Effects of wet and dry milling on the viscoelastic properties of tofu (meat analogue) from soybean (Glycine max) and sesame (Sesamum indicum) blends coagulated with tamarind

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Abstract: A study investigated the impact of wet and dry milling on the viscoelastic properties of tofu produced from soybean and sesame blends coagulated with tamarind. The soybean-to-sesame ratios examined were 100:0, 82.5:17.5, 65:35, 47.5:52.5, 30:70, and 0:100. The physical properties of the processed flour were evaluated, and the wet and dry milled blends were subsequently converted into tofu using tamarind as a coagulant. Mechanical tests, including stress-strain and stress relaxation analyses, were conducted. The results showed that 100% soybean dry-milled tofu coagulated with tamarind (100:0) exhibited the highest initial weight (446.6 kg) and coagulation time (13 mins). Notably, the dry-milled soybean tofu demonstrated superior stress-strain yield (1.002 N/mm2) and relaxation time (240 s), indicating a harder chewability compared to wet-milled tofu. These findings suggest that dry milling produces tofu with enhanced textural properties, making it more suitable for applications requiring a firmer texture.

Keywords: Coagulants, Milling, Physicochemical properties, Stress relaxation, Stress strain, Tofu

Introduction

In Nigeria, the consumption of animal protein is an indication of social and economic class. This is because meat is one of the nutritious foods used for human consumption. The trend has changed from animal protein consumption to vegetable protein consumption due to the health challenges caused by high consumption of animal meat. Soybean protein's three-dimensional structure makes it suitable for textured protein products, such as tofu, a fermented soybean product used as a meat analogue. According to historical records, tofu originated in Northern China around 164 BC, attributed to Lord Liu An, a Han Dynasty prince (Sacks et al., 2006). Alternatively, its production method may have been discovered accidentally when boiled soybean slurry mixed with impure sea salt, containing calcium and magnesium salts, caused the mixture to curdle and form a tofu-like gel.

Tofu offers numerous health benefits, including reduced cancer risk, antioxidant properties, and increased availability of essential nutrients like folate, vitamin K, calcium, magnesium, iron, and fiber (Ezeama & Dobson, 2019). As a nutritious food, tofu typically contains 11-12.4% protein and various phytonutrients,

such as flavonoids, isoflavonoids, phenolic acids, protein, and polyptides Tofu also plays a role in preventing and treating obesity, type 2 diabetes, and chronic obstructive pulmonary diseases (Iwe, 2003). Sesame, an underutilized legume, boasts high oil (48-58% fat), protein (16.96%), and carbohydrate (26.04%) content, along with significant dietary fiber (16.9%) (Nzikou, 2009). Sesame seeds are exceptionally rich in iron, magnesium, manganese, copper, calcium, thiamine, and tocopherol (Bedigian, 2003). Lignans, particularly sesamin, exhibit antioxidant and anti-cancer properties, while phytosterols help reduce blood cholesterol levels (Obiajunwa et al., 2005). Although sesame seeds lack lysine, they are rich in sulfur amino acids like methionine and cystine, making them a suitable supplement to soybean-based diets. This will also help to diversify the use of under-utilized legumes such as sesame in tofu production.

Milling or size reduction is the unit operation in which the average size of solid pieces of food is reduced by the application of grinding, compression, or impact forces. It is one of the factors that affect the surface sulfhydryl content and surface hydrophobicity of soymilk protein. This in turn affected the rheological properties of soymilk as well as the texture of soycurd (Tofu) (Makoto et al., 2012). Cereals of various kinds are processed by soaking, fermentation, and milling (wet or dry) to detoxify the anti-nutritional factors, increase palatability, and improve bio-availability of nutrients (Otitoju, 2009). Likewise, tofu from soybean is generally produced using wet or dry milling methods. Wet grinding of soybean reduces the particle size and has a profound effect on the protein recovery in soymilk (Vishwanathan et al., 2011). This wet milling method is not only used for tofu products but also in other grains such as rice flour (Sukson & Naivikul, 2006), Ogi products (Otitoju, 2009), soymilk products (Vishwanathan et al., 2011). It is also believed that the soaking period leads to a reduction in nutritional inhibitors and toxic substances thus improving dietary protein digestibility (Iwe, 2003). However, wet milling results in a large amount of waste water and the leaching of nutrients during soaking (Chen et al., 2003). Nevertheless, studies have shown that dry milled flour retains components such as protein, lipid, and ash at higher levels than wet milled flour thus offering more nutritive products. However, dry milling causes more damage to the starch leading to higher solubility of nutrients (Jitranut & Jirarat, 2016, Preece et al., 2017).

Tamarind is a leguminous tree in the family of Fabaceae indigenous to Tropical Africa. The genus Tamarindus is a monotypic taxon having a single species (Locke & Remer, 1991). Tamarind's raw nutritional value per 100g according to the USDA Database entry is given as follows – Carbohydrate 62.5g, Dietary fibre 5.1g, fat 0.6g, protein 2.8g, Thiamine 0.428mg, Riboflavin 0.152mg, Niacin 1.938mg, Pantothenic acid 0.143mg, Vitamin E 0.1mg, Vitamin K 2.8mg, Calcium 74mg, Iron 2.8mg, Magnesium 92mg, Phosphorus 113mg, Potassium 6.28mg, Sodium 28mg.

Tamarind contains high potassium, sodium, and iron. Tofu coagulated with tamarind produced 0.85% of potassium, 2.99% in sodium, iron content also ranked 5.11%, and a high 6.05% in phosphorus indicating that tamarind coagulated tofu is very rich in mineral content that comes from the coagulant (Ezeama & Dobson, 2019). Therefore, this study investigates the effect of wet and dry milling on the proximate composition, and physical and viscoelastic properties of tofu from blends of soybean and sesame using tamarind as a coagulant.

Materials and methods
Source of materials
The soybean and coagulant (Tarmarind) were obtained from Aba market, *Ahia Ohuru* in Abia State. The sesame seeds were purchased from Abakpa market in Ebonyi State, Nigeria.

