



Research article

Effect of xanthan gum and carboxymethyl cellulose on structure, functional and sensorial properties of yam balls

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ABSTRACT

Yam and its products can be modified during processing to reduce losses and ensure food security in the developing world. Xanthan gum (XG) and carboxymethyl cellulose (CMC) were added at different concentrations to yam balls and their effect on the structural, functional, and sensory properties of frozen yam balls were investigated in this study. Freeze-thaw stability and oil absorption capacity of yam ball mix were determined. Sensory evaluation and instrumental texture profile analysis (TPA) were done on samples of deep-fried yam balls using TA-XT Texture Analyser. Yam balls mixture containing XG and CMC had significantly ($p < 0.05$) lower oil uptake and water migration rates of 0.19 g/g and 4.10% as compared to control products 0.25 g/g and 11.05% respectively. Deep-fried yam balls samples containing 1 g of both XG and CMC obtained higher scores for their sensory attributes, while samples containing 2 g of both hydrocolloids were the chewiest. The findings suggest that the addition of hydrocolloids; XG and CMC enhances the freeze-thaw stability and reduces the oil absorption potential of the yam balls mix, and improve the sensory and texture properties of deep-fried yam balls.

1. Introduction

Yam (*Dioscorea* spp.) is a tropical plant cultivated for its starchy tubers especially among Asians and Africans (Hou et al., 2002). Ovono et al. (2010) reported that about 400 million people thrive on yam as their main food source. About 72.58 million metric tons of yam are produced globally with major producers being Nigeria (73%), Ghana (12.5%), Côte d'Ivoire (10.5%), and Benin (4.5%) (Neina, 2021). They are good source of carbohydrate, and provides about 200 calories of energy per capita on daily consumption (Okoro and Ajieh, 2014). Despite its economic importance, nearly 50% of the crop is perished over short period because of rotting and sprouting. Processing of yam into more shelf stable and convenient products can minimize post-harvest losses and broaden utilization (Princewill-Ogbonna, and Ibeji, 2015)

Yam is processed into products such as flour, flakes, pounded fufu, pounded yam, boiled yam, roasted yam, grilled yam, mashed yam, yam chips, and yam balls. One of the most popular yam products is yam balls. Yam balls are obtained by cooking and mashing boiled yam, spicing and molding it into a ball, then frying (Achi and Akubor, 2000). Before frying, the yam balls may be kept in frozen storage for preservation, and this

consequently promotes rapid retrogradation and gel syneresis leading to detrimental textural defects. To resolve this, the addition of hydrocolloids has been recommended to stabilize the starch and enhance the structural and functional integrity of yam balls while in frozen storage (Bahaji et al., 2014).

Hydrocolloids are mostly use in food systems as mechanical, rheological, and sensory modifiers. They are also used to control retrogradation, syneresis, texture, and overall quality of the final product (Mahmood et al., 2017; Bahaji et al., 2014; Saha and Bhattacharya, 2010; Kruger et al., 2003). Xanthan gum (XG) and carboxymethyl cellulose (CMC) are two of the most common hydrocolloids used in food applications. Structurally, they both consist of a cellulose backbone of β (1, 4)-D-glucose units with substituents protruding from the main chain (Lee and Brandt, 2002). Whereas xanthan gum has a trisaccharide side chain substitute, CMC, has carboxymethyl group substitutes (Lee and Brandt, 2002).

Several studies have reported the application of these hydrocolloids to induce changes in starch functionality in the frozen starch disperse phase (Bahaji et al., 2014). The main mechanism of action is the interaction between leached starch components (amyloses) and hydrocolloids

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Table 1. Hydrocolloid combination in yam balls mash.

Sample designation	Amount of hydrocolloid (g)	
	XG	CMC
XG1	1.0	-
XG2	2.0	-
CMC1	-	1.0
CMC2	-	2.0
XG.CMC1	0.5	0.5
XG.CMC2	1.0	1.0
Control	-	-

(Zhang et al., 2018). Based on this, it is hypothesized that XG or CMC could enhance the freeze-thaw stability and other quality characteristics of yam balls since it is essentially a starch-based product. This work, therefore, sought to examine the impact of XG/CMC addition on yam ball structural, functional, and sensory properties after frozen.

