Determination of the Functional Properties of Raw and Processed Nigerian Mungbean (*Vigna radiata*) and Effects of NaCl and pH Variations on Selected Functional Properties

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Abstract
The functional properties and effects of variations in pH and NaCl concentrations on foam capacity, emulsion capacity and stability of Nigerian mungbean (*Vigna radiata*) were determined in three forms: as raw, sprouted and autoclaved samples. The data obtained from this study shows that the processing methods affected the raw sample's functional properties. The foam capacity of each of the three samples tested was significantly affected by variations in NaCl concentrations with the sprouted reporting the highest at 0.2M concentration. The emulsion capacity was slightly affected initially, but a stable emulsion was reported at increasing NaCl concentrations. The effect of pH variations on emulsion capacity and stability showed that the tested flour samples form a better emulsion in an alkaline medium than in an acidic medium.

Keywords: Functional properties, pH, NaCl, concentrations, mungbean, raw, sprouted, autoclaved

Introduction

The determination of the functional properties of food substances is fundamental to their theoretical acceptance in industries. Functionality in a broad sense is any property of a food other than its nutritional value, which affects utilization such as texture, flavour and shelf life (Kumar *et al*., 2022). The usefulness of any particular raw material in the fabrication of a new product or ingredients depends on its possession of an appropriate range of functional properties (Lalit and Kaur, 2022). Some of the functional properties include water holding/absorption capacity, oil absorption capacity, bulk density, least gelation concentration, wettability, emulsion capacity/stability and activity, foam capacity and stability, solubility, swelling index, pH, boiling points and melting point. These functional properties can be adversely or moderately affected by variations in salt concentration (Torreggiani and Torres, 2022).

The effect of salt is significant because, in many foods, salt concentrations are approximately 0.2 - 0.3M (Raikos and Kumaran, 2022). Sodium chloride or table salt at appropriate concentration aids foaming presumably by aiding diffusion and spreading at the interface (Lalit and Kaur, 2022), however, this is concentration-dependent. Thus, high salt concentration depresses foaming. At high concentrations, a reduction in hydration may occur. The relative effect of cations and anions is influenced by the atomic radii (Damodaran, 2008). At this salt concentration, electrostatic interactions are of little importance with regards to the amount of water bound to protein because competition of the ions and proteins for water becomes predominant.

The mungbean (*Vigna radiata*) seeds are small, ovoid in shape, green in colour with husk but yellow when dehusked. They are grown widely for use as human food (as dry beans or fresh sprouts) but can be used as green manure for crops and as forage for livestock (Oplinger *et al*., 1990). The seeds are sprouted for fresh use or canned for shipment to restaurants where they are used mostly in 'salad' making. Industrially, it can be fabricated in the production of drugs, as a binder or as an active ingredient in cosmetics and bakery industries due to its high vitamin C content (Mmuta *et al*., 2017). Mungbean (*Vigna radiata*) requires slightly acidic soil for best growth and are warm season annuals which can germinate, grow and mature for harvest under three months. Therefore, it can be planted and harvested two times yearly during planting season; at the early time of scanty rainfall and at the late time of scanty rainfall or four times under irrigation (Mmuta *et al*., 2017).

Studies have revealed that different processing methods either reduce or improve the functional properties of food legumes. Processing methods such as sprouting have been reported to improve the functional properties of plant seeds (Jirapa *et al*., 2001). Therefore, investigation of the effects of different processing methods on the functional properties of mungbean (*Vigna radiata*) may increase its utilization in the food industries in Nigeria. This study aims to assess the effects of processing methods such as autoclaving and sprouting on the changes in the functional properties of mungbean (*Vigna radiata*) grown in Nigeria. Also, there has been no study reported on the effects of variations in pH values and NaCl concentrations on the functional properties of the

mungbean (*Vigna radiata*) seeds.

The specific objectives of this study include;

1. To determine the functional properties of the raw mungbean (*Vigna radiata*) flour sample.
2. Determination of the effect of processing methods on the functional properties of the raw and processed test flour samples.
3. Determination of the effect of variations in pH values and NaCl concentrations on foam capacity, emulsion capacity and stability of the raw relative to the processed mungbean (*Vigna radiata*) flours.

