

**THE THICKENING EFFECT OF ELEPHANT FOOT YAM IN  
MILK SYSTEMS**



**THESIS SUBMITTED TO THE  
NATIONAL DAIRY RESEARCH INSTITUTE, KARNAL  
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IN THE PARTIAL FULFILLMENT OF THE REQUIREMENT  
FOR THE AWARD OF THE DEGREE OF**

**MASTER OF TECHNOLOGY  
IN  
DAIRYING  
(DAIRY TECHNOLOGY)**

**BY  
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**DIVISION OF DAIRY TECHNOLOGY  
NATIONAL DAIRY RESEARCH INSTITUTE  
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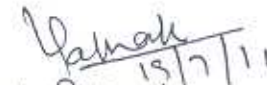
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This is to certify that the thesis entitled "THE THICKENING EFFECT OF ELEPHANT FOOT YAM IN MILK SYSTEMS" submitted by Mr. POLA RAMAKUMAR towards the partial fulfillment of the requirement for the award of the degree of MASTER OF TECHNOLOGY IN DAIRYING (DAIRY TECHNOLOGY) of the National Dairy Research Institute (Deemed University), Karnal (Haryana), India, is a bonafide research work carried out by him under my supervision and guidance and no part of the thesis has been submitted for any other degree or diploma.

Dated : 25<sup>th</sup> June 2011

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Major Advisor & Chairman  
(GUIDE)



*Dedicated  
To My  
Beloved Parents*



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## ABSTRACT

Elephant foot yam [*Amorphophallus paeoniifolius* (Dennst.) Nicolson] is a staple food crop which is widely grown in tropical and subtropical zones. It is commonly known as Jimmikand/ Ol/ Suran and used as vegetable, *chutney*, pickle, etc. in different parts of India. It is a good source of starch (approx 20%). As starches act as thickeners, the thickening effect of processed-yam powder in milk was studied. Effects of time of cooking in excess water and drying temperature for the preparation of yam powder on properties including pasting behaviour of the powder were investigated. Darkening of yam powder increased with increasing cooking time and drying temperature. The pasting properties as determined by a visco-amylgraph (Rapid Visco-Analyser, RVA) revealed that the un-cooked yam powder prepared by tray-drying at 70°C had the highest final viscosity (3313 mPa.s), setback (952 mPa.s) and pasting temperature (88.8°C) but exhibited low sensory scores, when added to milk. The powder prepared by 30 min cooking and 60°C drying having medium final viscosity (2862 mPa.s) and low breakdown viscosity (38 mPa.s) was selected on the basis of sensory evaluation (2.5% powder admixed with milk and heated to 75°C/5 min). In order to quantify the role of yam solids and milk solids in the physico-chemical characteristics of the yam-milk mixture, the two variables were investigated employing Central Composite Rotatable Design of response surface methodology (RSM). The yam-milk mixture was analyzed for apparent viscosity, Hunter lab colour parameters, heat stability in terms of heat coagulation time (HCT) at 130°C, as also sensory attributes. With the increasing level of yam powder, the sensory scores and HCT of the mix decreased, and the dispersion tended to be less white. The combination of yam solids (0.5%) and total milk solids (14%) aimed at having maximum values for the desirable sensory attributes in the yam-milk mix resulted in a moderate viscosity, reasonable HCT and good sensory status.

## सारांश

एलिफेन्ट फुट येम/ जिमिकन्द [*Amorphophallus paeoniifolius* (Dennst.) Nicolson] उष्णकटिबन्धीय एवं उपोष्ण क्षेत्र की एक प्रमुख फसल है। यह जिमिकन्द/ओल/सूरन के नाम से जाना जाता है। जिसका उपयोग देश के विभिन्न हिस्सों में सब्जी, चटनी एवं अचार बनाने में किया जाता है। इसमें प्रायः 20 प्रतिशत तक मंड (स्टार्च) होता है। यह मंड किसी पदार्थ में गाढापान बढ़ाता है इसलिए संसाधित जिमिकन्द चूर्ण को दूध में मिलाकर इसके प्रभाव का निरीक्षण किया गया। जिमिकन्द चूर्ण के निर्माण के लिए पानी की उपस्थिति में अधिउष्मित समय, सुखाने का तापमान और लेप गुणों का अन्वेषण किया गया। जिमिकन्द चूर्ण का रंग अधिउष्मित समय और सुखाने के तापमान को बढ़ाने पर गहरा भूरा होता गया। इस चूर्ण के लेप गुणों का निरीक्षण रेपिड विस्को एनालाईजर (RVA) मशीन द्वारा किया गया जिससे यह अवगत हुआ कि 70°C पर जाली पर सुखाने की मशीन द्वारा सुखाने पर सबसे अधिक शयनता (3313 mPa.s), सेट बेक (952 mPa.s) और लेप तापमान (88.8°C) मिला लेकिन इसे दूध में मिलाने पर इसके संवेदी गुण अच्छे नहीं थे। 30 मिनट के अधिउष्मित समय और 60°C के तापमान पर निर्मित जिमिकन्द चूर्ण मध्यम शयनता (2862 mPa.s) और निम्न शयनता में गिरावट (38 mPa.s) का रहा। इसी चूर्ण से निर्मित (2.5 प्रतिशत जिमिकन्द चूर्ण को दूध में मिलाकर 75°C पर 5 मिनट तक गर्म करने पर) दूध का संवेदी मूल्यांकन के आधार पर चयन किया गया। जिमिकन्द चूर्ण एवं दूध मिश्रण में जिमिकन्द टोस और दूध में मिले टोस की मात्रा के भौतिक एवं रासायनिक मूल्यांकन के लिए दोनों परिवर्तों को केन्द्रीय घटक धूर्णन डिजाईन (सी.सी.आर.डी.) से अनुक्रिया फलक प्रणाली (आर.एस.एम.) के माध्यम से अध्ययन किया गया। जिमिकन्द चूर्ण निर्मित दूध मिश्रण का विश्लेषण इसकी आभासी शयनता, हन्टर रंग ( $L^*$ ,  $a^*$ ,  $b^*$ ) उष्मा स्थिरता (130°C पर उष्मा क्लॉटन समय पर आधारित) और संवेदी गुणों से किया गया। जिमिकन्द चूर्ण मिश्रण में जिमिकन्द चूर्ण की मात्रा और उष्मा क्लॉटन समय कम होता गया और मिश्रण की सफेदी भी कम होती गयी। जिमिकन्द टोस (0.5 प्रतिशत) और कुल दूध टोस (14 प्रतिशत) के संयोजन से निर्मित जिमिकन्द दूध मिश्रण के संवेदी गुणों के आकड़ों को आर.एस.एम. तकनीक में अधिकतम रखने पर मध्यस्थ शयनता, उपयुक्त उष्मा क्लॉटन समय (HCT) और अच्छे संवेदी गुण प्राप्त हुए।

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## LIST OF ABBREVIATIONS

|       |   |                                    |
|-------|---|------------------------------------|
| g     | : | gram                               |
| ml    | : | millilitre                         |
| mg    | : | milligram                          |
| TMS   | : | Total milk solids                  |
| BD    | : | Bulk density                       |
| PD    | : | Particle density                   |
| WAI   | : | Water absorption index             |
| WSI   | : | Water solubility index             |
| EFY   | : | Elephant foot yam                  |
| CCRD  | : | Central composite rotatable design |
| RSM   | : | Response surface methodology       |
| HCT   | : | Heat coagulation time              |
| RVA   | : | Rapid visco analyser               |
| °C    | : | degree Celsius                     |
| mPa.s | : | milli Pascal second                |
| TPA   | : | Texture profile analysis           |
| N     | : | Newton                             |
| Fig.  | : | Figure                             |
| min   | : | Minutes                            |
| PS    | : | Potato starch                      |
| WMS   | : | Wheat starch milk sugar            |
| CMS   | : | Corn starch milk sugar             |
| WPI   | : | Whey protein isolate               |
| STD   | : | Starch dispersions                 |

# *CHAPTER - 1*

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## **Introduction**

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## 1. INTRODUCTION

Root and tuber crops are plants, which produce underground structures that are used as human or animal feed. Roots and tubers are edible, fleshy (high water content), underground storage organs rich in starch, sugar or both, and with varying amounts of other nutrients (Terry *et al.*, 1986). These crops belong to over 20 diverse families in different parts of the world (Kay, 1973; Janick, 1981). They are third most important food crops of humankind after cereals and grain legumes, and constitute either staple or subsidiary food for about a fifth of the world's population (Singh *et al.*, 2008). Tropical root and tuber crops are staple food crops in several countries of South America, Africa and South-East Asia. Tuber crops have higher biological efficiency as food producers and show the highest rate of dry matter production per day per unit area among all the crops (Basant Ram, 2008). These crops are known to supply cheap sources of energy, especially for the weaker sections of the population.

Although, root crops have generally been branded as “poor man's crops”, supplying low cost energy and bulk to the diet and nutrition, their potential as nutritionally rich source of vitamins, antioxidants, dietary fibre and minerals like calcium has begun to be recognized, as a result of multifarious research programs worldwide. Tuber crops are cultivated in India, mainly in the Southern, Eastern and North eastern states. Even today these are considered as vegetables only and their full potential remains largely untapped. In the context of surplus food sources, the role of tuber crops may seem to be trivial. However, being concentrated sources of energy, they can definitely turn out to be saviours of hunger in times of food crisis and famine. Root and tuber crops offer immense scope as food, feed and industrial raw material. Further, tuber crops as such provide a vast scope for diversification and value addition, offering a great opportunity for non-traditional uses within the country and for exports.

Elephant foot yam (*Amorphophallus paeoniifolius* (Dennst.) Nicolson) is an important vegetable tuber crop belonging to family Araceae and is

indigenous to tropical Asia and Africa. It is a perennial herb with rounded large corm which grows underground. It is a good source of carbohydrates, certain minerals (calcium, phosphorus, iron, potassium) and vitamins (vitamin A, thiamine, riboflavin, niacin). It contains a wide range of phytochemicals i.e. alkaloids, phenols, flavonoids, glycosides, saponins, steroids and tannins (Ramalingam, 2010).

Medicinal properties of elephant foot yam (EFY) are well recognized in Ayurveda. It is used as a medicine for piles, asthma, swelling of lungs, vomiting and abdominal pain. It is also believed to act as blood purifier. Its juice is also used as a cure for high blood pressure. The tuber, rich in bioactive components, is carminative and recommended for use in the treatment of abdominal pressure. The corms are anti-inflammatory, anti-haemorrhoidal, haemostatic, expectorant, carminative, digestive, appetizer, stomachic, liver tonic, aphrodisiac, rejuvenating. They are useful in vitiated conditions of *vata* and *kapha*. EFY is also useful in asthma, cough, bronchitis, arthralgia, respiratory disorders (Sharma, 1998), inflammations, tumours, elephantiasis, anorexia, constipation, amenorrhoea, seminal weakness, anaemia and splenopathy (Kirtikar and Basu, 1935). EFY is traditionally used for treatment of arthralgia, elephantiasis, cough, tumors, inflammations, hemorrhoids, bronchitis, asthma and haemorrhages (Hedrick and Nair, 1993). The tuberous roots of the plant have been used traditionally for the treatment of piles, abdominal pain, enlargement of spleen and rheumatism (Kirtikar and Basu, 1994). The extracts of the tuber exhibited anti-helmintic activity (Ramalingam *et al.* 2010), hepatoprotective and antioxidant activity (Shastry *et al.*, 2008). The methanol extract of tuber has shown anti-inflammatory activity (De *et al.*, 2010). Antibacterial, antifungal and cytotoxic activities of tuberous root extract have also been reported (Khan, 2008).

Starch is one of the most abundant carbohydrates distributed in green plants, where it is accumulated as a reserve material in the form of microscopic granules. Starch has played an important nutritional role in man's diet since the beginnings of agriculture and, more recently, has become a major industrial raw material used widely in food and pharmaceutical applications. Starches

serve a variety of roles in food production. Starch has the ability to gelatinize upon heating in the presence sufficient amount of water leading to increase in the viscosity of the aqueous phase. Principally they are used to take up water and to produce viscous fluids/pastes and gels and to give desired textural qualities. Starches and modified starches from corn, waxy corn (waxy maize), high-amylose corn, wheat, and various rices, as also from tubers and roots, particularly potato, sweet potato, and tapioca (cassava) have a large number of food uses, including adhesive, binding, clouding, film forming, foam strengthening, antistaling, gelling, moisture retaining, stabilizing, texturizing and thickening applications. Starches are extensively used in a variety of food products such as ice cream, chocolate, milk-based sweets, jellies, sauces, custards and desserts. It imparts body and mouthfeel to the product (Verbeken *et al.*, 2006). It is often used as a thickening agent in food systems with other ingredients, such as milk in custard.

