein, and fiber, which in their native form having a water-binding capacity (Huang *et al.*, 2016). Nevertheless, in the edible straw network, such components in higher concentrations will inhibit the creation of glucomannan and kappa-carrageenan networks and are responsible for increasing *aw* value.

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3.2 Texture

In this research, the examined texture parameter was fracturability. This test could describe the strength or sturdiness of edible straws during transportation, distribution, and utilization. Fracturability is the maximum force in Newtons (N) required to break the product. Therefore, the higher fracturability value indicates the strength of edible straw.

The effect of the proportion of kappa-carrageenan and konjac flour on the fracturability of wheat-based edible is presented in Figure 3. The fracturability ranged from 14.995-29.954 N, and a significant difference was observed with the different proportions of kappa-carrageenan and konjac flour (α = 5%). The lowest fracturability value was found when 100% of the konjac flour or kappa-carrageenan were used in the formulation of edible straw because the kappa-carrageenan and konjac flour could not optimally contribute to the formation of the firm structure of edible straw constructed by wheat and other ingredients. In contrast, the highest fracturability value was found in the 60:40 (P3) proportion of kappa-carrageenan and konjac flour. The interaction between kappa-carrageenan and konjac flour contributes to the gel strength of edible straw. The synergistic effect of the solid but brittle structure of kappa-carrageenan together with elastic and robust structure of konjac flour produces a strong structure of edible straw with a higher fracturability value (Penroj *et al.*, 2005). The brittleness of kappa-carrageenan will be reduced by the presence of konjac flour in the edible straw dough due to the elasticity properties of konjac and the ability of konjac to preserve water in their structure (Yang *et al.*, 2017).

A solid and elastic gel from the combination of kappa-carrageenan and konjac flour will produce a firm edible straw. Glucomannan compounds in konjac flour are believed to be absorbed in the junction zone of the kappa-carrageenan double helix structure, thereby reducing the brittleness of the kappa-carrageenan gel and producing a solid and elastic gel. In addition, the combination of kappa-carrageenan and konjac flour increases the fracturability, while on the contrary, the proportions of 40:60 (P4) and 20:80 (P5) decrease the fracturability of edible straw. The increase of fracturability in the proportions of 80:20 (P2) and 60:40 (P3) was due to konjac flour's role in reducing gel fragility of kappa-carrageenan the edible straw became sturdy and elastic. On the other hand, the proportions of 40:60 (P4) and 20:80 (P5) was responsible for the decrease of fracturability due to the higher proportion of konjac flour that inhibits the gluten formation as the primary structure builder of edible straw (Akesowan, 2015). The results in this study support the previous research conducted by Akesowan and Choonhahirun (2014) on the effect of kappa-carrageenan and konjac flour used in the production of orange juice jelly, which reported that the gel strength of the combination of kappa-carrageenan and konjac flour yielded a strong jelly structure.

3.3 Water absorption

Water absorption capacity is the ability of edible straw to absorb water. The higher water absorption capacity leads to a higher amount of water absorbed resulted in the decrease of the hardness of the edible straw. Edible straw made of flour is susceptible to water absorption when soaked in water or liquid. The addition of kappa-carrageenan and konjac is intended to decrease edible straw's water absorption capacity, thus retaining the structure and inhibiting the soggy structure changes of edible straw. This research used three different temperatures to describe a cold, a room temperature, and a warm drink. The water absorption capacity of edible straw is presented in Figures 4a, 4b, 4c.

It can be seen that longer soaking time and higher water temperature were responsible for the increase of the water absorption capacity. When the edible straw is soaked, the water penetrates the structure of the straw, resulting in increased water absorption. Moreover, the higher the water temperature, the mechanical movement of water will assist the water molecules to penetrate the straw structure (Zhu *et al.*, 2019). Meanwhile, the water absorption was increased significantly in the 5th minute due to a large amount of water transferred to the immersed dried straw. Immersing the edible straw for more than five minutes affects the water absorption capacity because some amount of water is already absorbed by the straw. The existence of water in the structure inhibits the water absorption rate due to the water equilibrium stage (Turhan, Sayar and Gunasekaran, 2002). A study by Yu et al. (2017) on the effect of soaking brown rice reported that the water temperature and cooking time affected the water absorption capacity. The higher temperature of the water provided mechanical movement, thus exuviating the rice's surface and creating access for water to penetrate the structure of the brown rice. Meanwhile, time also contributed to the water absorption due to the breakdown of rice structure and immersing time until the equilibrium condition.

