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Sea Grapes Paper Towel Enriched with Activated Carbon: A Practical Innovation to Reduce Acrylamide in Fried Food

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HIGHLIGHTS

- Sea grapes paper towels enriched with activated carbon can absorb acrylamide in fried foods.
- Sea grapes paper towels enriched with activated carbon can also reduce the oil percentage in fried foods.
- This paper towel innovation is a practical innovation to reduce acrylamide in fried foods.

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Acronyms and abbreviations
AA=Acrylamide

ABSTRACT

Background: One of the possible carcinogenic substances found in foods is Acrylamide (AA). This study aims to combine and innovate sea grapes (*Caulerpa racemosa*) extract with activated carbon into paper towels that can absorb AA levels in fried foods.
Methods: The paper towel was created with composition of activated carbon:sea grapes extract:paper pulp using following formula: F0=0:0:100; F1=5:5:100; F2=10:5:100; F3=20:5:100. The optimal paper towel formulation was chosen based on AA reduction, fat absorption, and organoleptic properties. Data were statistically analyzed by SPSS 26.
Results: Wrapping a fried potato using the sea grapes paper towel enriched with activated carbon for a min decreased significantly the levels of AA and oil. Although, it significantly reduced the levels of AA and percent of oil in the fried potato, but it did not change the taste and texture ($p=0.566$ and $p=0.330$). The best formulation of paper towels with composition of activated carbon, sea grapes extract, and paper pulp of 20:5:100 had the best AA level reduction, oil absorption properties, and a good taste score.
Conclusion: This study is the first to successfully combine and innovate sea grapes extract with activated carbon as a food tissue that can reduce AA in fried foods.

Introduction

As of now, cancer remains one of the leading causes of death, with the numbers increasing worldwide. Cancer prevention needs to be enforced to reduce the burden. Humans could develop cancer through exposure to carcinogens found in the diet. One of the possible carcinogenic substances found in foods is Acrylamide (AA)

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(Virk-Baker et al., 2014). AA is a secondary product of the Maillard reaction, a reaction between reducing sugars and the amino acid, asparagine (Pelucchi et al., 2011). AA is found in foods prepared at a high temperature, such as plant-based starchy foods when baked and fried (deep-fried potatoes) (Pelucchi et al., 2011). AA has been classified as a group 2A carcinogen for humans by the International Agency for Research on Cancer (Pelucchi et al., 2011; Virk-Baker et al., 2014). The United States of America Food and Drug Administration (FDA) warns people to reduce AA since AA consumption is strongly linked to neurotoxicity, genotoxicity, cardiotoxicity, and lower reproductive function (Bušová et al., 2020; Pruser and Flynn, 2011; Singh and Kushwah, 2018).

Currently, known methods to reduce AA in foods are soaking and using industrial technologies (Nematollahi et al., 2021). There are many challenges in reducing AA content in foods. Soaking the food ingredient before frying doesn't guarantee to reduce the AA formed in the cooking process, while many laboratory methods were not applicable in daily life (Beitāne et al., 2022). Reducing AA is achieved through prevention before and during the cooking process, yet no method has been found to reduce AA after the cooking process (Deribew and Woldegiorgis, 2021). A new convenient way is needed to reduce AA in commercial or home-cooked fried foods.

Paper towel is commonly used to absorb oil in fried foods. Paper towels can significantly reduce oil absorption in various fried foods. By infusing certain substances, the paper towel could potentially be used to reduce AA content in fried foods. The primary proposed substance is activated carbon since it possesses a large surface area with a porous structure, making it optimal for the adsorption of materials (liquids or gases) (Alkhatib and Alzaailay, 2018). On the other hand, sea grapes (*Caulerpa racemosa*) – an edible marine alga that grows in Asian sea water in Indonesia – have been explored for their nutraceutical properties (Peñalver et al., 2020). The addition of sea grapes could potentially be beneficial in preventing cancer due to their high antioxidant activity (Permatasari et al., 2021; Susilowati et al., 2019). Sea grapes also have high fiber content, accounting for 3.11–3.18% of their dry weight. It can be used as an advantage to fortify the structure of the paper towel product. By doing so, activated carbon and sea grapes-infused paper towel could potentially absorb excess oil and AA, also reducing cancer risk. . This study aimed to combine and innovate sea grapes (*Caulerpa racemosa*) extract rich in natural antioxidants with activated carbon into paper towels that can absorb AA levels in fried foods.