Hence the addition of processed elephant foot yam in milk system can be expected to have thickening effect and also to affect the physico-chemical characteristics of the milk systems. Taking this into consideration the present study was proposed with the following objectives-

1. To study the effect of pre-processing of elephant foot yam on consistency and other physico-chemical characteristics of yam-milk mix.
2. To study the effect of blending conditions on the physico-chemical and sensory properties of the mix.

# *CHAPTER - 2*

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## **Review of Literature**

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## 2. REVIEW OF LITERATURE

### 2.1 ROOT AND TUBER CROPS

Tropical root and tuber crops including cassava, sweet potato, yams and aroids are consumed as vegetables and used as staple foods especially in the less developed countries (Ravi *et al.*, 1996). They were critical components in the diet during the early evolution of mankind and were the most important food crops of very ancient origin in the tropics and sub-tropics, associated with human existence, survival and socio-economic history (Asha and Nair, 2002). Their production, with the exception of sweet potato, is limited to the warmer regions because of lack of tolerance to freezing temperatures (O'Hair, 1990).

Apart from providing basic food security and a source of income and diversity in diet, they also serve as source of proteins for the less affluent and as additional source of essential vitamins and minerals. Root and tuber crops are found in a wide variety of production systems and do well under various levels of management from low to high input systems. This is a distinctive feature which makes them important for improving the productivity and richness of agro-systems. Even though their agronomic properties have been well documented, their food and industrial quality characteristics have not been studied extensively. The full potential of these staples is being realized in more and more regions and they would continue to contribute to energy and nutrient requirements for the increasing population.

### 2.2 ELEPHANT FOOT YAM

Elephant foot yam is one of the most nutritious tuberous vegetable crops. Because of its higher yield potential, culinary properties, medicinal utility and therapeutic values, it is referred to as 'King of Tuber Crops' (Sengupta *et al.*, 2008) and also as "Money Spinning Tuber Crop" due to high mean profit associated with it (Singh *et al.*, 2008).

Elephant foot yam (EFY) belongs to the family Araceae (Aroid family) along with taro, giant taro, swamp taro and cocoyam. Its botanical name is *Amorphophallus paeoniifolius* (Dennst.) Nicolson (synonym- *Amorphophallus*

*campanulatus* (Decne)). In Hindi, it is known as *Zaminkand/ Zimmikand*. Other names of EFY include *Suran, Ol, Kanda*, etc. The geographical origin of the crop lies in Asia, South East Asia and Melanesia (Lebot, 2009).

### **2.2.1 Production**

There is no authentic published area, production and yield statistics for aroids in India. However attempts to compile area under elephant foot yam in different parts of the country indicates that it is grown in an area of 32,000 ha producing 6.7 lakh tonnes with a productivity of 21t ha<sup>-1</sup>(CTCRI, 2010). It is grown largely in Andhra Pradesh, Tamil Nadu, West Bengal and Kerala.

### **2.2.2 Botanical Description**

EFY is a robust herbaceous plant, with an erect solitary stem, usually 1-2.5 m in height and bearing at the top one or two tripartite leaves, each part of which is deeply dissected into numerous segments. Towards the end of the plant's cycle (usually 4-6 years) a large terminal inflorescence is produced, consisting of a short stalk and spathe and a spadix, which emits a malodorous smell, reminiscent of rotten meat. The corms are large globose depressed tubers, usually dull-yellow or brownish-yellow in colour, and these produce 5-10 cormels at the end of each growing season. The growth cycle of the corms normally takes about 8-12 months but the tubers are small and unmarketable after only one season and 3-4 seasons are required for an economic crop. The depressed globose corms often have a diameter of 30 cm or more, and under good cultural conditions can weigh 7-9 kg by the fourth season (Kay, 1987).

### **2.2.3 Nutritive Value of Elephant foot yam**

Wide variations are seen in the composition of elephant foot yam tuber as reported by different workers. Bradbury and Holloway (1988) reported the composition of the corm of elephant foot yam as follows:

**Table 2.1 Average composition of elephant foot yam**

| <b>Constituent</b> | <b>% by wt.</b> |
|--------------------|-----------------|
| Moisture           | 77.8            |
| Starch             | 16.6            |
| Protein            | 2.24            |
| Fat                | 0.06            |
| Ash                | 1.36            |
| Fibre              | 1.45            |
| Energy(kcal/100g ) | 77.43           |

Starch is the major storage form of carbohydrate in roots and tubers. Starch content of different cultivars of EFY ranges from 11.75-28.70% (Chattopadhyay *et al.*, 2010). The digestibility of *Amorphophallus* starch by  $\alpha$ -amylase was studied by Wankhede and Sajjan (1981), who observed 98% digestibility for gelatinized starch as compared to 21% for raw starch. EFY starch consists of amylopectin, a branched-chain polymer of glucose, and amylose, a straight-chain polymer. Moorthy (2002) found that soluble amylose content in the tuber crop starches ranged from 10-40% of total amylose and in *Amorphophallus* starch from different accessions, the soluble amylose content ranges from 9-11% forming nearly 45% of the total amylase content. The total amylose content of *Amorphophallus paeoniifolius* is ranged from 21.9-23.9% (Moorthy *et al.*, 1994).

Elephant foot yam is not a good source of protein. Crude protein content of this tuber ranges from 0.84-2.60% which is much less than that in cereals and pulses. Roots and tubers are very poor in fat content. The fat of the EFY is just 0.07- 0.40%. It is a good source of minerals. Varying mineral composition was observed among different cultivars by Chattopadhyay *et al.* (2010). Potassium was the most abundant macro-mineral (230-477mg/100g) followed by phosphorus (130-247mg/100g) and calcium (109-247mg/100g). Iron was the abundant minor

mineral (1.97-4.04mg/100mg) followed by zinc (0.12-1.92mg/100g) and manganese (0.18-0.65mg/100g). EFY is good source of vitamin A. It also contains thiamine, riboflavin, nicotinic acid in smaller quantities.

#### **2.2.4 Anti-nutritional/toxic factors**

Even though, elephant foot yam has good nutritional value, the itching sensation in mouth and throat known as 'acridity' associated with the corm is a major factor limiting its food value. The acridity is associated with all aroid plants (taro, cocoyam, giant taro, etc). This acrid sensation is because of oxalates present in it. Depending on variety, they may contain varying levels of oxalic acid deposited in plant tissues as crystals of calcium oxalate (Englberger *et al.*, 2003). These crystals also occur in many other botanical families. When in sufficient quantity, calcium oxalate crystals cause mechanical abrasion of the mucous membranes and causes irritation and burning sensation in the mouth and throat. This effect is related to the presence of needle like raphides of calcium oxalate.

Calcium oxalate crystals occur in different forms throughout the Plant Kingdom. Two distinct types of crystal idioblasts (cells which differ from neighboring plant tissues and contain non-living substances) occurring in the *Amorphophallus* species observed are: (1) cells containing grooved raphide crystals, and (2) cells that contain a single large or several smaller multi-faceted druses. Both raphides and druses are often concentrated in the mesophyll tissues of Araceae (Mayo *et al.*, 1997; Keating, 2003, 2004). Members of Araceae family possess highly unusual grooved raphide crystals that appear as an 'H' or dumb-bell in cross section (Kostman and Franceschi, 2000). These raphides are usually about 50-200  $\mu\text{m}$  long, 2-4  $\mu\text{m}$  in diameter and are capable of penetrating the skin (Sakai *et al.*, 1972; Bradbury and Holloway, 1988). The intensity of irritation was found to differ widely among different cultivars. Large variation was reported in calcium oxalate content in acrid cultivars. Acrid cultivars showed calcium oxalate in the range of 660-850 mg/100g (Sundaresan, 2005). The acridity has been attributed to the action of the raphides acting alone, but evidence has been found by different workers for the presence of another substance that causes irritation of the skin (Bradbury and Holloway, 1988). Paull *et al.* (1999) proposed that some

kind of irritant on the raphide surface caused the acidity, with the raphides apparently functioning to carry the acidity factor. They found, a 26 kDa protein, possibly a cysteine proteinase to be responsible for acidity.

### **2.2.5 Non-acrid-varieties**

All India Coordinated Research Project on Tuber Crops (other than potato) started development of non-acrid/less varieties in 1976. A non acrid variety was selected in West Godavari district of Andhra Pradesh and released as *Gajendra* for commercial cultivation in 1989. From then onwards, various non-acrid varieties having high yield and good cooking qualities have been released by AICRP centres. Some of these cultivars are *Sree Padma*, *Sree Athira*, *Bidan Kusum* and *NDA-9*. Non acrid cultivars contain calcium oxalates ranging from 120-140 mg/100g (Sundaresan, 2005).

### **2.2.6 Processing of yam**

The acidity of tubers can be reduced or eliminated by suitable processing methods. Boiling, baking, frying and drying by different modes are the major processing methods usually followed.

#### *2.2.6.1 Traditional methods*

Various traditional processing methods are followed in different regions of India for elimination of acidity. Presoaking, boiling, addition of ingredients like tamarind, curd, buttermilk etc. in cooking medium are some common traditional methods. In North-Eastern states, the elephant foot yam is boiled in bamboo shoot ash water for removing acidity. The bamboo shoot acts as alkali and repeated boiling and drying helps in breaking down the calcium oxalate crystals (Sankaran *et al.*, 2008b).

#### *2.2.6.2 Boiling*

Moy *et al.* (1979) reported that prolonged cooking (boiling or baking) removed the acidity of taro tubers. Banks (1963) reported that acidity of taro tubers and leaves could be removed by cooking. Boiling removed all the measurable soluble oxalate from the tissue of different cultivars of taro by leaching

into the cooking water. Wanasundera and Ravindran (1992), Savage *et al.* (2000) and Quinteros *et al.* (2003) reported decrease in the oxalate content after boiling. Iwuoha and Kalu (1995) noticed that boiling reduced the oxalate content of cocoyam by 82.1%.

Chai and Liebman (2005) found that total oxalate content decreased by 30% to 87% in vegetables by boiling, primarily through the loss of soluble oxalate and, in spinach and carrots the decrease in total oxalate corresponded to the amount of oxalate found in the cooking water. Boiling may cause considerable skin rupture and facilitate the leakage of soluble oxalate into cooking water. Wanasundera and Ravindran (1992) reported 40–50% loss of total oxalates when two kinds of yam tubers (*Dioscorea alata* and *D. esculenta*) were boiled compared to steamed (20–25%). Bhandari and Kawabatta (2006) reported that decrease in the oxalate content was highest in *Dioscorea* upon boiling when compared to pressure cooking and baking. Blanching has also been reported to decrease the oxalic acid content in spinach (Kim *et al.*, 1993).

Huang and Hollyer (Patent No.5464646 dated Nov. 7, 1995) invented a method of removing acidity substances from *Araceae* tubers without cooking. The process involves the cutting of tubers, soaking in warm water (38-48<sup>0</sup>C) for 4 hours, alkali treatment (0.02-0.1%) for 0.5 hour, drying and flour making.

#### 2.2.6.3 *Fermentation*

Oxalic acid decreased by 37% during souring of poi (a cooked taro paste) at 20°C (Huang *et al.*, 1994). Carpenter and Steinke (1983) found that anaerobic fermentation of leaves in an underground pit for several weeks removed the acidity. Antai and Obong (1992) observed marked decrease in *Icacinia manni* (a starch tuber) upon fermentation.

#### 2.2.6.4 *Drying and Baking*

Sundaresan and Nambisan (2008) reported drum drying of elephant foot yam reduced the calcium oxalate by 25% and it was acid free. And it was also effective in 50% reduction of calcium oxalate content in taro and cocoyam. However the acidity levels of the fresh and drum dried product was not reported.

Baking was found to increase the percent concentration of soluble oxalates in the cooked tissue (Savage *et al.*, 2000; Albihn and Savage, 2001a and Quinteros *et al.*, 2003). In contrast, Sefa-Dedeh and Agyir-Sackey (2004) showed that drying methods, similar to baking, decreased the concentration of oxalate in taro species to about 50%, due to reported oxalate degradation. Decrease in oxalate content by 61.9% due to roasting (165°C for 40 min) in cocoyam was reported by Iwuoha and Kalu (1995). Baking potatoes (Chai and Liebman 2005) or roasting peanuts (Judprasong *et al.*, 2006) or sesame seeds (Toma *et al.*, 1979) does not affect oxalate content.

