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Estimation of thermo-physical properties of selected Ethiopian indigenous foods and industrialization of *Tef Injera*, traditional bread

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Abstract

Thermo-physical properties were estimated from the composition and temperature of foods to generate data for use in industrialization. Food composition tables were used to estimate thermal conductivity (λ), thermal diffusivity (α), specific heat (C_p) and density (ρ) of eighteen Ethiopian indigenous foods at 20 °C. For this, FYSCONST.xls program was used. Thereafter the generated information was recommended for designing electric baking equipment for mixed grain *Tef* (Eragrostis tef (Zucc.) Troter) *injera*, Ethiopian staple bread. The results showed that the estimated value of the most important thermal conductivity, $\lambda_{parallel}$,ranged from 0.19 to 0.60 J/sm°C, α=0.96-1.43x10^{-7} m/s^2, C_p=1898.08-4134.69 kJ/kg°C, ρ=1000.56-1280.95 kg/m^3. The moisture versus density/thermal conductivity graphs of *Tef* injera of previous researchers showed the same density (1150 kg/m^3) and closer value of thermal conductivity (0.58 J/sm°C) at 62.2 % moisture. As *Tef* is the favorite grain, the traditional method of *Tef injera* making was considered as the basis for industrialization.

Keywords: Estimation, Ethiopia, indigenous foods, industrialization, thermo-physical properties.

1. Introduction

Thermo-physical properties of food products are useful parameters for research in the area of food engineering, post-harvest technology and chemical engineering. Specific heat, thermal conductivity, density and thermal diffusivity are some of the essential thermo-physical properties of foods for successful design processes of heat transfer, sterilization, pasteurization, evaporation, concentration, drying, dehydration, freezing and refrigeration [1,2]. Instrumentally determined values of all physical properties of indigenous foods are not usually available for easy reference. In general, thermo-physical properties can be reasonably estimated from the composition of foods and their temperatures using a computer program- FYSCONST#2.0.xls [3,4] or by instrumental methods. Specific heat, thermal conductivity and thermal diffusivity may be obtained using adiabatic calorimeter, probe and Dickerson methods, respectively [2].

Industrialization or scaling up of process technologies and equipment for mass production of indigenous foods requires the availability of these data [5].

With a population of more than 100 million, Ethiopia requires sustainable supply of food for feeding its population. It has enormous plant, animal and aquatic resources from which food can be derived. However, the food habit and culture persuades researchers to think of massive production of the available indigenous or local food items. Of all the indigenous foods, *Injera* (the Ethiopian traditional bread) and *doro-wot* (stewed chicken) are the most popular among the bread types and stews, respectively [6]. *Injera* is the staple food of most Ethiopians. It is normally served with stew from plant or animal products. Consequently the country needs millions of *injera* daily, and the traditional/batch baking equipment is not efficient to satisfy the demand of consumers.

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The major problem of industrializing injera is absence of modern starter and efficient baking equipment.

The use of thermo-physical properties is exemplified in the industrialization process of the Ethiopian traditional bread known as *injera*. It is a thin fermented bread made from grain flour, water and starter (*ersho*) which is a fluid saved from previously fermented dough. To this effect, Tef (Eragrostis tef (Zucc.) Troter is the most favorite grain for making *injera* although sorghum, maize, barely, wheat and finger millet are sometimes used. *Tef* is a tiny cereal grain mainly growing in Ethiopia and available in three different types (white, red and mixed). The objective of this study was to estimate the thermo-physical properties of some indigenous foods and to show the process flow for industrializing tef injera (Ethiopian traditional bread).

2. Methodology

The food composition table for use in Ethiopia [7] and Ethiopian traditional recipes [8] were used as sources of information to estimate the thermo-physical properties of indigenous foods of Ethiopia. All the thermo-physical properties were predicted at 20°C using a spread sheet. The data on the composition of some Ethiopian indigenous foods for the current estimation are given in Table 1. Accordingly the FYSCONST#2.0.xls spread sheet [3] was used to estimate the density, thermal conductivity, specific heat and thermal diffusivity of the Ethiopian traditional foods.

