Crispness measurement of potato crisps by single specimen using compression test

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Abstract. Commonly, crispy characteristic is the desirable texture of dry food, especially in crisp products. The term crispness itself is qualitatively determined by the perception of human sensory. Thus, a quantitative expression is needed. The present work introduces a study to analyze the correlation between the crispness and compressive mechanical behavior of potato crisps as a preliminary step to quantify crispness level of crisp products. Potato crisp samples were exposed to room air in several specific durations. The crisp samples were assessed one by one by running a uniaxial compression test using two parallel plates. The load and displacement curve relationship were measured simultaneously during crisp deformation at a constant speed. The result indicated that there is a relationship between the crispness of the crisps and the strain energy up to 10% strain. Yet, the result has not perfectly mimicked the apparent crispness of the samples. This analysis is expected to contribute to the food engineering field in terms of crispness quantification of a dry food.

1. Introduction

In general, crispness is one of the qualitative properties of dry food that determines its quality [1]. It is often defined as the level of freshness and firmness of food products, especially in dry food. In another way, the crispness is defined as the pleasingly cracking sound of chips at the time it is bitten. Crispness is also associated with the quality of dry food, indicating the freshness of the food’s material and the fineness of its cooking process.

As a result of qualitative measurements, crispness is described differently from many perspectives, including dictionaries, consumers, and researchers. Oxford dictionary defines crispness as the quality of being firm, dry, and brittle, especially in a way considered pleasing [2]. Barrett and Peleg [3] describe crispness as a complex failure mechanism in continuous deformation during the chewing process. Besides, Tunick et al. [4] correlate the crispness with the ease of fracture or brittleness of food structure when it is forced until it breaks into pieces.

The term crispness is extensively subjected to dry food products, such as extrudates, puffs and crisps [5]. Potato crisps, as one of the most popular dry snacks, and is well known for its crispness [6]. In order to achieve its most desirable crispness level, potato slices are fried to reduce its moisture content to ~1.8% [7]. A proper packaging is a way to protect the crispness of the crisp. However, once the
packaging is opened, the crisps are exposed to the moisture of the open air. As the time passes, the moisture content of the crisps is developed, causing the increase of the crisps’ sogginess [8].

The crispness of potato crisps is frequently related to the enjoyable cracking sensation when it is bitten, its sound emission during crunching, also the fractures and stiffness properties of the food [5]. By acoustic measurement, the crispness of dry food has been reported to have linearly proportional relation with its sound emission when it is bitten [8]. On the other hand, the relation of crispness and fracturability of dry food has also been studied, via critical stress intensity calculation [9]. Additionally, through a compression test, Verela et al. stated that higher crispness on food is indicated by the existence of force breakdown on early deformation [10].

Acoustic and mechanical tests have been studied to assess the crispness of dry food. However, the quantitative standard to decide the crispness of food by mechanical tests has not been concluded yet. This study is aimed to assess the crispness of potato chips using compressive mechanical testing methods by a single specimen. This experiment provides preliminary data to analyze the crispness of potato crisps from its compressive mechanical behavior. In the development, the analysis of this experiment can be built up as an alternative option to perform a simple mechanical quantification of crispness, which can be also useful for educational purposes [11].

2. Research methodology

2.1. Specimen preparation

There are many brands of potato crisps with various and unique crisps shapes. Most of the chips have irregular and curvy shapes, so it is hard to measure the mechanical properties using mechanical testing method. To deal with this irregularity, this experiment was using potato chips from Pringles brand in Original Taste. This brand is chosen due to its high homogeneity of the crisps shapes and dimension as illustrated in Figure 1.

Because of the irregular shape of the crisps, the measurement of the height of samples was done using two parallel plates to ensure that the measurement produced the desired data (see Figures 1 and 2). In order to measure the major and minor diameter, the center point of the crisp is taken. Then, the measurement is performed by taking the length of a straight line from the two edges of the crisp and passing through its center point. A vernier caliper with 0.05 mm accuracy was employed to measure the major diameter, minor diameter, and the height of the samples. Also, a balance with 0.01 g accuracy was utilized to measure the weight of the samples.

![Figure 1. Typical shape of crisp specimen.](image-url)
Figure 2. Measurement method the height of the crisp specimen using two parallel plates.

The dimension and weight measurement were executed to 60 samples of crisps to achieve data precision. These samples were randomly chosen from its packaging, without taking the crisps position on the packaging into account. In this experiment, only the perfect crisps were included to the samples. The chosen crisps were intact, undamaged, and ensured that there were no cracks on the crisp body. As the results, in general, the crisp samples have a major diameter of 54.20 ± 1.00 mm, minor diameter of 41.40 ± 0.70 mm, and height of 12.16 ± 0.60 mm. The crisps weight is 1.51 ± 0.05 g. In addition, the weight of the crisp is 1.51 ± 0.05 g.

