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Evaluation on suitability of differentially processed *D. bulbifera* tubers (Aerial and Underground) as alternative in composite flours for future food innovations

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Abstract

Proximate composition and functional properties of *D. bulbifera* (aerial and underground) tuber were studied. Tuber flours were prepared after differential processing (boiling, roasting and autoclaving), oven drying and milling. Higher ash content (7.74 g/100g) and protein content (10.13 g/100g) was registered with roasted and autoclaved underground tuber sample, respectively. Functionality of differentially processed tubers were analysed in comparison to commercially available refined flour. For water holding capacity, aerial and underground tuber was observed high at raw (3ml/g) and autoclaved (3.5ml/g) sample. On contrary oil holding capacity has given better results with roasted sample (4.08ml/g) of aerial tuber and raw sample (4.52 ml/g) of underground tuber. Swelling power has shown an increasing pattern with increase in temperature. Better swelling capacity was exhibited by underground tuber flour suggesting good associative force among the flour granules. Underground tuber has given gel formation at different concentration for both raw and processed tuber flours. In aerial tuber, raw sample has given gelation at 6% and no gel formation was observed at any concentration for processed tuber flour. Processing has enhanced the nutritional quality and functionality of underground tuber.

Keywords: functional property, yam flour, *D. bulbifera*, differential processing

1. Introduction

Composite flours are mixtures of varying proportions of flours from different plant sources including tubers, legumes and cereals with or without wheat flour for production of leavened or unleavened baked or snack products that are produced from wheat flour [1]. Economical and nutritional constraint has resulted in evolution of composite flour [2]. They have advantage for developing countries in promotion of high yielding native plants for flour production [3]. The growing market for confectioneries has increased the substitution of wheat flour with locally available raw materials [4]. In this regard, several developing countries have initiated programmes to evaluate the feasibility of alternative locally available flours as a substitute for wheat flour and several authors successfully developed composite flours where wheat flour is partially replaced by cassava, taro, banana, yam, sorghum, soybean, cocoyam, chickpea, lupin, sweet potato, or maize. Successful performance of flours as food ingredients depend upon the functional characteristics and sensory qualities they impart to the end product [5]. The beneficial uses of plant flours in food industry are directly depend on their functional properties. Any change in these properties during processing, transport and storage may significantly influence the nutritional and consumptional importance of the food materials. Functional properties such as water absorption, oil absorption, gelation, foaming and emulsifying capacities are the intrinsic physicochemical properties which illustrate the structural behaviour of the food systems.

Yam is considered as world's fourth important crop next to potato, cassava and sweet potato. They are herbaceous twining plants belonging to *Dioscoreaceae* and are suggested to have nutritional superiority when compared with other tropical root crops [6]. Presence of resistant starch and absence of gluten makes them good alternative in composite flours with reduced risk of obesity, diabetes or any other allergic diseases like celiac disease [7]. Tubers and roots are important sources food crop since time immemorial in tropical and sub tropical countries providing energy in the form of carbohydrates [8, 9]. *Dioscorea bulbifera* is a vigorous climber plant cultivated in the Southeast Asia, West Africa, and South and Central America. *D. bulbifera* being ostracized among other edible yams is consumed only among limited communities and thus generally underutilized both at subsistence and mercantile levels [10]. The tuber possess distinctive flavour and is comparable in nutritional content to the most preferred yam species, but does not possess the same appeal compared to *D. alata* L. and *D. rotundata* Poir [11, 12]. However, the potential of these plants has not been utilized fully, mainly due to lack of general knowledge on processability and functional properties of these materials. Yams have not been processed to any significant extent commercially, rather than production of instant yam flour in certain parts of Africa. High post-harvest loss is the main limiting factor in commercialization of these lesser known but high potential tubers. One of the ways to overcome this high perishability of fresh yam tubers is processing into flour using a well established method [8].

The challenge of feeding the anticipated 9 billion people can be achieved only through increasing food production by 70% above current level. In this juncture, diversification and sustainable intensification of agricultural play an important role in addressing these important issues. Thus exploration of diverse plant materials including underutilized starchy roots and tubers and transformation of these commodities into more acceptable forms such as flour or starch can be an alternative [9]. Moreover, these materials could be applied wider either in food or non-food industries. In recent times, the increasing urbanization with changing food habits and preferences of the population towards convenience food has created an urge for new food innovations. Processing aerial yam to flour can help to reduce the over dependent on wheat flour for our baked products [13]. The factors which affect the functional properties of food materials during storage and processing should be optimized to improve the functional characterization of the food materials. Since aerial yam has received very low attention by food processors and consumers, investigations about the functional properties of flours provide an advanced knowledge for their use in the preparation of different pharmaceutical and food products. Many researchers have explored both nutritional and functional properties of *D. bulbifera* aerial tuber. But studies on underground tubers, effect of processing on functionality of both tubers are scarce. This paper studies about suitability of differentially processed *D. bulbifera* tubers (bulbils and underground tuber) as composite flour alternative.