Sample preparation and tofu production
The soybean sample was cleaned by separating stones and other unwanted materials from it. Thereafter, it was dehulled and milled to flour using an attrition mill. The milled soybean was then allowed to cool before storing in a dry container. The sesame sample was cleaned and milled to flour and also allowed to cool before storing it in an airtight container. The processed soybean and sesame flours were used for Tofu production by dry milling method (Ezeama & Dobson, 2019). Another soybean and sesame seed samples were cleaned for Tofu production by wet milling method (Iwe, 2003). The Tamarind seeds were made into a solution by squeezing out the pulp from the seed with clean water. The pulp was stored in an airtight container.

Tofu formulation from soybean and sesame blends

An optimal mixture experimental design for two variables was adopted in this study for tofu formulation. The variables are X_1 and X_2,

X_1 = Content of soybean (%)

X_2 = Content of sesame (%).

The total number of experiments were five (5) each for wet and dry milling method of tofu production. The minimum and maximum values for the component proportion for the soybean/sesame blend for tofu formulation was $30 \leq X_1 \leq 100$, $0 \leq X_2 \leq 70$.

The D Optimal mixture design for the two variables for the tofu formulation

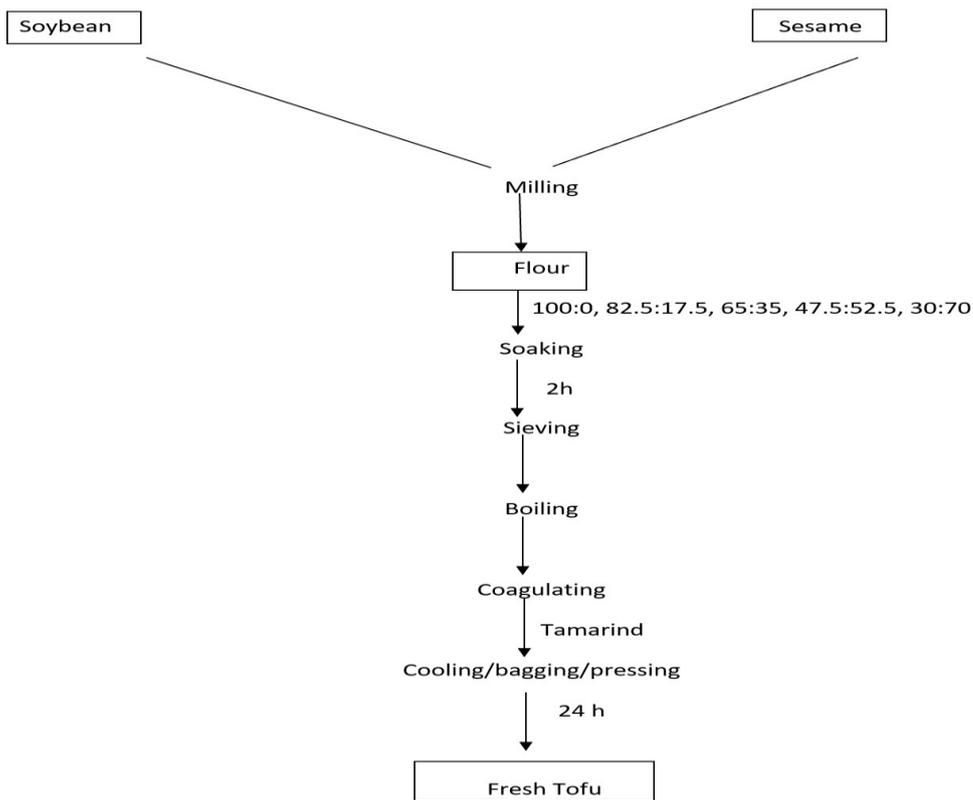| RUN	SOYBEAN (%)X_1	SESAME (%)X_2
1	100	0
2	82.5	17.5
3	65	35
4	42.5	57.5
5	30	70

Tofu production

In wet milled method, 1 Kg of soybean/sesame seeds were weighed in the ratios of 100:0, 82.5:17.5, 65:35, 47.5:52.5 and 30:70. The weighed blend ratios of soybean/sesame seeds were soaked in 5000ml of sterilized water for 12 h in five sterile containers for each blend ratio, according to the method described (Sacks et al., 2006). Thereafter, the soaked soybean/sesame seeds were ground, sieved with a muslin cloth and milk collected. Three thousand millilitre (3000 ml) each of soy/sesame milk (100:0 82.5:17.5, 65:35, 47.5:52.5, 30:70) was boiled for 15 min at 80⁰C. On reaching the boiling point, tamarind solution (0.314 mol/dm³) was added and allowed to coagulate the soy/sesame milk. After coagulation, the coagulated milk was poured in a cloth bag to drain the water.
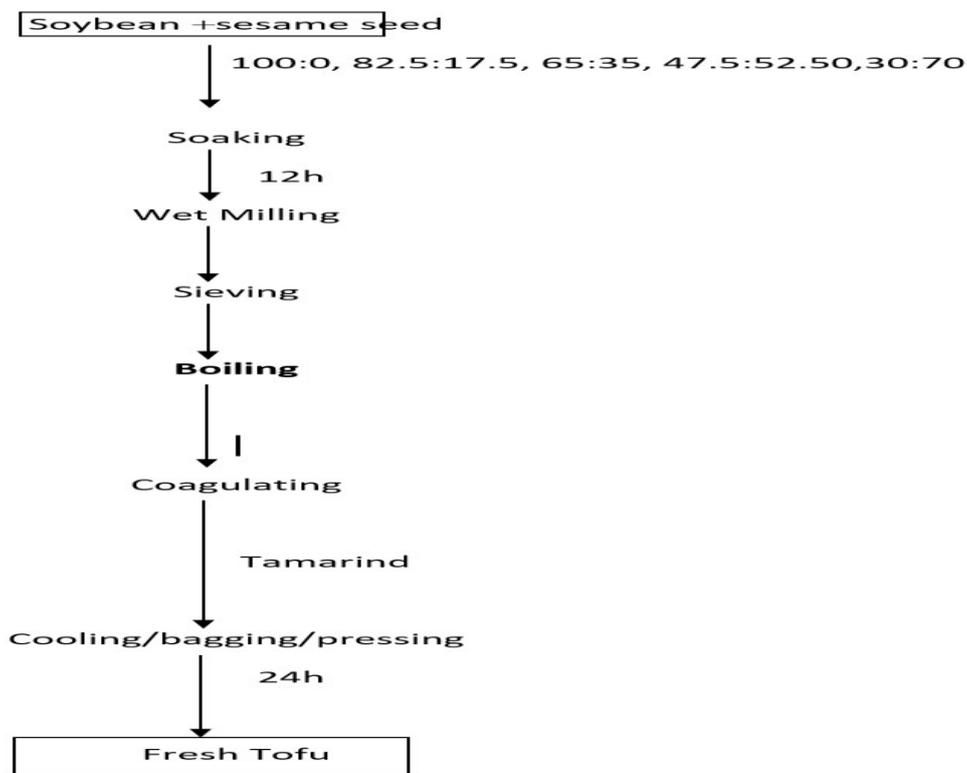
In dry milled method, 1 Kg of soybean/sesame seeds were weighed into blend ratios of 100:0. 82.5:17.5, 65:35, 47.5:52.5 and 30:70. The weighed blend ratios of soybean/sesame seed were ground to flour and the flour samples were soaked in five sterilized containers for 2 h. After soaking, the soybean/sesame flours were sieved with a muslin cloth and milk collected and coagulated with tamarind.

