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Chemical, physical and sensory characteristics of soymilk as affected by processing method, temperature and duration of storage

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Soymilk was produced from hot-water-blanched wet-dehulled beans (BWD), unblanched wet-dehulled beans (UWD), and toasted dry-dehulled beans milled into flour with particle sizes of less than 500 μm (TDF) and more than 500 μm (TDL). Each extract was stored at $29 \pm 1°C$, $10 \pm 2°C$ and $-3 \pm 1°C$ for up to 42 days, respectively. The effects of processing method, storage temperature and storage duration on the proximate chemical composition, physicochemical and sensory attributes were studied. Results showed that TDL and TDF gave rise to higher composition and physicochemical properties than BWD. Samples stored at $-3 \pm 1°C$ were most stable in sensory attributes, especially for BWD followed by TDF. Statistically, the main factors and their interactions were found to effect significant differences in the composition, physicochemical and sensory characteristics of the test soymilk, at different confidence levels. On the whole, the most affected parameters were protein, fat, fibre, viscosity and flavour, while the least affected included moisture, carbohydrates, specific gravity and mouthfeel.

INTRODUCTION

Soymilk is an aqueous extract of soybeans or a fine emulsion of soyflour (Kanthamani *et al.*, 1978). It is nutritionally superior to most legumes (Steinkraus *et al.*, 1968; Philip & Helen, 1973; Steinkraus, 1978). It contains substantial amounts of all the essential amino acids with less methionine (Ferrier, 1976; Weingartner, 1987).

The production of liquid soymilk generally involves thermal treatment of soybeans, dehulling, milling, suspending in water, boiling, and filtration to obtain a milk-like phase (Wilkens & Hackler, 1969; Nelson *et al.*, 1976; Patil & Ali, 1990).

Soymilk, which resembles and compares favourably with dairy milk, can be used as a vital and cheaper substitute for cows' milk. It is lactose- and cholesterol-free, and of low starch content, and hence qualifies for utilization in 'specialty' foods (Weingartner, 1987; Patil & Ali, 1990).

Substantial efforts have been made by many workers to conserve the quality of soymilk: elimination of off-flavour (Farkas & Goldblith, 1962; Fujimaki *et al.*, 1965; Wilkens *et al.*, 1967; Kon *et al.*, 1970; Ferrier, 1976; Nelson *et al.*, 1976; Chiba *et al.*, 1979; Matsuura *et al.*, 1989); inhibiting the antinutritional factors (Bressani, 1974; Nelson *et al.*, 1976; Luttrell *et al.*, 1981; Weingartner, 1987); reducing the phytic acid content (Ang *et al.*, 1962; Okubu *et al.*, 1975; Anonymous, 1976; Omosaiye & Cheryan, 1979; Ologhobo & Fetuga, 1984); improving soymilk yield (Kanthamani *et al.*, 1978; Lee & Karunanithy, 1990); improving colloidal stability (Nelson *et al.*, 1976); flavouring, supplementation and fortification of soymilk (Steinkraus *et al.*, 1968; Bressani, 1974; DaCosta & Arkcoll, 1974; Loo, 1975).

Currently, soymilk in its new domain is becoming a domestic affair (Weingartner, 1987). Unfortunately, attempts to preserve soymilk in rural households have remained a problem in that most soymilk, if it not consumed shortly after production, loses its appealing quality. Thus there is a need to systematically assess the influence of production method and storage on the quality of soymilk.

This work was initiated to study the effect of toasting and dry-milling, hot-water blanching and wet-milling, particle size, and storage temperature and duration on the chemical and physical properties and organoleptic quality of soymilk.

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MATERIALS AND METHODS

Materials

Soybean seeds (*Glycine max* (L) Merrill) were obtained from the Eke Ukwu market, Owerri, Nigeria; 150 g of seeds/flour were used for each extraction.

Methods of preparation

Soymilk was extracted by four different methods. In all the methods, the raw material was either wet-dehulled or dry-dehulled. After extensive review, the cooked-filtrate (i.e. filter before cooking) approach was adopted for all the extractions.