### **2.2.7 Food Uses of EFY**

EFY is highly esteemed for its nourishing quality. Various delicious dishes of *Zimikand* are prepared throughout the country such as curry is made with fresh tuber pieces along with curd/buttermilk and spices. It is cooked as a vegetable and is also used for pickling. It is boiled like potatoes and eaten with mustard; or it is cooked in curries, or it is cut into slices, boiled with tamarind leaves, and made into pickles; it is also cooked in syrup and made into preserve. Cooked with salt, chilly, tamarind and turmeric powder, it is used as curry (Yesodharan and Sujana, 2007). Stem and tubers are cut into pieces, sundried and used in preparation of delicious curry during off season is the common practice in some parts of the country. A typical food item of *Zimikand* is *badi*, a type of preparation made by stem pieces with pulses, spices and then sundried and eaten after deep frying, or cooking with other vegetables (Singh *et al.*, 2008). Powdered yam is encapsulated with pulp of seeded banana, and consumed for controlling stomach disorders and piles.

EFY can be used to produce *Chawanpras*, preserved candy, beverage, jam and dehydrated fruits, which can be helpful in setting processing industries (Kumar *et al.*, 2004). Value addition to the corms as for example through preparation of French fries, papads etc. has been attempted in small quantities (Murthy *et al.*, 2008). Its utilization through value added products like fried yam balls, yam flour, yam flakes chips, souce, pickles and baked yam is suggested by government agencies (Singh *et al.*, 2008). In Assam, EFY is consumed by farmers in month of *Bhadoh*, as a special diet which is thought to be strength giving (Borah *et al.*,

2008). Various value added products like *gulabjamun*, *kheer*, *cutlet* etc. were prepared and standardized by Acharya *et al.* (2005).

### **2.3 Drying of yam**

Drying involves moisture removal through simultaneous heat and mass transfer. It is also one of the conservation methods of agricultural products, which is most often used and is the most energy-intensive process in industry (Dincer, 1998). The main reason for drying a food is to extend its shelf life beyond that of the fresh material, without the need for refrigerated transport and storage. This goal is achieved by reducing the available moisture, or water activity to a level which inhibits the growth and development of spoilage and pathogenic microorganisms, reducing the activity of enzymes and the rate at which undesirable chemical changes occur.

Hot air drying is one of the most frequently used operations for food dehydration. It is a method in which heated air is blown over food materials with the aid of fan(s) to remove most of the moisture from the food material. The drying of wet materials induces a number of physico-chemical changes. Hot air drying is generally carried out in a cabinet/tray drier. It is a multipurpose, batch-operated hot air drier consisting an insulated cabinet, equipped with a fan, an air heater and a space occupied by trays of food. It can vary in size from a bench-scale unit holding one or two small trays of food to a large unit taking stacks of large trays.

The air may be directed by baffles to flow the across surface of the trays of food or through perforated trays and the layers of food, or both ways. The moist air is partly exhausted from the cabinet and partly recycled by means of dampers. Small cabinet driers are used in laboratories, while larger units are used as industrial driers, mainly for drying sliced or diced fruits and vegetables. Convective drying in hot air is still the most popular method applied to reduce the moisture content of fruits and vegetables (Lewicki 2006).

### 2.3.1 Effect of drying on colour

A major quality problem for vegetables is enzymatic browning and alternately, hot air-drying, which is commonly used in food production can cause non-enzymatic browning due to longer duration required for the drying operation.

Washing with water is not effective in preventing discoloration (Wiley, 1994). Traditionally, sulphites have been used to prevent browning. Sulphur dioxide (SO<sub>2</sub>) or inorganic sulphites (SO<sub>3</sub><sup>2-</sup>) may be added to foods to control enzymatic and non-enzymatic browning, to control microbial growth, or as bleaching or reducing agents or antioxidants. The main applications are preserving or preventing discoloration of fruit and vegetables. Calcium chloride can reduce browning in dried carrot (Baloch *et al.*, 1981) and tomato slices (Mehdi *et al.*, 2007). Utomo *et al.* (2008) and Mais and Brennan (2008) used blanching with sodium tripolyphosphate and sodium metabisulphite respectively to reduce discoloration in flour preparation from sweet potato.

Sajeev *et al.* (2010) worked on the process technology for the production of dehydrated cooking tubers. The tubers of EFY were cut into different sizes 10, 15 and 20 mm<sup>3</sup> cooked for 30 minutes and then frozen at -10, -20 and -30°C, respectively. The frozen product was dried using different modes viz. microwave drying, tray drying and convection oven drying. The drying rate of frozen tubers decreased with an increase in drying temperature under tray drying and oven drying, contrary to microwave drying. For tubers, frozen at -10°C, the maximum browning occurred for the samples exposed to high temperature of 70°C for 20 mm<sup>3</sup> samples. For the samples frozen at -20°C, the browning index decreased for 10 mm<sup>3</sup>, but for 20 and 30 mm<sup>3</sup> cubes, it increased with increasing drying temperatures. For samples frozen at -30°C, browning index changed very little, when the temperature increased from 50 to 70°C. Freeze-drying resulted in a higher whiteness index as compared to tray drying and drum drying (Hsu *et al.*, 2003). Ninjtang and Mbofung (2003) observed that browning developed rapidly in taro, as drying temperature increased above 80°C with development of an undesirable yellowish off-colour.

Severni *et al.* (2005) carried out drying operation of blanched and unblanched potatoes in an air cabinet, a microwave oven or a belt drier. They observed slowest browning in case of belt drying. For unblanched potatoes, those dried by microwave oven browned faster than the others. Colour of cubes blanched in the sodium chloride solution did not undergo great changes during drying process with the exception of the increase in Hunter b\* value. Flour produced using sun drying method had a higher brown-index (Jimoh *et al.*, 2009).

### **2.3.2 Effect of drying on pasting properties**

Yams comprise largely of starch. Hence many of their properties are similar to starch. Pasting or gelatinization is one such important property (vide 2.4.1.2). Akissoe *et al.* (2003) observed that oven-dried yam slices had a higher onset temperature than freeze-dried samples (74.5°C and 72°C, respectively). Neither blanching at 65°C for 20 min nor drying at 40°C for 5 days significantly affected gelatinization enthalpy. Oven-drying lowered the end viscosity after cooling to 50°C (V50) significantly (from 154 RVU to 77 RVU) whereas blanching had no significant effect (vide 2.4.1.2). Oven-drying drastically reduced swelling power. Amala (a traditional thick paste obtained from dry yam flour), viscosity decreased after oven-drying as swelling power decreased due to starch annealing.

Freeze-drying showed the least starch degradation of yam flour made of each type of yam variety, while hot air drying and drum-drying had more profound effects on starch degradation. Water absorption index (WAI) indicates the extent of starch gelatinization. The highest WAI was found in the flour made by drum-drying because extra water was added before drying and this resulted in a higher degree of starch gelatinization during the drying/heating process. Hot air-drying (60°C, 48 hours) resulted in the least gelatinization (Hsu *et al.*, 2003).

Jimoh *et al.* (2009) found blanching to have a significant effect on the pasting characteristics of the reconstituted flour. It reduced the peak viscosity, holding strength, final viscosity, set back and elasticity but had little or no significant effect on the adhesiveness, smoothness and cohesiveness of the paste. Sun-drying and oven-drying had no effect on the pasting characteristics or

physicochemical properties. However, yam flour produced using sun drying method had a more elastic paste.

Aviara *et al.* (2010) observed that water binding capacity and swelling power of the open air-dried sorghum starch were not significantly different from those of starch dried at 40°C. Also, water binding capacity increased from 79.63 to 88.5%, while swelling power, solubility and percentage syneresis decreased from 12.01 to 8.96 g/g, 7.08 to 2.85% and 14.0 to 10.80%, respectively as the drying temperature increased from 40 to 60°C. Paste clarity was low (22.50%–26.20%) but increased with an increase in drying temperature up to 50°C and decreased with a further increase in temperature. Pasting properties of open air dried starch differed significantly from those of starch dried at different temperatures. Peak viscosity decreased from 398.75 to 325.25 RVU as the drying temperature increased from 40 to 60°C. Setback increased with an increase in drying temperature up to a point and then decreased with a further increase in temperature. Final and breakdown viscosities as well as pasting temperature and peak time were found to have polynomial relationships of the third order with drying temperature.

## **2.4 STARCH AND ITS PROPERTIES**

It is the major carbohydrate storage material in many higher plants and is considered the second largest natural biopolymer next to cellulose. Starch contributes to the physicochemical properties of food products made from cereals, tubers, roots, legumes, and fruits. It is the basic source of energy for the majority of the world's population. In human nutrition, starch plays a major part in supplying the metabolic energy that enables the body to perform its different functions.

The two major macromolecular components of starch are amylose and amylopectin. Amylopectin is the major component of most starches. It is a much larger molecule than amylose, with a molecular weight of  $10^7$ - $10^9$  Da. It is a highly branched structure built from chains of  $\alpha$ -D-glucopyranosyl residues linked together mainly by  $\alpha$  (1→4) and 5-6%  $\alpha$  (1→6) linkages. Amylose is a heterogeneous mixture of molecules having variable molecular size and branching; the molecules are essentially linear polymers of (1→4)-linked  $\alpha$ -D-

glucopyranosyl units with short (<0.1%)  $\alpha$  -(1 $\rightarrow$ 6) branches and have a molecular weight of approximately  $10^5$ - $10^6$  Da. The content of amylose is between 15 and 25% for most starches. The ratio of amylose and amylopectin in starch varies from one starch to another.

### **2.4.1 Properties of starch**

During food processing, starch undergoes changes such as gelatinization and pasting which influence the texture and stability of the food products. The basic starch qualities or functionally important properties of starch are gelatinization, pasting properties, swelling power and solubility, enzymatic digestibility and retrogradation (Leach, 1965; Rickard *et al.*, 1991). These properties control the sensory attributes and stability of processed starch products.

#### **2.4.1.1 Swelling and solubility**

Unmodified starch granules are generally insoluble in water below 50°C and can hold up to about 30% of their dry weight in cold water. The subsequent changes in volume and moisture are reversible at this point.

As the temperature of an aqueous suspension of starch is increased above a certain range, hydrogen bonds holding molecules together disrupt and expose the hydroxyl units. At this point, water molecules become attached to the liberated hydroxyl groups and the granules continue to imbibe water and swell to many times their original size. Granules swell over a range of temperatures, indicating their heterogeneity of behaviour. As a direct result of granule swelling, there is an increase in starch solubility (Singh *et al.*, 2003). Amylose is reported to be the main component which leaches into the surrounding medium to increase solubility.

Swelling and solubility provide evidence of the magnitude of interaction between starch chains within the amorphous and crystalline domains or provide evidence of non-covalent bonding between molecules within the starch granules. The extent of this interaction is influenced by the amylose to amylopectin ratio in terms of molecular weight distribution, degree and length of branching and conformation (Hoover, 2001; Singh *et al.*, 2003). Starches with more phosphate groups, such as potato starch, are more prone to swelling (Hoover, 2001). Starch

phosphate monoesters carry negative charges and repel one another, thereby reducing interchain associations. This increases the level of hydrated molecules. Formation of amylose-lipid complexes could also restrict swelling and solubilization.