The Ph of the soymilk collected was tested before and after coagulation with a Digital PhMeter.
The coagulated milk from the various blends were bagged and weighed with an electronic weighing machine before and after pressing with a Press.

Soybean   Sesame

Milling

Flour

100:0, 82.5:17.5, 65:35, 47.5:52.5, 30:70

Soaking

2h

Sieving

Boiling

Coagulating

Tamarind

Cooling/bagging/pressing

24 h

Fresh Tofu

Flow chart of Tofu processing by using dry milling method from blends of soybean and sesame

Soybean +sesame seed

100:0, 82.5:17.5, 65:35, 47.5:52.50,30:70

Soaking

12h

Wet Milling

Sieving

Boiling

Coagulating

Tamarind

Cooling/bagging/pressing

24h

Fresh Tofu

Flow chart of Tofu processing by using wet milling method from blends of soybean and sesame

Stress relaxation test

The stress relaxation test of tofu was carried out using a Testometer Material Testing machine, 0500-10080 (Bourne, 2002). The tofu samples were cut in a rectangular shape of $20 \times 10 \times 8.00$ mm, a preload of 0.500 N at a preload speed of 200 mm/min was set. A step compression test type was done at 240 mm/min. the compression was at 50 % of the original height. The force decaying time curves was recorded at intervals and the stress relaxation curve was plotted and the following parameters calculated.

$$\text{Rate of decay of applied stress} = \frac{d\sigma}{d}$$

$d\sigma$ = change in stress

d= change in time

Stress strain test

The stress strain of the tofu was done with a Testometer material testing machine (Bourne, 2002). The tofu samples were cut to a regular dimension of 20 mm breath, 10.00 mm width and 8.00 mm height. The machine was set at a preload of 0.500 N at a speed test of 10.000 mm/min. The compression was at 50 % strain.

Determination of minerals

The mineral composition of the samples were determined by the method described by Onwuka (2005). The minerals determined were Calcium, Potassium, Sodium, Phosphorous, Magnesium and Iron using Atomic Absorption Spectophotometer. One gram of the dried sample weighed out for each of the minerals to be determined. Then 20ml of the acid mixture (650ml Conc HNO_3, 80ml PCA, 20ml Conc H_2SO_4) was added in the digestion flask with the 1g weighed dried sample. The flask was heated until a clear digest was obtained. The dilute was digested with distilled water made up to the 500 ml mark. Appropriate dilutions were made for each element.

Proximate analysis

Proximate analyses of the fresh tofu made from the three coagulants were determined. The moisture content, crude protein, fat, crude fibre and carbohydrate were determined.

Moisture content determination

The moisture content of the fresh tofu was determined by the conventional method (AOAC, 1990). Moisture cans were dried in the oven and put in the desiccators to cool. The cans were weighed after cooling and 2g of the samples were put in each moisture can and placed in the oven and heated at 150^0C for 3 hours. The samples were weighed after each hour until a constant weight was obtained and thereafter the cans were cooled in the desiccators before weighing. The difference was determined and expressed as a percentage of the original sample weight. The content of the fresh tofu sample was calculated as follows.

% moisture = weight of sample before drying – weight after drying x 100

Original weight of sample

Ash content determination

In determining the ash content of the samples, the method recommended by AOAC (1990) was used. Porcelain crucibles were thoroughly dried by heating at 600^0C and then cooled in the desiccators before weighing quickly to prevent moisture absorption. The crucible containing the sample were covered and placed into the muffle furnace whose temperature had already been set at 550^0C. This temperature was maintained for about two hours until a whitish ash was obtained. After two hours, the muffle furnace was switched off and the crucibles containing the sample weighed and percentage ash content determined as outlined below.

% ash = (weight of crucible + Ash) – weight of crucible x 100

Original weight of sample

Crude fibre determination

This is determined by the method described by James (1996). Two grams (2g) of sample was treated with 150ml of 1.25% H_2SO_4 solution for 30 minutes. It was washed with several portion of hot distilled water using a two-fold muslin cloth to retain the sample particles. When drained dried, the washed sample was carefully transferred back to the flask and 150ml of 1.25% NaOH solution was added to it. It was again boiled for 30 minutes, washed as before with hot water and allowed to drain dry. It was then very carefully transferred quantitatively to be weighed in a porecelain crucible. The sample in the crucible was dried for one hour, at 105^0C in the oven, cooled in a desiccators and re-weighed. It was then finally burnt to ashes in a muffle furnace, cooled and weighed crude fibre content was calculated using the formula below.

