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Research article

ASSESSMENT OF COMMERCIAL HYDROCOLLOIDS, *Neolitsea cassia* LEAVES EXTRACT, AND SPIRULINA IN ENHANCING CRUMB PROPERTIES OF RICE-BASED LEAVENED FOOD PRODUCTS

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Abstract

Hydrocolloids are usually applied in leavened food products for the purpose of improving crumb textural and structural properties along with the storage stability. The current study was focused on assessing the effect of selected commercially available hydrocolloid materials (Xanthan gum, Guar gum, Sodium alginate), *Neolitsea cassia* leaves mucilage, and dehydrated Spirulina (*Spirulina maxima*) powder on the quality characteristics of rice-based leavened products that are fermented and gelatinized under slightly high initial air pressure conditions. Eleven rice-based (rice: wheat, 50: 50 w/w) dough samples, comprising different levels of commercial hydrocolloids (0.5%, 0.75%), *N. cassia* leaves extract (5%, 10%), and dehydrated Spirulina powder (1%, 1.5%) were prepared. Then, they were fermented and gelatinized in an enclosed chamber at 1.0 kg/cm^2 initial air pressure. Crumb volume, texture, cellular structure properties, and the storage stability of each crumb sample were evaluated and compared with a control. Results revealed the application of 0.75% Guar gum imparted to having a comparatively high crumb volume, specific volume and low bulk density, hardness, and a low crumb hardening rate during storage, despite uneven crumb cellular structure due to coalesced gas cells. Mucilaginous materials extracted from *N. cassia* leaves contributed to having a higher moisture retention capacity of the crumb during storage. The addition of dehydrated Spirulina powder also contributes resulting in a product with better volume and texture with an acceptable effect on preserving crumb characteristics during the storage.

1.Introduction

In case of developing leavened food products from composite flour, particularly comprising non-glutinous sources, hydrocolloids are frequently applied to improve the functional dough properties as well as to improve the keeping quality of the finished products (Shittu, Aminu, & Abulude, 2009). Xanthan gum, Guar gum, Alginates, Locust bean gum, Gum arabic, Carrageenan can be named as some examples of commercially available natural hydrocolloids that are commonly used in developing leavened baked products (Das, Raychaudhuri, & Chakraborty, 2015; Hager & Arendt, 2013; Salehi, 2019; Wang, Lu, Li, Zhao, & Han, 2017). Other than these hydrocolloids, various plant mucilage and algae are being utilized to enhance the texture of leavened food products.

The most common plant sources with edible grade mucilaginous materials available in Sri Lanka are, *Neolitsea cassia* (locally called Dawul kurundu) leaf extracts, *Abelmoschus esculentus* (Ladies' fingers) extract, *Durio zibethinus* (Durian) seeds extracts, and *Dillenia retusa* (locally called Goda Para) fruits extracts (Kasunmala, Navaratne, & Wickramasinghe, 2017; Navaratne, 2007). However, *A. esculentus* extract and *D. zibethinus* seeds extracts are heat stable; thus, can disturb the texture and the mouthfeel of the finished product. Mucilaginous materials in *N. cassia* leaves contain certain complex polysaccharides, which can bind with water and form a hydrocolloid solution (Wijerathne, Chandrajith, & Navaratne, 2018). *N. cassia* leaves extracts are commonly used in Sri Lanka as a texture improver and a binding agent in making a traditional sweet named "Aasmie". A previous study conducted by Navaratne (2007) has proved that the application of *N. cassia* leaves extracts (10%) can result a lower bulk density and an improved sensory profile in wheat flour bread while retarding the crumb staling by 6 to 8 hours.

Spirulina, an edible blue-green microalga belong to two genera of Spirulina and Arthrospira is rich in protein (55%-70%) with essential amino acids. Besides, Spirulina contains essential fatty acids (18%), vitamins (Vitamin B12, Vitamin E, and β-carotene), minerals (Calcium, Iron, Phosphorous, Potassium, Sodium, etc.), and pigments (Chlorophyll a, Phycocyanin, Allophycocyanin, Lutein, and Zeaxanthin) (Hosseini, Shahbazizadeh, Khosravi-Darani, & Mozafari, 2013; Massoud, Khosravi-darani, Nakhsaz, & Varga, 2016; Minh, 2014). Massoud et al. (2016) have stated that Spirulina can produce hydrocolloids, which contribute to reducing the degree of moisture loss, thereby reducing the dehydrating and hardening of crumb during storage. Moreover, the application of Spirulina can add a special color and a flavor to the finished product as well (Hosseini et al., 2013; Minh, 2014).