2. Materials and methods

2.1. Materials

Xanthan gum (XG), and carboxymethyl cellulose (CMC) was kindly provided by CSIR-Food Research Institute (Accra, Ghana), and matured white yam tubers were purchased from the Local market (Haatso Yam Market, Accra-Ghana).

2.2. Preparation of the yam balls

Yam balls were prepared according to Zhu (2015) and Otagbayo et al. (2007) with slight modifications. About 5.5 kg of peeled yam tubers were washed, sliced (4 cm), and boiled in 3056 ml with water for 25–35 min until tender. The boiled slices were mashed manually, mixed with XG, CMC, or XG + CMC (Table 1) and (Scheme 1), and molded into spherical balls weighing 28 g each. A control devoid of hydrocolloids was

prepared. Thereafter, the samples were packaged in clear high-density polyethylene pouches, vacuum sealed, and stored at -18°C for 14 days. Before analysis, the samples were thawed at room temperature.

2.3. Freeze-thaw stability of yam balls

Freeze–thaw stability of the yam balls was evaluated according to method by Babu et al. (2019). Six gram of yam ball paste stored at -18°C for 24 h in a plastic centrifuge tube was defrosted at room temperature and centrifuged at $2000 \times g$ for 20 min. Thereafter, the supernatant was discarded, and the water migration rate was calculated as:

$$R = A - B \div A * 100\%$$

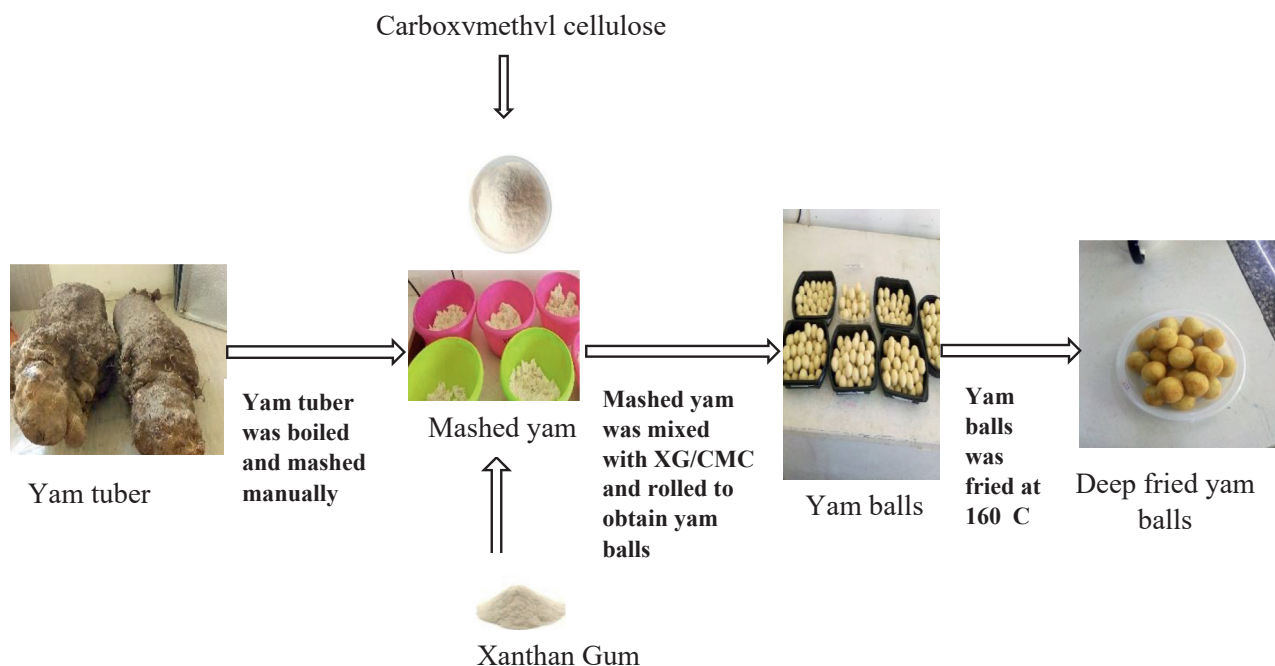
where R is water migration rate, A is the weight of yam ball paste, and B is the weight of sediment.