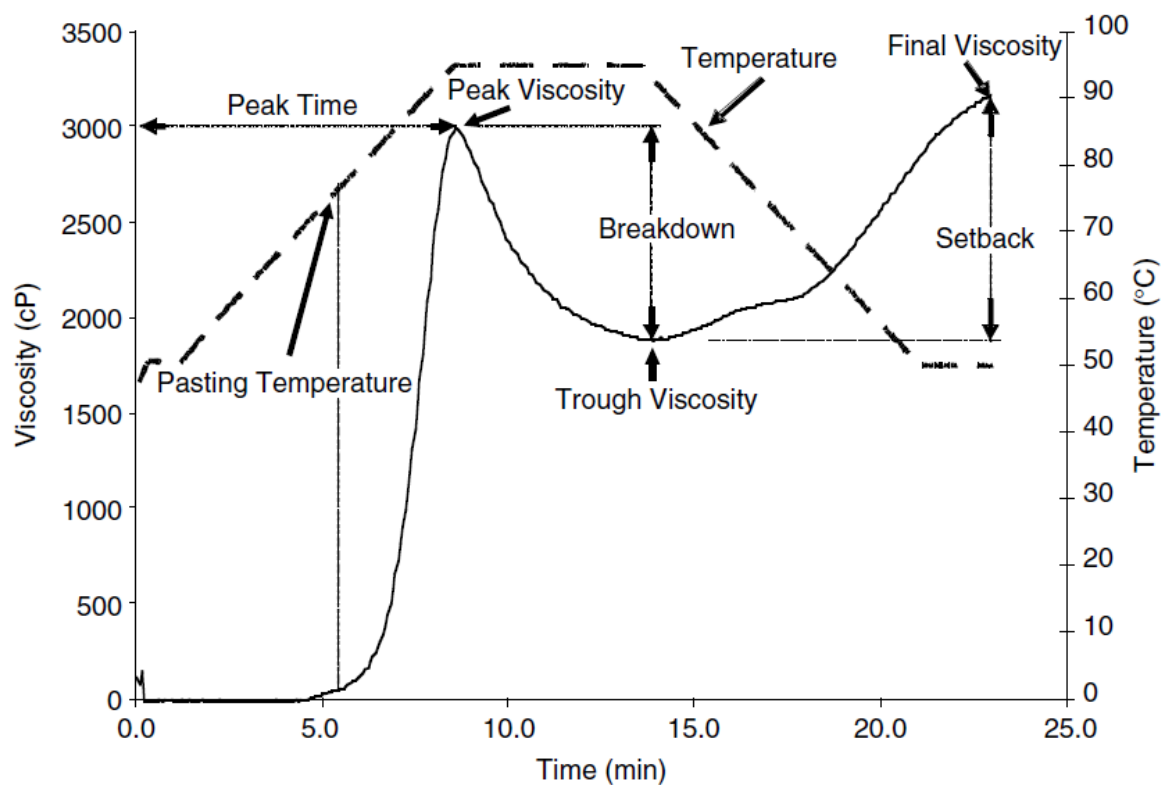
#### 2.4.1.2 *Gelatinization and pasting*

As the temperature of starch/flour slurry increases further, the granules rupture and deform irreversibly in a process called gelatinization. Gelatinization is a swelling-driven process, which results in an irreversible order-disorder of the molecules within the starch granule, also observed as irreversible granule swelling, loss of birefringence, loss of crystallinity and leaching of amylose and/or amylopectin.

Gelatinization of starch takes place over a definite range of temperature known as the gelatinization temperature. The initial point of gelatinization and the range over which it occurs are governed by starch concentration, method of observation, granule type and heterogeneities within the granule population under observation (Atwel *et al.*, 1988). This range is reflected in the steepness of the initial rise in viscosity in the pasting curve. Modification of starch such as annealing or cross-linking will usually reduce this range.

The temperature at the onset of the rise in viscosity is the pasting temperature. It provides an indication of the minimum temperature required to cook a given sample, and has implications for the stability of other components in a food formula. As the temperature increases further, the starch granules are disrupted, particularly when shear force is applied, which results in the formation of a starch paste. This starch paste consists of a continuous phase of solubilized amylose/amylopectin and a discontinuous phase of swollen starch granules/granule remnants, granule ghosts and fragments. When the majority of the granules have undergone disruption, the starch is said to be pasted. This is of high importance in the food industry, since it affects the texture and digestibility of starchy foods.

An empirical rheological test of the gelatinization properties of starches is the measurement of the viscosity of starch dispersions in a temperature/time profile using Rapid Visco Analyser, a viscoamylograph designed as a simple-to-use viscometer. The RVA (Rapid Visco Analyser) is such an instrument which is able to reasonably imitate the cooking of flour/starch and provide results that are closely correlated with the quality of the end product (Newport Scientific 1998). The RVA profile depicts six significant points: pasting temperature, peak viscosity, viscosity at 95°C (trough or holding strength), viscosity at constant 95°C (breakdown), viscosity at 50°C (final viscosity) and viscosity at constant 50°C (setback). The pasting behaviour of starches is very important for starch characterization and applications.



**Fig. 2.1 Typical RVA pasting profile showing the significant points during heating and cooling of flour/starch sample**

The peak viscosity is attained when the largest percentage of the starch granules are fully swollen. Peak viscosity is often correlated with final product

quality, and also provides an indication of the viscous load likely to be encountered by a mixing cooker.

During the hold period of a typical pasting test, the sample is subjected to a period of constant temperature (95°C) and mechanical shear stress. This further disrupts the granules and amylose molecules will generally leach out into solution, aligned in the direction of the shear. This period is commonly accompanied by a breakdown in viscosity, sometimes called shear thinning, holding strength, hot paste viscosity or trough. The ability of a mixture to withstand this heating and shear stress is an important factor for many processes. Cross-linked starches are more resistant to breakdown.

Changes in viscosity also accompany the formation of gels upon cooling of starch paste. Viscosity will usually increase to a final viscosity at this point. Final viscosity is the most commonly used parameter to define a particular sample's quality, as it indicates the stability of the material to form a viscous paste or gel after cooking and cooling. There is a progressive re-association of the starch molecules upon ageing or cooling which results in gel formation. The phase is referred to as setback and involves retrogradation which is the re-crystallization or re-association between starch molecules (Eliasson and Gudmundsson, 1996).

Retrogradation is most rapid with amylose and much slower with amylopectin due to the short chain length branches of the former. In food products which are based on starch gels, retrogradation can lead to liquid being expressed from the gel, a phenomenon known as syneresis or weeping, which is generally undesirable. High setback is associated with syneresis during freeze thaw. The rate at which viscosity increases in yam starches during cooling is dependent on the degree of starch-water binding (Ayernor, 1985).

Retrogradation is, however, sometimes promoted to modify structural, mechanical, or organoleptic properties of certain starch-based products as practiced in the production of breakfast cereals and parboiled products. This is because retrogradation results in hardening and reduces stickiness (Colonna *et al.* 1992). It is also applied in the production of mashed potatoes, to decrease the amount of soluble starch and to improve the consistency of the reconstituted

product. It is also used in Japanese noodles and Chinese rice vermicelli to reduce stickiness and to obtain the characteristic chewiness (Watanabe, 1981; Seow and Teo, 1996).

#### 2.4.2 Elephant foot yam starch

The tropical tuber crops contain starch as the major component and thus act as important source of starch. Except cassava and to a smaller extent sweet potato, starch from other tuber crops has not been exploited for industrial applications partly because of difficulty in the extraction of the pure starches and partly because of non-availability of information about the properties of these lesser known starches.

**Table 2.2 Pasting properties of 8% w/w suspension of EFY starch in comparison with different starches, as measured by Rapid Visco-Analyzer (RVA)**

| Source            | PT<br>(°C) | PkT<br>(min) | Viscosity (RVU) |       |       |      |       |       |
|-------------------|------------|--------------|-----------------|-------|-------|------|-------|-------|
|                   |            |              | PkV             | HV    | BD    | BD%  | FV    | SB    |
| Elephant foot yam | 81.6       | 7.5          | 204.3           | 111.1 | 92.5  | 45.3 | 197.5 | 85.7  |
| New cocoyam       | 73.6       | 7.3          | 248.0           | 149.4 | 98.0  | 39.8 | 269.8 | 120.3 |
| Sweet potato      | 75.2       | 7.0          | 265.1           | 114.0 | 151.1 | 57.0 | 187.3 | 73.3  |
| Taro              | 78.0       | 7.7          | 251.2           | 139.6 | 111.6 | 44.4 | 249.4 | 109.8 |
| Cassava           | 67.4       | 6.1          | 188.1           | 66.3  | 121.8 | 64.8 | 113.3 | 47.0  |
| Lesser yam        | 75.7       | 8.2          | 291.7           | 172.8 | 118.9 | 40.8 | 246.3 | 73.5  |
| Water yam         | 83.2       | 11.1         | 394.6           | 376.9 | 17.7  | 4.5  | 556.3 | 179.4 |
| Potato            | 67.3       | 5.1          | 791.4           | 228.3 | 563.1 | 71.2 | 286.8 | 58.5  |

PT-pasting temperature; PkT-peak time; PkV-peak viscosity; HV-hot paste viscosity; BD-breakdown viscosity (PkV-HV); BD%-percentage of breakdown  $[(BD/PkV)*100]$ ; FV-final viscosity; SB- setback viscosity (FV-HV). (Srichuwong *et al.*, 2005)

*A. paeoniifolius* starch granule is in round, polygonal, with granule size 3-30µm (Moorthy *et al.*, 1994).The granule size is reported to affect functional

properties such as swelling, solubility and digestibility. Moorthy *et al.* (1994) reported that there was only minor variation among ten accessions of *Amorphophallus*.

Starch has a definite crystalline nature and the crystallinity has been assigned to the well-ordered structure of the amylopectin molecules inside the granules. Different starches possess either 'A', 'B' or 'C' pattern. *Amorphophallus* starches possess 'A' pattern (Gallant, 1982).

The linear component of starch, viz., amylose, imparts definite characteristics to starch. Amylose content varies considerably among different starches. Part of amylose can exist as soluble amylose in the amorphous regions of the starch granules. The amylose content of ten cultivars of *A. paeoniifolius* was found to vary very little (Moorthy *et al.*, 1994).

Soluble amylose can play a significant role in determining the textural properties. This fraction is easily leached out and hence considered responsible for cohesiveness in cooked tubers (Hoover and Hadziyev, 1981). The soluble amylose content ranged from 40-50% of total amylose, similar to other tuber crops. For *Amorphophallus* starch from different accessions, the soluble amylose content ranged from 9-11% forming nearly 45% of the total amylose content (Moorthy *et al.*, 1994).

The total amylose content of *A. paeoniifolius* ranged from 21.9-23.9% and swelling volume 21.5-24.4 ml/g, solubility(%) is 1.4, 17, 20.8 at 75°C, 80°C and 100°C, respectively (Moorthy *et al.*, 1994) and pasting temperature 75-80°C (Rodriguez-Sosa *et al.*, 1981).

### **2.4.3 Starch functionality**

Functionality in a broad sense is any property of the food component, other than its nutritional value, that affects its utilization (Pomeranz, 1991). Saccharides and polysaccharides are commonly used in food preparation for controlling texture of the products (Lai and Lii, 2004). The intermolecular interactions of various polysaccharides can be used as an important tool in controlling the texture of foodstuffs (Morris, 1990). Starch is the most widely used thickening and gelling agent in the food industry because of the wide variety of

texture and mouthful sensations it provides. Starch has numerous useful functional properties for food and non-food applications. These include thickening, coating, gelling, adhesion, and encapsulation. Some of these functionalities are unique to the polymer due to the structure of amylose and amylopectin and their organization.

Gelatinization, retrogradation, and pasting, which underlie starch functionality, are the three most important phenomena in starch applications. In a food system, the roles of starch are to stabilize the structure and interact with other components to deliver or maintain nutrient and flavor. For example, starch can serve as a thickening agent for sauces, cream soups, and pie fillings; colloidal stabilizer for salad dressing; moisture retention for cake toppings; gel-forming agent for gum confections; binder for wafers and ice cream cones; and coating and glazing agent for nut meats and candies. Starch imparts body and mouthfeel to the product (Verbeke *et al.*, 2006).

Starch is often used as a thickening agent in food systems with other ingredients, such as milk in custard. These ingredients may alter the rheological behaviour of the starch. Different combinations of polysaccharides have to be applied for starch pastes, gels, mixes, processed starch products, drinks, dairy products, whipped and emulsified products, dressings, meat, and other products. The starch–xanthan gum combinations are suitable thickeners for dessert strawberry sauces which can provide stable sensory and textural properties of the sauces for at least 3 months (Sikora *et al.*, 2007). Thickening generally involves swelling of granular starches by thermal processing. Modified waxy maize, potato and tapioca starches are generally preferred because of their comparative stability to textural changes during distribution. However, granular starch will not thicken effectively at low concentrations unless other thickeners are present, because it will settle out; so soluble, stabilized hydrolyzates are used instead in thin fluids. In beverages and light syrups, these have the advantage of minimal opacity.

Starch properties depend on the botanical source of the starch, the presence or otherwise of chemical modifications (modified or native starch), the starch concentration, the cooking procedure (temperature, pH, heating time,

shearing time and intensity, among others) and the presence of other ingredients or additives. Native starches have limitations in industrial applications due to their high thermal and shearing instability and their tendency to retrograde during cooling or/and freezing, causing a decrease in food product quality. In order to meet the requirement of some food products, starch is chemically and/or biotechnologically modified as an ingredient.

Pregelatinized starches, also referred to as instant starch slurries, are those that have been simply precooked to give products that readily disperse in cold water to form moderately stable suspensions (Hodge and Osman, 1976). Such products have been mainly applied as thickener in many food products such as baby foods, instant soups and instant desserts. Thin boiling starch, made by partial acid hydrolysis, is utilized as thickener and as protective films. In these starches, retrogradation is slow. Heating of starch at 100-200°C with small amount of acidic or basic catalyst, leads to formation of dextrans. These products are used as adhesives in sweets and as fat substitutes. Starch esters have better thickening and paste clarifying properties, and improved freeze-thaw stability. These starches are utilized as thickeners and stabilizers in bakery products, soup powders, sauces, puddings, refrigerated foods, heat sterilized canned foods and in margarines (Belitz and Grosch, 1999).