According to the study conducted by Rathnayake, Navaratne, and Navaratne (2019), fermentation followed by gelatinization of rice-related dough under slightly high pressurized condition (initial pressure at 1.0 kg/cm^2) contributed to having a higher leavened gas retention capacity with improved crumb cellular structure properties against a crumb sample developed under normal atmospheric conditions. Under this tell-tale, the current study was conducted by combining the two concepts of "incorporating a food hydrocolloid material" and "conducting the fermentation and gelatinization under slightly high air pressure condition" to obtain rice-related crumb samples with better crumb quality attributes, mechanical properties and storage stability.

2. Materials and methods

2.1. Materials

Paddy (BG300) was obtained from Rice Research and Development Institute, Bathalegoda, Sri Lanka. The obtained paddy was cleaned, de-hulled, and polished. The well-polished rice was soaked in an excess amount of water (25±2 ºC for 4 hours), drained off, and ground (National Grinder, MX 110PN, Japan). The obtained rice flour was dried (65±2 ºC, 3 hours) in a hot air oven (Lader, GPME350SSVISS080, UK) and passed through an 180 μm sieve (Sieve shaker, Endicotts, minor 200, UK).

Refined wheat flour, baker's dry yeast, salt, sugar, and shortening were purchased from a supermarket in Colombo, Sri Lanka.

Food grade hydrocolloids namely Xanthan gum, Guar gum, and Sodium alginate were purchased from Glorchem Enterprises, Bankshell Street, Colombo 11, Sri Lanka. Fresh

Neolitsea cassia leaves were collected directly from growers near Colombo, Sri Lanka. The plucked *N. cassia* leaves were stored under refrigerated conditions for the subsequent use of the study. Dehydrated Spirulina (*Spirulina maxima*) powder (DSP) was received from a grower near Kalutara, Sri Lanka and sieved using a 90 µm sieve to obtain particles less than 90 µm.

2.2. Methods

2.2.1. Preparation of N. cassia leaves extract (NCLE)

Approximately 10.00±0.05 g (Axis analytical balance, ALN220, Poland) of partially dehydrated (under refrigerated condition) *N. cassia* leaves were hot water blanched for about 3 minutes. Thereafter, the leaves were gently rubbed in 100 ml water (25±1 ºC) until the water get viscous with the mucilaginous materials of *N. cassia* leaves. Then, the extraction was filtered through several layers of muslin cloths. A similar procedure was followed to obtain the 5 % NCLE using approximately 5.00±0.05 g of partially dehydrated *N. cassia* leaves in 100 ml of water.

2.2.2. Preparation of rice-based leavened crumb samples

All the dough formulations comprised 50.00, 50.00, 1.00, 2.00, 1.60, and 2.00 grams of rice flour, wheat flour, salt, baker's dry yeast, sugar, and shortening respectively (on 100 g flour basis). Different levels of hydrocolloids, NCLE, and DSP were added to these formulations separately as illustrated in Table 1, to prepare eleven dough samples. These dough samples were subjected to fermentation (29±1 ºC for 180 minutes) at 1.0 kg/cm^2 initial air pressure condition in an enclosed fermentation chamber followed by gelatinization (15 minutes) within the same chamber (15 minutes) while releasing the internal pressure with parallel to the starch gelatinization (Rathnayake et al., 2019).

Table 1 The levels of different hydrocolloids, NCLE and DSP added in to the dough formulations

Sample number	**Abbreviation**	**Hydrocolloid/NCLE/DSP***	**Level of different hydrocolloids/NCLE/DSP* incorporated into 100g of flour†**
1	C	Control	No
2	XG0.5	Xanthan gum	0.5g
3	XG0.75	Xanthan gum	0.75g
4	GG0.5	Guar gum	0.5g
5	GG0.75	Guar gum	0.75g
6	SA0.5	Sodium alginate	0.5g
7	SA0.75	Sodium alginate	0.75g
8	NCLE5	5% NCLE	60ml
9	NCLE10	10% NCLE	62ml
10	DSP1	DSP	1g
11	DSP1.5	DSP	1.5g

*NCLE: *N. cassia* Leaves Extract; DSP: Dehydrated Spirulina Powder

†The level of hydrocolloid materials were selected based on literature; Xanthan gum, Guar gum, Sodium alginate (Collar et al., 1999; Das et al., 2015), NCLE (Navaratne, 2007), DSP (Massoud et al., 2016).