2.4. Oil absorption capacity

The oil absorption capacity (OAC) of yam ball paste was determined according to Lu et al. (2020) with slight modifications. A 10 g sample was dispersed in 60 g sunflower contained in a centrifuge tube, stirred continuously in a 50°C water bath for 20 min, and left to stand in the water bath for a further 30 min. The tube was then inverted to drain the upper oil slick after it was centrifuged at $2000 \times g$ for 20 min, and the percentage of mass increase per gram of sample was calculated.

2.5. Structural analysis of yam balls using Fourier transform infrared spectroscopy (FTIR)

To obtain the absorbance spectra of yam paste, sample was analyzed using FTIR spectrometer (Spectrum Two, PerkinElmer LTD. UK) adopting modified method of Dumoulin et al. (1998). Samples were freeze-dried overnight. The samples were placed on Mercury cadmium telluride (MCT) plate and scanned at 256 with a resolution of 4 cm^{-1} and frequency from 400 to 4000 cm^{-1} .



Scheme 1. Fundamental steps in preparation of yam balls; yam tuber was boiled, mashed and mixed with different Concentrations of XG and CMC, molded into balls which was finally deep fried at 160°C for 20 min to obtain yam balls.

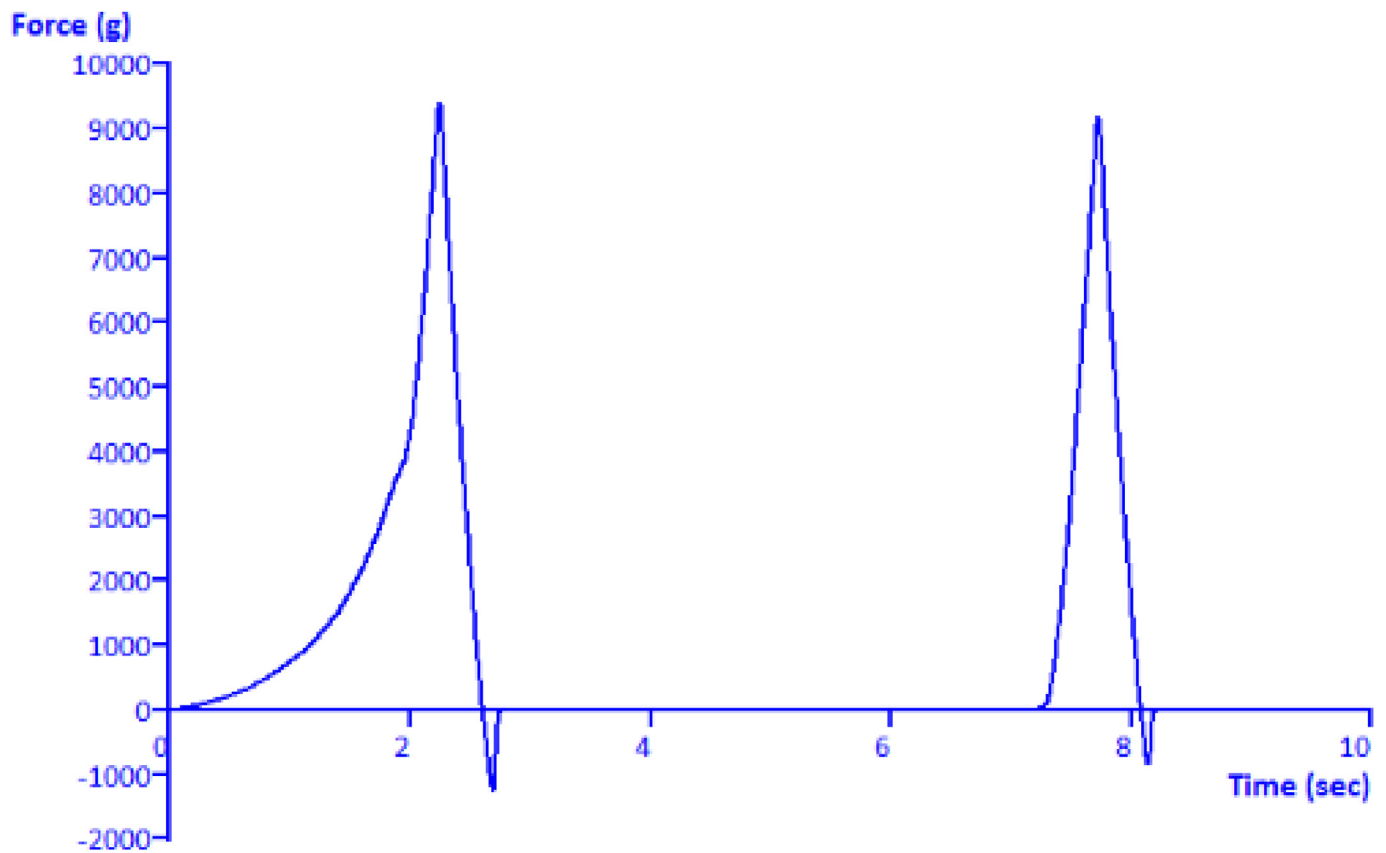


Figure 1. A typical TPA curve.

2.6. Texture profile analysis (TPA)