Method 1 (BWD)
Clean, whole soybeans (150 g) were soaked in water (30°C) for 6 h and blanched at 98°C for 15 min; after cooling, the bean seeds were dehulled in fresh water, wet-milled at a bean:water ratio of 1:5 (w/v), and made up to 1:10 prior to filtration, based on the mass of original starting seeds. The slurry was filtered through a 475 μm mesh sieve, heated to 98°C for 3 min, bottled and then pasteurized at 63°C for 30 min, cooled and stored for further analyses.

Method 2 (UWD)
Same as Method 1 except that the blanching process was excluded.

Method 3 (TDF)
A batch of soybeans was toasted in an open pan over a low gas fire for up to 30 min (this simulates the practice in rural communities). The toasted seeds were dry-dehulled after cooling, and winnowed. The resulting cotyledons were dry-milled using a Kenwood Major A979 (Thorn EMI, Hampshire, UK), and then sieved on an Endecott test sieve shaker using a 500 μm mesh sieve. The 'throughs' (150 g) were sprinkled into water (30°C) to give a 1:10 flour:water mixture. The slurry was stirred for 30 min, then filtered and finished off as in Method 1.

Method 4 (TDL)
The 'overtails' (150 g) from the dry-milling and dry-sieving of Method 3 were treated according to the procedure in Method 3.

Storage stability

A storage stability experiment was conducted by placing the bottled samples from all four methods at different temperatures (29 ± 1°C, 10 ± 2°C and −3 ± 1°C) and monitoring the quality parameters of interest over time.

Chemical and physical analyses

All samples, both the starting seeds and the soymilk, were assayed in duplicate.

Moisture, protein, fibre and ash contents of starting seeds and prepared soymilk were analysed by standard methods (AOAC, 1984). The fat content of soybeans was determined by the Soxhlet method (Egan *et al.*, 1981), while that for soymilk was tested using the Babcock method as described by Bradley (1972). pH values of soymilk were recorded with a glass-electrode pH meter (PHYWE1104). Titratable acidity was determined by titration to a phenolphthalein end-point (Bradley, 1972). Specific gravity was evaluated at 30°C using a hydrometer. Viscosity for all soymilk samples was obtained at 30°C and 60 rpm using a synchrolectric viscometer Model LVF (Brookfield Engineering Labs, Stoughton MA, USA).

Sensory quality assessment

Organoleptic attributes of appearance, flavour and mouthfeel of both fresh and stored soymilk samples were assessed as functions of the preparation method for each storage temperature. The stored samples were first pasteurized, while both fresh and stored samples were served at 50°C. A nine-point hedonic scale was used: 9 for 'like extremely', down to 1 for 'dislike extremely' (Watts *et al.*, 1989). The different taste sessions were conducted with a 20-member in-house consumer panel selected from among staff and students of the university. The panel was familiar with soymilk and was prepared to judge the milk on its own merits. The test was conducted three times.

Statistical analyses

The mean proximate chemical composition (PCC) of soybeans, yield and total solids of soymilk as functions of the processing method were separated using Fisher's LSD (least significant difference) procedure (Roessler, 1984). Each PCC, physical and chemical properties, and sensory attributes of soymilk samples were analysed by a three-way ANOVA (analysis of variance) based on a 4×3×3 [(processing method, PM)×(storage temperature, ST)×(storage duration, SD)] factorial design (Steel & Torrie, 1980).

RESULTS AND DISCUSSION

Effect of processing method, temperature and storage time on the proximate composition of soymilk

The different methods of soymilk preparation are found to influence its protein content (Table 1). The differences in protein values might be due to the effects of the heat treatments of blanching, toasting, boiling and pasteurization. Because proteins are susceptible to high temperatures they might undergo varying degrees of denaturation. The wet-dehulled process (BWD) involved 6 h of soaking followed by blanching, and

Table 1. Effect of processing method and storage[a] on the proximate composition and other chemical and physical properties of soymilk