2.2.3. Analysis of crumb quality attributes

All the gelatinized crumbs were allowed to cool for 25 minutes (29±1 ºC, 67 % RH). Crumb volume (cm^3) was determined according to the seed displacement method as described by Aplevicz, Ogliari, and Sant'Anna (2013). Thereafter, specific volume (cm^3/g) and bulk density (g/cm^3) of the crumb samples were calculated based on the results obtained for crumb volume.

After cooling the gelatinized crumbs for 90 minutes (29±1 ºC, 67 % RH), the texture profile was analyzed using CT3 texture profile analyzer (Brookfield, M08-372-F1116, USA) considering the guidelines mentioned by Angioloni and Collar (2009) with selected adjustments. Sample height of 20±1 mm, two compression cycles, 25 mm diameter probe (TA11/1000), 50 % deformation, 5 g trigger load, 1 mm/s test speed, and 4500 g cell load. Hardness (g), Springiness (mm), Cohesiveness, Gumminess (g), and Chewiness (mJ) of the crumb samples were calculated from the compression curve of force vs. time using Brookfield TexturePro CT software.

2.2.4. Analysis of crumb cellular structure properties (Image analysis)

Cellular structure properties of scanned images (300 dpi) of the gelatinized crumbs (flatbed scanner, Canon Lide-120) (30 images per sample) were evaluated using ImageJ software following the guidelines depicted by Pérez-Nieto et al. (2010) with some adjustments. Before the image analysis, the scale of measurement was adjusted for "cm" concerning a known distance. Thereafter, a selected area of the scanned image was converted into a grayscale image (8 bit) and thresholded. Crumb porosity (%), cell density (gas cell count per unit area), average cell area (cm^2), and cell circularity were assessed using the ImageJ software. Fractal dimension of scanned, grayscale, threshold images were also evaluated (box-counting method) by the same software.

2.2.5. Analysis of crumb storage stability

Gelatinized crumbs were packed in double laminated packaging material (OPP/LLDPE; Gauge 200) and stored at normal atmospheric conditions (29±2 ºC, 67 % RH) for 48 hours. Moisture content (%) (Kern and Sohn, DBS 60-3, Germany) and hardness (g) (CT3 texture profile analyzer) of the gelatinized crumb samples were evaluated at 24-hour intervals.

2.3. Data analysis

All the experiments were triplicated. Analysis of variance (ANOVA) followed by Tukey comparison was used to compare the mean values under 95 % confidence level using Minitab 17.1.0 statistical software. Graphical illustrations were performed using Microsoft Excel 2013.

3. Results and discussions

3.1. Crumb quality attributes

Crumb volume (cm^3), specific volume (cm^3/g), and bulk density (g/cm^3) are categorized as the major parameters that represent the leavened gas retention ability of a dough structure (Selmo & Salas-Mellado, 2014). Numfon (2007) has reviewed that the application of hydrocolloids can elevate the dough viscosity resulting in a higher gas retention capacity. According to the results given in Table 2, GG0.75 shows the highest crumb volume, highest crumb specific volume, and the lowest bulk density among the eleven crumbs. Moreover, almost all the crumbs prepared by incorporating different types of hydrocolloids, NCLE, and DSP have significantly high ($P<0.05$) volume, specific volume, and significantly low ($P<0.05$) bulk density compared to the control; except the crumbs containing Xanthan gum. The strong gluten–hydrocolloid interactions available with xanthan gum may cause to limit the dough extension and hence reduce the loaf volume (Zannini, Waters & Arendt 2014). Nevertheless, as per the results given in Table 2, the application of NCLE (NCLE5, NCLE10) and DSP1.5 contributed to a crumb volume, specific volume, and bulk density that do not significantly different ($P<0.05$) to GG0.75.

Selmo and Salas-Mellado (2014) have observed that with the increment of dehydrated Spirulina powder concentration (from 1 to 4%), crumb specific volume gets increased. The results of the current study also represent significantly high crumb volume, crumb specific volume, and a significantly low bulk density in DSP1.5 compared to DSP1. The addition of a protein source like Spirulina supports preventing the dough system collapse during fermentation of gluten-free products. This phenomenon assists in forming a network to entrap leavened gas, thereby improving the loaf volume (Minh, 2014; Selmo & Salas-Mellado, 2014).