Yam balls samples were deep fat fried in refined vegetable oil using a sample to oil ratio of 1:5. The samples were fried at 160 °C for 20 min (Scheme 1) and allowed to cool to room temperature before texture measurements were conducted.

The texture profile analysis of the fried yam balls was done as described in Otegbayo et al. (2007) with minor changes. The texture of the fried sample was measured at room temperature using a texture analyzer (TA.XTplus, Stable Microsystems, Surrey, UK) equipped with cylindrical probe (20 mm diameter). Spherical yam balls were

compressed to 70% of its height, using a P75 probe, mimicking a double bite at a test rate of 1.0 mm/s. The texture parameters (hardness, cohesiveness, adhesiveness, and chewiness) were extracted from the texture profiles with Exponent software (Stable Microsystems, Surrey, UK). Ten replicates were analyzed per sample.

A typical TPA curve is shown in Figure 1.

2.6. Sensory evaluation

Samples from the deep-fried yam balls (described previously in section 2.6) were used in the sensory evaluation. Sixty untrained panelists

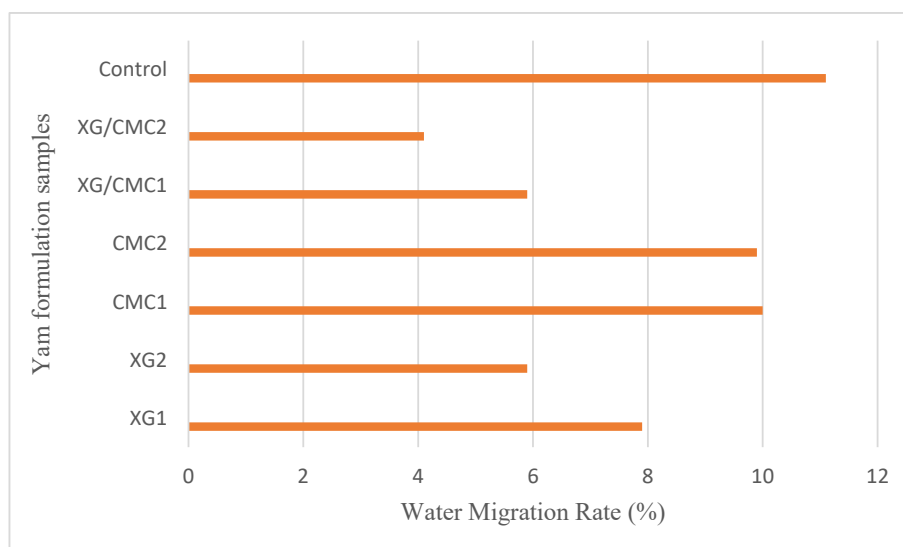


Figure 2. Freeze-Thaw stability of yam balls treated with xanthan gum (XG) and carboxymethyl cellulose (CMC).

Table 2. Oil absorption capacity of xanthan gum and CMC induced yam balls paste.