Parameter	BWD				UWD				TDF				TDL			
	Fresh[b]	Stored[b,c]			Fresh[b]	Stored[b,c]			Fresh[b]	Stored[b,c]			Fresh[b]	Stored[b,c]		
		29 ± 1°C	10 ± 2°C	−3 ± 1°C		29 ± 1°C	10 ± 2°C	−3 ± 1°C		29 ± 1°C	10 ± 2°C	−3 ± 1°C		29 ± 1°C	10 ± 2°C	−3 ± 1°C
Proximate composition (%)																
Moisture	91·56	91·55 ± 0·01	91·55 ± 0·01	91·56 ± 0·01	88·09	88·09 ± 0·00	88·04 ± 0·05	88·10 ± 0·01	90·51	89·97 ± 0·31	90·38 ± 0·17	90·30 ± 0·23	91·00	91·57 ± 0·33	91·39 ± 0·27	90·66 ± 0·30
Crude protein	3·07	2·83 ± 0·14	3·01 ± 0·04	3·04 ± 0·02	4·06	3·51 ± 0·32	3·93 ± 0·08	4·00 ± 0·03	3·85	3·49 ± 0·21	3·73 ± 0·11	3·80 ± 0·03	3·84	3·69 ± 0·09	3·79 ± 0·03	3·81 ± 0·02
Crude fat	1·82	1·77 ± 0·03	1·78 ± 0·03	1·82 ± 0·00	1·90	1·88 ± 0·01	1·86 ± 0·03	1·90 ± 0·00	1·95	1·93 ± 0·02	1·93 ± 0·02	1·93 ± 0·02	1·93	1·91 ± 0·01	1·87 ± 0·04	1·93 ± 0·00
Crude fibre	0·28	0·32 ± 0·02	0·30 ± 0·01	0·27 ± 0·02	0·67	0·75 ± 0·04	0·71 ± 0·02	0·68 ± 0·01	0·11	0·17 ± 0·03	0·13 ± 0·02	0·13 ± 0·02	0·08	0·06 ± 0·01	0·06 ± 0·02	0·09 ± 0·02
Ash	0·94	0·94 ± 0·01	0·94 ± 0·00	0·93 ± 0·01	0·92	0·91 ± 0·01	0·92 ± 0·01	0·90 ± 0·01	1·92	1·92 ± 0·00	1·88 ± 0·03	1·91 ± 0·01	1·92	1·91 ± 0·01	1·91 ± 0·01	1·90 ± 0·02
Carbo-hydrate	2·33	2·60 ± 0·15	2·43 ± 0·06	2·36 ± 0·02	4·36	4·87 ± 0·29	4·56 ± 0·14	4·42 ± 0·03	1·66	1·54 ± 0·08	1·73 ± 0·05	1·94 ± 0·26	1·23	0·86 ± 0·22	0·84 ± 0·23	1·34 ± 0·07
Other chemical and physical properties																
pH	6·60	6·60 ± 0·01	6·22 ± 0·50	6·95 ± 0·01	6·61	6·36 ± 0·30	6·03 ± 0·82	6·56 ± 0·06	6·62	6·37 ± 0·35	6·30 ± 0·42	6·59 ± 0·02	6·62	5·81 ± 0·70	6·18 ± 0·62	6·60 ± 0·01
Titratable acidity (%)	2·67	2·87 ± 0·31	2·83 ± 0·22	2·67 ± 0·01	2·67	2·89 ± 0·32	3·11 ± 0·64	2·68 ± 0·05	2·66	2·88 ± 0·35	2·80 ± 0·18	2·66 ± 0·02	2·65	3·14 ± 0·46	2·83 ± 0·24	2·64 ± 0·02
Viscosity (cP)	38·00	40·33 ± 2·63	38·00 ± 2·83	40·00 ± 1·00	50·00	50·00 ± 0·00	50·00 ± 0·00	50·67 ± 0·58	45·00	42·33 ± 2·45	39·30 ± 4·03	44·00 ± 1·50	45·00	36·67 ± 7·50	39·33 ± 7·18	43·67 ± 2·00
Specific gravity	1·055	1·049 ± 0·014	1·052 ± 0·023	1·052 0·003	1·250	1·250 ± 0·000	1·250 ± 0·000	1·253 ± 0·003	1·155	1·132 ± 0·028	1·122 ± 0·028	1·151 ± 0·002	1·152	1·086 ± 0·061	1·083 ± 0·038	1·152 ± 0·002

BWD, soymilk from blanched wet-dehulled seeds; UWD, soymilk from unblanched wet-dehulled; TDF, soymilk from toasted dry-dehulled, large flour particles.