Table 2. Volume, Specific volume, and Bulk density of the eleven gelatinized crumbs prepared by incorporating different types of hydrocolloids, NCLE, and DSP

	Sample	Crumb volume (cm^3)	Specific volume (cm^3/g)	Bulk density (g/cm^3)
1	C	52.23 ± 0.87^{d}	1.84 ± 0.02^{de}	0.54 ± 0.01^{ab}
2	XG0.5	54.46 ± 1.70^{cd}	1.87 ± 0.05^{cde}	0.54 ± 0.01^{abc}
3	XG0.75	51.83 ± 1.47^{d}	1.78 ± 0.06^{e}	0.56 ± 0.02^{a}
4	GG0.5	60.52 ± 1.47^{ab}	2.14 ± 0.05^{a}	0.47 ± 0.01^{de}
5	GG0.75	61.63 ± 1.27^{a}	2.16 ± 0.05^{a}	0.46 ± 0.01^{e}
6	SA0.5	60.73 ± 0.78^{ab}	2.11 ± 0.02^{ab}	0.47 ± 0.01^{de}
7	SA0.75	57.51 ± 2.42^{abc}	2.02 ± 0.11^{abc}	0.50 ± 0.03^{cde}
8	NCLE5	57.45 ± 0.44^{abc}	1.20 ± 0.03^{abcd}	0.50 ± 0.01^{bcde}
9	NCLE10	57.66 ± 1.48^{abc}	1.20 ± 0.05^{abcd}	0.50 ± 0.01^{bcde}
10	DSP1	56.09 ± 1.42^{bcd}	1.96 ± 0.05^{bcd}	0.51 ± 0.01^{bcd}
11	DSP1.5	60.83 ± 2.28^{ab}	2.14 ± 0.09^{a}	0.47 ± 0.02^{de}

Results are represented as mean±SD of replicates; mean values in the same column with different superscripts are significantly different at 0.05 significant level

Table 3. Texture Profile analysis of the eleven gelatinized crumb samples prepared by incorporating different hydrocolloids, NCLE, and DSP

	Sample	Hardness (g)	Springiness (mm)	Cohesiveness	Gumminess (G)	Chewiness (mJ)
1	C	1318.30 ± 78.50^{ab}	9.72 ± 0.48^{ab}	0.54 ± 0.02^{abc}	735.90 ± 61.30^{ab}	70.36 ± 8.97^{ab}
2	XG0.5	1146.70 ± 97.00^{bc}	10.29 ± 0.65^{a}	0.57 ± 0.02^{a}	665.10 ± 47.70^{bcd}	68.42 ± 9.20^{ab}
3	XG0.75	1480.00 ± 55.70^{a}	9.88 ± 0.21^{ab}	0.56 ± 0.02^{ab}	823.40 ± 55.20^{a}	78.67 ± 4.44^{a}
4	GG0.5	1038.30 ± 62.40^{c}	9.43 ± 0.31^{ab}	0.50 ± 0.02^{abcd}	654.30 ± 62.60^{bcd}	60.53 ± 5.01^{b}
5	GG0.75	1010.00 ± 30.40^{c}	9.80 ± 0.28^{ab}	0.42 ± 0.05^{d}	465.50 ± 34.90^{e}	41.45 ± 7.43^{c}
6	SA0.5	1095.00 ± 56.80^{c}	9.85 ± 0.14^{ab}	0.52 ± 0.03^{abc}	573.50 ± 59.90^{cde}	55.31 ± 5.22^{bc}
7	SA0.75	1146.70 ± 59.70^{bc}	9.17 ± 0.02^{b}	0.48 ± 0.02^{bcd}	569.90 ± 48.50^{cde}	54.40 ± 6.69^{bc}
8	NCLE5	1141.70 ± 80.10^{bc}	9.83 ± 0.46^{ab}	0.55 ± 0.04^{abc}	539.07 ± 6.40^{de}	52.84 ± 3.11^{bc}
9	NCLE10	1198.30 ± 46.50^{bc}	9.71 ± 0.09^{ab}	0.52 ± 0.03^{abc}	474.30 ± 24.00^{e}	42.60 ± 2.53^{c}
10	DSP1	1483.30 ± 92.50^{a}	9.46 ± 0.40^{ab}	0.47 ± 0.03^{cd}	688.00 ± 6.20^{abc}	62.94 ± 4.06^{ab}
11	DSP1.5	1135.00 ± 69.00^{c}	9.29 ± 0.27^{ab}	0.54 ± 0.04^{abc}	605.00 ± 72.70^{bcde}	55.36 ± 5.33^{bc}