Table 1. Chemical composition of selected indigenous foods of Ethiopia (per 100 g)**

*Indigenous Food Type	Moisture, g	Protein, g	Fat, g	Carbohydrat., g	Fiber, g	Ash, g
Pea flour stew (*shiro wot*)	81.4	2.9	4.0	9.9	1.1	1.9
Splitted lentil stew *(misir wot)*	74.8	4.8	3.4	14.7	1.0	2.3
Chicken stew*(doro wot)*	72.3	6.9	8.7	8.2	1.9	3.8
Meat stew*(siga wot)*	74.7	7.3	9.1	6.1	1.3	2.8
Mixed*Tef Injera*(bread)	62.2	3.80	0.6	31.0	1.40	1.0
Mixed Sorghum *Injera*	58.0	3.60	0.5	35.7	1.60	0.6
Ambasha	35.2	8.3	1.2	49.4	1.7	1.3
Besso	30.6	4.9	19.5	43.9	1.3	1.1
Chechebsa	29.8	7.1	13.9	48.1	1.4	1.1
Bulla porridge	80.9	2.0	5.2	6.4	1.9	0.5
Elbet	84.3	4.3	0.2	9.7	0.8	1.5
Siljo	83.4	4.7	2.4	7.9	0.9	1.6
Chiko	3.7	5.3	42.0	46.7	1.3	2.3
Tella	98.3	0.3	0.3	1.0	0.0	0.1
Tej	90.1	2.2	0.5	6.5	1.6	0.7
Abish	47.5	2.9	0.7	48.6	1.1	0.3
Qocho	46.7	0.6	0.3	50.3	1.20	0.9
Gulban	63.2	7.4	0.7	27.9	1.4	0.8

**Source: *EHNRI (1997); ENI (1980)*

**Italicised words indicate names of indigenous foods in Amharic/Ethiopian language.*

Wot-stew**,** mixed(white and red) ***Tef***-tiny seeded grain**,** ***Injera***-thin bread, ***Ambasha***- wheat bread, ***Besso***-roasted and ground barley flour, ***Chechebsa***-wheat bread chips with butter, ***Bulla***-Enset flour, ***Elbet***-ground and soaked bean, ***Siljo***-bean flour mixed with safflower water and spices, ***Chicko***-roasted and ground sorghum flour with butter, ***T*ella**-beer with local hops, ***Tej***-honey wine with local hops, ***Abish***-fenugreek drink with honey, ***Qocho***-Enset bread, ***Gulban***-cooked wheat with broad bean

Based on the outcome, it was tried to demonstrate the role of the thermo-physical properties in the design of the flow sheet for industrializing the most popular and traditional bread (*injera*).

Accordingly the traditional processing method of *injera* making was used as a base line information to develop the industrialization process.

2.1. Traditional method of Tef injera making

Normal and typical *injera* is fermented, round, soft, spongy and resilient, about 4 to 6 mm thick, about 60 cm in diameter with uniformly spaced honey-comb like 'eyes' on the top(Figure 1). The major unit operations involved in tef *injera* making are drying, cleaning, milling, sieving, dough making, first stage fermentation (2-3 days), second stage fermentation with gruel (*Absit*), baking and storage. In this connection, traditionally tef is sun dried in open air, cleaned using grass or wire sieves by hand, milled with a set of stones or simple attrition mills, kneaded by hand in a bowl, left for three-day fermentation followed by the second stage of fermentation to thin down the dough and form a batter immediately before baking, which will then be ready for baking [6,9,10]. *Injera* is still baked on a round, flat and oiled pure clay pan for 2-3 min placed on three fire stones in a triangular position. However, high income families use batch type locally made electric *injera* baking equipment.

Figure 1. Typical Ethiopian *Injera* (round and folded)

3. Results and Discussion

The results of the prediction are given in Table 2 and are reasonable values except that the thermal conductivities in the case of perpendicular heat flow against fibers produced the same result in all foods. However variations were observed in the values of the normal thermal conductivities (parallel) for all indigenous foods.