Materials and Methods

Sample collection and preparation

Mungbean (*Vigna radiata*) seeds were collected from the Bioresources Development Center, Abagana, Anambra State, sorted out to remove the bad ones, cleaned and divided into three portions. One portion was autoclaved at a temperature of 115°C for about 10 minutes. The second portion germinated at room temperature (27°C) with constant sprinkling of water for four days (96 hours) to allow proper sprouting. By the end of the sprouting period, the seeds were dried in the oven at 40°C for two hours. The third portion was left as raw which serves as the control. These various portions were milled separately to pass a 0.4mm sieve and kept in an air-tight container for further analysis which was carried out at the Central Laboratory Unit of Research Institute, Umudike in Abia State.

Functional properties determination

Water Absorption Capacity (WAC) determination

This was done using the method described by Abbey and Ibeh (1988) 1g position of each flour sample was measured into a known weight of each clean dry centrifuge tube (g/f medium speed centrifuge – Gallenkamp, England). Each sample was mixed thoroughly with 10 mL of distilled water for 30 seconds. This was then centrifuged at a speed of 3500 rpm for 15 minutes. The supernatant was discarded and the tube with its content re-weighed. The gain in mass is the water absorption capacity of the (*Vigna radiata*) seed flour samples.

Oil absorption capacity determination

The method described by Abbey and Ibeh (1988) was adopted. The sample (1g of each) was weighed and placed in various clean weighed centrifuge tubes. Refined Vegetable Oil Life Brand Density, 0.89gml^{-1}, was mixed with each sample to make up to 10ml dispersion. It was then centrifuged at a speed of 3500rpm for 15min, the supernatant was discarded and the tube with its content re-weighed. The gain in weight is the oil absorption capacity of the sample.

Bulk density determination

Each measuring cylinder of known volume (10 mL) was filled with 5kg of the test samples respectively and tapped gently to level the sample in the cylinder. The volume occupied by the sample in the cylinder was measured.

$$\text{Bulk density} = \frac{\text{Weight of sample (g)}}{\text{Volume of sample (cm}^3\text{)}}$$

pH determination

The pH of samples was determined using the method of Okezie and Bello (1988). The pH was measured by a 10%, w/v suspension of each sample. The pH meter uses a glass electrode with a saturated potassium chloride solution. The flour sample (1g) was weighed into a clean dried glass beaker, and distilled water was added. It was made up to 10 mL dispersion, stirred and allowed to stabilize for 30 minutes. The pH meter was switched on and allowed to stabilize for 30 minutes, then standardized with a pH buffer solution of pH 7. The electrode of the pH meter was inserted into the sample solution and the pH values were read and recorded.

Swelling index determination

The method of Ukpabi and Ndimele, (1990) was employed whereby 1g portion of each flour sample was transferred into a clean dry graduated cylinder. The samples were gently levelled and the volumes were noted. 30 mL of distilled water was added to the sample and the cylinder was swirled and allowed to stand for 60minutes while the change in volume (swelling) was recorded.

Form capacity determination

The flour sample (1 g) was blended with 50 mL distilled water in a blender (National Japan) at 1600rpm for 5minutes and the mixture was poured into a 250 mL measuring cylinder and the volume was recorded after 30seconds as described by Abbey and Ibeh (1988).

$$\text{Foam Capacity (\%)} = \frac{V_2 - V_1}{V_1} \times 100\%$$

Where;

V_I = Volume before whipping

V_2 = Volume after whipping

Foam Stability Determination

Emulsion Capacity Determination

The sample of weight 5g of each was blended with 25 mL distilled water, at room temperature after 30seconds at 1600rpm and dispersed. 25 mL vegetable oil (Life vegetable oil) added gradually and the blending continued for another 30seconds. The resulting mixture was separated in a centrifuge at 1600rpm for 5 minutes and the volume of oil separated from the sample was noted, as the emulsion capacity of the sample, as described by Padmashree *et al.* (1987).

$$\text{Emulsion Capacity} = \frac{X}{Y} \times \frac{100\%}{1}$$

Where X = Height of the emulsified layer
Y = Height of the whole solution in the centrifuge tube