Results are represented as mean±SD of replicates; mean values in the same column with different superscripts are significantly different at 0.05 significant level

Texture Profile is another important quality parameter that highly depends on the crumb cellular structure properties. It resembles the aesthetic sensation within the human mouth in order to determine the consumer acceptability (Hager & Arendt, 2013; Li & Nie, 2015). The application of hydrocolloids contributes to increasing the water-binding ability of the dough to obtain moist and softer crumbs (Hager & Arendt, 2013).

The application of hydrocolloids in developing leavened baked products contributes to increase the water-binding ability and to obtain moist and softer crumbs (Hager & Arendt 2013). According to the results given in Table 3, the application of different types of hydrocolloids, NCLE, and DSP contributed to lowering the hardness of the crumbs compared to the control (except XG0.75 and DSP1). Souther (2005), Hager and Arendt (2013), and Kondakci et al. (2015) have also observed that the crumb hardness gets increased with the increment of hydrocolloid concentration, particularly with xanthan gum. The reason for this phenomenon is that the addition of higher concentrations of hydrocolloids may contribute to increasing the dough/ batter viscosity. Thus, the viscosity itself can negatively affect in increasing the crumb hardness (Numfon 2007). Besides, this may also occur as a result of the increment of the thickness of the crumb cell walls that surround the air space (Rosell, Rojas & Barber 2001; Guarda et al. 2004).

As per the results given in Table 3, DSP1.5 shows a significantly low ($P<0.05$) hardness compared to DSP1. Because, the microalgal biomass can increase the water-holding capability of the dough and, hence contributes to obtaining a softer crumb in leavened baked products (Massoud et al., 2016). However, the hardness of the crumbs that contained NCLE and DSP show higher values compared to the crumbs that contained Guar gum. When considering the gumminess and chewiness values, all the crumb samples with different hydrocolloids, except XG0.75 have lower gumminess and chewiness values compared to the control (C).

There is no significant difference ($P>0.05$) between the springiness of all the crumbs with different hydrocolloids and DSP. Hydrocolloids can withhold the thickening and gelling characteristics and have the ability to form links between the molecules in a food system. Thus, the formed network can build a three-dimensional lattice; of which, oil droplets or particles can be permanently trapped without separating. That results in having a higher springiness value (Souther, 2005). Generally, those higher springiness values represent the higher recoverability from the first deformation in texture profile analysis (Singh, Jha, Chaudhary, & Upadhyay, 2014).

3.2. Cellular structure properties (Image analysis)

Crumb cellular structural properties play a significant influence on the physical and organoleptic properties of leavened baked products (Falcone et al., 2004; Lassoued, Babin, Della Valle, Devaux, & Réguerre, 2007). Acceptable crumb cellular structure, softer texture with more elastic properties are excellent parameters that represent improved crumb cellular structure properties containing a greater number of small, uniform, and thin-walled gas cells (Tebben & Li, 2019). Higher number of gas cells per unit area (cell density) with an acceptable average cell area, higher cell circularity, and lower FD validate the fineness and the uniformity of crumb cellular structure, while a higher porosity indicates the presence of a greater number of larger gas cells (Che Pa et al., 2013). Figure 1 and Table 4 represent the scanned images and the cellular structure properties of the eleven gelatinized crumbs respectively.

According to Table 4, XG0.5 and XG0.75 have the highest cell density, lowest porosity, lowest average cell area, higher cell circularity values, and lower FD values compared to the other crumbs. This represents a finer crumb cellular structure of XG0.5 and XG0.75 (Figure 1). Even though, xanthan gum shows comparatively negative effects in crumb volume (Table 2) and texture related properties (Table 3), it contributed to developing crumb samples with more uniform and finer cellular structure compared to the other hydrocolloids, NCLE, and DSP. During the leavening process, hydrocolloids may contribute to reinforcing the gluten network around the gas cells while increasing their stability resulting in a higher number of gas cells in a unit area (Tebben & Li, 2019). Crumbs that contained DSP (DSP1, DSP1.5) exhibit higher cell density values compared to the crumbs that contained Guar gum, Sodium alginate, and NCLE. Nevertheless, crumbs comprising DSP having higher porosity, FD, and lower cell circularity than that of the crumbs that contained Xanthan gum, Sodium alginate, and NCLE, representing the presence of more coalesced and irregular cell structure.