2. Materials and methods

2.1 Sample collection and processing

Tubers of *Dioscorea bulbifera* were collected from their respective wild vicinity in Idukki, Kerala, during the period of December, 2014.

Authentication (No. BSI/SRC/5/23/2017/Tech./1245) of the collected plant sample was done at Botanical Survey of India, Southern Regional centre, Coimbatore. The tubers were peeled, sliced, washed and subjected to various processing methods including boiling (100°C for 50 minutes), roasting (200°C for 90 minutes) and Autoclaving (15 lbs pressure, 121°C for 30 minutes). After processing the water was decanted in case of boiling and autoclaving. Then, the samples were oven dried at 45°C and were ground to powder and stored air tight for further analysis.

2.2 Proximate analysis

Raw and Processed yam tubers were analysed for moisture, ash, crude fibre, crude protein, crude lipid, carbohydrate and energy value. The moisture content of raw and processed samples was determined using Moisture Analyzer MA35 (Sartorius AG, Germany) at 105 °C. Micro-kjeldahl method was employed to determine the total nitrogen and a nitrogen-protein conversion factor 6.25 is used for crude protein (N×6.25) determination. Crude lipid (Soxhlet extraction), crude fibre and ash contents (gravimetric) were also determined based on the methods outlined in Association of Official Analytical Chemists (AOAC, 1990). The carbohydrate content was estimated by the percentile difference from all other constituents. The proximate composition was expressed as g/100 g DM. The gross energy (KJ) was determined by multiplying the percentage of crude protein, crude lipid and carbohydrate by 16.7, 13.7 and 16.7 respectively [14].

2.3. Functional Properties of Yam Flour

2.3.1 Water and oil absorption capacity

Water and oil absorption capacity were determined in triplicate according to Beuchat [15]. One gram of raw and processed samples was mixed by shaking with 10 mL distilled water or oil (refined sunflower oil) for 30 s in centrifuge tube. The solution was allowed to stand at room temperature (28 ± 2 °C) for 30 min, centrifuged (5000 *g*, 30 min) and volume of supernatant was determined.

2.3.2 Swelling Power and Solubility Index

About 1 g of raw and processed samples was accurately weighed and quantitatively transferred into a clear dried test tube and re-weighed (W_1). The samples were then dispersed in 50 cm^3 of distilled water using a mixer. The resultant slurry was heated at the desired temperatures (65, 75, 85 and 95 °C) for 30 min in a water bath. The mixture was cooled to 28 ± 2 °C and centrifuged at 2200 rpm for 15 min to separate the gel and supernatant. Then the aqueous supernatant was removed and poured into dish for subsequent analysis of solubility pattern. After this, the weight of the swollen sediment was determined (W_2). Supernatant liquid (5 mL) was poured into a tarred evaporating dish and dried to a constant weighed in air oven at 100 °C for 4 h. Water solubility index was determined from the amount of dried solids obtained after drying the supernatant and was expressed as gram dried solids per gram of sample [16].

$$\text{Swelling power of sample (\%)} = \frac{W_2 - W_1}{\text{Weight of sample}}$$

2.3.3 Gelation properties

The gelation properties were determined by the method outlined by Coffman and Garcia [17]. Ten millilitres of each of the raw and processed sample suspension in distilled water (2–30%) were transferred to test tubes and heated in a boiling water bath for 1 h and cooled. The samples in tubes were further cooled for 2 h at 4 °C and the least gelation concentration (LGC) was detected when the sample from the inverted test tube did not fall or slip.

2.4 Statistical Analysis

The data were subjected to one-way analysis of variance (ANOVA), and the significance of the difference between means were determined by Duncan's multiple-range test ($P < 0.05$) using SPSS (Version 13.0, SPSS Inc., Wacker Drive, Chicago, USA). Values expressed are means of triplicate determinations ± standard deviation.