% crude fibre = 100 $\underline{(W_2- W_3)}$

W

Where

W = weight of sample analyzed

W_2 = weight of crucible + sample after drying the oven

W_3 = weight of crucible + sample after ashing.

Fat determination

Fat content was determined by the continuous solvent extraction in soxhlet reflux apparatus (Pearson, 1976). Two grams (2g) of each sample was wrapped in a porous filter paper and placed in a soxhlet reflux filter. An oil extraction flask was weighed and filled with 200ml petroleum ether. The reflux flask was mounted on the extraction flask and connected to a condenser. The solvent was brought to boil on an electro thermal heater. The vaporized solvent (petroleum ether) was condensed into the reflux flask to completely submerged the wrapped sample and extract the fat therein. When the reflux flask is filled, it refluxed carrying the extracted oil back into the extraction flask while the boiling continued. The cycle of boiling, vaporization, condensation extraction and reflux was allowed to go on for four hours before the solvent was recovered leaving the extracted oil in the flask. The flask (with oil) was further dried in the oven at 60^0C for 30 minutes to remove any remaining solvent. It was cooled in the desiccators and weighed. The fat content was calculated as:-

% fat = $\underline{W_2 – W_1}$ x 100

Weight of sample

Where W_1 = weight of empty extraction flask

W_2 = weight of flask + oil extraction

Protein content determination

This was carried out by the Kjedahi method (Pearson, 1976). Half a gram (0.5g) of the sample was digested by boiling in 10ml of conc. H_2SO_4 in the presence of one selenium catalyst tablet. Digestion was done under a fume cupboard until a clear solution (digest) was obtained. The digest was diluted with distilled water and transferred to a 100ml volume flask where it was made up to mark with the distilled water.

An aliquot (10ml) of the digest was mixed with equal volume of 45% NaOH solution in a Kjedahi apparatus and distilled. The distillate was collected in 10m/s of 4% boric acid solution into which three drop of mixed indicator (methyl red/bromocressol green) was added. A total of 50ml distillate was collected and titrated against 0.02N H_2SO_4 from green to a deep red endpoint. A reagent blank without sample was also digested, distilled and titrated as described above.

Results and discussion

Soybean flour has high protein, ash, and carbohydrate content with low moisture. It also has high mineral content which when combined together affects the processing and behaviour of food system as judged by the

quality of the final products (Hayta et al., 2002). More so, sesame flour is nutritionally rich in protein, fats and essential minerals (Ogungbenle & Onoge, 2014).

The proximate compositions of wet and dry milled soybean /sesame flour as shown in Table 1 showed that the protein content of the samples ranged from 16.89-30.45%. The sample with 100% dry milled soybean flour ranked the highest (30.45%) while the flour with 100% wet milled sesame ranked the lowest (18.25%). There were significant differences (p<0.05) in the protein content of the flour samples. There was a decrease in protein content as sesame flour was added to soybean flour. Thus soybean flour is a remarkable source of protein for both animal and human consumption (Ogungbenle & Onoge, 2014).

The moisture content ranked highest in 100% wet milled soybean flour (W100:0) (13.07%) and lowest in dry milled soybean/sesame flour with 47.5% soybean and 52.5% sesame (D47.5:52.5) (6.36%). The high moisture content in wet milled soybean/sesame flour could be as a result of soaking time of the sample. Absorption of water led to some decrease in fats, protein, ash, fibre and carbohydrate. The low moisture content in the samples would enhance their shelf-life by preventing the growth of microorganisms during storage (Ezeama, 2007).

The fibre content of dry milled soybean/ sesame flour ranged from (4.69-6.16%). The D30:70 and W30:70 ranked the highest while D0:100 ranked lowest. The combination of the fibre content in soybean and sesame made D30:70 to rank high in fibre content. The moderate fibre content in these flour samples make them suitable for easy digestion in the colon and also help to reduce the risk of bowel cancer and gallstones when soybean and sesame flour are used in various ratio for food production.

The fat content from wet and dry milled soybean/sesame flour ranged from 23.34-46.37% with 100% dry milled sesame flour ranking highest while 100% wet milled soybean ranked the lowest. There were significant differences (P < 0.05) in the fat content of the samples. As the sesame flour was added to the soybean flour it increased the fat content of the mixture. This result showed that sesame flour can be used as better source of oil than soybean flour .Oil improve overall food palatability, flavor and month feel. It also enhanced the tocopherol and Vitamin E action that is supposed to help in prevention of cancer and other heart ailment (Ogungbenle & Onoge, 2014). Therefore, incorporating soybean and sesame in the daily diet is very nutritious.

The ash content increased as more sesame flour was added to the mixture of soybean flour. The ash content ranged from 4.01– 6.71% with the 100% dry milled sesame flour ranking the highest while 100% soybean flour ranked the lowest (Table 2).

Table 1: Proximate composition of wet and dry milled soybean/ sesame flour (%)

Soybean: sesame	Moisture content	Fat	Ash	Protein	Fiber	Carbohydrate
D100:0	7.24^g±3.15	26.39^g±0.02	4.16^e±0.01	30.47^a±0.21*	5.22^e±0.11	25.52^a±0.10*
D82.5:17.5	6.89^h±5.20	30.34^e±0.05	4.21^e±0.01	30.13^a±0.15	5.46^d±0.23	20.50^b±0.15
D65:35	6.54^i±3.00	33.56^d±0.10	4.65^d±0.01	29.50^b±0.20	5.76^c±0.25	18.02^d±0.17
D47.5:52.5	6.36^j±2.50	35.47^c±0.07	5.35^{cd}±0.01	29.36^b±0.21	6.04^b±0.20	14.05^g±0.10
D30:70	6.68^h±5.00	38.62^b±0.05	6.23^b±0.01	29.65^b±0.11	6.15^a±0.19	11.69^h±0.10
D0.100	6.72^h±2.00	46.36^a±0.10*	6.70^a±0.01*	18.24^e±0.17	4.69^f±0.10	15.75^f±0.20
W100:0	12.64^c±7.40	23.34^h±0.05	4.01^f±0.22	27.34^e±0.01	5.46^d±1.05	25.65^a±2.00*
W82.5:17.5	13.07^a±8.15*	28.69^f±0.08	4.18^e±0.50	27.06^e±0.01	5.72^c±2.00	19.83^c±3.35
W65:35	12.78^b±5.20	30.42^d±0.10	4.63^d±0.75	26.48^d±0.01	6.19^a±1.20	18.08^d±2.24
W47.5.52.5	11.14^d±4.30	33.09^c±0.15	4.92^b±0.25	26.65^d±0.01	6.15^a±1.50	16.88^e±4.00
W30:70	10.36^c±5.00	35.78^c±0.20	5.38^{cd}±0.31	26.76^d±0.01	6.22^a±1.70*	14.05^g±2.20
W0:100	10.25^f±7.50	45.01^{ab}±0.35*	5.90^c±0.80	16.89^f±0.01	4.86^e±1.83	15.60^f±2.00