Despite contributing for a higher crumb volume and better texture properties, Figure 1 and Table 4 evident that Guar gum (GG0.5 and GG0.75) resulting in a crumb with more coalesced gas cells, denoting a lower cell density, higher porosity and higher average cell area.

Table 4 Cellular structure properties (Image analysis) of the eleven gelatinized crumbs prepared by incorporating different types of hydrocolloids, NCLE, and DSP

	Sample	Cell density (number of cells/cm^2)	Porosity (%)	Average cell area (cm^2)	Cell circularity	Fractal dimension (FD)
1	C	23.544 ± 4.510^{de}	32.943 ± 2.796^{bc}	0.015 ± 0.003^{bc}	0.487 ± 0.050^{ab}	1.668 ± 0.033^{ab}
2	XG0.5	33.373 ± 3.532^{ab}	27.001 ± 2.563^{e}	0.008 ± 0.001^{d}	0.503 ± 0.033^{ab}	1.657 ± 0.029^{b}
3	XG0.75	34.787 ± 4.860^{a}	28.681 ± 2.008^{de}	0.008 ± 0.001^{d}	0.512 ± 0.032^{a}	1.672 ± 0.028^{ab}
4	GG0.5	19.084 ± 3.638^{e}	36.709 ± 4.450^{a}	0.020 ± 0.006^{a}	0.471 ± 0.033^{ab}	1.690 ± 0.031^{ab}
5	GG0.75	24.032 ± 4.290^{d}	35.929 ± 4.480^{ab}	0.016 ± 0.005^{b}	0.500 ± 0.057^{ab}	1.696 ± 0.037^{ab}
6	SA0.5	25.160 ± 5.780^{cd}	31.195 ± 3.161^{cd}	0.014 ± 0.003^{bc}	0.509 ± 0.040^{ab}	1.653 ± 0.033^{b}
7	SA0.75	25.922 ± 3.023^{cd}	33.516 ± 2.764^{abc}	0.013 ± 0.002^{bc}	0.500 ± 0.029^{ab}	1.688 ± 0.027^{ab}
8	NCLE5	24.897 ± 3.771^{cd}	32.045 ± 3.279^{cd}	0.013 ± 0.002^{bc}	0.494 ± 0.038^{ab}	1.679 ± 0.050^{ab}
9	NCLE10	25.612 ± 2.822^{cd}	32.678 ± 1.947^{bc}	0.013 ± 0.002^{bc}	0.495 ± 0.043^{ab}	1.687 ± 0.034^{ab}
10	DSP1	28.991 ± 4.220^{bc}	32.360 ± 2.738^{bcd}	0.011 ± 0.002^{cd}	0.471 ± 0.078^{ab}	1.697 ± 0.049^{ab}
11	DSP1.5	26.354 ± 4.250^{cd}	34.600 ± 3.379^{abc}	0.014 ± 0.003^{bc}	0.455 ± 0.061^{b}	1.703 ± 0.052^{a}

Results are represented as mean±SD of replicates; mean values in the same column with different superscripts are significantly different at 0.05 significant level.