Emulsion Stability

This is expressed as a percentage that was calculated as the ratio of the height of the emulsified layer to the total height of the mixture.

$$\% \text{ ES} = \frac{\text{Height of the emulsified layer after 15min in tube x 100}}{\text{Height of the total fluid in the tube}}$$

Determination of Least Gelation Concentration

The method of Onimawo and Akubor (2005) was adopted to determine the least gelation concentration. The sample dispersions of 2, 4, 6, 10, 12, 14, 16, 18 and 20% (W/V) were prepared in 5 mL distilled water in test tubes. They were heated in a water bath for one hour and cooled rapidly under tap water at 10°C and further cooled in the refrigerator at 5°C for one hour. The least gelation concentration was determined as that concentration of the test sample prepared, which did not slip when the test tube was inverted.

Food Energy Determination

This was determined by calculation using the factors 4, 4, and 9 for protein, carbohydrate and fat respectively according to the Atwater factor described by Pearson (1976).

Food energy (kca/g) = 4 x Protein + 4 x CHO + 9 x Fat

Determination of the effect of different Nacl concentrations on the foam capacity

The effect of different concentrations of NaCl on the foam capacity was determined by preparing a 2% (W/V) dispersion of each sample with 0.2, 0.4, 0.6, 0.8, and 1.0 molar concentrations of sodium chloride after the methods of McWatters and Holmes, (1979) and the foam capacity determined as in the method mentioned above.

Determination of the effect of different Nacl concentrations on the emulsion capacity and stability

The effect of different concentrations of NaCl on the Emulsion capacity and stability of the test samples was determined by preparing 2% (W/V) dispersion of each sample with 0.2, 0.4, 0.6, 0.8, and 1.0 molar concentrations of sodium chloride after the methods of McWatters and Holmes, (1979b) and the emulsion capacity and stability determined as in the method mentioned above.

Determination of the effects of pH variation on the emulsion capacity and stability

Different pH values were prepared by adjusting the pH of the water to 2, 4, 6, 8, 10 and 12 using concentrated NaOH and H_2S0_4 solutions after which the Emulsion capacity/stability was determined using 25ml of each pH and 25ml of refined vegetable oil (Life brand) as in the method described previously.

Table 1: Functional Properties

Parameter	Raw	Sprouted	Autoclaved
Bulk Density (g/cm^3)	0.71 ± 0.01	0.69 ± 0.01	0.73 ± 0.02
Water Absorption Capacity (WAC) (%)	1.93 ±0.01	1.98 ± 0.04	1.61 ± 0.03
Oil Absorption Capacity (OAC) (%)	1.78 ±0.02	1.98 ± 0.01	2.08 ± 0.01
Foam Capacity (%)	17.83 ± 0.23	16.33 ± 0.36	14.17 ± 0.17
Swelling Index (%)	1.75 ± 0.02	2.24 ± 0.12	2.91 ± 0.02
Foam Stability (%)			
30 mins	87.47 ± 0.98	70.67 ± 0.30	67.80 ± 0.51
60 mins	71.10 ± 1.12	60.50 ± 2.08	51.73 ±364
120 mins	60.50 ± 0.81	55.50 ± 2.08	43.50 ± 5.01
Least Gelation	9	8	12
pH Value	6.21 ± 0.14	5.90 ± 0.15	6.35 ± 0.12
Emulsion Capacity (%)	15.47 ± 0.08	13 95 ± 0.15	12.63 ± 0.29
Emulsion Stability (%)	10.03 ± 0.06	10.00 ± 0.40	7.13 ± 0.13

Values are represented as mean ± S.D (n=3).

Results and Discussion

The results obtained from the analysis of the functional properties of the Nigerian mungbean recorded as mean values (± standard deviation) are shown in Table 1. From this table, the bulk density of mungbean decreased slightly from 0.71 ± 0.01g/cm^3 of the raw sample to 0.69 ± 0.01g/cm^3 by sprouting and was slightly to 0.73 ± 0.02g/cm^3 by autoclaving. Kumar *et al.*, (2017) reported that an increase in moisture content can lead to a decrease in bulk density. This can be attributed to the increased porosity caused by the penetration of the water molecules into the bean particles thereby reducing the bulk density. Lopez *et al.* (2018), also stated that sprouting can lead to a decrease in bulk density, possibly caused by increased seed coat thickness and reduced seed density. Consequentially, an increase in bulk density is expected for the autoclaved sample which involves removal of moisture content. Sprouting and autoclaving are two reverse actions involving the addition of moisture and the removal of moisture respectively. Bulk density indicates the relative volume of packaging material required. Generally, higher bulk density is desirable for the greater ease of dispersibility and reduction of paste thickness which is an important factor in convalescent child feeding but low bulk density is desirable for normal healthy infants (Amagloh *et al.*, 2007).