Hydrocolloids	OAC (g/g)
XG1	0.20 ± 0.01 ^{bc}
XG2	0.23 ± 0.01 ^{ab}
CMC1	0.21 ± 0.01 ^{bc}
CMC2	0.21 ± 0.01 ^{bc}
XG/CMC1	0.23 ± 0.01 ^{ab}
XG/CMC2	0.19 ± 0.01 ^c
Control	0.25 ± 0.01 ^a

Mean values in the same column with different letters are significantly different ($p < 0.05$).

comprising 34 Males and 26 females evaluated the deep-fried yam balls using a 9-point hedonic scale to assess sample attributes such as appearance, color, aroma, texture, taste, mouthfeel, and overall acceptance. Each panelist evaluated seven samples in a two-day session, with four samples on day one and three on the second day. The samples were presented to panelists following a randomized matrix generated by XLSTAT 2014 software (Addinsoft, USA). The panelists were provided with still water and cucumber to refresh their palate in between each sample. Regarding ethics, Panelists consent was sought prior to the sensory evaluation, since the product (yam balls) is already known and consumed by the panelists and the XG and CMC used in the product as food additives is well known food additives (GRAS-General Recognized as Safe).

2.7. Statistical analysis

A one-way analysis of variance (one-way ANOVA) was used to analyze the data and significantly different means were separated ($p < 0.05$) using the Tukey test (Minitab 14, Minitab Inc, Brandon Court, United Kingdom). Ominic software was used to extract the transmission spectra of FT-IR. Excel 2013 was used in the graphical illustration.

3. Results and discussion

3.1. Effect of hydrocolloids on freeze-thaw stability of yam ball paste

Functional properties of starch such as freeze-thaw property are affected by thermal fluctuation. This freeze-thaw influences textural and product shelf stability (Charoenrein et al., 2011). The incorporation of hydrocolloids into yam balls markedly reduced the water migration rate (retrogradation tendency index) (Figure 2), and this was influenced by both the type and quantity of hydrocolloids used.

There were significant differences ($p < 0.05$) in the freeze-thaw stability between the sample treatments. High levels of either hydrocolloid were more effective in reducing moisture migration from the yam balls mash, although a more pronounced effect was recorded in samples containing xanthan gum. The combination of the two hydrocolloids showed more stable moisture migration in the product. The control, devoid of hydrocolloids had significantly ($p < 0.05$) more pronounced syneresis of 11.1% as compared to treated samples; 7.9%, 5.9%, 10.0%, 9.9%, 5.9%, 4.1% for XG1, XG2, CMC1, CMC2, XG.CMC1, XG.CMC2 respectively.

During freezing and thawing cycles, there is extensive association and reorganization of starch polymer constituents, leading to marked release from the starch granules (Muadklay and Charoenrein, 2008). Additionally, in the absence of hydrocolloids, freezing causes severe structural damage to starch gels. Similar observations were reported by Chen et al. (2019) of 56.87%–72.36% syneresis in potato starch gel control sample during the freeze-thaw cycle as compared to lower syneresis observed in samples with gums added. The low water release by XG/CMC2 yam balls in this study could be attributed to the synergistic interaction between the two gums used. The hydrocolloids possess more hydroxyl group, and this could increase the accessible sites for hydrogen bonding resulting in a higher affinity for binding water (Alimi et al., 2013). This could improve storage stability and texture of starchy frozen food. Similar finding was reported by Jiaxu and Baojun (2019) who concluded that, the addition of 2.5, 5, 7.5, and 10% of XG reduced syneresis of binary gels made from selected starch and edible gums.