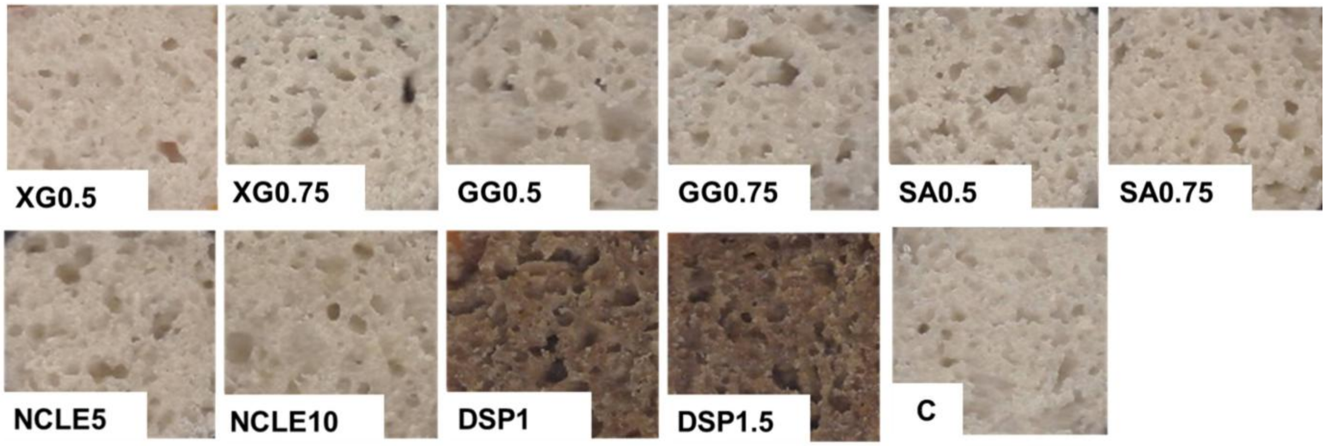

Figure 1. Scanned images (300dpi) of the eleven gelatinized crumbs prepared by incorporating different types of hydrocolloids, NCLE, and DSP

3.3. Storage stability

Usually, leavened baked products begin to undergo certain chemical and physical changes during storage which causes deterioration of the quality of the product (staling) (Angioloni & Collar, 2009; Mondal & Datta, 2008). The most common deteriorative effects of crumb staling include retrogradation of amylopectin, re-organization of polymers within the amorphous region, loss of moisture content, and moisture migration (Guarda, Rosell, Benedito, & Galotto, 2004). Thus, decrement of crumb moisture content and crumb hardening are the most prominent indications of crumb staling (Shittu et al., 2009). However, the ability of retarding the crumb staling of different hydrocolloids can vary due to the molecular structure of the hydrocolloids and the interaction of each hydrocolloid material with the starch molecules (Das et al., 2015).

According to plot "A" in Figure 2, the initial moisture contents of crumbs prepared by incorporating Xanthan gum, Guar gum, and DSP1.5 are higher than that of the control sample. Moreover, crumbs prepared by incorporating NCLE (NCLE5 and NCLE10) show the lowest moisture loss during storage. Further, according to plot "A" in Figure 2, the rate of the crumb moisture reduction within the first 24 hours is higher than the second 24 hours in almost all the eleven crumbs. However, the rate of crumb moisture reduction within the first 24 hours is more prominent in the control crumb (C) as well as XG0.5, GG0.5, and GG0.75.

Plot "B" in Figure 2 depicts that the control crumb (C) having the highest increment in the hardness while GG0.75 having the lowest values during the storage period. The increment of hardness within the first 24 hours is more prominent in XG0.5, XG0.75, SA0.75, NCLE5, DSP1, and C in comparison to the other crumbs. Plot "B" in Figure 2 further demonstrates that, XG0.75, SA0.5, NCLE10, DSP1.5, and C exhibit a relatively higher degree of crumb hardening within the second 24 hours of storage. However, the hardness value of GG0.5 show a declined manner within the second 24 hours' period.