[a]Samples were stored at indicated temperatures for 2–6 weeks.

[b]Samples were from two observations, two replications each (i.e. four determinations).

[c]Samples were from three observations, two replications each (i.e. six determinations).

some soluble protein could possibly have leached out. This reasoning is based on the values for zero-week storage time when BWD is compared to its unblanched counterpart, UWD. However, Ferrier (1976) and Nelson *et al.* (1976) reported that what is essentially lost during soaking is the non-protein nitrogen. Whichever is the case, the effect will be reflected in the net crude protein or soluble nitrogen or total nitrogen content of the soymilk. The higher protein value of the dry-dehulled samples (TDF and TDL) compared to the BWD samples may be attributed to the fact that dry heat has a less damaging effect on protein than moist heat.

No marked change was noted for the fat content of the samples of soymilk, or the ash content for the wet-dehulled material. A lower ash content was obtained from soymilk extracted from wet-dehulled beans (BWD and UWD) compared with the dry-dehulled beans (TDF and TDL). The lack of soaking in the latter case must have conserved the minerals. The marked difference in the carbohydrate content could be a result of many factors, among which is the efficiency of dehulling. Dry-dehulling was believed to be sufficiently effective. It led to a reduction of fibre and, hence, relatively lower values for carbohydrate plus fibre for TDF and TDL.

Soymilk samples stored at ambient temperature (29 ± 1°C) showed a reduction in protein and fat, and an increase in moisture content and carbohydrate. The changes on refrigeration (10 ± 2°C) and frozen (−3 ± 1°C) storage were slower and slowest with time, respectively. The relatively pronounced changes in soymilk stored at ambient temperature are indicative that, at that temperature, biological and chemical changes are encouraged or stimulated to continue, resulting in further degradation of the components, in addition to the effect due to the basic processing.

Results of ANOVA showed that the main factors, i.e. processing or preparation methods (PM), storage temperature (ST) and storage duration (SD), and their interactions (PM×ST, PM×SD, ST×SD) effected significant variations on the proximate chemical composition at diverse levels of confidence (Table 2). These indicate the extent of influence the prevailing factor(s) or group(s) had on the quality parameters: combined/joint factors of PM×SD had the least statistical effect on the proximate composition of the soymilk while their singular effects were different, except that SD does not significantly influence moisture and carbohydrate in soymilk.

Effect of processing method, temperature and duration of storage on physical and other chemical properties of soymilk

Results in Table 1 also show that pH, titratable acidity (TA), viscosity and specific gravity are influenced by the milk extraction method, temperature and period of storage. The same bean:water ratio was used in all extractions. Processing variables integrated in the experiment included blanching, moist- and dry-heating, wet- and dry-dehulling, wet- and dry-milling. Despite the variables, the pH and TA for all samples remained consistent for the fresh soymilk samples. Viscosity and specific gravity changed. These two parameters are usually influenced by the amount, nature and dispersion of solids present in soymilk. The particle size factor tends to have a negligible effect on viscosity and specific gravity; however, it is thought that the particle size variation prior to extraction was marginal.