Materials and methods

Study design

The design of the sea grapes paper towel research enriched with activated carbon to lower the levels of AA in fried foods is as follows. First, sea grapes were extracted through maceration. Then, the paper towel was formulated based on the composition of activated carbon, sea grapes extract, and paper pulp (F0=0:0:100; F1=5:5:100; F2=10:5:100; F3=20:5:100). Next to that, the best formulation of paper towel will be decided based on the AA reduction, fat absorption, and organoleptic parameters of three fried food samples, with three different wrapping times. More detailed methods have been written below.

Sea grapes extraction

Fresh sea grapes were harvested in the shallow water (10-20 m above sea level) of North Sulawesi, Indonesia. To lower the water content, fresh sea grapes were drained at 25 °C for around 5 h. One kg of dried sea grapes was macerated in 96% ethanol for 72 h, with each extraction done in triplicates, resulting in a 34% yield. Crude extracts were filtered by using Whatman 41 filter paper (PT Laborindo Sarana–Sidoarjo, Indonesia). To make a thick extract, the entire filtrate was concentrated and evaporated at 40 °C for 90 min with a rotary evaporator RV 8 IKA (IKA® Works Asia Sdn Bhd–Selangor, Malaysia) at decreased pressure (100 mbars) and then finally dried in 40 °C using Sharp R-220MA-WH microwave (Wiraniaga Cahaya Semesta–Jakarta, Indonesia). The extract was kept at 10 °C in the refrigerator until it was employed in the study.

Formulation of active carbon

Activated carbon is a porous, processed form of carbon that has a variety of applications, including adsorption and chemical reaction requirements for water and gas purification. Because activated carbon particles are porous, they have large surface areas tucked into the holes and tunnels across their surface. Commercially activated carbon under the "Norit" brand (Lang, Indonesia) was used in this study. Norit is an extruded activated carbon with exceptional adsorption characteristics and ultra-high purity. Norit is made by steam activation and is well suited for thermal reactivation due to its excellent hardness and tailored particle form.

Paper towel formulation

The paper towel was created using a bleached pulp which was further crushed and refined to roughen the

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surface of the fibers (Bajpai, 2018). Next, water was added to the pulp slurry to make a thin mixture that normally contains <1% fiber. Food-grade Carboxymethyl Cellulose (CMC; Wealthy, China) was used as a food-friendly glue to create a better structure. The mixture was poured into a molding media, then dried and heated under the sun for two days.

Fried food samples preparation

The selected foods for the study were included French fries, fried chicken sausages, and chicken nuggets. These foods were analyzed using three replications of each of the paper towel formulas. These foods were cooked in January 2022 using the stir-frying method, which replicates regular practice in Indonesian people. A brown surface on the food indicated that the food is cooked so that it can be lifted to be rested for approximately 5 min. After that, the food samples were wrapped using the sea grapes paper towel enriched with activated carbon.

AA level test

AA content quantification was done according to the method used by Hermanto and Adawiyah (2010). Samples of food that had been mashed weighed as much as 15 g were then dissolved in 45 ml dichloromethane (Merck, Germany) and 3 ml ethanol (Merck, Germany). Then, it was shaken with an incubator shaker at 250 rpm for 60 min. The sample solution was washed with 3 ml dichloromethane twice and filtered. Twenty ml of active phase was added to the filtrate. Then, it was centrifuged at 16,000 rpm for 15 min. The sample was injected as much as 10 μl into the High-Performance Liquid Chromatography (HPLC) column, and then the peak area was recorded. The experiment was repeated twice. AA levels are calculated using regression equations obtained from calibration curves.

In the first section of the analysis, the AA level test was done for 1 min to determine the best formulation of paper towels. Consequently, further investigation of AA levels on five different fried foods was done to further explore the efficiency of AA reduction using the best formulation of paper towels added with activated carbon.