3. Result and Discussion

3.1 Proximate Composition

The proximate composition of the flour fractions from the raw and differentially processed bulbils and underground tuber of *Dioscorea bulbifera* showed that the chemical composition was quite varied, except for the level of crude fibre (Table 1). Processing has shown less impact on moisture content of the sample except for roasted underground tuber sample (9.14%). Ash content of the tubers was high when compared to other investigated tubers [18]. Boiling for 90 mins at 100°C has shown significant decrease in ash content (53%) for both air and underground tuber which is in agreement with previous investigation in tubers of same species [19, 20]. The mean fibre content of bulbils and underground tubers of *Dioscorea bulbifera* studied ranged from 2.02g/100g – 3.26g/100g. High dietary content in food is reported to be beneficial in promoting various physiological effects, including laxation, blood cholesterol and glucose attenuation. Processing has increased the level of fibre content in the yam samples thus it may be assumed to be positively beneficial if taken cooked. Lipid content of the samples ranged from 3.22 g/100g - 5.66g/100g. Processing methods adopted in present study has not much effect on the level of lipids. Boiling has reduced the protein content in both bulbils (raw: 8.48 g/100g; boiled: 6.48 g/100g) and underground tuber (raw: 5.01 g/100g; boiled: 4.08g/100g) suggesting leaching of free amino acids in the cooking water. The levels of total carbohydrate, obtained by difference, ranged from 75.98–85.72 g/100 g. High carbohydrates content in the samples contribute to high starch fraction in the sample. Calorific value of raw and processed samples ranged from 1597.68-1674.63 KJ/100g which is similar with other studied Dioscorea tubers [18].

Table 1: Proximate composition of Raw and Processed *D. bulbifera* (air tuber and underground tuber)

Sample	Moisture (%)	Ash (g/100g)	Crude Fibre (g/100g)	Crude lipid (g/100g)	Crude protein (g/100g)	Carbohydrate (g/100g)	Energy value (KJ/100g)
BaR	$6.96^{cde}\pm0.44$	$5.30^{bc}\pm0.06$	$2.02^{d}\pm0.03$	$3.22^{d}\pm0.05$	$8.48^{b}\pm0.02$	80.94	1615.30
BaB	$6.12^{de}\pm0.23$	$2.83^{g}\pm0.87$	$2.96^{ab}\pm0.05$	$4.14^{c}\pm0.37$	$6.48^{c}\pm0.60$	83.58	1660.53
BaRo	$5.72^{e}\pm0.32$	$4.79^{cd}\pm0.06$	$3.16^{a}\pm0.27$	$3.51^{d}\pm0.11$	$6.13^{c}\pm0.64$	82.31	1609.54
BaA	$6.78^{cde}\pm0.14$	$4.46^{cde}\pm1.37$	$3.26^{a}\pm0.31$	$3.27^{d}\pm0.15$	$6.26^{c}\pm0.60$	82.64	1608.006
BuR	$7.76^{bc}\pm0.31$	$6.10^{b}\pm0.19$	$2.24^{cd}\pm0.18$	$5.66^{a}\pm0.12$	$5.01^{d}\pm0.13$	80.92	1648.65
BuB	$7.34^{bcd}\pm0.98$	$3.50^{fg}\pm0.18$	$2.05^{d}\pm0.003$	$4.63^{b}\pm0.18$	$4.08^{e}\pm0.29$	85.72	1674.63
BuRo	$9.14^{a}\pm0.46$	$7.74^{a}\pm0.12$	$2.61^{bc}\pm0.23$	$4.85^{b}\pm0.21$	$8.72^{b}\pm0.66$	75.98	1597.68
BuA	$8.2^{ab}\pm0.41$	$4.18^{ef}\pm0.12$	$2.41^{cd}\pm0.45$	$4.1^{c}\pm0.05$	$10.13^{a}\pm0.59$	79.29	1648.12

Each value is expressed as mean ± standard deviation (n=3). BaR- *D. bulbifera* Raw(Air), BaB- *D. bulbifera* Boiled (Air), BaRo- *D. bulbifera* Roasted (Air), BaA- *D. Bulbifera* Autoclaved(Air), BuR- *D. bulbifera* Raw(Under), BuB- *D. bulbifera* Boiled (Under), BuRo- *D. bulbifera* Roasted(Under), BuA- *D. bulbifera* autoclaved (Under). Mean values different letters in a column are significantly different (p<0.05)