Values are means ± standard deviation of three determinations.
Values in column with different superscripts are significantly different (P<0.05)
Dry =Dry milled soybean/sesame flour
W = Wet milled soybean/sesame flour

Table 2 showed the physical characteristics of fresh tofu from wet and dry milled soybean/sesame blend coagulated with tamarind. The pH of the tofu before and after coagulation ranged from 4.91 –4.95 and 4.50–4.90, respectively. The reduction in the acidity of the sample before and after coagulation could be as a result of the addition of tamarind used as coagulant with a pH value of 3.30. The use of tamarind as coagulant with

high citric and tartaric acid content brought the sample pH to an isoelectric range of 4.2 – 5.6 where the solubility of protein is at minimum. This led to the precipitation of protein. This agreed with Shurtleff and Aoyagi (2000) that at isoelectric range of 4.2-5.6 soybean protein coagulates. There were no significant differences (P<0.05) between the pH of the samples before the coagulation. This could be as a result of the fact that the isoelectric point of both soy protein and sesame protein are the same at 4.5 (Shurtleff & Aoyagi, 2000; Zhao et al., 2012).

The coagulation time ranged from 12.00 – 13.00 min. The coagulation time of wet and dry milled soybean/sesame tofu at 100:0, 82.5:17.5 and 65:35 ranked the highest while the coagulation time of wet and dry milled soybean/sesame tofu at 30:70 and 47.5:52.5 ranked lowest. This could be as a result of the high oil content in sesame compared to soybean. When high fat soymilk is subjected to boiling, a marked viscosity increase accompanying coagulation will be observed (Abe et al., 2015). This could be as a result of the lipophilic bonding with the protein from the high fat soymilk which formed an association of soft gel. The exposed SH groups that result from further heat transformation of this gel are thought to form SS bonds and a hard gel is therefore formed. Therefore, higher oil content led to lower coagulation time.

The initial weights of the soy/sesame milk samples were the same before coagulation at 300 ml. After coagulation, the final weight of the coagulated milk ranged from 170.00– 446.00 kg. There were significant differences (P<0.05) in the final weight of the coagulated milk in all the samples. The final weight of the coagulated milk of TD100:0 (446.00 kg) ranked highest while the final weight of the coagulated milk of TW30:70 (170.00 kg) ranked lowest. The decrease in weight of TW30:70 could be as a result of some of the soluble proteins (oleosin proteins) which are wedged in the oil body surfaces (Chen & Omu, 2010). Upon coagulation and pressing, these proteins together with the oil are removed from Tofu, therefore having a lower final weight. As the sesame with high oil content increased, the final weight decreased. The weight of the dry matter ranged from 71.74– 126 kg. There were significant differences (P<0.05) in all the weight of the dry matter in all samples. The weight of the dry matter of TD47.5:62.5 ranked highest while TW82.5:17.5 ranked the lowest. Wet milling increases the amount of total dietary fibre due to the hydration and break down of insoluble fibres (Lehtinen, 2012). This may be result to the leaching of dry matter contained in the food materials. This could be the reason why wet milled soybean/sesame tofu produced lower dry matter. This agreed with the finding of Nnam and Otitoju (Nnam, 2002 & Otitoju 2009).

Table 2: Physical characteristics of fresh Tofu from wet and dry milled Soybean Sesame blend coagulated with tamarind

Soybean: Sesame	Sample pH			Coagulation Time (Min)	Sample Weight (Kg)		
	Coagulant	Before Coagulation	After Coagulation		Initial	Final	Dry Matter
TD 100:0	3.30	4.80	4.50[a]	13.00[a]	300	446.00[a]	110.40[c]
TD 82.5:17.5	3.30	4.80	4.56[a]	13.00[a]	300	363.40[b]	107.00[d]
TD 65:35	3.30	4.83	4.50[a]	13.00[a]	300	266.20[d]	106.00[d]
TD 47.5:52.5	3.30	4.82	4.52[a]	12.00[c]	300	208.90[e]	126.00[a]
TD 30:70	3.30	4.70	4.50[a]	12.50[b]	300	184.50[e]	118.00[c]
TW 100:0	3.30	4.95	4.87[b]	13.00a	300	345.00c	68.60g
TW 82.5:17.5	3.30	4.91	4.86[b]	13.00a	300	343.00c	71.74f
TW 65:35	3.30	4.90	4.87[b]	13.00a	300	240.00e	120.40b
TW 47.5:52.5	3.30	4.90	4.89[b]	12.00b	300	240.00e	84.80e
TW 30:70	3.30	4.95	4.90[b]	12.00b	300	170.00f	81.07e

Values are means ± standard deviation of three determinations.

Values in column with different superscripts are significantly different (P<0.05)

TW = Wet milled soybean/sesame flour coagulated with tamarind.

TD = Dry milled soybean/sesame flour coagulated with tamarind.