Oil absorption test

Oil absorption capacity may affect a food product's flavor, texture, and mouthfeel. Oil absorption testing was done at three different times (M1=1 min; M1.5=1.5 min; M2.5=2.5 min) on the food samples using each formulation of a paper towel (De Lima et al., 2019). Testing was done to determine the effectiveness of oil absorption by paper towels on different types of food types, nutritional composition, and size dimensions. Both fried items and paper towels were weighed before and after the designated time. The following formula was used to calculate the percentage of oil absorption (%) of fried foods.

Oil Absorption (%)=(amount of absorbed oil/final weight of food)×100

Organoleptic test

The integrated sensory analysis and hedonic evaluation were done according to Gatti et al. (2011). Twelve untrained panelists assessed three different types of fried dishes. Parameters for organoleptic properties such as firmness, sharpness, scent, taste, and color were selected. Panelists received specialized instruction to evaluate the degree of fried meal features to ensure panel uniformity. For the panel test, samples were sliced into slices down the axis before being presented to the panelist with a three-digit code.

Data analysis and visualization

Data obtained from the best wipe formulations against decreased levels of AA in French fries, fried chicken sausages, and chicken nuggets; and the statistical analysis of oil absorption percentage data, AA, and organoleptic was analyzed using one-way ANOVA at a Confidence Interval (CI) of 95% (0.05) with the version of SPSS 26 software. Visualize the scheme or mechanism of activated carbon-enriched sea grapes tissue against AA reduction using a premium BioRender licensed by Fahrul Nurkolis (the license owned by author or researcher legally).

Results

Wrapping a fried potato using the sea grapes paper towel enriched with activated carbon for a min can significantly lower the levels of AA and oil (Table 1 and 2). Although it significantly decreased the levels of AA and percent of the oil in the fried potato, wrapping the food using the sea grapes paper towel enriched with activated carbon did not significantly change the taste and texture of the fried potato (p=0.566 and p=0.330). F3 has the best AA level reduction, oil absorption properties, and a good taste score.

In addition to fried potatoes, wrapping chicken sausages and chicken nuggets significantly lowered their AA levels. But as it turned out, wrapping duration had no significant effect on reducing AA levels in all three types of food by this activated carbon-enriched sea grapes paper towel (p>0.05). This finding suggests that 1 min wrapping of activated carbon-enriched sea grapes paper towel has reached the effective time limit absorbing AA (no need to wrap more than 1 min).

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Table 1: Effect of paper towel sample variations on Acrylamide (AA) levels, oil absorption, and organoleptic parameters

Variable	F0	F1	F2	F3	*p**
AA (µg/kg)	604.15±0.14	590.33±2.53	578.39±7.32	403.41±6.39	0.000
Total Oil (%)	12.37±2.53	9.19±0.84	8.99±0.07	7.97±0.18	0.021
Taste Organoleptic Score	2.76±0.40	2.90±0.10	2.96±0.05	3.00±0.00	0.566
Texture Organoleptic Score	3.00±0.00	2.9±0.10	2.96±0.05	2.93±0.05	0.330

Interval organoleptic: 1.00=Dislike; 2.00=Neutral and 3.00=Like
F0: Ordinary paper towels without any treatment
F1: Sample 1 paper towels
F2: Sample 2 paper towels
F3: Sample 3 paper towels
*Significance value from F0, F1, F2, and F3 within 95% Confidence Interval (CI) or 0.05 using one-way ANOVA.
Data presented in Mean±SEM

Table 2: Effect of wrapping the best formulation of paper towel (F3) on Acrylamide (AA) levels in fried potato, fried chicken sausages, and chicken nuggets

Foods	M0	M1	M1.5	M2.5	*p**	*p***
French fries	603.77±0.93	403.61±5.05	400.53±1.21	400.34±2.53	0.000	0.454
Fried chicken sausages	393.54±5.41	322.27±58.37	277.70±6.77	281.99±8.83	0.005	0.288
Chicken nuggets	371.15±15.95	316.67±3.83	308.95±3.10	309.42±6.53	0.000	0.161

M0=0 min or before wrapping
M1=1 min of wrapping
M1.5=1.5 min of wrapping
M2.5=2.5 min of wrapping
*Significance value from M0, M1, M2, and M3 within 95% Confidence Interval (CI) or 0.05 using one-way ANOVA.
**Significance value from M1, M2, and M3 within 95% CI or 0.05 using one-way ANOVA.
Data presented in Mean±SEM.