From Figures 4a, 4b, and 4c, it can be seen that the individual treatment of kappa-carrageenan and konjac flour resulted in the highest water absorption capacity. On the other hand, the synergistic effect of mixed kappa-carrageenan and konjac flour successfully decreased the water absorption capacity because of the ability of konjac gel to form a strong network with kappa-carrageenan, thus inhibits the water penetration to the edible straw structure. Moreover, the gluten formed in the edible straw dough also plays a significant role in supporting the network initiated by kappa-carrageenan and konjac flour, thus forming a stronger network bond.

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3.4 Turbidity

The turbidity test was intended to determine the ability of edible straw to maintain its structure and examine the solubility of edible straw. In addition, the result of the turbidity test will provide an overview of whether the structure of edible straw is rupture and creating turbidity in the beverage system and affecting the taste of the beverage consumed (Yildiz and Karhan, 2021). The turbidity occurs because of the release of solids from the edible straw structure into the beverage product. The results of turbidity test presented in Figure 5 shows the turbidity unit values ranged from 77.1-100.1 NTU, with the highest turbidity unit in edible straw with 100% kappa carrageenan. On the other hand, the combination of kappa-carrageenan and konjac flour at 60:40 resulted in the lowest turbidity unit, which means that the hydrocolloids could prevent solids from the edible straw structure their capacity to create a matrix network and bond with other ingredients. Moreover, other interactions contribute to a firm structure: water-starch, water-hydrocolloid, water-protein, protein-hydrocolloid, and protein-starch bindings (Yemenicioğlu *et al.*, 2020) absorption capacity is the ability of edible straw to absorb water. The higher water absorption capacity leads to a higher amount of water absorbed resulted in the decrease of the hardness of the edible straw. Edible straw made of flour is susceptible to water absorption when soaked in water or liquid.

3.5 Organoleptic evaluation

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Organoleptic properties of color and flavor were examined with the preference test using a hedonic scale. The preference test was conducted for the edible straw made with the kappa-carrageenan and konjac flour proportion of 60:40 that exhibited the best objective parameters, including moisture content, fracturability, water absorption capacity, and turbidity value. A number of 100 untrained panelists contributed to the preference test. The result in Figure 6 revealed that the score for edible straw's color was 3.52 (slightly like), which means that the panelists still could accept the edible straw. The dark brownish color of edible straw is influenced by the baked wheat flour color and Maillard reaction. Meanwhile, the average score of the flavor preference test was 3.47 (slightly like). The lower organoleptic score for flavor could be due to the baked flour aroma that dominated the edible straw.

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4. Conclusion

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Edible straw as one form of cutlery can be developed using wheat flour and a combination of kappa-carrageenan and konjac flour to improve its physicochemical and organoleptic properties. The synergistic effect of kappa-carrageenan and konjac flour decreased edible straw's moisture content and water activity, thus prolonging its shelf life. Meanwhile, the increased fracturability of edible straw was increased, which means that the structure became firmer and elastic with the addition of kappa-carrageenan and konjac flour. Furthermore, the combination of kappa-carrageenan and konjac flour decreases the water absorption capacity of edible straw, which enables it to be used to consume beverages and stand firm for a more extended time. The turbidity test of the beverage after immersion of edible straw shows that the combination of kappa-carrageenan and konjac flour decreases the turbidity of the beverage. Moreover, the organoleptic test revealed that the best treatment of edible straw has a score of like slightly in the preference test.

Conflict of interest

The authors declare no conflict of interest.

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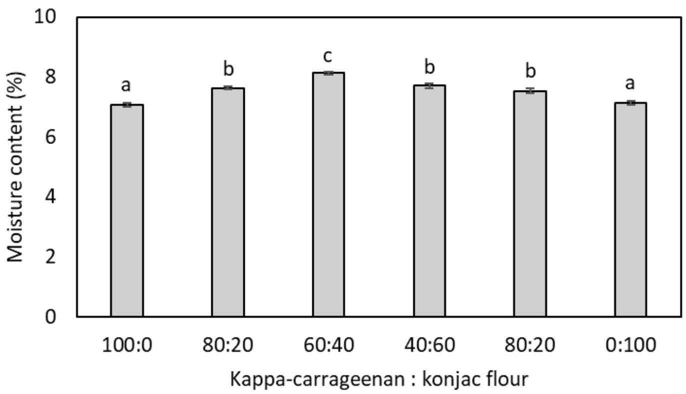

Figure 1. Moisture content of wheat-based edible straw. Bars that do not share similar letters denote statistical significance at α = 5%.