Water absorption capacity (WAC) mean values (± standard deviation) recorded a slight increase from 1.93 ± 0.01 of the raw sample to 1.98 ± 0.04 by sprouting and a decrease in value was recorded for the autoclaved sample to 1.61 ± 0.03. Singh and Singh (2017) reported that sprouting activates enzymes that break down starches and proteins, increasing water absorption while autoclaving gelatinizes starches, reducing water absorption, maintains starches in a more absorbent state (Liao and Hung, 2017). Water absorption capacity is a useful indication of whether flour can be incorporated into aqueous food formulations especially those involving dough handling. The highest water absorption capacity sample could be useful in food systems such as bakery products which require hydration to improve handling characteristics (Udensi *et al.*, 2006).

Oil absorption capacity (OAC) mean values (± standard deviation) show a significant increase in values by both sprouting and autoclaving. It recorded an increase from 1.78 ± 0.02% of the raw sample to 1.98 ± 0.01% by sprouting while autoclaving increased the mean values (± standard deviation) of the raw sample to 2.08 ±0.01%. Higher oil absorption capacity can lead to increased susceptibility to oxidation and spoilage. The result of the foam capacity presented in the table recorded a decrease in value by both sprouting and autoclaving. The mean value (± standard deviation) of the foam capacity of the raw mung bean was reduced from 17.83 ± 0.23% to 16.33 ± 0.36% by sprouting while autoclaving reduced the value of the raw mungbean sample to 14.17 ± 0.17%. All the test samples of the mungbean flour could not retain stable foam after 2-hour intervals. Foam stability is a critical factor in the production of bean-based whipped toppings, as it directly affects the final product's texture and appearance. Data for Least Gelation Capacity presented in Table 1 shows that the sprouted test sample was able to gel at a very low concentration of 8, followed by the raw sample which attained its least gelation capacity at a concentration of 9, while the autoclaved test sample could not gel until a concentration of 12 was reached. This parameter can be used to predict the textural properties of the final products, ensuring desired consistency.

The mean value (± standard deviation) of the pH of the raw ungbean samples was drastically reduced by sprouting from 6.21 ± 0.14 to 5.90 + 0.22. This can be attributed to the increase in the breakdown of the protein content to amino acid which increases the acidity of the sprouted mungbean sample and thereby

reducing its pH Value, while autoclaving does not have a significant effect on the pH values which recorded an infinitesimal increase on the pH from 6.21 ± 0.14 of the raw sample to 6.35 ± 0.12 of the autoclaved sample.

The data of the emulsion capacity presented in Table 1 reveals that emulsion capacity was reduced from 15.47 ± 0.08% of the raw sample to 13.97 ± 0.15% by sprouting while autoclaving reduced the mean values of the raw bean sample to 12.63 ± 0.29%. This parameter helps to predict emulsion stability and shelf life and also in the optimization of the ingredient ratio during formulation. Samples with better emulsion capacity are desired as additives in the formulation of products. The emulsion stability of the raw sample was significantly affected by autoclaving which reduced the mean value of the raw sample from 10.03 ± 0.06% to 7.13 ± 0.39%. Sprouting does not have a significant effect on the Emulsion stability. High emulsion stability indicates a longer shelf life of the final product. This parameter is very crucial in many industrial applications, including coating, food products, and personal care product formulations.