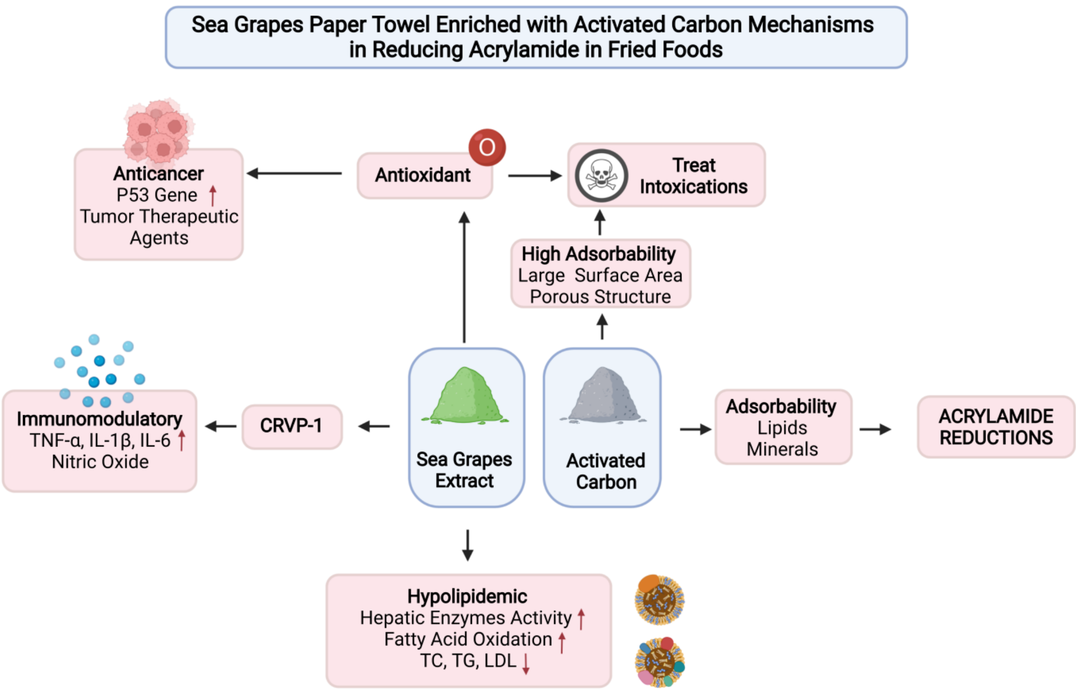

Figure 1: Possible mechanism of sea grapes paper towel in reducing Acrylamide (AA) in fried foods

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Discussion

This research was conducted to discover the most optimal composition of activated carbon in a paper pulp and sea grapes extract mixture. Three formulations were tested based on their performance in absorbing AA and oil. Based on the AA absorption parameter, F3 performed better than the rest of the formulation, and the difference was significant (p=0.000). Furthermore, results confirmed that the higher the activated carbon content, the higher the AA absorption. As explained before, activated carbon possesses a large surface area with a porous structure that could function for the adsorption of liquids or gases (Alkhatib and Alzaailay, 2018). Activated carbon, in the form of charcoal, may adsorb and treat intoxications (Juurlink, 2016; Zellner et al., 2019). Hence, the activated carbon composition in this experiment may absorb the AA content of the fried food. Activated carbon also plays a role in cancer therapy (Chu et al., 2013; Kim et al., 2019; Wu et al., 2021), indicating the potential of activated carbon as a tumor therapeutic agent. Based on the oil absorption parameter, higher activated carbon content on the paper towel will result in higher food oil absorption. The difference between treatment groups was significant (p=0.021). As more activated carbon was added, the ability of the paper towel to absorb oil was increased since activated carbon allowed the adsorption of liquids (Alkhatib and Alzaailay, 2018). This finding also spotted activated carbon functionality in reducing lipid content, which can only be applied in the leather industry (Pounsamy et al., 2019). On the other hand, the polyphenols content in sea grapes may also interact with the lipid, binding, and changing the bioactivity of the phenols (Jakobek, 2015).