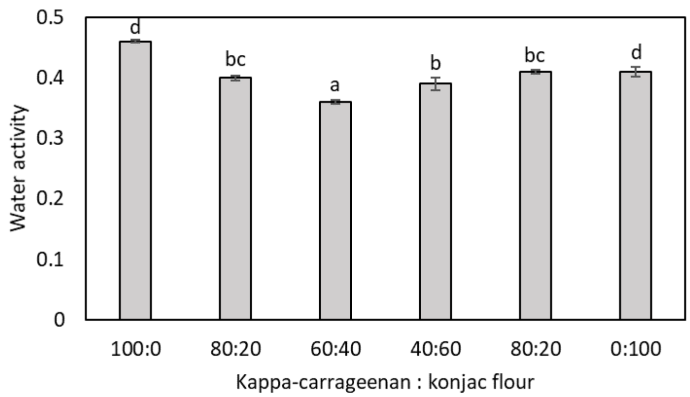

Figure 2. Water activity of wheat-based edible straw. Bars that do not share similar letters denote statistical significance at α = 5%.

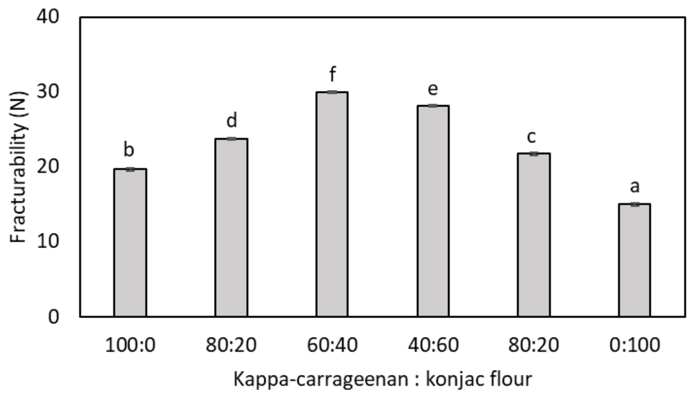

Figure 3. Fracturability of wheat-based edible straw. Bars that do not share similar letters denote statistical significance at α = 5%.

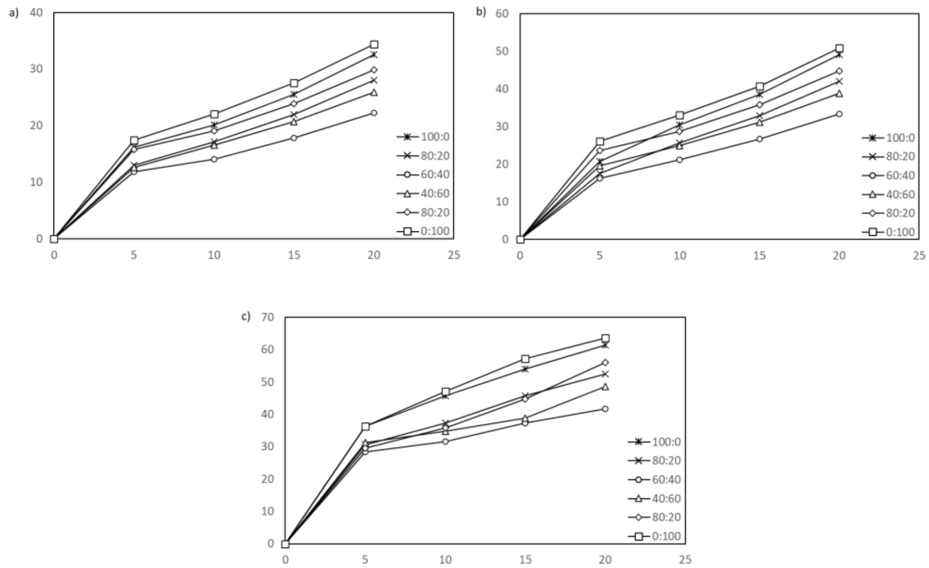

Figure 4. Water absorptivity of wheat-based edible straw at (a) 5-10^{o}C, (b) 25-30^{o}C, and (c) 65-70^{o}C.