Table 2. Estimated thermo-physical properties of selected indigenous foods of Ethiopia

Indigenous Food Type	**ρ**, kg/m^3	**$\lambda_{parallel}$**, J/sm°C	**λ_{perp}**, J/s m°C	**C$_p$**, kJ/kg.°C	**α**, x10^{-7} m^2/s	**α= λ_{par}/ ρCp** x10^{-7} m^2/s
Pea flour stew (*shiro wot*)	1052.51	0.54	0.38	3738.24	1.36	1.38
Splitted lentil stew *(misir wot)*	1081.24	0.53	0.38	3567.87	1.33	1.36
Chicken *wot(*stew*)*	1065.98	0.50	0.38	3543.54	1.31	1.33
Meat *wot(*stew*)*	1050.21	0.51	0.38	3604.08	1.32	1.35
Mixed*Tef Enjera(bread)*	1150.11	0.50	0.38	3216.29	1.28	1.34
Mixed Sorghum *Enjera*	1170.84	0.48	0.38	3108.57	1.26	1.33
Ambasha	1280.95	0.40	0.38	2492.91	1.14	1.25
Besso	1195.78	0.34	0.38	2502.86	1.11	1.13
Chechebsa	1233.77	0.34	0.38	2469.97	1.10	1.13
Bulla porridge	1029.62	0.55	0.38	3666.95	1.36	1.45
Elbet	1055.93	0.56	0.38	3798.03	1.37	1.40
Siljo	1048.35	0.55	0.38	3787.30	1.36	1.39
Chiko	1194.75	0.19	0.38	1898.08	0.96	0.83
Tella	1000.56	0.60	0.46	4134.69	1.43	1.45
Tej	1033.63	0.57	0.38	3958.91	1.39	1.40
Abish	1230.79	0.44	0.38	2851.59	1.21	1.27
Qocho	1241.44	0.45	0.38	2799.00	1.21	1.28
Gulban	1142.39	0.49	0.38	3281.80	1.28	1.32

λ= thermal conductivity (parallel and perpendicular)
α=thermal diffusivity (estimated and calculated)
ρ=density
C_p=specific heat

As the estimation is based on the composition and temperature of the foods, the thermo-physical properties may change if the input values change. For instance, the composition of white, red and mixed tef *injera* may show slight difference. Furthermore, the processing condition affects the physicochemical properties of any food type. The values of the normal thermal conductivities ($\lambda_{parallel}$) of different foods varied with each other unlike the $\lambda_{perpend.}$, which remained the same (0.38 J/sm°C) for all. The direction of heat flow to the fibers of the indigenous foods caused appreciable difference between the two types of thermal conductivities. In fact, exceptionally, the same value of $\lambda_{perpend}$ shows that it doesn't depend on the composition of the food provided the temperature remains constant. The estimated and calculated thermal diffusivities (α) were found to be very close to each other.

The moisture versus thermal conductivity/density graphs constructed by Tekle [1] showed the same density(1150 kg/m^3) and closer values of thermal conductivity (0.58 J/sm°C) at 62.2% moisture which is in agreement with the current finding. In all cases, the estimated and instrumentally determined values are equally acceptable although slight variations exist between them.

3.1. Industrialization of Tef injera

The process flow sheet for making *injera* from the three types of *tef* is the same. However the mixed *tef* (white and red) is used to balance the color and fairly represent the middle income *injera* consumers. To reflect the actual meaning of industrialization, it is tried to give equal emphasis on the technological and equipment aspects [5].

Table 3. Unit operations and equipment for traditional and modern *injera* making (industrialization)