Based on the taste organoleptic score, it was found that the food wrapped with the F3 formulation of the paper towel had the best taste compared to the other formulations, although the difference was non-significant (p=0.566). The activated carbon content probably contributed to the result. The organoleptic texture score confirmed that food wrapped in an ordinary paper towel gave the best result. The trend was not found in this parameter. Although the F3 paper towel was not the best in this parameter, the score was not very much different, and the difference was not significant (p=0.330). Since a prior study highlighted that different compositions and levels of oil didn’t cause a significant difference in sensory evaluation (Siddeeg and Xia, 2015), the activated carbon might contribute to creating a texture similar to crumbs, along with a bitter aftertaste.

Further testing was done on the best formulation found on the preliminary test. The best formulation is F3 since it possesses the best AA and oil-lowering effect. Although, its taste and texture effect on foods wrapped was not considerably different compared to a standard paper towel or before the treatment of the coating with a tissue, which means this tissue tapping does not give a change in taste and texture effect on the fried food or still maintain the taste and texture). Further testing demonstrated that wrapping fried foods (fried potatoes, fried chicken sausages, and fried chicken nuggets) significantly decreased AA content. The longer the duration it took to wrap the foods, the lower the AA content, but the effect was insignificant. Wrapping fried foods in the F3 paper towel for a more extended period, for instance, 2.5 min compared to 1 min, did not significantly differ in the food's AA content. It means that 1 min of wrapping was just as effective as a longer period, reaching its effective time limit. However, this finding was not in line with De Lima et al. (2019) who found that 10 min of wrapping will result in higher oil absorption (reduced total oil) in foods. These tests found that F3 formulation could function well in various fried foods other than fried potatoes.

Antioxidants derived from the extraction of sea grapes are also thought to lower the levels of AA in tested food samples since natural antioxidants play a role in binding to toxins, including the toxicity of AA (Ou et al., 2010). The combination in this study, namely mixing sea grapes extract with activated carbon, was felt to be suitable and in harmony with the test results, which showed the significance of decreasing levels of AA and even percent of the oil.

Besides the practical benefits to reduce AA and oil levels, sea grapes paper towels may also prevent the adverse effects of AA since they possess antioxidant and anti-proliferative activities; which could prevent cancer growth. Sea grapes showed radical inhibition in cancer cells (Tanna et al., 2020). Furthermore, sea grapes have the potential to upregulate the expression of the *p53* gene that leads to the synthesis of p53 protein, a protein with the function of slowing cell growth, activating DNA repair, or executing apoptosis if the damage to the DNA could not be repaired (Tanna et al., 2020). Sea grapes also possess a potential hypolipidemic effect (Ara et al., 2002). An ethanol extract of sea grapes (*C. racemosa*) at 10 mg/200 g body weight fed on hyperlipidemic rats reduces lipid profile (Ara et al., 2002). Serum cholesterol, Triglyceride (TG), and Low-Density Lipoprotein (LDL) cholesterol reduction are possible through increased activity of hepatic enzymes that cause fatty acid oxidation, hence causing lipid profile reduction (Ara et al., 2002). In immunomodulatory parameters, a water-soluble polysaccharide (CRVP-1) isolated from sea grapes (*C. racemosa*) possesses significant immunomodulatory activity (Hao et al., 2019). The sea grapes polysaccharide could enhance the secretion of cytokines such as Tumor Necrosis Factor Alpha (TNF-α),

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Interleukin 1 Beta (IL-1β), and IL-6. It also enhanced the production of nitric oxide (Hao et al., 2019). Altogether, the combination of activated carbon and sea grapes could be helpful in cancer prevention and health promotion of their specific mechanism (Figure 1).

Conclusion

This study is the first to successfully combine and innovate sea grapes extract with activated carbon as a food tissue or paper towel that can significantly reduce AA and oil percent as well as maintain the taste and texture of fried foods (French fries, fried chicken sausages, and fried chicken chips).

Author contributions

H.K.P., F.N., W.B.G., D.A.K. conduct experiments, analyze data, write manuscripts, design research, and conceptualize ideas; while M.N.H., D.N.A., K.N., S.A.S., Y.N.A., N.R.F., R.S.D. and A.R.D.P.S contribute to data analysis, critiquing manuscripts, interpreting manuscript results, and editing. All writers and contributors have read and also approved this final manuscript.

Conflicts of interest

All the authors declared that this is no conflict of interest in the study.

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