3.2 Functional properties

3.2.1 Water / Oil holding capacity

Water absorption capacity is the ability of flour to absorb water and swell for improved consistency in food [21]. Water absorption capacity of differentially processed yam tubers in comparison to refined flour commonly used in baking industry is summarized in Table 2. Water holding capacity of the samples ranged from 2.4-3.5 ml/g. Aerial tuber flour registered higher water absorption capacity with raw tuber and least with autoclaved sample. Processing has not much affected the water holding ability of aerial tuber flour. But for underground tubers processing has increased the water holding ability. The increase in the water holding capacity has always been associated with the increase in the amylose leaching and solubility and loss of starch crystalline structure. Higher absorption capacity was with autoclaved sample (3.5ml/g).The flours with high water absorption may have more hydrophilic constituents, such as polysaccharides [22]. Oil holding capacity was higher than refined flour for all analysed flours except that from boiled air tubers. Oil has the capacity to bring about good flavour and soft texture to food. Also it is equally important in improvement of mouth feel. Higher oil absorption capacity was registered with underground tuber of *D. bulbifera* (4.52 ml/g) which suggests the presence of apolar amino acids [23]. Domestic processing of underground tuber has not much affected their oil holding capacities but for aerial tubers roasting has resulted in slight increase. High oil absorption capacity is relevant in improvement of palatability and extension of shelf life of bakery products. Results of this preliminary investigations suggests that flour produced from tubers after simple domestic cooking can be useful in baking industry where products require fat absorptions [24-26].

Table 2: Water/ Oil holding capacity of aerial and underground tubers of *D. bulbifera*

Sample	Water holding capacity(ml/g)	Oil holding capacity(ml/g)
BaR	$3.00^{abc}\pm0.00$	$4.04^{ab}\pm0.29$
BaB	$2.73^{cd}\pm0.11$	$3.19^{b}\pm0.41$
BaRo	$2.46^{d}\pm0.11$	$4.08^{ab}\pm0.28$
BaA	$2.4^{d}\pm0.20$	$3.75^{ab}\pm0.59$
BuR	$3.00^{abc}\pm0.20$	$4.52^{a}\pm1.16$
BuB	$3.26^{ab}\pm0.11$	$4.11^{ab}\pm0.06$
BuRo	$3.13^{abc}\pm0.11$	$4.37^{ab}\pm0.96$
BuA	$3.5^{a}\pm0.51$	$4.50^{a}\pm0.78$
Wh	$2.9^{bcd}\pm0.51$	$3.56^{ab}\pm0.41$

Each value is expressed as mean ± standard deviation (n=3). BaR- *D. bulbifera* Raw(Air),BaB- *D. bulbifera* Boiled(Air),BaRo- *D. bulbifera* Roasted (Air), BaA- *D. bulbifera* Autoclaved(Air), BuR- *D. bulbifera* Raw(Under), BuB- *D. bulbifera* Boiled(Under),BuRo- *D. bulbifera* Roasted(Under),BuA- *D. bulbifera* autoclaved (Under), Wh- refined flour. Mean values different letters in a column are significantly different (p<0.05)

3.2.2 Swelling power and Solubility

Swelling power and solubility of differentially processed tuber flours along with commercially available refined flour was assessed over varying temperature with interval of 10 °C is shown in fig1 and fig 2. Swelling power of the samples ranged from 3.42%-12.61%. Swelling power has shown an increasing pattern with increase in temperature. The variation in the swelling capacity indicates the degree of exposure of the internal structure of the starch present in the flour to the action of water [27]. High swelling power is an indication of good quality flour [28]. In both aerial and underground tuber boiling has registered for high swelling power with an exemption for higher temperature (95 °C). This might be due to the disruption of crystalline structure of the present starch molecules leading to exposure of hydroxyl groups of amylase and amylopectin resulting in dissolution and swelling [29]. Better swelling capacity was exhibited by underground tuber flour suggesting good associative force among the flour granules. High swelling power is an important criterion for good quality flour for noodle production [30]. Solubility is a measure of the ease with which the flour particles are able to dissolve in cooking water. It reflects the extent of intermolecular cross bonding with the granule. Solubility of the differentially processed yam tuber flours range from 2.17-8.41%. Solubility data determines optimum conditions for flour extraction. On contrary to aerial tuber roasting has improved solubility with increase in temperature for underground tubers. This suggests that high temperature might weaken the starch granules of flour leading to improved solubility [31]. Previous studies suggest that high solubility indicates good quality and digestibility of food and thus it could be used for preparation of improved baby food formulations [28].