No.	**Unit Operations/Processing Technology**		**Processing Equipment/storage units**	
	Traditional	**Suggested/Modern**	**Traditional**	**Suggested/Modern**
1	Receiving Tef grain with visual inspection	Receiving Tef with scientific quality evaluation	Plastic/fiber /animal skin sacks	Stainless steel storage silos
2	Sun drying	Mechanical drying	Open air/sun	Driers
3	Cleaning with traditional sieving	Cleaning with modern sieving procedures	Wooden/Grass sieves	Vibrating screens/sieves
4	Grinding manually by hand	Commercial milling	A set of two stones-the small one gliding on the bigger curved stone	Commercial attrition/roller mill
5	Dough making by kneading the flour with water and starter (*Ersho*) by hand	Machine mixing	Purely by human force/hand	Continuous or batch type horizontal/vertical mixer
6	Leaving the dough for 2-3 days for first stage fermentation	Scientific/Controlled fermentation	Clay or wooden bowel	Modern Fermentation tank
7	Reworking/kneading the dough by hand after adding hot gruel/paste for second stage fermentation to obtain batter	Machine remixing	Hand mixing	Mixers/beaters
8	Oiling the hot clay pan with ground oil crop	Oiling uniformly with pure crop oil	Hand oiling	Oiling equipment
9	Baking on hot clay pan with a cover (lid) for 2-3 min using fire wood	Continuous/batch type baking process with electrical energy (use estimated λ, α, ρ, C_p)	Conventional clay pan heated by fire wood	Improved clay/ceramic/or metallic continuous or batch type electric/ digital pan
10	Injera removal from the pan by a flat basket	Modern injera removing system	Woven grass/straw for pulling the *injera*	Modern injera removing device
11	Cooling	Low temperature cooling	Ambient/ natural air cooling	Refrigeration/air conditioning system
12	Storage in a traditional basket	Controlled atmosphere or modern storage system	Straw baskets	Well designed packaging/ plastic/wooden/fiber storage baskets

Obviously there is an urgent need for improvement of unit operations and technologies for increasing the efficiency of the baking equipment. For example, the use of mechanical driers, vibrating screens, continuous type roller mills/attrition mills, high capacity dough mixers, fermentation tankers, modern and continuous flow baking equipment is absolutely necessary for industrialization. More importantly, the properties of the raw *tef* grain and the ground *tef* flour should be carefully standardized. The fluid which is used for the first stage fermentation is called *ersho*(starter) which is saved from the previously fermented dough. There is an urgent need to develop a new ready-to-use starter which is commercially produced. Based on the information obtained from the traditional method of *injera* making, modern technologies and corresponding equipment are recommended for industrialization as indicated in Table 3.

3.2. Importance of thermo-physical properties in the design of process equipment

In the design and development of processes and equipment for *injera* production ρ,C_p, λ, and α of the flour, batter and *injera* should be known. Tekle [1] developed conventional and improved clay pans and compared their performance in terms of energy efficiency, and used ρ,C_p, λ, and α to calculate the heat and mass transfer phenomena to justify his investigation. In fact he clearly showed the applications of the thermo-physical properties in designing and development of the baking equipment. Similarly, the current study suggests the development of new mixers, starter, fermentation techniques, continuous flow baking equipment and storage baskets. Obviously all the three modes of heat transfer (conduction, convection and radiation) involve in the baking process. If so, the thickness, thermal conductivity, specific heat capacity and diameter of the pans will be considered along with the properties of *injera*. This indicates the impact of thermo-physical properties in the industrialization effort.

Physical properties like density play a major role in designing cleaning, milling, mixing, fermentation, storage and materials handling processes and equipment. For example, grain and flour silos can be filled and emptied by pneumatic conveying if the densities of the materials are known. It is also true that the process of drying and the design of grain driers require a thorough understanding of heat and mass transfer involving thermo-physical properties of the food materials at different stages. Most importantly, modern heating and cooling machineries in food industries work on the application of these properties. The case of *injera* production in large scale is dependent on how deep we understand the importance of thermo-physical properties at different stages of the process. Currently Ethiopian and Chinese companies have introduced new types of continuous flow *injera* baking equipment. However, there are still some operations that could not be automated like *injera* removal from the hot baking pan.

4. Conclusions

Cereal and animal products are thermally processed to increase their palatability and to make them safe for consumption. As a result both the physical and thermal properties of raw, semi-processed and final products are required by food engineers. Equally, they are input variables for designing and manufacturing the processing equipment. However laboratory determination is not always possible because of financial constraint and absence of facilities. Therefore, the current estimation method from the composition and temperature of foods enables researchers to quantify thermo-physical properties so as to scale up and industrialize indigenous foods at lower financial requirement.

Compliance with Ethics Requirements. Authors declare that they respect the journal's ethics requirements. Authors declare that they have no conflict of interest and all procedures involving human or animal subjects (if exist) respect the specific regulation and standards.

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