The changes in the physical properties observed in the samples stored under (29 ± 1°C) can be related to the

Table 2. Three-way analysis of variance (ANOVA) for proximate composition and other chemical and physical properties of soymilk

Source of variation	Degree of freedom[a]	Sum of squares of parameters									
		Proximate composition (%)						Other chemical and physical properties			
		Moisture	Protein	Fat	Fibre	Ash	CHO[b]	pH	TA[c]	Viscosity[d]	Specific gravity
Processing method (PM)	3(3)	64·75***	4·53***	0·095***	2·134***	8·725***	60·61***	0·29NS	0·06NS	838·56***	0·247***
Storage temperature (ST)	2(2)	0·10NS	0·24***	0·003***	0·002**	0·000NS	0·04NS	0·79**	0·41***	42·04**	0·004**
Storage duration (SD)	2(3)	0·11NS	0·20***	0·006***	0·003**	0·001**	0·06NS	2·26**	0·76***	82·56**	0·004**
PM×ST	6(6)	0·64	0·06**	0·002**	0·005*	0·001**	0·46**	0·56NS	0·19NS	47·12NS	0·004NS
PM×SD	6(9)	0·32NS	0·04NS	0·000NS	0·003*	0·000NS	0·26NS	0·53NS	0·19NS	214·35***	0·007NS
ST×SD	4(6)	0·10NS	0·12***	0·003**	0·002NS	0·000NS	0·03NS	2·94***	1·94***	88·13**	0·003NS
Error	12(18)	0·37	0·04	0·001	0·002	0·001	0·27	0·82	0·36	72·71	0·008

[a]Values in parentheses are degrees of freedom for other chemical and physical properties.
[b]Carbohydrate.
[c]Titratable acidity (%)
[d]Viscosity is measured in cP (1 cP = 10^{-3} N s m^{-2}).
*, **, ***Significant at $P < 0·10$, $P < 0·05$ and $P < 0·001$ levels of confidence, respectively; NSnot significant.

variations in their chemical composition. All samples exhibited a reduction in pH and an increase in TA, especially during the first week of storage. Specific gravity and viscosity also changed slightly. The blanched sample (BWD) behaved differently. From its colloidal stability it was thought that a gelation process had set in; the soymilk protein is supposed to be undergoing a transition from viscous solution to a state approaching that of a gel, hence the consistent higher values for viscosity and slightly lower specific gravity from 2 weeks of storage.

Under refrigerated and frozen storage, the viscosity and specific gravity were relatively stable over time. The reason might be a low temperature effect which must have slowed or stopped the biochemical transformations of fat, protein and carbohydrates. The ANOVA data in Table 2 show that the interactive (joint) influence of PM×ST and PM×SD had the least significance for the test parameters. This outcome emphasized the importance of the roles of ST and SD on the physicochemical properties of soymilk.

Effect of processing method, storage temperature and time on the organoleptic quality of soymilk

Organoleptic assessment in any experimental study of food processing is vital since sensory characteristics constitute intrinsic factors with which consumers can judge a food sample for acceptance. The values recorded in Table 3 show that the method of extracting soymilk, temperature and duration of storage all influence the sensory quality parameters measured.

For the fresh soymilk samples, the appearance of BWD (blanched) and UWD (unblanched) did not differ extensively and their mean scores were almost the same, indicating that blanching had little effect on the colour development in soymilk. A distinct difference existed between wet-dehulled, wet-milled (WD) and dry-dehulled (DD) samples. The DD samples assumed a light golden colour which can be attributed to the toasting process. This resulted in a lower rating by panellists because such a colour is different from soymilk which is cream-white due to its carotene content, resembling that of cows' milk (Steinkraus, 1978). Among the DD samples, the fine particle size sample (TDF) was relatively more acceptable in appearance and other parameters. The flavour target in milk production is a bland product. In the present study, only BWD and TDF were so. The UWD sample had a strong residual beany flavour which gave the lowest score. Nelson *et al.* (1976) and Kanthamani *et al.* (1978) have claimed to produce bland soymilk. We are of the view that this can only happen under carefully controlled conditions. Generally, a slight beany flavour is usually perceptible which confers on soymilk a unique identity. The statistical equivalence in the flavour scores for BWD and TDF seems to conflict. However, the toasted flavour and smaller particle size have modified TDF to create the difference. Mouthfeel values can be explained similarly and, also, no marked difference existed due to the particle size variation. The reason for the latter observation is that the margin is very narrow.