Figure 3 and 4 shows the stress strain test for wet and dry milled tofu treated with tamarind . From the graph, TW30:70 and TD30:70 had the lowest stress and strain yield while TW 100:0 and TD100:0 had the highest stress yield as well as the highest strain yield. A material with low stress and low strain yield is a soft and weak material. In soft materials, a large stress (pressure) will produce a large strain (low deformation) but in weak material large stress will produce a low shear stress (high breakage). A material with a high stress is a hard material. A strong material is a material with a high strain yield. From figure 3 and 4, TW 65:35 and TD65:35 had the highest stress yield and a low strain yield. This indicates its hardness, high strength, and higher force to break as well as high ductility. This could be as a result of the 35% addition of sesame with a high mucilaginous gum as the soluble fibre to the soybean (Ali et al. 2014). Thus the 65% soybean and 35% sesame blend produced harder and more elastic tofu compared to the other blends.
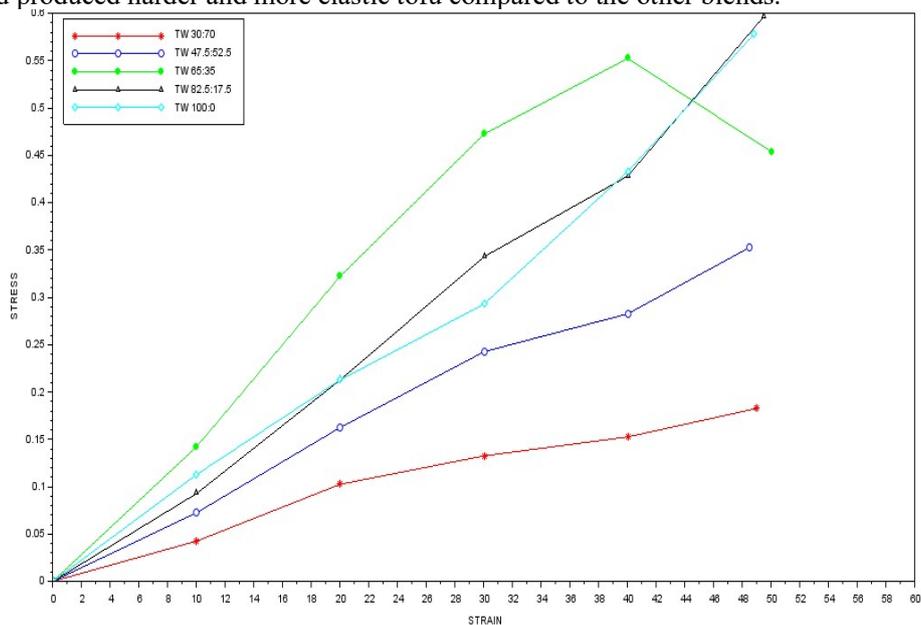

Figure 3: Stress strain test of tofu processed from wet milled soybean/sesame blend coagulated with Tamarind
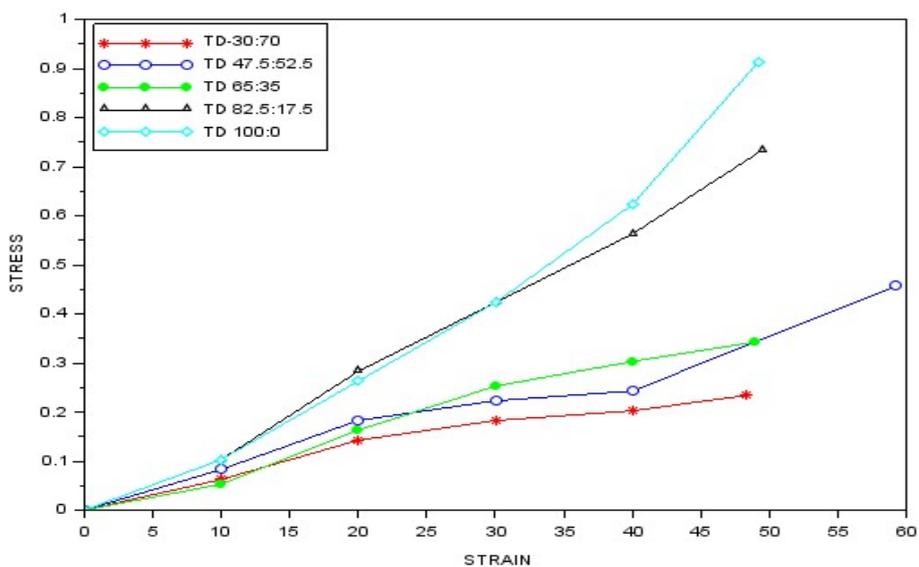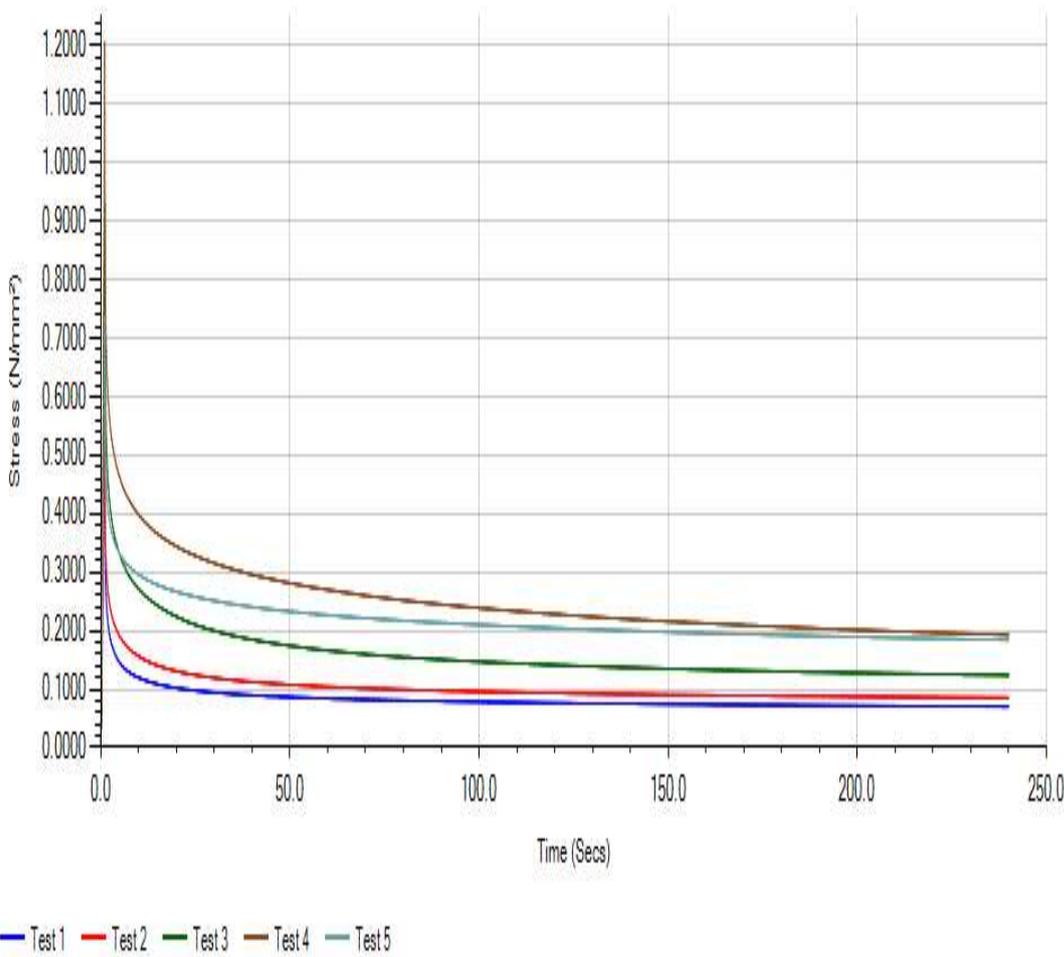