Resistant starch has a low calorie profile and can be used as a bulking agent in reduced sugar or reduced fat food formulations. Resistant starch does not compete for the water needed by other ingredients and allows for easier processing because it does not contribute to stickiness. This may be advantageous in the production of low moisture products such as cookies and crackers. Products ranging from bread, crackers to muffins have better taste, mouth feel, and appearance when resistant starch is used to replace traditional fiber sources. It can be used as a functional food ingredient for making breads, buns, crumpets, muffins, cakes, biscuits, breakfast cereals, snacks, confectionery, pasta, drinks, yogurts, and ice cream (Liu, 2005).

Both native and modified starches show different behaviour during heating and cooling processes, due to differences in composition. Native starch pastes

can be considered structurally as biphasic systems with a continuous phase, essentially an aqueous solution of amylose, leached during granule swelling, and a dispersed phase constituted by swollen starch granules (Tecante and Doublier, 1999). Depending on the starch type, its concentration, and the particular thermo-mechanical treatment, the resultant system will behave as a viscous fluid or a gel (Lagarrigue and Alvarez, 2001; Thebaudin *et al.*, 1998).

#### **2.4.4 STARCH BEHAVIOUR IN MILK**

Many commercial dairy desserts consist classically of milk mixed with starch to which a gelling agent such as carrageenan is added. These systems can have different designations depending on the country, such as 'vla', 'natillas', 'cre`me-dessert' or 'custard sauce' (Doublier and Durand, 2008). Starch plays a major role in the properties of these systems. However, the other components such as milk proteins, fat, and other polysaccharides are involved in the final texture of the dispersion.

Basically, these dairy systems are composed of full fat milk to which a cross-linked starch is added together with a very low amount of a gelling carrageenan and sucrose. As a result, custard can be merely described as a suspension of deformable particles (the swollen starch granules) dispersed in a continuous medium containing milk proteins as well as carrageenan (van de Velde *et al.*, 2002; van de Velde *et al.*, 2003). The rheological properties of a custard type system are mostly governed by the packing of the swollen starch granules. Custard desserts contain milk, sugar, colorants, flavors, hydrocolloids like carrageenans, and modified starch. Custard dessert consists of two phases, a continuous aqueous phase containing starch and carrageenan and a dispersed phase of oil droplets that are stabilized by proteins. The "Natillas", semisolid dairy dessert of wide consumption in Spain, are composed of milk, starch, hydrocolloids, sugars, colorants and flavourings.

Starches are becoming an increasingly popular addition to dairy systems because of their relatively low cost, availability and benefits. Both native and modified starches are commonly used in dairy products. A broad range of ready-to-eat milk-based desserts is available to the consumer, offering a wide variety of

textures, flavours and appearances due to the use of different thickening and gelling agents, equipment and process conditions. Starches are extensively used in a variety of food products such as ice cream, chocolate, milk-based sweets, jellies, sauces, custards and desserts. In these products, the method of preparation such as water content, temperature and the presence of other organic/inorganic materials is an important factor that determines the rheological behavior of starch dispersions (STDs) (Matser and Steeneken, 1997; Willet *et al.*, 1995).

When two complex systems such as starch and milk ingredients are mixed together, the range of interactions is large and the effect on the physico-chemical properties of the mixed system depends on their relative concentrations, the physico-chemical properties of the starch and milk ingredients as well as the composition of the milk ingredients. The presence of lactose and minerals in skim milk, even in small amounts, has been found to affect the onset of swelling and gelatinization of starches.

A thorough understanding of the interactions between starch and milk ingredients paves the way for manipulation of the composition and processing of foodstuffs to tailor textural consistency and as a consequence the sensory characteristics at ease. Provided the concentration is high enough, the rheological properties of the dispersions of cross-linked starch in milk display all the features of starch-in-water systems with solid-like properties and pronounced shear-thinning flow behaviour. These systems can be described as suspensions of close-packed deformable swollen particles. The rheological properties of a custard type system are mostly governed by the packing of the swollen starch granules.

Modified starches are primarily used to impart viscosity and a smooth, short texture to dairy products such as ready-to-eat (RTE) puddings, sauces and desserts. Fat content in dairy products contributes to the rich creamy mouthfeel when homogenized, due to the formation of an oil-in-water emulsion. The higher the fat level, however, the harder it becomes to fully gelatinize a starch because of the protective coating effect of the fat.

The presence of milk may affect the system structure, depending on the nature of the starch. It has been reported that milk–starch systems are more

viscous than water–starch ones for the same starch concentration (Abu-Jdayil *et al.*, 2004; Descamps *et al.*, 1986). The viscosity of certain amount of starch in milk is higher than the viscosity of that same amount in water (Descamps *et al.*, 1986). The change in the characteristics of the dispersing medium, due to substitution of milk for water, alters the rheological properties of dispersion. This effect could be attributed to the increase in the starch granules rigidity and to the fact that some milk components, like casein or fat, may affect the whole system structure. The rheological behaviour of cross-linked starch dispersions, prepared by following the same thermo-mechanical treatment, mainly depends on the type of starch and on the granules volumetric fraction.

Sodium caseinate which is different from the casein micelles in milk increases the swelling volume of certain starches. This results in an increase of the viscosity (Lelievre and Husbands, 1989). Casein micelles contribute significantly to the storage modulus or elasticity of starch-skim milk systems. This is probably caused by the exclusion of the casein micelles from the swollen starch granules. This results in an increase in the concentration of proteins between the swollen starch granules to a sufficiently high level and an increase in the concentration of starch between the milk proteins.

Doublier *et al.* (1994) reported the effect of sodium caseinate addition on the behaviour of wheat, potato and tapioca starches. They showed a large decrease in the volume fraction occupied by swollen granules in the paste and in the concentration of starch macromolecules solubilized in the continuous phase. The addition of sodium caseinate resulted in a decrease in the swelling and solubility indices for all starches but had the greatest effect on potato and tapioca starches. A decrease in apparent viscosity was shown only for casein-tapioca starch. Bertolini *et al.* (2005) reported that the addition of sodium caseinate resulted in an increase in the storage modulus and the viscosity of the starch gels, with the exception of potato starch. They also reported an increase in onset temperature, gelatinization temperature and end temperature.

Noisuwan *et al.* (2007) explored the viscosity, swelling and starch leaching during the early stages of the pasting of waxy and normal rice starch suspensions

containing sodium caseinate, whey protein isolate or SMP. They found that WPI did not affect the swelling onset temperature or the viscosity onset temperature of rice starches; both sodium caseinate and SMP did affect these temperatures, and suggested that it may be the competition for water between sodium caseinate and starch granules that resulted in the increase in swelling onset temperature 40°C respectively.

Noisuwan *et al.* (2007) suggested that adsorption of the milk proteins to the starch granule, through hydrophobic interactions, may restrict the diffusion of water into the starch granules, which can result in a delay to the swelling of the starch granule. The substitution of milk for water in the modified starch systems originated an increase in the registered shear stress and in the hysteresis loop area. Tarrega *et al.* (2005) observed that some samples showing anti-thixotropy in water showed thixotropy in the milk systems. These results could be attributed to the higher rigidity of starch granules in milk dispersions (Abu-Jdayil *et al.*, 2004; Matser and Steeneken, 1997).

Abu Jdayil *et al.* (2004) studied the effect of milk on native wheat starch dispersions and found that milk addition increased the apparent viscosity, as compared to the aqueous systems, the differences being higher at higher starch concentrations and also at higher milk fat contents. Samples with starch concentrations over 4% in water systems and over 2% in milk systems showed time-dependent flow. At the same starch concentration, both, viscosity after heating period and viscosity after cooling period, showed higher values for milk dispersions, attributable to the higher viscosity of the dispersing phase, due to the presence of caseins, lactoglobulins, fat and the other milk components (Velez-Ruiz and Barbosa-Ca´novas, 1997) and to the possible interactions between these components and starch (Abu-Jdayil *et al.*, 2004; Matser and Steeneken, 1997).

Modified starch granules show higher thermomechanical resistance. If the granules remain whole after pasting, the resultant system is an aqueous dispersion whose rheological behaviour mainly depends on the granules volumetric fraction and on their rigidity or deformability (Nayouf *et al.* 2003). Chamberlain *et al.* (1999) showed that cross-linked waxy maize dispersions (2.6

wt %) in water, heated in the range 60–120°C, exhibit shear thinning behavior. On the other hand, dispersions heated for 15 min at 60 °C showed slight shear thickening. Power law model was used to characterize the flow behavior of starch dispersion. The corn starch milk sugar (CMS) paste exhibited higher viscosity than wheat starch milk sugar (WMS) paste except those prepared at 75 °C, whereas the viscosity of WMS paste was greater. It is likely that the degree of gelatinization of WMS paste at 75°C was greater than that of CMS paste.

The WMS paste exhibited a typical shear-thinning behaviour, where the apparent viscosity decreased with shear rate. The addition of sugars to wheat starch–milk system elevated the apparent viscosity of the paste. In addition, as the sugar concentration increased the apparent viscosity of WMS paste increased, which is an indication that the percentage of starch granule gelatinized increased. Regardless of sugar concentration used, the apparent viscosity of WMS paste decreased upon changing the sugar type from fructose to sucrose to glucose. The apparent viscosity of wheat starch–milk–sugar pastes was higher than the viscosity of wheat starch–water–sugar pastes. The increase of the paste apparent viscosity due to the presence of milk was more explicit at high starch concentration. Matser and Steeneken (1997) studied the influence of some skim milk components on the rheological properties of highly cross-linked waxy maize starch suspensions. They found that lactose increased the system storage modulus, which could be due to the increase in rigidity of the starch granules.

Abu-Jdayil *et al.* (2004) and Matser and Steeneken (1997) observed that the apparent viscosity of 6% wheat starch pastes at  $2.2 \text{ s}^{-1}$  increased by 5% using low fat (1.5%) milk and by 15% using high fat (3%) milk, compared with using skim milk (0.2% fat).

They concluded that besides the effect of milk on the increase in rigidity of the starch granules, the three dimensional fat polymers contributed to the increase in apparent viscosity of starch milk pastes. Apparent viscosity at  $1 \text{ s}^{-1}$  was higher in whole milk model systems, the increment being relatively bigger at 3.25% starch concentration than at 2.5% or 4% starch concentrations (Abu-Jdayil *et al.* 2004).

Verbeken *et al.* (2004) concluded that starch has a positive effect on the complex modulus and gelation temperature. In sterilized dairy desserts interactions between k-carrageenan and milk protein are involved in the formation of the carrageenan gel network and contribute to the physicochemical properties of the desserts. Starch granules act as non-interacting fillers and cause a concentration of the other ingredients in the continuous phase as a result of the exclusion effect. These granules, importantly, affect the rheological behaviour of the dessert under shear, but seem to be easily deformed when subjected to large, uniaxial forces (Verbeken *et al.* 2006). They observed an increase in the complex modulus when they raised starch and carrageenan concentrations, this increase being more pronounced at higher carrageenan concentration. At any constant carrageenan concentration, the substitution of SMP by starch led to an increase of both complex modulus and gelation temperature.

Vu Dang *et al.* (2009) investigated whey protein isolate (WPI)/cross-linked waxy maize starch mixtures, with lower protein concentration (0.5, 1 and 1.5%) and lower starch concentration (3 and 4%). They reported that the flow behaviour of the WPI/starch mixtures was different from that of the starch dispersion alone, and that the visco-elastic behaviour of the mixture changed from a solid-like to a liquid-like behaviour when the WPI concentration is increased. Their microscopic observations showed that the mixtures were made of swollen starch granules dispersed in a protein continuous phase. They have also reported that the WPI continuous phase was heterogeneous and contained large protein aggregates near the starch granules, which could explain both the rheological behaviour and the grainy texture of food products containing WPI and waxy maize starch. When starch is added to a casein-based solution, in some instances apparent viscosity increase, and others it decreases.