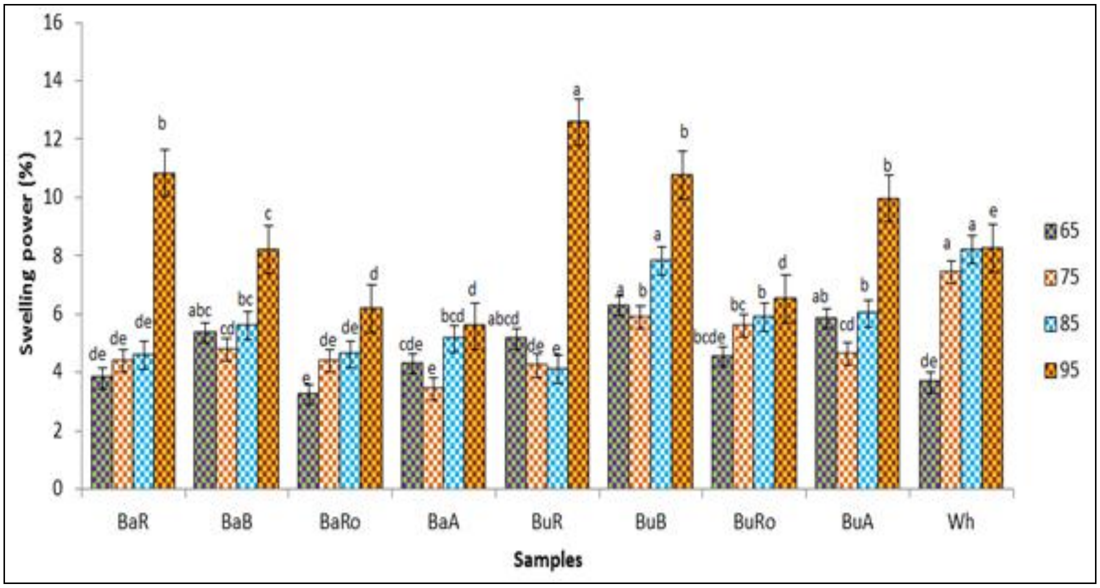

Fig 1: Swelling power of aerial and underground tuber of *D. bulbifera*

Each value is expressed as mean ± standard deviation (n=3). BaR- *D. bulbifera* Raw(Air),BaB- *D. bulbifera* Boiled (Air), BaRo- *D. bulbifera* Roasted (Air), BaA- *D. Bulbifera* Autoclaved(Air), BuR- *D. bulbifera* Raw (Under), BuB- *D. bulbifera* Boiled (Under), BuRo- *D. bulbifera* Roasted (Under), BuA- *D. bulbifera* autoclaved (Under), Wh- refined flour. Bars having different letters are significantly different (P<0.05).