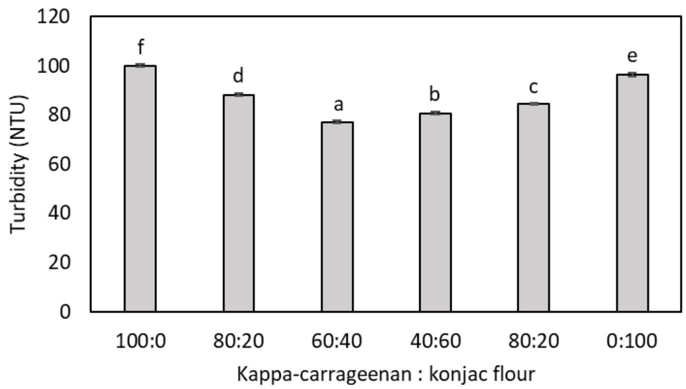

Figure 5. Turbidity test of wheat-based edible straw. Bars that do not share similar letters denote statistical significance at α = 5%.

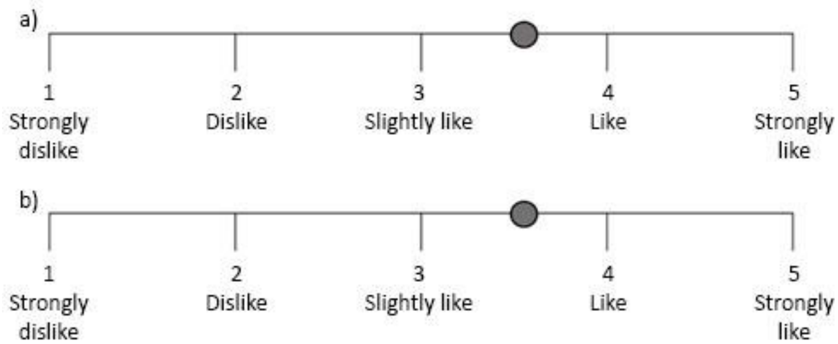

Figure 6. The organoleptic test results for (a) color and (b) aroma of wheat-based edible straw.

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MANUSCRIPT EVALUATION FORM

Date : 11th March 2022

Manuscript ID : FR-IFC-035

Please return by : 11th April 2022

Title of Manuscript : Synergistic effect of kappa-carrageenan and konjac flour in enhancing physicochemical and organoleptic properties of wheat-based edible straw

1. IF YOU CANNOT REVIEW THIS MANUSCRIPT OR MEET THE DEADLINE, PLEASE INFORM US WITHOUT DELAY.

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4. Research Methodology					
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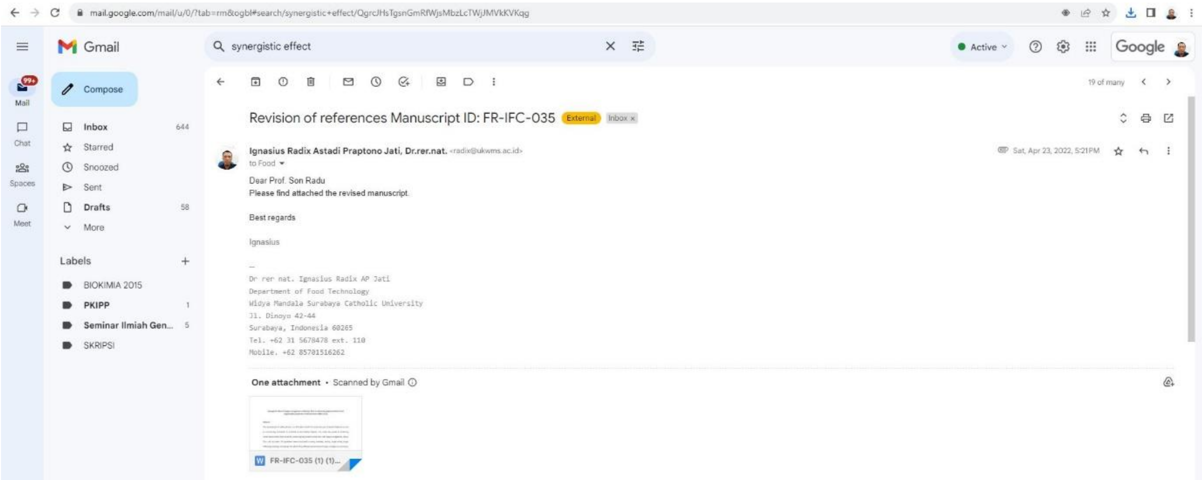