Figure 4: Stress strain test of tofu processed from dry milled soybean and sesame blend coagulated with Tamarind

Figure 5 shows the stress relaxation time of tofu from wet milled soybean sesame flour coagulated with tamarind. The stress relaxation time is a measure of how fast the stress decays (Bark & Mittai, 2006) a material that has a longer relaxation time indicates less viscous than elastic in nature. The stress relaxation time ranged from (50 – 240s) with TW65:35 ranking the highest while TW30:70 ranked the lowest. This shows that TW65:35 had the highest elasticity compared to other tofu samples while TW30:70 is more viscous in nature.

Figure 6 shows the stress relaxation time of tofu from dry milled soybean sesame flour coagulated with tamarind. The internal stress ranged from $(0.244 – 1.005 N/mm^2)$ with TD100.0 ranking the highest. The stress relaxation time ranged from (50 – 240s). TD100:0 had the highest relaxation time while TD30:70 had the lowest. This shows that TD100:0 was harder and more elastic, while TD30:70 was more viscous and softer. TD47.5:52.5 had the highest internal stress and lowest relaxation time (50s). This indicates a hard and less elastic tofu (Bark & Mittai, 2006; Rao, 2012). The combination of soybean and sesame led to the high internal stress (Makinde & Adebite, 2018).

Test1=TW30:70,Test2=TW47.5:52.5,Test3=TW65:35,Test4=TW82.5:17.5,Test5=TW100:0

Figure 5: Stress relaxation test of tofu processed from wet milled soybean and sesame blend coagulated with tamarind
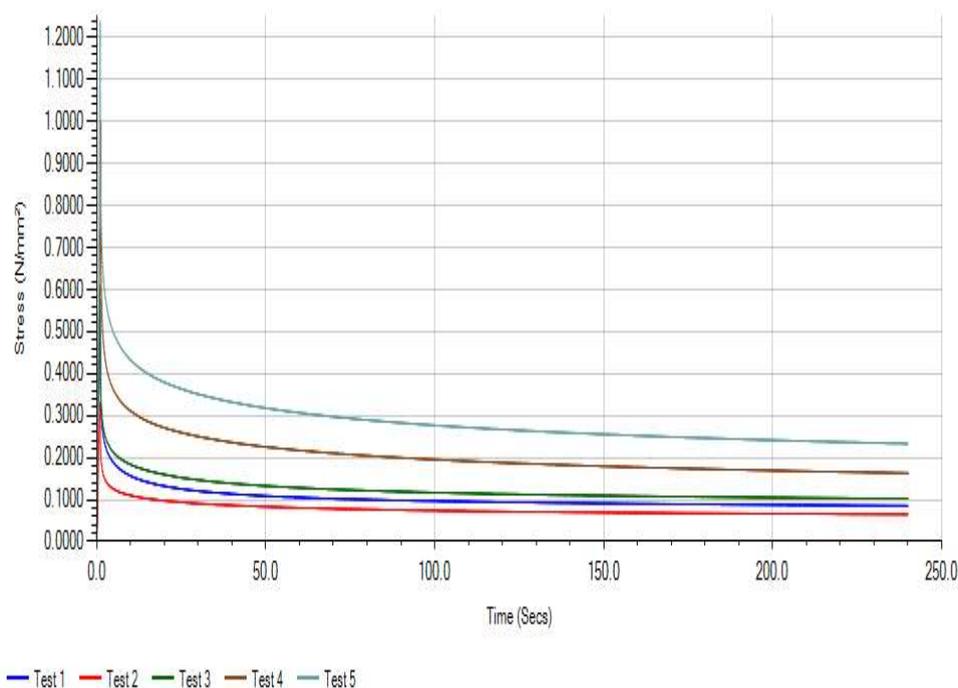
Test1=TD30:70,Test2=TD47.5:52.5,Test3=TD65:35,Test4=TD82.5:17.5,Test5=TD100:0
Figure 6: Stress relaxation test of tofu processed from dry milled soybean and sesame blend coagulated with Tamarind

Provide a dedicated section that show "the contributions of the study".

Recommendations

Based on the research use dry milling method in the production of tofu is recommended,because it saves time and energy.
Tamarind is highly available and affordable, it should be used both as coagulant and colorant.
Sasame seed should be made popularand produced in larger quantity for the production of tofu in Nigeria.
Further research should be made to mechanise tofu processing so as improve texture and shelf life stability.