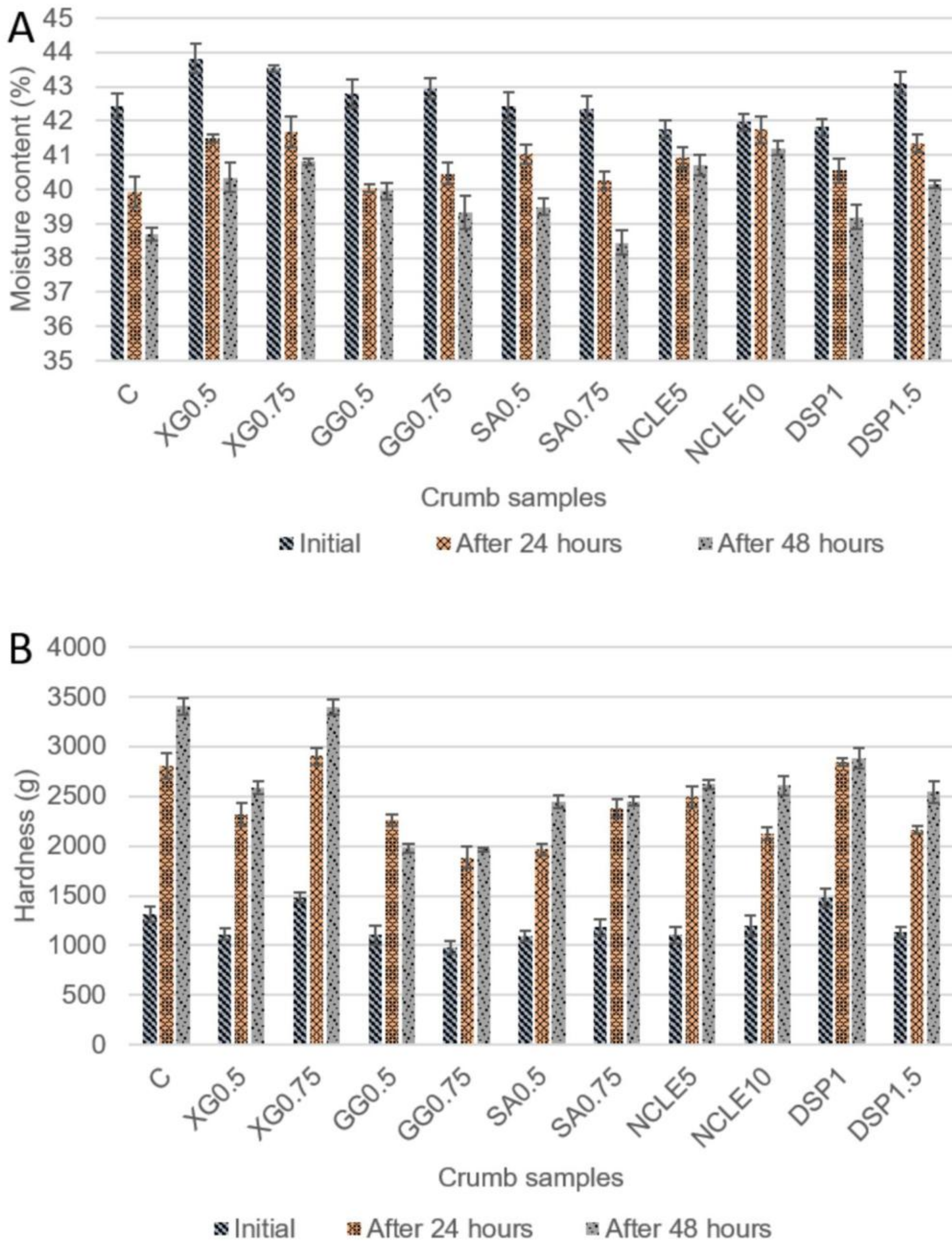

Figure 2. Storage stability of the eleven gelatinized crumbs prepared by incorporating different types of hydrocolloids, NCLE, and DSP (A) Deviation of the moisture content during the storage period, (B) Deviation of crumb hardness during the storage period. (Results are represented as mean±SD of replicates)

Since the moisture in the crumb of a leavened food product acts as a plasticizer, the moisture retention capability of the crumb shows a huge role in reducing the rate of crumb firming during storage. Otherwise, the reduction of the moisture content in a crumb during storage may lead to the formation of bonds either between starch polymers themselves or between protein and starch. This causes the increment of the hardness of the crumb (Das et al., 2015). The application of hydrocolloids causes retarding the staling process by improving the water retention capacity and also showing a potential hindering effect on amylopectin retrogradation (Guarda et al., 2004). However, the ability of retarding the crumb staling of each hydrocolloid varies due to the molecular structure of the hydrocolloids and the interaction of each hydrocolloid material with the starch molecules (Das et al., 2015).

4. Conclusions

Type and the dosage of hydrocolloids can significantly affect the textural and structural properties of gelatinized crumbs. Despite uneven crumb cellular structure, the application of Guar gum at 0.75% has contributed to improving crumb volume and texture-related properties as well as reduce the crumb hardening rate during storage comparatively Xanthun Gum and Sodium Alginate. NCLE helped to have a higher moisture retention capacity than the other hydrocolloid materials but it did not significantly contribute to reducing the rate of crumb hardening. Moreover, the application of DSP in 1.5% also imparts a significant role in improving crumb volume and texture of leavened food products coupled with an acceptable role in reducing the staling effect similar to Guar gum and Sodium alginate.

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