Little is known about the influence of lactose on the rheological properties of starch. Sugars increase the gelatinization temperature of starch (Kohyama and Nishinari, 1991; Spies and Hosney, 1982). The influence of sugars on viscosity is less clear. This depends on the concentrations of starch and sugar used (Savage and Osman, 1978; Cheer and Lelievre, 1983). Cheer and Lelievre (1983) found

that sucrose increased the viscosity of wheat starch at low concentrations of sucrose. However, above a certain concentration, sucrose decreased the viscosity of wheat starch. Lactose increases the particle rigidity of this starch. Interaction between starch and sugars could be a cause for this increase in particle rigidity (Chinachoti *et al.*, 1991; Hansen *et al.*, 1989). The gelatinization temperature of corn starch milk system paste is greater than that of corn starch–water system, which was found to be in the range of 65–76°C (Ross, 1992). This increase in the gelatinization temperature can be attributed to the presence of sugar (Ahmad and Williams, 1999).

Perry and Donald (2002) found that the addition of sugars and other polyols to starch–water systems elevates the starch gelatinization temperature. They explained this phenomenon that the reduced level of solvent plasticization, resulting from the addition of non-aqueous solutes to the pure water system resulted in the elevation of the gelatinization temperature. A reduced level of solvent plasticization of the amorphous growth ring regions requires that a greater level of thermal energy be input before the starch granule can swell and begin to gelatinize. It is difficult to distinguish the influences of the different components in skim milk on the rheological behaviour of starch.

Starches along with other hydrocolloids have been evaluated in yoghurt formulations as means to achieve a desired viscosity and reduce syneresis (Keogh and O’Kennedy, 1998). Williams *et al.* (2003) reported that the addition of modified waxy corn starch to yoghurt made from only skim milk solids increased the viscosity, but developed a grainy texture. Oh *et al.* (2007) examined the effect of adding low levels of potato starch (0-1.5% w/w) on the acid gelation of low heat SMP (10% w/w). Starch addition (1.5%) caused a decrease in the gelation time of SMP, an increase in the gelation pH and a 45% increase in gel firmness. The gel breaking strain was unaffected by the level of starch. However, the breaking stress was affected by different starch level.

Starch has been extensively studied for its use in imitation cheese and it has been found that the physical properties, such as the rheological properties, and the microstructure are influenced by the interaction between the added starch

and the milk protein. Physical properties of imitation cheese were affected by the amylose content, the swelling ability, the shape and size of the starch granules, and the concentration of starch. High amylose starch increased the hardness of imitation cheese more than low amylose starch, because high amylose starch undergoes retrogradation more readily than low amylose starch during the storage of imitation cheese (Mounsey and O’Riordan, 2001).

In addition, the hardness of imitation cheese increased linearly with the concentration of added starch (Montesinos-Herrero *et al.* 2006; Mounsey and O’Riordan, 2008c). The storage modulus and the loss modulus of imitation cheese were also found to increase, as a consequence of high levels of added starch. This was probably due to the binding of water by the starch (Montesinos-Herrero *et al.* 2006). The addition of starch affected the microstructure of imitation cheese as the interactions between casein and starch resulted in the mutual exclusion of each component (Montesinos-Herrero *et al.*, 2006; Mounsey and O’Riordan, 2008c, 2008d).

El-Garawany and Abd El Salam (2005) found that the gel strength, expressed as log stress, showed linear relationships to the concentrations of WPC and PS used and log concentration of i-carrageenan. In all gels obtained, the loss modulus was higher than. The types of thickening and gelling agents and their levels determine the dessert rheological dessert properties. Formulation with 4% WPC, 3% PS and 0.1% i-carrageenan with 10% sucrose, 3% milk fat and 3% chocolate was found to produce products that had acceptable rheological properties and good shelf life. Wischmann *et al.* (2002) studied the effects of starch concentration in dairy dessert model systems, which showed time dependent and pseudoplastic flow and viscoelastic properties typical of structured gels.

#### **2.4.5 Starch and heat stability of milk**

Milk based desserts, sauces and toppings with long shelf life are becoming increasingly popular. Heat treatment of such products is essential, but loss of colloidal stability of the milk proteins and appearance of flocculates and/or settling and wheying off in the sterilized products is often a problem.

Physical stability of milk colloid is a critical attribute of heat processed milk products. It becomes even more important when additives like starch are used. It has been reported that addition of small amounts of starch to bovine milk leads to appreciable destabilization of the colloid (Muir *et al.*, 1991; Tziboula and Muir, 1993a).

The addition of corn starch and subsequently gelatinization at 85°C decreased the heat coagulation time (HCT) of the preheated buffalo skim milk depending on concentration of starch (1 and 2%, w/w) and gelatinization time (10–80 min) (Nayak *et al.*, 2007). The higher level of starch had a greater effect, and increasing gelatinization time caused decreasing HCT for both the starch levels. The HCT of the concentrated skim milk (24.5–27.0 min) was lower than that of un-concentrated milk (30.8–32.0 min). The addition of native corn starch to concentrated buffalo skim milk (18% TS) followed by heat treatment drastically decreased the HCT. Progressive decrease in heat stability of un-concentrated skim milk– starch mixture as the gelatinization period increased from 10 to 80 min was non-significant in case of 1% starch level, but it was highly significant ( $p < 0.01$ ) for 2% added starch. In case of skim milk concentrate (SMC), the effect of the treatment time on HCT was non-significant for both the starch levels, apparently because of the fact that at 10 min itself the system was almost completely destabilized (Nayak *et al.*, 2007).

Tziboula and Muir, (1993a,b) observed that increasing concentration of added starch (0.5–1.5%, w/w) caused a decrease in HCT of milk and the detrimental effect of starch additions was greater in concentrated milk even at the lowest level of addition. The cause of the reduction of heat stability of milk on starch addition was suggested to be the competition by the polyglucan with milk proteins for water. The reduction in the heat stability of milk proteins was not related to the amylose/amylopectin composition or to the granular structure of the starches. Modification of the molecular properties of the starches components by acid hydrolysis or cross linking resulted in an enhancement of the heat stability of the mixtures.

# *CHAPTER - 3*

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## **Material and Methods**

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## **3. MATERIALS AND METHODS**

This chapter contains experimental details employed in the present investigation, including information pertaining to the raw materials utilized along with methodologies adopted and analytical procedures (sensory, physico-chemical and statistical), equipment and instruments used in the studies of elephant foot yam and its mixture with milk.

### **3.1 MATERIALS**

#### **3.1.1 Buffalo Milk**

Fresh buffalo milk was collected from cattle yard of National Dairy Research Institute, Karnal, India.

#### **3.1.2 Elephant foot yam**

Local variety was purchased from wholesale vegetable market, Adarsh Nagar, New Delhi.

#### **3.1.3 Chemicals**

All the chemicals used in the preparation of different reagents were of analytical grade (AR) and were procured from standard companies. The reagents required for analysis were freshly prepared adopting standard procedures.

### **3.2 EQUIPMENT**

In this section detail of equipments used in the preparation Elephant foot yam (EFY) powder are given.

#### **3.2.1 Cheese grinder**

For mashing of cooked elephant foot yam cubes, motor operated cheese grinder was used.

#### **3.2.2 Tray dryer**

Drying of the Elephant foot yam (EFY) mash was done by hot air dryer. Mashed elephant foot yam after cooking was spread on perforated aluminum trays in uniform layer and drying was carried out at required temperatures.

### 3.2.3 Colloid mill

After complete drying of the mash in hot air dryer, trays were scraped to remove sheets of the dried mash. The sheets were broken and pre grinding was done in a kitchen grinder. Then the resulting powder was milled to fine particle size using 1093 Cyclotec™ sample mill, (FOSS TECATOR AB, Sweden).

### 3.2.4 Homogenizer

A two stage homogenizer (H-102, GOMA engineering Pvt. Ltd., Mumbai) was used to homogenize yam-milk mix.

### 3.2.5 BOD incubator

A BOD incubator, (SANYO electric Biomedical Co., Ltd., Japan) maintained at 15°C was used to temper the samples of yam milk mix before sensory evaluation.

### 3.2.6 Texture Analyzer

Various textural characteristics such as hardness, cohesiveness, springiness, gumminess and chewiness were measured on cooked cubes, using Stable Micro Systems Texture Analyzer (Model TA.XT2i, fitted with 25 kg load cell) in a double cycle compression mode.

The test conditions employed while testing the rheology of cooked cubes samples were as under: The cooked samples were cut into 1 cm<sup>3</sup> and subjected to mono-axial compression of 80% of the initial sample height which were already tempered to 25°C. The force-distance curve was obtained for a two-bite compression cycle employing a cross head speed of 10.0 mm/sec. The test conditions maintained were as under:

|                      |   |            |
|----------------------|---|------------|
| Test mode and option | : | TPA        |
| Pre-test speed       | : | 2.0 mm/sec |
| Test speed           | : | 2.0 mm/sec |
| Post –test speed     | : | 2.0 mm/sec |
| Strain               | : | 80%        |
| Probe                | : | P 75       |
| Temperature          | : | 25°C       |

The typical graphs obtained were analyzed using Texture Expert Exceed Software supplied along with the instrument.

### **3.3 METHODOLOGY**

#### **3.3.1 Elephant foot yam processing**

The raw EFY was cleaned and washed with water to remove any external soil or dust and then processed as shown in the Fig. 3.1

##### *3.3.1.1 Washing and peeling*

The raw EFY was cleaned and washed thoroughly with water to remove any external soil or dust and then it was kept for some time to dry the surface water. The corm was peeled using stainless steel knife

##### *3.3.1.2 Slicing / Cutting*

The corm was sliced ( $\sim 6 \times 3 \times 0.2 \text{cm}^3$ ) using hand slicer or cut into cubes ( $2 \times 2 \times 2 \text{cm}^3$ ) using stainless steel knife. The slices/cubes dipped immediately in 0.1% potassium metabisulphite solution to prevent the enzymatic browning and kept for 5 minutes. Then slices/cubes were removed from the solution.

##### *3.3.1.3 Selection of cooking conditions*

Preliminary experiments were carried out for selection of cooking conditions of yam. Two cooking treatment were tried in this part of experiment. Two methods of cooking were adopted viz. pressure cooking and cooking under atmospheric condition. The cubes (2cm) of yam were cooked in excess water for 30 minutes or more in both the methods. Then the cooking water was drained and the cooked cubes were kept at room temperature for cooling. Then the cubes were judged for its sensory attributes. Also Hunter colour  $L^*$ ,  $a^*$ ,  $b^*$  measurement and texture profile analysis were done. Based on these attributes cooking method was selected for further studies.

When desired the pH of the cooking water was adjusted to 3.5 using lactic acid, citric acid or tartaric acid. The cooked cubes were judged for its sensory characteristics.

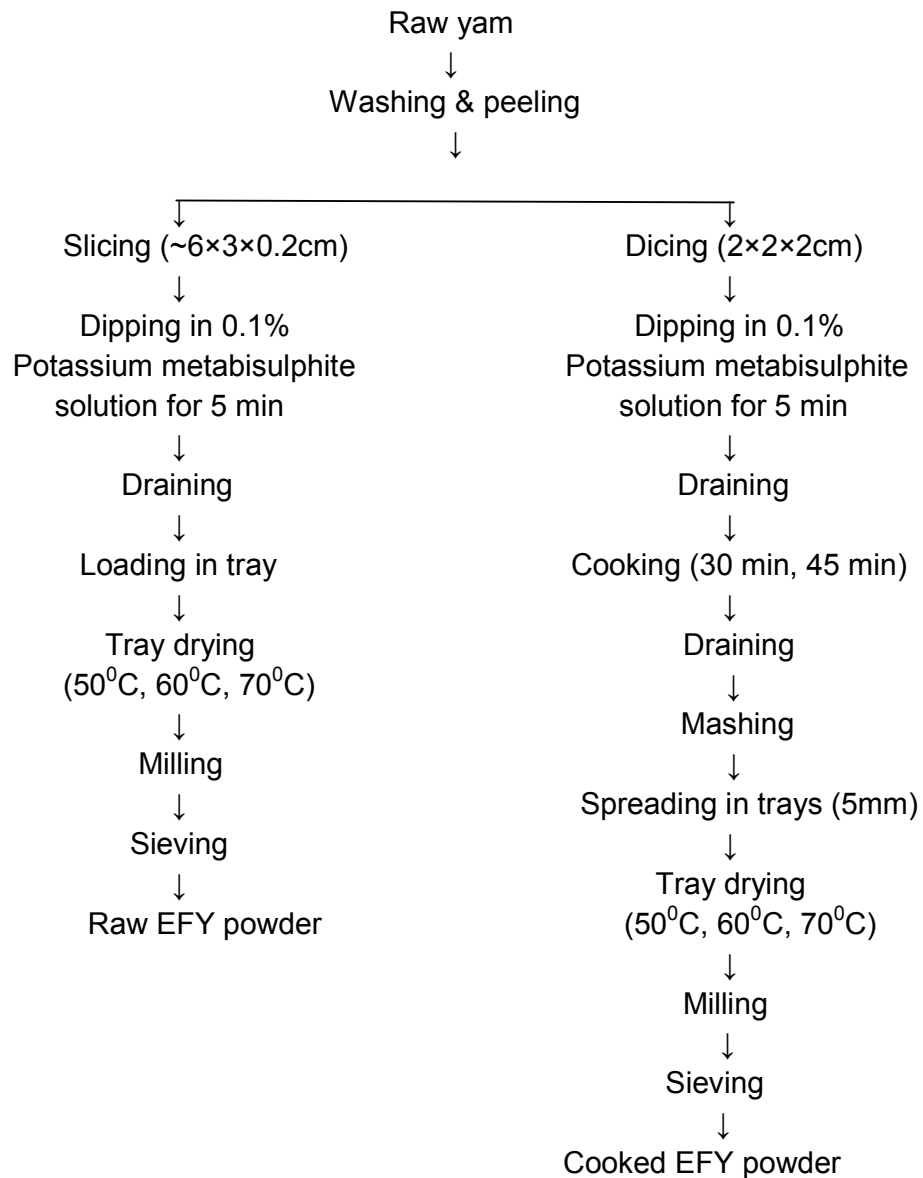
Based on the results of the above preliminary experiments cooking conditions were selected for further studies.