Conclusion

Milling process affected the physical , chemical and viscoelastic properties of tofu. Dry mlled soybean/sesame flour gave a higher protein content value. Wet milled flour gave tofu with more elastic than viscous nature. Wet and dry milled flour from 65% soybean and 35% sesame (TD65:35) produced tofu with the highest stress and strain yield. Therefore the blend of soybean and sesame for production of meat analogue is highly acceptable nutritionally, texturally and physically for all age brackets at the blend of 65% soybean and 35% sesame.

References

1. Abe, N., Wu, C, Y., & Kim, Y, K/. (2015). Development of an efficient soymilk cream production method by papan digestive, heat treatment and low speed centrifugation. *Bioscience. Biotechnology and Biochemistry 79(11):1890-2*.
2. AOAC (1990). Association of Official Analytical Chemist.
3. Bark, O., & Mittai, G. S. (2006). Dynamics Of Changes In Viscoelastic Properties Of Tofu During Frying *International Journal Of Food Properties,9(1),73-83*
4. Bedigian, D (2003). Sesame in Africa: Origin and dispersals. In Neumann, K. Butler, A. and Kahlheber, S. Food, fuel and fields – Progress in African archaeobotany. Africa praehistorica colognes. Heinrich-Barth Institute. Pp. 17, 36.
5. Bourne, M. C. (2002). Food Texture and Viscosity Concept and Measurement. (2nd edition). San Diego, C.A. Academic Press.

6. Chen, J. J., Lu, S., & Lii, C. Y. (2003). Physiochemical and Morphological analysis on damaged ice status. *Journal of food drug and analysis, 11: 283-289.*

7. Chen, Y., & Omu, T. (2010). Simple extraction methods of non-allergic intact soybean oil bodies that are thermally stable in an aqueous medium. *Journal of Agricultural Food Chemistry, 58:7402-7407.*

8. Ezeama, C., & Dobson, G. N. (2019). Effect of coagulants on the physicochemical properties of fresh tofu. *African Journal of Food Science,13 (12): 287-296.*

9. Ezeama, C. F. (2007), Food Microbiology. Fundamentals and Applications. Prints, Lagos

10. Hayta M., Alphaslan, M., & Baysar, A. (2002). Effect of Drying Method on Functional Properties of Tarhana. *A Wheat Flour-yougurt Mixture Journal of Food Science 67(2): 740-744.*

11. Iwe, M. O. (2003). The science and Technology of Soybean. Published by Rojoint Communication Services Ltd, Enugu, Nigeria. James C.S. (1996). *Analytical Chemistry of Foods. Blackie Academic & Professional New York.*

12. James, C. S. (1996). Analytical Chemistry of Foods. Blackie Academic & Professional New Yor

13. Jitranut, L., & Jirarat, A. (2016). Effects of dry milling and wet milling on chemical, Physical and gelatinization properties of rice flour. *Science Direct Rice Science 23(5) 274-281.*

14. Lehtinen, P. O. (2012). Modifying wheat bran for food applications: Effect of Wet Milling and Enzymatic Treatment, *Technical Research Centre Nutritech 1; 1-11*

15. Locke, J, & Remer, N. (1991). Pod form and Non Pod form Variants of Tamarind in Guadelype Yaghoubian Agricultural Review. 2, 122-149.

16. Makoto, S., Shingo, M., Kimiko, T., & Yoshitaka, H. (2012). Characterization of Soymilk prepared by milling and pressing at High Temperature. *Journal of Food Processing and Preservation (38) :12037-12045*

17. Nnam, N. M. (2002). Evaluation of complementary food based on maize, groundnut, pawpaw and mango flour blends. *Nigeria Journal of Nutritional Science, 23 (182): 8-16.*

18. Nzikou, M. L, Matos, G. K, Bouanga Kalou, C. B., Ndangui, N. P. G., Pambou, A., Kimbonguila, T., Silou, M., & Descobry, S. (2009). Chemical Composition on the seeds and oil of sesame (*Sesamum indicum L.*) Gown in Congo- Brazzaville. *Advance Journal of Food Science and Technology,* 1:6-11.

19. Obiajunwa,E. I., Adebiyi, F. M., & Omode, P. E (2005). Determination of essential minerals and trace elements in Nigerian sesame seeds using TXRF technique. *Pakistan Journal of Nutrition, 4:393-395.*

20. Ogungbenle, H. N., & Onoge, F. (2014). Nutrient Composition And Functional Properties Of Raw, Defatted Protein Concentrate Of Sesame (*Sesame indicum*) Flour. *European Journal Of Biotechnology And Bioscience 2(4) 37-43.*

21. Onwuka, G. I. (2005). Food Analysis and Instrumentation Theory and Practice. Naphtali Prints. Lagos .

22. Otitoju, G. T. (2009). Effect of dry and wet milling process techniques on the nutrient composition and organoleptic attributes of fermented yellow maize (*Zea mays*). *African Journal of Food Science, 3(4): 113-116.*

23. Preece, K. E, Hooshyar, N., & Zuidan, N. J. (2017). Whole soybean protein extraction processes, *a Review Innovative Food Science & Emerging Technologies 43; 163-172.*

24. Sacks, F. M., Lichtenstein, A., Van, H. L., Harris, W., Kris-Etherton, P., & Winston, M. (2006). American Heart Association Nutrition Committee Soy Protein, Isoflavones, and Cardiovascular Health. *An American Heart Association Science Advisory for Professionals From the Nutrition Committee, Circulation 113(7): 1034–1044*

25. Sukson, A., & Naivikul, O. (2006). Effect of dry and wet milling process and chemical, physiochemical properties and starch molecular structure of rice statutes, *Kaselstart Journal: Nutritive Science 40: 125-134.*

26. Vishwanathon, K. H., Vasudeva, S., & Subramanian, R. (2011). Wet grinding characteristics of soymilk extraction *Journal of Food Engineering 106(1) 28-38.*

27. Zhao, J., Liu, D., Chen, F., & Liu, G. (2012). Functional properties of sesame seed protein prepared by two different methods. *Journal of Chemistry, 34, 1- 5.*