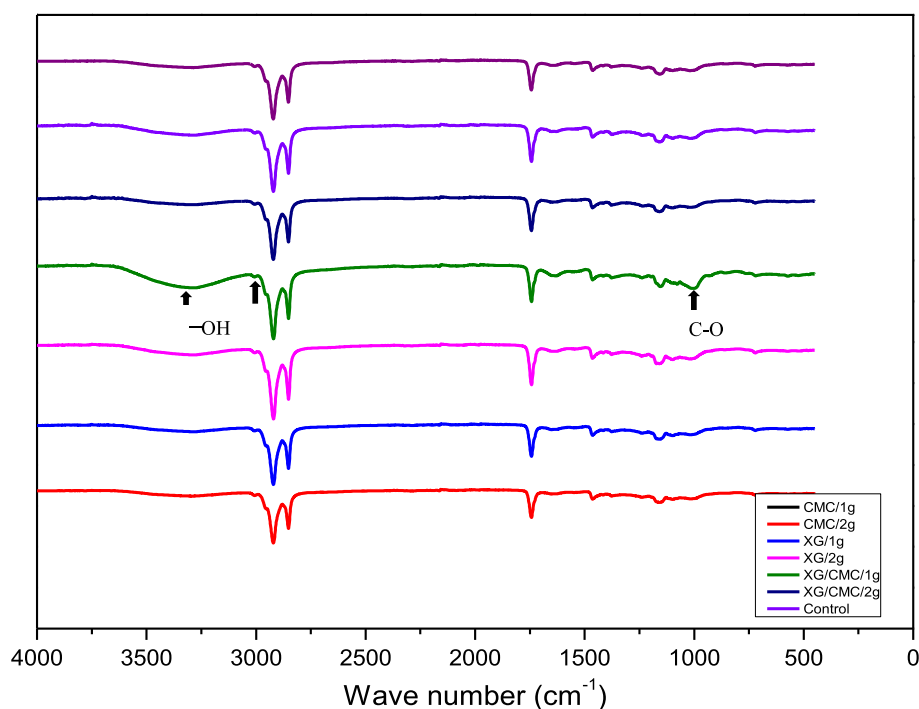


Figure 3. FT-IR spectra of yam balls formulated with or without XG/CMC over the frequency range of mid-region from 400 to 4000 cm^{-1}

Table 3. Texture profile analysis of yam balls formulated without or with XG and CMC.

Sample	Texture			
	Hardness (g.force)	Chewiness (g.force)	Cohesiveness	Springiness (mm)
XG1	647.85 ± 4.33 ^b	1501.84 ± 4.17 ^{bc}	0.58 ± 0.01 ^a	3.60 ± 0.01 ^{bc}
XG2	616.30 ± 14.20 ^a	1416.20 ± 16.50 ^c	0.61 ± 0.01 ^a	3.71 ± 0.06 ^{bc}
CMC1	610.08 ± 0.73 ^{bcd}	1503.20 ± 2.26 ^{bc}	0.59 ± 0.01 ^a	3.64 ± 0.07 ^{bc}
CMC2	656.97 ± 10.32 ^d	1429.17 ± 0.43 ^c	0.58 ± 0.11 ^a	3.64 ± 0.04 ^{bc}
XG/CMC1	611.17 ± 3.69 ^a	1621.30 ± 18.90 ^{ab}	0.61 ± 0.01 ^a	3.84 ± 0.09 ^b
XG/CMC2	608.21 ± 0.76 ^{bc}	1701.19 ± 0.83 ^a	0.66 ± 0.01 ^a	4.13 ± 0.04 ^a
Control	647.85 ± 4.33 ^{cd}	1471.1 ± 82.30 ^c	0.61 ± 0.01 ^a	3.54 ± 0.11 ^{bc}

Within a column, means with different letters are significant different ($p < 0.05$).

3.2. Effect of hydrocolloids on oil absorption capacity (OAC)

The impact of hydrocolloids on yam balls' affinity to oil is summarized in Table 2. The samples recorded significant differences ($p < 0.05$) in oil absorption capacity. Generally, samples containing hydrocolloids had lower oil absorption capacity compared to the control. XG/CMC2 yam balls had the least oil absorption capacity of 0.19 g/g, which was significantly ($p < 0.05$) different from the oil holding capacity of XG1, CMC1, and CMC2.

The reduction of oil uptake in yam balls, as influenced by the gums can be attributed to their synergized thermo-gelling properties and film-forming characteristics (Naghavi et al., 2018). These hydrocolloids usually form an oil-resistant barrier film on the surface of fried products due to changes in surface hydrophilicity (Kowalczyk and Gustaw, 2009). Elsewhere, carrageenan (4%) and xanthan (0.3%) coatings resulted in the highest oil reductions of fried potato chip-based pellets than uncoated samples. Consequently, Kim et al. (2011) reported that gum coating reduced the oil content up to 41% in potato strips compared to control. The use of hydrocolloids can provide low oil food in contrast to high oily food associated with diseases like obesity, high cholesterol levels, or high blood pressure (Dourado et al., 2019).

3.3. Structural modification of yam balls

FT-IR spectroscopy was done to ascertain possible chemical interactions occurring during the processing of yam balls. The patterns and analysis of the bands from 400 to 4000 cm^{-1} of the order of yam balls-gums structure are shown in Figure 3.