Samples stored frozen had the best scores, followed by refrigerated ones. At ambient temperature for 1–2 weeks

Table 3. Scores for sensory attributes of soymilk as affected by processing method, temperature and duration of storage[a]

Attribute	Processing method (sample code)[b]	Storage temperature						
		29 ± 1°C			10 ± 2°C		−3 ± 1°C	
		Storage duration (week)						
		0[c]	1	2	1	2	1	2
Appearance	BWD	7·30	6·30	5·51	6·65	6·20	7·10	7·00
	UWD	7·40	6·00	5·25	6·26	6·04	5·80	5·47
	TDF	5·15	4·56	4·07	6·30	6·13	6·45	6·30
	TDL	4·35	3·75	3·28	6·55	6·40	6·90	6·80
Flavour	BWD	6·85	3·56	3·11	6·55	6·25	6·40	6·25
	UWD	4·90	2·68	2·24	4·30	4·00	4·50	4·00
	TDF	7·00	3·90	3·41	6·40	6·18	6·50	6·23
	TDL	5·80	2·95	2·60	6·50	6·50	6·70	6·19
Mouthfeel	BWD	6·65	6·35	5·56	6·35	6·46	6·40	6·20
	UWD	4·85	3·72	2·80	4·20	3·74	5·00	4·36
	TDF	6·40	6·00	4·80	6·30	6·01	6·35	6·53
	TDL	6·15	5·75	4·51	5·55	5·30	6·25	6·06
Overall acceptance	BWD	6·93	5·40	4·74	6·52	6·30	6·65	6·48
	UWD	5·72	4·13	3·43	4·90	4·60	5·10	4·61
	TDF	6·18	4·85	4·10	6·30	6·11	6·62	6·35
	TDL	5·43	4·15	3·46	6·20	6·07	6·43	6·35

[a]Values are mean values ($n = 20$). The taste test was conducted three times.
[b]Defined in Table 1.
[c]Freshly produced samples. The information serves for all the storage temperatures as zero-week duration of storage.

Table 4. Analysis of variance (ANOVA) for sensory attributes of soymilk

Source of variation	DF[a]	Appearance	Flavour	Mouthfeel	Overall acceptance
Processing method (PM)	3	14·08***	20·91***	24·12***	10·20***
Storage temperature (ST)	2	8·56***	27·57***	2·44***	10·38***
Storage duration (SD)	2	0·98NS	12·67***	4·05***	4·33*
PM×ST	6	4·80**	1·79**	0·55NS	1·03*
PM×SD	6	10·02**	1·28*	0·42NS	1·87**
ST×SD	4	4·54**	13·84***	2·10NS	5·44**
Error	12	2·43	0·96	0·48	0·54

[a]Degree of freedom.
*, **, ***Significant at $P < 0{\cdot}10$, $P < 0{\cdot}05$ and $P < 0{\cdot}001$ levels of confidence, respectively; NSnot significant.

products underwent further degradative processes which affected the flavour adversely. Truong and Mendoza (1982) have reported a similar phenomenon in legume-based products.

Results of ANOVA on sensory attributes (SA) (Table 4) show that both the main factors and their interactions had diverse degrees of influence on them. This means that both single and joint effects can be used to manipulate or predict the SA of soymilk.

CONCLUSIONS

The simplicity associated with this experiment was a deliberate design to resemble the rural preparation of soymilk from blanched soybean seeds (BWD) or dry-heat-blanched, dry-dehulled, or dry-milled flour (TDF or TDL).

It has been demonstrated that both blanching (moist-heating and dry-heating) and wet- and dry-dehulling of soybeans affect the characteristics of the soymilk. The influence of particle size of flour is negligible. However, it was obvious that differences exist in the proximate composition of soymilk when it is extracted from whole bean seeds (wet-milled) or from flour (dry-milled).

Results of the quality parameters studied showed that longevity, stability of physical and chemical characteristics, and organoleptic acceptance of the soymilk were better under refrigeration and best under frozen storage. In view of the colloidal instability of the soymilk produced in rural Nigeria, reconstitution from soyflour at the time of consumption should be the interim alternative.

Prevalent among the Nigerian rural populace is the practice of producing soyflour by dry-milling of soybean seeds from miscellaneous toasting schemes. Further studies are necessary to determine the effect of this toasting.

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