##### *3.3.1.4 Mashing*

The cubes (while warm) were mashed sufficient enough in a kitchen mixture for about 15 sec at its low speed to make mash easily spreadable on trays for cabinet drying.

### 3.3.1.5 Tray loading

The mash was evenly spread in perforated aluminum trays as a thin layer of about 5mm thickness to get cooked EFY powder. The cut slices (sec: 3.3.1.2) were spread in single layer in the trays to get raw EFY powder.



**Fig 3.1 Process flow chart for preparation of raw-yam and cooked-yam powders**

### 3.3.1.6 Tray drying

The trays loaded with slices/mash were dried at different temperatures (50°C, 60°C, 70°C) individually. The dryer was run for 30 min to obtain steady

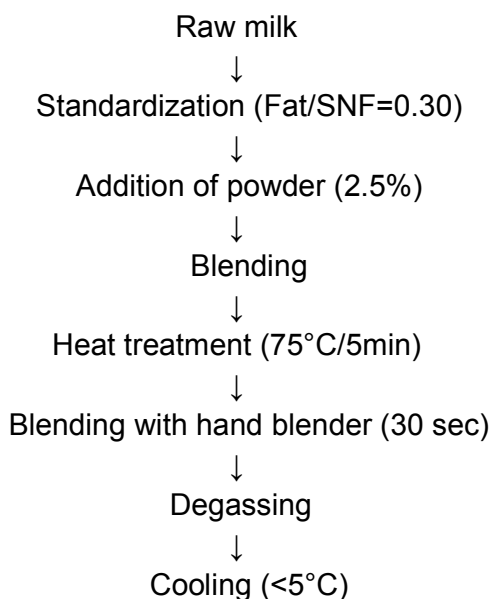
conditions before placing product in the dryer. The product was dried until the three subsequent weights of tray with the sample were equal. The weight of the tray with the product was taken for every 60 min to ensure the proper drying of slice/mash.

### 3.3.1.7 Milling & sieving

After completion of drying trays were taken out from the dryer and kept for some time at room temperature for cooling. In case of mash drying the product was scrapped to remove from the trays. Milling of the product to fine particle size was done using colloid mill. Pre grinding of the dried product was done in kitchen mixture before milling to make it easily pass through the colloid mill. The powder thus obtained was sieved through 52 mesh size standard sieve with particle size around 290 microns.

### 3.3.2 Yam-milk blending

The powders obtained from different cooking time viz. 0 min (raw), 30 min, 45 min and different drying temperatures viz. 50°C, 60°C, 70°C. All the powders were blended individually with standardized milk and heated to 75°C/5min in a water bath constantly maintained at 75°C with continuous constant stirring. Then the mix was removed from water bath and blended with hand blender for 30 sec to make it homogenous and smooth.



**Fig 3.2 Preparation of EFY-milk mix**

As blending cause foaming, degassing was done using Mytivac II (USA) degasser until complete removal of air bubbles. Then the mix was cooled to <5°C. Samples were tempered at 15°C for 60 min in a BOD incubator. Then properly stirred samples were given for judging for its flavour and mouthfeel.

### **3.4 Effects of the yam solids and total milk solids on the properties of yam-milk mix (Response surface methodology- RSM experiment)**

On the basis of the preliminary trials, range of elephant foot yam powder (0.5% and 2.0%), TMS (10% and 14%) were selected for the optimization of product. The levels of elephant foot yam powder and total milk solids were optimized using central composite rotatable design (CCRD) of response surface methodology (RSM) using Design-Expert® software (ver 8.0.1). The independent factors were the elephant foot yam powder (A) and Total milk solids (TMS) (B) in mix preparation. The coded and actual values of the variables in the RSM experiment are given in Table 4.14. The full experimental design matrix consisting of 13 experimental trials in coded and actual levels of yam solids and total milk solids is shown in Table 4.15. The response functions (y) were the organoleptic attributes (flavour, mouthfeel, colour, consistency, sediment and overall acceptability), instrumental colour coordinates i.e. lightness (L\*), redness (a\*) and yellowness (b\*), acidity, pH, sediment, heat coagulation time (HCT) at 130°C. These responses were related with the coded factors by a second-degree polynomial (Eq. 1) using the method of least squares.

$$Y = b_0 + b_1A + b_2B + b_{11}A^2 + b_{22}B^2 + b_{12}AB + \varepsilon \quad (\text{Eq: 1})$$

The coefficients of the polynomial were represented by  $b_0$  (constant term),  $b_1$ ,  $b_2$  (linear terms),  $b_{11}$ ,  $b_{22}$  (quadratic terms) and  $b_{12}$  (interactive terms) and  $\varepsilon$  (random error).

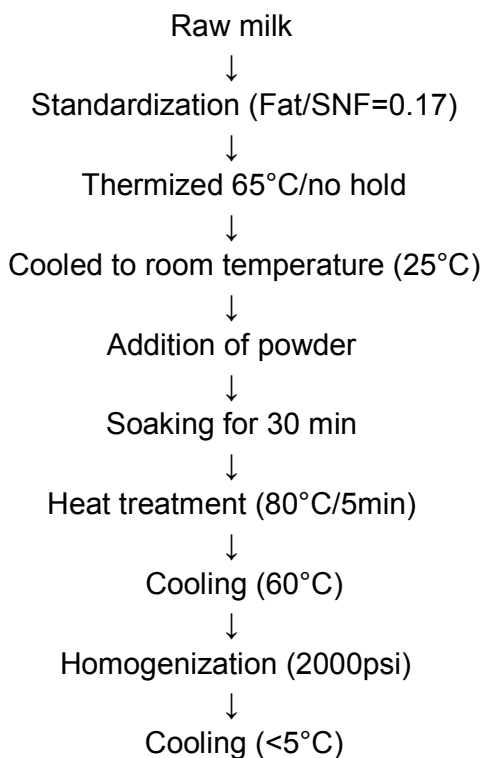
#### **3.4.1 Optimization of responses for yam-milk mix using RSM**

Responses obtained from the various trials under RSM experiments were optimized using Design Expert® software (ver. 8.0.1) for yam solids level and total milk solids. For optimization purpose numerical optimization was done using Hunter colour values (L, a\* and b\*), apparent viscosity, sediment value, acidity, pH, heat coagulation time (HCT) at 130°C, flavor, mouthfeel, colour,

consistency, sediment, overall acceptability scores as responses. The predicted values for different factors and responses were compared with the actual values obtained.

### 3.4.2 Preparation EFY-milk mix

Fresh cow milk was collected from cattle yard and warmed to 40°C and the milk was filtered using muslin cloth to remove any foreign materials. Then, the milk was standardized to fat to SNF ratio of 0.17. The milk was thermized to 65°C/no hold and then cooled to room temperature. The selected powder was blended with standardized milk and kept in refrigerator for 30 min heated to 80°C/5min in a water bath constantly maintained at 80°C. While heating, the samples were gently stirred constantly. Then the mix was removed from the water bath and cooled to room temperature.



**Fig 3.3 Final protocol for preparation of EFY-milk mix**

### 3.5 SENSORY EVALUATION

The prepared mix was evaluated for sensory characteristics by a panel of trained judges selected from the Division, a 9-point hedonic scale or a structured, linear scale (0-100) score card. Panel members were asked to

judge for sediment, colour, consistency, flavour, mouthfeel and overall acceptability using the respective linear scales and to put a vertical mark along the scale to indicate the attribute intensity (Appendix).

### **3.6 ANALYTICAL METHODS**

The raw elephant foot yam and powder used in the manufacture EFY-milk mix, intermediate as well as the finished developed mix was analyzed for various physical, chemical and rheological parameters using the following methods:

#### **3.6.1 Chemical Analysis**

Various analytical methods and techniques that were used for chemical analysis are described in the following section.

##### **3.6.1.1 *Sample preparation***

From the whole lot of raw elephant foot yam, three corms were selected randomly. 100gms of portions were cut from each peeled corm. All three portions were cut, grinded and blended homogeneously. Sample from this blend was taken for proximate analysis and the results were expressed as fresh weight basis of edible portion. Moisture content of all 9 prepared powders and proximate analysis of the selected EFY powder was done.

##### **3.6.1.2 *Moisture***

Moisture content was determined by the gravimetric method as described in AOAC (2000). A dry, empty and clean dish was weighed. About 5 g of raw sample was taken in the dish and weighed accurately. In case of powders 2 g of sample was taken. The dishes were kept in the oven at 105°C for until constant weight (about 5 hr). After drying the samples in the oven, they were transferred into desiccators to cool for 30 min and then weighed accurately. The dried raw sample after moisture was collected for estimation of crude fat and crude fibre.

##### **3.6.1.3 *Fat***

Crude fat was estimated in raw sample and selected powder using standard method of AOAC (1995). 5 g of sample was weighed and transferred to extraction thimble. The thimble was extracted with petroleum ether for 45 min using SOCS PLUS, Pelican Equipments, India. The beaker containing

extracted fat was placed in an oven at 102<sup>0</sup>C and the contents were dried until a constant weight was reached (1-2 h). The beaker was cooled in a desiccator and weighed along with its contents. The contents left in the beaker after the extraction was estimated as crude fat in the sample and expressed as per cent crude fat in the sample.

$$\text{Crude fat (\%)} = \frac{(W_2 - W_1) \times 100}{S}$$

Where,

Weight of empty flask (g) = W<sub>1</sub>

Weight of flask and extracted fat (g) = W<sub>2</sub>

Weight of sample = S

#### 3.6.1.4 Protein

The protein content of raw sample powder was determined by micro Kjeldahl method as described in AOAC (2000). Accurately weighed 100mg of sample was transferred to a 30 ml kjeldahl digestion tube followed by addition of 1.9 g of K<sub>2</sub>SO<sub>4</sub>, 40 mg of HgO, 5 ml of concentrated H<sub>2</sub>SO<sub>4</sub>. The contents were then digested to a transparent clear fluid. The digested material was transferred to a 100 ml volumetric flask and distilled water was added to make the volume up to the mark. An aliquot (10 ml) of digest was distilled with 50% sodium hydroxide and the liberated ammonia was collected in 10 ml saturated boric acid containing 2-3 drops of mixed indicator (prepared by mixing one part of 0.2% alcoholic methyl red and five parts of 0.2% alcoholic bromocresol green solution).

Approximately 65 to 70 ml of distillate was collected in a 100 ml conical flask. The contents of the flask were titrated against 0.02M HCl. A blank determination using distilled water in place of sample was also carried out. The total nitrogen and percent protein were calculated as follows:

$$\text{Percent Nitrogen} = \frac{14.007(S-B) \times \text{Molarity of HCl} \times \text{dilution factor} \times 100}{\text{mg of sample}}$$

where,

S = ml of HCl required for sample

B = ml of HCl required for blank

M = Normality of HCl used, and

W= Weight of the sample in mg.

Percent Total Protein = Percent total nitrogen x 6.25

#### 3.6.1.5 Starch

The starch in the raw sample and selected powder was determined by using acid hydrolysis method as described in IS: SP (Part III, 1984).

#### 3.6.1.6 Ash

Ash content of raw sample and powder were estimated by using standard method of AOAC (2000). Three gram of sample was weighed and transferred in pre-weighed porcelain crucible. The weighed sample was charred till smoke ceases. The crucible was then transferred to muffle furnace maintained at  $550 \pm 5^{\circ}\text{C}$  and incinerated until light gray ash was obtained. The crucibles were then cooled in desiccator and weighed.