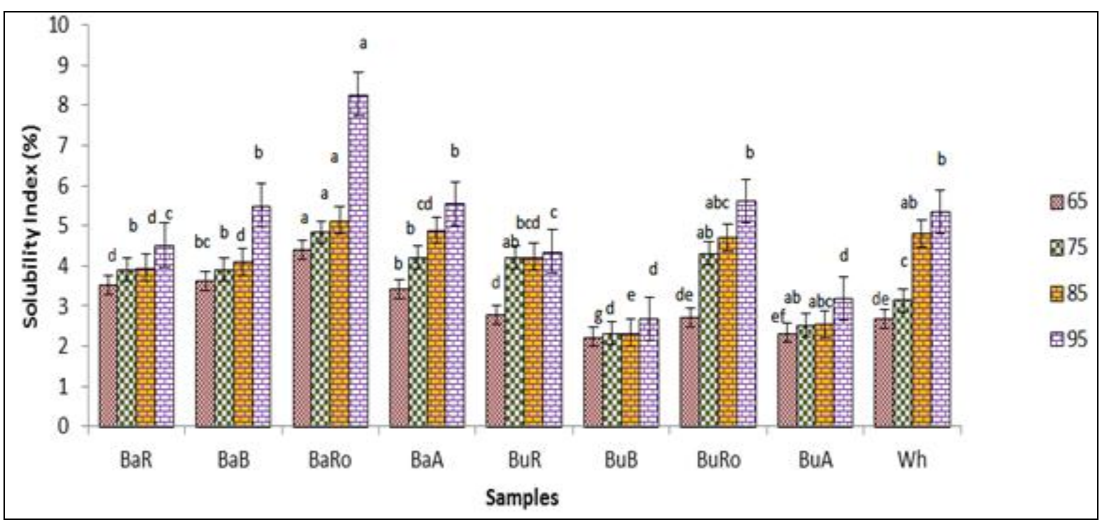

Fig 2: Solubility index of aerial and underground tuber of *D. bulbifera*

Each value is expressed as mean ± standard deviation (n=3). BaR- *D. bulbifera* Raw(Air), BaB- *D. bulbifera* Boiled (Air), BaRo- *D. bulbifera* Roasted (Air), BaA- *D. Bulbifera* Autoclaved(Air), BuR- *D. bulbifera* Raw (Under), BuB- *D. bulbifera* Boiled (Under), BuRo- *D. bulbifera* Roasted (Under), BuA- *D. bulbifera* autoclaved (Under), Wh- refined flour. Bars having different letters are significantly different (P<0.05).

3.2.3 Least gel concentration

Least gel concentration is defined as the minimum amount of starch/flour/starch –flour blend/ protein needed to form gel in a given volume of water or aggregation of denatured molecules which is used as an index of gelation capacity [1]. The least gel concentration for analysed samples occurred at different concentration base on adopted processing methods (Table 3). In aerial tuber, raw sample has given gelation at 6% and no gel formation was observed at any concentration for processed tuber flour. Underground tuber has given gel formation at different concentration for both raw and processed tuber flours. This variation might be due to the different treatments given to the samples which are likely to bring about variation in different constituents such as carbohydrates, proteins and lipids [32]. Compared to *D. alata* varieties (30-055%) studied by Udensi *et al.* [33] the tuber sample possess lower gel concentration (6-16%). The variation observed in this property of the yam flours could be due to the relative ratios of different constituents like proteins, carbohydrates, and lipids. Different flour has been reported to posses different least gelation concentration [34]. Result of least gelation concentration of the samples suggests that they are good gelling agent and may be useful in food systems such as puddings, tatale, snacks and glazing agent formulations which require thickening and gelling [28, 35].

Table 3: Least gel concentration for aerial and underground tuber of *D. bulbifera*

Sample		Flour concentration (%)								
	2	4	6	8	10	12	14	16	18	20
BaR	No gel	No gel	Gel	Firm gel	Firm gel	Firm gel	Firm gel	Firm gel	Firm gel	Firm gel
BaB	No gel	No gel	No gel	No gel	No gel	No gel	No gel	No gel	No gel	No gel
BaRo	No gel	No gel	No gel	No gel	No gel	No gel	No gel	No gel	No gel	No gel
BaA	No gel	No gel	No gel	No gel	No gel	No gel	No gel	No gel	No gel	No gel
BuR	No gel	No gel	No gel	No gel	No gel	Gel	Gel	Gel	Gel	Gel
BuB	No gel	No gel	No gel	No gel	Gel	Firm gel	Firm gel	Firm gel	Firm gel	Firm gel
BuRo	No gel	No gel	No gel	No gel	No gel	No gel	Gel	Gel	Gel	Gel
BuA	No gel	No gel	No gel	No gel	Gel	Gel	Gel	Gel	Firm gel	Firm gel
Wh	No gel	No gel	No gel	No gel	No gel	No gel	No gel	Gel	Gel	Firm gel

BaR- *D. bulbifera* Raw (Air), BaB- *D. bulbifera* Boiled(Air),BaRo- *D. bulbifera* Roasted (Air), BaA- *D. Bulbifera* Autoclaved(Air), BuR- *D. bulbifera* Raw(Under),BuB- *D. bulbifera* Boiled(Under),BuRo- *D. bulbifera* Roasted(Under),BuA- *D. bulbifera* autoclaved (Under) Wh- refined flour.

4. Conclusion

This preliminary investigation was an attempt to study feasibility of differentially processed yam flour as an alternative in composite flour. The results indicated that different domestic cooking methods affected significantly (P <0.05) on functionality and nutritional quality of both aerial and underground tubers. Water absorption capacity and oil absorption capacity was good with underground tuber flour and can be useful in baking industry where products require fat absorptions. High swelling capacity was exhibited by underground tuber flour suggesting good associative force among the flour granules and can serve better as a good binder or provider of consistency in food preparations such as semisolid beverages. High solubility indicates good quality and digestibility of food and thus it could be used for preparation of improved baby food formulations. Also, observed gelation capacity of the samples suggests that they are good gelling/ glazing agent. Compared with commercial refined flour and aerial tuber flour, differentially processed underground tubers have given better functionality and can be a good alternative for future innovations in food industry.

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