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1. IF YOU CANNOT REVIEW THIS MANUSCRIPT OR MEET THE DEADLINE, PLEASE INFORM US WITHOUT DELAY.

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Evaluation Criteria	Grade				
	A (Excellent)	B	C	D	E (Worst)
1. Appropriateness of Contents		V			
2. Originality of Topic		V			
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It should reflect the article</td><td>The title reflects the content of the study, although the organoleptic study was only done in Formula 60:40. No other formulas were tested, so it is unknown which formula gives the best enhanced organoleptic.
The author can consider that organoleptic is the additional examined property. The synergistic effect is seen only in physicochemical properties, with robust comparison to other Formulas.</td></tr>
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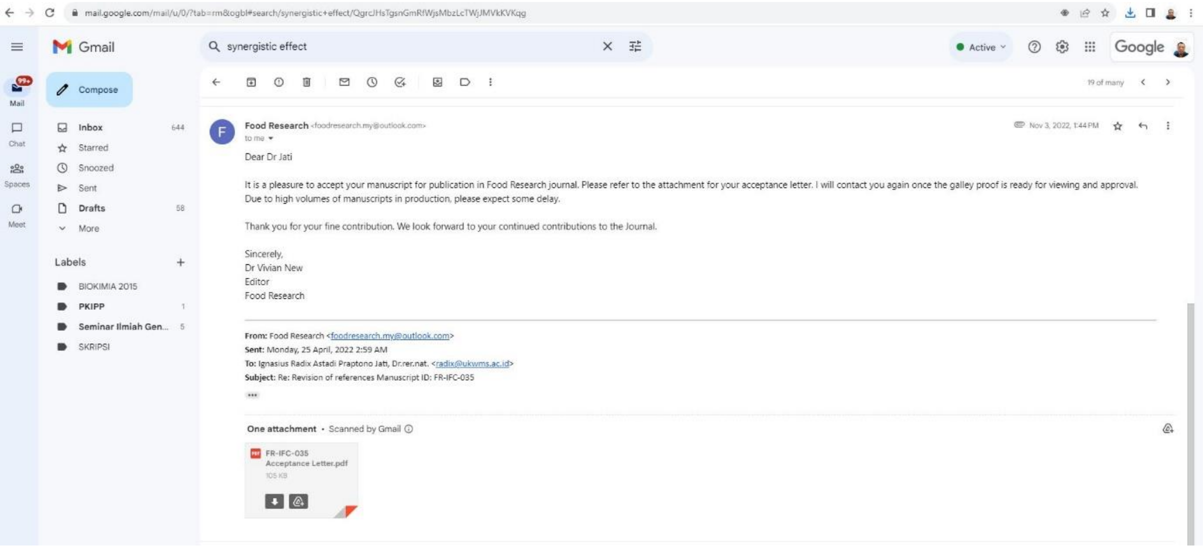
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Nov 3, 2022, 1:44 PM

Dear Dr Jati

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Thank you for your fine contribution. We look forward to your continued contributions to the Journal.

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3rd November 2022

Dear Dr Jati,

ACCEPTANCE LETTER

Food Research is pleased to inform you that the following manuscript has been accepted for publication in Food Research journal.

Manuscript Title	:	Synergistic effect of kappa-carrageenan and konjac flour in enhancing physicochemical and organoleptic properties of wheat-based edible straw
Authors	:	Jati, I.R.A.P., Natasha, L., Nugraha, D.T., Virly and Setijawaty, E.

We thank you for your fine contribution to the Food Research journal and encourage you to submit other articles to the Journal.

Yours sincerely,

Professor Dr. Son Radu
Chief Editor
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