Figure 3. Graphical representation of dimension measurement result.

The formula of an elliptical area was used in order to calculate the cross-section area of the crisps, providing the major and minor diameter of the crisps. The cross-section area calculation produced a value of 1763.64 ± 7.00 mm². This cross-section area will be used to calculate stress in compression testing.

For the purpose of examining the effect of moist air exposure to the crispness level of the crisps, the air was conditioned to have 18°C temperature and 50% relative humidity. This condition was chosen to represent the common condition of the air in open air where the crisps are stored after the package is opened. Then, the crisp samples were divided into three groups, with 20 specimens per group. The first group was fresh from the package, not exposed to the air. This group of chips is considered as the most-crispy specimens, as it has the lowest moisture content. Samples in group 2 were exposed to the open air in 3 hours and considered as half-crispy. Lastly, the samples in group 3 were exposed in 6 hours and considered as the least-crispy specimens. In this experiment, the three-hours increment of air exposure duration was determined to see the closeness of the data from the three groups.

2.2. Compressive mechanical testing

Compression testing was done to gain the force and displacement data from the crisp samples. This test was done using a Test Resource 313 Universal Testing Machine at 10mm/min speed with logging rate of 30/s. The local overload is set to be 50 N, which allows the machine to automatically stop when the load reaches the magnitude of 50 N. This local overload value was chosen because at 50 N load, the top plate will force the bottom plate, meaning that the crisp has been totally crushed. The surfaces of both compression platens were greased to minimize friction force effect on the measured data [12,13]. During the compression test, the crisp was positioned to face upward as shown in the Figure 4.
The compression testing machine was connected to the DAQ device to minimize the noise from the load cell before the data was displayed on the computer. The machine provided the load and displacement data that will be further processed to calculate the stress and strain. The stress is calculated by dividing the load data by the defined cross-section area of the crisp. Moreover, the strain is gained by dividing the displacement data by the height of the crisp. The strain energy of the crisp was obtained by calculating the area under the stress-strain curve.

3. Results and discussion

3.1. Stress-strain curve
The crisp specimen is divided into three groups, the crisps with 0-hour air exposure, 3-hour exposure, and 6-hour exposure. The load and displacement data from the machine were processed to produce stress and strain data by making use of the calculated cross section area and height of the crisps. The typical stress-strain curves of the three specimens’ groups are shown in Figure 5. In addition, Figure 6 shows the fragmented specimens from each group after the compression test.

As seen in Figure 5, the stress and strain data are fluctuating, thus we introduce a curve fitting by power series method to easily distinguish and analyze each curve. The power series uses 0.4 power for each data. For observation, the data is limited until 10% strain. From the obtained curves fitting, the crisp with more exposure to moist air has relatively higher stress in between 3-10% strain. This indicates that the crispier the product, the lower the stress. This also can be interpreted that the crispier product requires less force to break.

![stress-strain curves](image_url)

**Figure 5.** Stress-strain curves of crisp specimens with moist air exposure of 0, 3, and 6 hours.
Figure 6. (a) 0-hour air exposure crisps fragments, (b) 3-hour air exposure crisps fragments, and (c) 6-hour air exposure crisps fragments after it was crushed by the compression test machine.

3.2. Strain energy
The obtained stress–strain curve was used to calculate the strain energy. The strain energy is considered as a parameter that can also characterize the crispness of potato chips. From the experimental data, by calculating the area under the stress-strain curve up to 10% strain, the fresh crisp demonstrated lower strain energy than the other crisps as shown in Figure 7. The graphs also reveal that the gap of strain energy between 3-hour and 6-hour specimen groups are smaller compared with that of between 0-hour and 3 hours specimen groups. This indicates the exposure to moisture did give a significant effect in the first 3 hours. A more detailed time increment is therefore needed to investigate the optimum time before the crispness level drop sharply. This will be reported in the next paper.

Figure 7. Strain Energy vs. duration of moist air exposure.

4. Conclusion
In this paper, the crispness level of Pringles crisps specimen is quantified and evaluated by performing compression tests on a single specimen which has been exposed to three different air exposure times. The quantification was done in between 0-10% strain. The results show that the crisps in group 1, which is the most-crispy (fresh) group, has the lowest stress and lowest strain energy. On the other hand, the crisps in group 3, the least-crispy group, has the highest stress and highest strain energy. However, this experimental work is most likely only applicable for potato crisps that have high uniformity in shape and dimension. More advanced testing method needs to be considered to analyze potato crisps that have uncommon shapes and dimensions. The results obtained from this study demonstrated that the strain energy at a certain range of strain can be useful to quantify the crispness level of dry foods, in this study 0-10% strain. Moreover, the results also indicated that there may be a maximum tolerable time of air exposure that keeps the crispness not to drop drastically. Further investigation is therefore needed.
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