Three peaks have been designated as characteristics of carbohydrates as absorption regions; 995 cm^{-1} , 1082 cm^{-1} , and 1160 cm^{-1} (Lopez-Rubio et al., 2009). The bands at 1082 cm^{-1} and 1160 cm^{-1} could be attributed to the vibrational peak of the C–O group and the symmetric stretching vibration of CH_2 . These relate to the ordered structures of starch. The band at 995 cm^{-1} could be attributed to the vibrational peak of C–O in the alcoholic hydroxyl group. This is responsible for the amorphous structure possessed by starch granules (Li et al., 2004a,

2004b). The visual analysis of the FT-IR profile reveals the transmission intensity difference among the yam balls-hydrocolloid mixtures at the spectrum of 990, 1000, 1158 cm^{-1} which were due to the C–O–C, C–C stretch-vibration, and C–H bending vibration (Sevenou et al., 2002). All the formulated samples presented a similar spectrum, except for the bands at 3000–3300 cm^{-1} which contain hydrocolloids (XG/CMC/1g). The samples with hydrocolloids (XG/CMC/1g) had a broad spectrum which in the bands of 3000–3300 cm^{-1} reflects the –OH stretching vibration. Furthermore, there was a broad peak at 1000 cm^{-1} . The occurrence of this broad peak could be attributed to the strong C–O stretching in the hydrocolloids (Mohit et al., 2019). This [E1] possibly corresponds to the hydroxyl bond present in the hydrocolloids. The hydrocolloids in the starch of yam balls especially XG enhanced the hydrogen bonding in the matrix. The attributed reason is the COOH and –OH of the starch chains in the yam balls at a relatively high concentration of hydrocolloids [E1].

3.4. Texture properties of hydrocolloids-yam balls

The textural profile of deep-fried yam balls was analyzed to simulate the mastication of food in the mouth. The results of yam balls' textural characteristics showed notable differences ($p < 0.05$) in hardness, chewiness, and springiness (Table 3). The cohesiveness of all the samples was comparable to the control ($p < 0.05$).

The yam balls recorded significant differences ($p < 0.05$) in texture due to treatments. Increasing the concentration of gums, generally resulted in softer and most chewy deep fried yam balls. This is consistent with Jiayu and Baojun (2019) who reported that, increasing XG or KGM at 10% decreased the hardness of the binary gel to form a spongy structure. Similarly, Ji Hyun et al. (2015) also observed that soy donuts containing no hydrocolloid were harder (20.82 N) than soy donuts coated with hydroxypropyl methylcellulose (HPMC) (30 N). Springiness of yam balls increased significantly ($p < 0.05$) with an increase in the concentration of XG and CMC in this study. This could be attributed to the resistance of yam balls to deformation during compression because samples containing gums had strong and compact network structure,

Table 4. Sensory scores of deep fried yam balls.

Samples	App	Color	Aroma	Texture	Taste	Mouthfeel	Acceptability
XG1	7.5 ± 1.2 ^{ab}	7.4 ± 1.1 ^a	7.4 ± 1.0 ^a	7.2 ± 1.2 ^{ab}	7.0 ± 1.5 ^a	7.0 ± 1.4 ^{ab}	6.9 ± 1.4 ^a
XG2	7.4 ± 1.2 ^{ab}	7.3 ± 1.3 ^a	7.3 ± 1.0 ^a	6.9 ± 1.4 ^b	6.9 ± 1.4 ^a	6.7 ± 1.1 ^b	7.0 ± 1.6 ^a
CMC1	7.5 ± 1.2 ^{ab}	7.4 ± 1.2 ^a	7.4 ± 1.4 ^a	7.2 ± 1.2 ^{ab}	6.9 ± 1.3 ^a	6.8 ± 1.3 ^{ab}	6.9 ± 1.4 ^a
CMC2	7.3 ± 1.4 ^{ab}	7.3 ± 1.3 ^a	7.5 ± 1.1 ^a	7.5 ± 1.2 ^{ab}	7.2 ± 1.1 ^a	7.5 ± 1.0 ^{ab}	7.4 ± 1.1 ^a
XG.CMC1	7.7 ± 1.0 ^a	7.5 ± 1.0 ^a	7.7 ± 1.0 ^a	7.5 ± 0.8 ^a	7.4 ± 1.5 ^a	7.6 ± 1.2 ^a	7.4 ± 1.4 ^a
XG.CMC2	6.9 ± 1.6 ^b	7.1 ± 1.3 ^a	7.1 ± 1.6 ^a	6.9 ± 1.6 ^{ab}	7.3 ± 1.6 ^a	7.4 ± 1.1 ^{ab}	7.3 ± 1.3 ^a
Control	7.5 ± 1.1 ^{ab}	7.5 ± 1.1 ^a	7.4 ± 1.2 ^a	7.4 ± 1.1 ^{ab}	7.3 ± 1.2 ^a	7.4 ± 1.4 ^{ab}	7.2 ± 1.4 ^a