The trend of the mean Values (± standard deviation) of the effect of different NaCl concentrations on foam capacity presented in Table 2 shows a gradual increase in the foam capacity of the raw sample and a gradual decrease in the foam capacities of both the sprouted sample and the autoclaved sample from 0.2M concentration of NaCl until a concentration of 0.6M was reached. The 0.6M concentration of NaCl became the peak at which a drop in the foam capacity of the raw sample was recorded against the rapid increase in the foam capacities of both the sprouted and the autoclaved samples. This is an indication that the highest concentration of the NaCl that will yield better foaming capacity of output as applicable in mungbean formulation of products has 0.6 M as the maximum level, for every 1 dm^3 of the solution depending on the desired output. Any concentration of NaCl above 0.6 M will lead to a reduction in the foaming capacity of the product. Ogungbenle *et al*. (2009) reported a similar result for Quinoa (*Chenopodium quinoa*) flour.

The mean values of the effect of different concentrations of NaCl on emulsion capacity presented in Table 3 showed a slight decrease in the emulsion capacity of the raw sample as the concentration of NaCl increased from 0.2M to 0.4M. However, the mean values recorded for the sprouted sample remained constant, and the autoclaved sample recorded a 0.10 increase. 0.4M concentration of NaCl recorded the peak at which the emulsion capacity of the raw and sprouted samples started decreasing gradually at different rates while the emulsion capacity of the autoclaved sample recorded a constant value at 0.4M and 0.6M concentration of NaCl. At 0.6M concentration of NaCl, the emulsion capacity of the autoclaved sample started decreasing. In comparison to previous findings, Ogungbenle *et al*. (2009) reported a similar result for Quinoa (*Chenopodium quinoa*) flour. Akubor and Adedeji (2016) also reported that sodium chloride at high concentrations (>0.4M) decreased the emulsion properties of locust bean pulp flour which may limit its use to low sodium chloride food systems. The mean values (± standard deviation) of the result of the effect of different concentrations of NaCl on emulsion stability presented in Table 4 showed a stable emulsion recorded for the three samples as NaCl concentration increased, except at the concentration of 0.6M NaCl which recorded a slight increase in the emulsion stability of the raw sample only. Three separate mechanisms that appear to be involved in the formation of a stable emulsion may be (i) reduction of interfacial tension (ii) formation of a rigid interfacial film and (iii) electric charge (McClements, 2015). The surfactancy of high protein food content is related to their ability to lower the interfacial tension between water and oil in the emulsion (Ogungbenle et al., 2002). Ogungbenle et al. (2009) reported a similar result for Quinoa (Chenopodium quinoa) flour. The effect of varying pH values shown in Table 5 recorded an increase in emulsion capacity for all three test samples; raw, sprouted and autoclaved, as the pH values increased, except at the concentration of 0.6M NaCl which recorded a slight increase in the emulsion stability of the raw sample only.

Table 2: Effect of different Concentrations of NaCl on Foam Capacity

NaCl Concentration	Raw (%)	Sprouted (%)	Autoclaved (%)
0.2 M	9.2 ± 0.02	14.3 ± 0.03	9.6 ± 0.01
0.4 M	12.2 ± 0.01	12.6 ± 0.01	8.6 ± 0.04
0.6 M	13.0 ± 0.02	12.0 ± 0.01	8.2 ± 0.01
0.8 M	12.1 ± 0.14	12.2 ± 0.02	8.8 ± 0.02
1.0 M	11.6 ± 0.01	12.8 ± 0.10	9.2 ±0.02

Values are represented as mean ± S.D (n=3).

Table 3: Effect of different Concentrations of Nacl on Emulsion Capacity

NaCl Concentration	Raw (%)	Sprouted (%)	Autoclaved (%)
0.2 M	28.00 ± 0.02	30.00 ± 0.00	27.70 ± 0.0
0.4 M	27.90 ± 0.02	30.00 ± 0.02	27.80 ± 0.0
0.6 M	27.60 ± 0.01	29.80 ± 0.04	27.80 ± 0.001
0.8 M	27.20 ± 0.10	29.60 ± 0.01	27.70 ± 0.02
1.0 M	27.20 ± 0.02	28.90 ± 0.01	26.20 ± 0.01

Values are represented as mean ± S.D (n=3).