Within a column, means with different letters are significant different ($p < 0.05$). App – appearance Interpretation scores: 9 = like extremely, 8 = like very much, 7 = like moderately, 6 = like slightly, 5 = neither like nor dislike, 4 = dislike slightly, 3 = dislike moderately, 2 = dislike very much, 1 = dislike extremely.

after frying. Chewiness indicates the degree of mastication by energy input or applied (Huang et al., 2007). As hydrocolloids concentration increased, there was direct proportional increment in yam balls chewiness (Table 4) with XG/CMC2 being the chewiest of all the samples. The increase in chewiness indicates that more energy was needed to masticate the yam balls and their texture was softer as compared to control yam balls. Starch network structure in the control was not protected from damage, and at lower gum concentration, the protection was not as effective, compared to higher gum concentrations. Similar results with the addition of hydrocolloids in fried food have been reported previously (Shine et al., 2013). Furthermore, our findings were similar to Jihyun et al. (2015) where the chewiness of control sample was lower than HPMC coated-soy donuts hydrocolloids.

3.5. Sensory characteristics

Sensory scores of fried yam ball samples treated with or without XG and CMC are presented in Table 4.

Yam balls with XG/CMC1 demonstrated superior sensory characteristics, and this was closely followed by CMC2. There were no significant differences ($p > 0.05$) in taste, aroma, and color among all the samples. Similarly, the overall acceptability of all the samples was comparable. Nonetheless, significant differences were observed among samples in terms of mouthfeel, texture, and appearance ($p < 0.05$). The addition of 1 g of XG and CMC to yam balls increased the hardness of the yam balls with improved textural properties (Table 4) which were moderately liked by the panelist. The results are consistent with the effects of XG and CMC on the overall sensory quality of fried yam balls. Hydrophilic hydrocolloids; xanthan gum and carboxymethyl cellulose act as coating agents to prevent water loss and prevent oil entrapment in fried food during frying giving good sensory attributes to the final product (Varela and Fiszman, 2011). Consequently, hydrocolloids act as thermogelling properties as oil uptake inhibitors without having any negative impact on the sensory property of fried foodstuff (Zeng et al., 2016). XG and CMC improve the appearance of the yam balls. The appearance of XG/CMC/1 g had the highest score of 7.65. This observation could be attributed to the smooth surface of XG/CMC/1 g yam balls.

Conclusion

The results of this study indicate that it possible to improve and enhance the quality of yam balls with the addition of XG and CMC. Incorporation of gums reduced oil uptake and moisture loss which are useful for stabilizing frozen and fried foods to maintain texture and prolong shelf life. Other attributes such as texture, starch structure, and sensory characteristics were improved by incorporating hydrocolloids in the yam balls formulation. Generally, addition of hydrocolloids at high concentration performed better for functional, rheological except sensory traits which was rather improved by moderate application of the hydrocolloids. The findings suggested that incorporating XG and CMC into yam balls offer a final fried product with good physicochemical and sensorial properties.

Declarations

Author contribution statement

Ebenezer Asiamah: Conceived and design the experiment; Performed the experiments; Wrote the paper.

Papa Toah Akonor: Analyzed and interpreted the data; Wrote the paper.

Evelyn Serwah Buckman; Frank Peget: Analyzed and interpreted the data; Contributes reagents, materials, analysis tools or data.

Allice Padi; Constance Boateng: Contributes reagents, materials, analysis tools or data.

Nicole Sharon affrifah: Performed the experiments; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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