Table 4: Effect of Different Concentrations of Nacl on Emulsion Capacity Stability

NaCl Concentration	Raw (%)	Sprouted (%)	Autoclaved (%)
0.2 M	25.80 ± 2.28	26.10 ± 1.42	25.40 ± 2.07
0.4 M	25.80 ±0.08	26.20 ± 0.58	25.40 ± 0.67
0.6 M	26.0 ± 0.45	26.20 ± 0.58	25.40 ± 1.53
0.8 M	26.0 ± 1.98	26.10 ± 3.51	25.40 ± 2.54
1.0 M	26.0 ± 0.67	26.10 ± 1.00	25.40 ± 0.04

Values are represented as mean ± S.D (n=3).

Table 5: Effect of varying pH Values on Emulsion Capacity

pH Values	Raw (%)	Sprouted (%)	Autoclaved (%)
2	26.81 ± 1.20	26.10 ± 3.51	28.90 ± 0.55
4	27.20 ±3.05	26.40 ± 0.07	28.90 ±0.20
6	28.70 ± 2.00	26.80 ± 1.06	32.60 ± 0.57
8	30.20 ± 2.46	28.40 ± 2.05	33.40 ± 0.50
10	31.60 ± 0.21	29.60 ± 0.76	35.20 ± 0.84
12	33.40 ± 0.40	30.80 ± 0.10	37.60 ± 0.98

Values are represented as mean ± S.D (n=3).

Table 6: Effect of varying pH values on Emulsion Stability

pH Values	Raw	Sprouted	Autoclaved
2	26.00 ± 35.1	25.60 ± 0.08	26.20 ± 2.44
4	26.20 ± 2.00	26 .10 ± 0.13	26.70 ± 1.35
6	26.80 ± 4.48	26.30 ± 0.05	27.00 ± 1.90
8	27.00 ± 2.00	26.80 ± 0.29	27.20 ± 2.92
10	27.80 ± 1.05	27.40 ± 0.41	29.50 ± 1.00
12	28.60 ± 4.03	28.10 ± 0.70	29.50 ± 1.00

Values are represented as mean ± S.D (n=3).

The higher the PH values the better the emulsion capacity for the raw, sprouted and autoclaved samples. Wang et al. (2024) reported that an alkaline medium enhances the emulsion capacity and stability of protein-based foods. This can be attributed to the neutralization of the negative charge on the bean proteins, allowing them to interact more effectively with oil droplets. Remer *et al.* (2014) stated that a diet high in alkaline-forming foods and low in acidic-forming foods can help maintain a healthy pH balance in the body hence alkaline formulated mungbean food products are more desirable. The mean values (± standard deviation) of the result of the effect of varying P^H values on emulsion stability presented in Table 6 recorded a gradual increase in the emulsion stability of all test samples as the pH value increased. This indicates that the emulsion capacity and stability of mungbean flour samples tested, form better in an alkaline medium than in an acidic medium. This can be attributed to the improved water-oil interactions by the alkaline pH which enhances the interactions between water and oil, reducing the interfacial tension and improving emulsion stability Ke et al. (2023). Therefore shelf-life of a product which is of utmost priority in the formulation of viscous products shall be increased in an alkaline medium within the acceptable range.

Conclusion

The result of this study showed that sprouting is a better processing method for improving the functional properties of the mungbean (*Vigna radiata*) seeds. This can be attributed to the increased enzymatic activities on the protein content of the sprouted bean flour. Protein is digested to amino acid during this period which accounts for the decrease in the pH value of the sprouted flour sample which is lower than that of the raw flour sample.

Recommendation

The sprouted flour sample is recommended as a binder in food production industries because of its higher emulsion stability value when compared to that of the autoclaved sample. In Nigeria where sprouted seeds are normally overlooked and discarded, there is a great need to create awareness about these improved functional qualities of the sprouted mungbean (*Vigna radiata*) seed flour. This will make it acceptable as a raw material in food production industries because of its lower gelation concentration when compared with the raw and autoclaved flour samples. In the factories where mungbean (*Vigna radiata*) flours are being used in the production of children's cereals, autoclaving is recommended because of the increased bulk density which is preferred. Increasing the pH gives a better emulsion capacity, therefore addition of alkaline medium to mungbean (*Vigna radiata*) flours as a raw material in food production industries that desire higher emulsion capacity is recommended.

Declaration of interest

The authors declare that no conflict of interest exists.

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