#### 3.6.1.7 Crude fibre

The crude fibre was estimated in defatted raw sample and selected powder by using Fibraplus, Pelican Equipments, India. Accurately weigh 1 g defatted sample in the extraction crucibles. The crucible was inserted in to the hot extraction system and the sample was digested in 1.25% sulphuric acid. The sample was first boiled with acid at  $550^{\circ}\text{C}$  and kept for digestion at  $450^{\circ}\text{C}$  for 45 min. After digestion, the acid was filtered through the crucible and the sample was rinsed with distilled water. The same procedure was repeated for alkali digestion using 1.25% sodium Hydroxide solution. The sample crucibles were kept in the oven maintained at  $102^{\circ}\text{C}$  for 1 hr to remove moisture and kept for ashing in the muffle furnace at  $450^{\circ}\text{C}$  for 4 hr.

$$\text{Crude fibre (\%)} = \frac{(W_1 - W_2) \times 100}{W}$$

Where,

Weight of sample = W g

Residue (crude fibre + mineral matter) =  $W_1$  g

Weight after ashing =  $W_2$  g

### 3.6.2 Physical Analysis

#### 3.6.2.1 Hunter L\*, a\* and b\* values

Hunter L, a, b values of EFY powders were measured by reflectance spectroscopy technique employing reflectance meter, Colorflex® (Hunter lab, Reston, Virginia, USA). Before the test, the instrument was calibrated with standard black glass and white tile as specified by the manufacturer. The light source was dual beam xenon flash lamp. Data are received from the software in terms of L\* (Lightness) ranging from 0 (black) to 100 (white), a\* (Redness) positive 'a' is red and negative 'a' is green, and b\* (Yellowness) positive 'b' is yellow and negative 'b' is blue as per the international colour system. Whiteness index (WI) was calculated according to Sheen (1990) and the calculation equation was as follows:

$$WI = 100 - \sqrt{(100 - L)^2 + a^2 + b^2}$$

Where, L, a, and b were Hunter L\*, a\*, and b\* values.

#### 3.6.2.2 Bulk density (BD), Particle density (PD), and porosity measurements

The volume displacement method described by Hsu *et al.* (2003) was used to determine particle density (PD), bulk density (BD), and porosity of yam powders. A portion of yam powder ( $W_2$ ) was added to a preweighed volumetric cylinder ( $W_1$ ) and the volume was read as  $V_1$ . After the same volume ( $V_1$ ) of displacement fluid (isobutyl alcohol:phthalic acid diethyl ester=1:1) was added to the cylinder, the total volume of the powder plus solvent in the cylinder was taken as  $V_2$ . TD, BD, and porosity were calculated according following equations.

$$\text{Particle density (PD)} = (W_2 - W_1) / (V_2 - V_1)$$

$$\text{Bulk density (BD)} = (W_2 - W_1) / V_1$$

$$\text{Porosity} = 1 - (\text{BD} / \text{TD})$$

### 3.6.3 Functional Analysis

#### 3.6.3.1 Water solubility index (WSI) and water absorption index (WAI)

WSI and WAI were determined according to Anderson *et al.* (1969). Yam powder (2.5 g) and water (30 ml) were vigorously mixed in a 50 ml centrifuge tube, incubated in a 37°C water bath for 30 min, and then

centrifuged (3500 rpm, 15 min). The supernatant was collected in a pre-weighed beaker and the residue was weighed after the water was evaporated below 105<sup>0</sup>C. The percentage of residue with respect to the amount of yam powder used in the test was taken as water solubility index (WSI). The weight ratio of centrifuged precipitate to the amount of yam powder used in the test was taken as the water absorption index (WAI).

#### 3.6.3.2 *Pasting properties of EFY powder*

Pasting properties of EFY powders were measured on a Rapid Visco Analyser (RVA-4), using the RVA General Pasting Method (Newport Scientific Pvt. Ltd., Warriewood, Australia). A sample of 3.5 g of powder (14% moisture basis) was transferred into a canister and approximately 25 ± 0.1 ml distilled water were added (corrected to compensate for 14% moisture basis). The slurry was heated to 50°C and stirred at 960 rpm for 10 sec for thorough dispersion followed by constant stirring at 160 rpm. The slurry was held at 50°C for up to 1 min, and then heated to 95°C in 3 min 42 sec and held at 95°C for 2 min 30 sec, and cooled to 50°C in 3 min 48 sec and holding at 50°C for 2 min. Each analysis took 13 min and triplicate analyses were performed on each sample.

The pasting temperature (the temperature where viscosity first increases by at least 25 cP over a 20s period), peak time (the time at which peak viscosity occurred), peak viscosity (the maximum hot paste viscosity), holding strength or trough viscosity (the trough at the minimum hot paste viscosity), final viscosity (the viscosity at the end of test after cooling to 50°C and holding at this temperature), breakdown (peak viscosity - holding strength or trough viscosity) and setback (final viscosity- holding strength) were calculated from the pasting curve, using Thermocline version 2.2 software Newport Scientific Pty. Ltd. (Warriewood, Australia).

### **3.7 PROXIMATE ANALYSIS OF YAM-MILK MIXTURE**

#### **3.7.1 Total Solids**

The method given in sec. 3.6.1.2 was used taking about 3 g sample and dried in the oven at 100 ± 2°C for 4 h.

### **3.7.2 Fat**

Fat content of EFY-milk mix was determined by the Gerber method described in IS: SP (Part XI, 1981). Ten ml of Gerber sulphuric acid was transferred into the butyrometer and then 10.75 ml of warm sample (27°C) was added against the wall of the body of butyrometer. One ml of amyl alcohol was then added into the butyrometer and the neck of butyrometer was closed firmly with the stopper. The contents were mixed thoroughly by shaking the butyrometer and inverting it few times. The butyrometer was quickly transferred in the water bath at 65±2°C for 5 min and then centrifuged for 4 min. The butyrometer was then again transferred into the water bath at 65±2°C for 3 min and the reading was noted directly from the butyrometer.

### **3.7.3 Protein**

The method as described in sec 3.6.1.4 was used.

### **3.7.4 Lactose content**

The protein content of EFY-milk mix was determined by Lane-Eynon method as described in IS: SP (Part XI, 1981). As per the method Fehling solution was prepared by mixing immediately before use, equal volumes of solutions (A) and (B). Standardization of Fehling solution was done by taking 5 ml of each of the solutions (A) and (B) into a flask of 300 to 400 ml capacity. A standard solution of pure lactose of such concentration that more than 15 ml and less than 50 ml will be required to reduce all the copper was prepared. The whole of the lactose solution required to effect reduction of all the copper was added under boiling condition so that not more than 0.5 to 1.0 ml was required later to complete titration. Without removing flame, add 2 to 5 drops of one percent aqueous methylene blue solution the titration within a total boiling time of about three minutes, by small additions of sugar solution, to the point of decolourization of the indicator. Multiply the titre by the number of milligrams in one millilitre of the standard solution to obtain the factor.

5 ml each of Fehling A and Fehling B solution were taken in 100 ml conical flask and test solution was added under boiling condition. Boil for about 15 seconds and add rapidly further quantities of the solution until only faintest

perceptible blue colour remains. Then 2 to 5 drops of 1% methylene blue was added and the titration was completed by adding the test solution drop wise. Factor was calculated from the table given in manual corresponding to titre and correction was applied.

$$\text{Lactose (\%)} = \frac{\text{Factor}}{\text{Titre}} \times 100$$

### **3.7.5 Ash**

The procedure described in sec. 3.6.1.6 was used taking 5 g of sample.

## **3.8 PHYSICO-CHEMICAL PROPERTIES OF EFY- MILK MIX**

### **3.8.1 pH**

The pH of milk and experimental sample was determined electrometrically with the pH meter by method described in IS: SP (Part XI, 1981). The pH meter was first calibrated using standard buffers of pH 4.0 and 9.2 and standardized using pH buffer of 7.0 at 20±0.1°C.

### **3.8.2 Titrable acidity**

Titrate acidity was determined as per IS: SP (Part XI, 1981)

### **3.8.3 Colour characteristics**

As per procedure given in sec. 3.6.2.2 using Hunter Colour Flex colour meter.

### **3.8.4 Sediment**

Centrifugal method was used to determine the sediment of the prepared mix. 10 ml of mix was taken in 15ml centrifuged tubes having minimum scale up to 0.1 ml. The tubes were centrifuged at 1000 rpm for 5 minutes. The volume of the sediment was directly read and expressed in ml.

### **3.8.5 Apparent Viscosity**

The apparent viscosity of elephant foot yam-milk mix was measured at 20°C using coaxial cylindrical rotational viscometer VISCO STAR plus (FUNGILAB, S. A.) with digital display fitted with spindle TL5 at 100 rpm (corresponding shear rate 132 s<sup>-1</sup>). The samples were tempered at 20°C in a

BOD incubator for 1 hour prior to the viscosity measurement. 8 ml of properly stirred sample was taken as mentioned in the manual of VISCO STAR plus. The temperature of the sample was maintained in the sample tube by a water jacket which was connected to a water bath constantly maintained at 20<sup>0</sup>C

### **3.8.6 Heat stability**

Heat stability of standardized milk and elephant foot yam milk mix was determined according to the method developed by Davies and White (1966). Milk sample (1.5 ml) was taken in a pyrex tube (both ends open) of 10 cm length and 0.8 cm internal diameter. The two ends of the tube were closed with the silicone rubber corks. After shaking gently the tubes were clamped crosswise on an aluminum carriage of 12 tubes capacity. The carriage was tilted so that the sample solution could wet all inside surface of tube. The carriage was placed in a paraffin oil bath previously maintained at 130<sup>0</sup>C and simultaneously a stop watch and rocking at the rate of 8 cycle / min. were started. The tubes were illuminated from above by a lamp to facilitate the observation of milk clotting. As soon as the milk clotted, time was noted in terms of minutes.

### **3.9 Statistical analysis**

The data obtained during the present investigation were suitably analyzed by employing statistical designs viz., two-way ANOVA using the LSD model of SPSS software (ver 13.0). Response surface methodology (RSM) with Design-Expert<sup>®</sup> software version 8.0.1.0 was used to study the effects of yam solids and total milk solids concentrations. Student t-test was used to compare predicted values with observed values.

# *CHAPTER - 4*

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## **Results and Discussion**

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## **4. RESULTS AND DISCUSSIONS**

**4.0** In order to work out the effectiveness of elephant foot yam (EFY) as a thickener in milk, EFY was processed and converted into a powder using tray drying and then the powder was blended with milk having different solids level. The product at various stages was evaluated for sensory and physico-chemical properties. The results obtained in this study are presented in this chapter under the following major heads:

1. Processing of EFY into a powder
2. Compatibility of the EFY powder in milk.
3. Effects of yam solids and milk solids on the properties of yam-milk mix
4. Optimization of yam-milk mix with the desired properties.

### **4.1 PRELIMINARY STUDIES ON ACRIDITY AND OTHER SENSORY ATTRIBUTES OF COOKED YAM**

Acridity i.e. a pricking sensation in the mouth and throat is often associated with consumption of elephant foot yam. Hence, preliminary studies were conducted to examine the possibility of minimizing this problem employing various cooking alternatives for peeled and diced yam. Since acridity is believed to be due to the presence of oxalate crystals in yam, attempts were made to study the effects of cooking time, pH of cooking water and salt pretreatment on the sensory attributes of the cooked yam.

#### **4.1.1 Effect of cooking time**

Yam cubes (2cm) cooked in water (cubes/water ratio, 1:6) in a pressure cooker for 30, 35, 40, 45 or 50 min revealed that there was no definite impact of cooking time on sensory scores (on a 9-point hedonic scale) for colour and appearance (5.5-7.0), body and texture (8.0-8.5), flavour (6.5-7.5) and acridity (5.0-7.5), although with increasing cooking time, the product had a tendency to become slightly darker and softer. The acridity of the product however was perceived to be increasing with increasing cooking time, which may not actually be the case, as it was discovered later, the samples judged in a quick succession appeared to feel progressively more acrid irrespective of the

treatment. One of the reasons for the irregular impact observed above could presumably be the non-homogeneity of the product with respect to the different portions of the yam corm. Hence, it was next attempted to examine the texture of yam corm fractionated into outer layer, middle layer and the core.

**Table 4.1 Effect of pressure cooking (20 min) on textural parameters of different parts of corm (diced sample)**

| TPA parameter    | Portion of the yam corm* |        |        |
|------------------|--------------------------|--------|--------|
|                  | Outer                    | Middle | Core   |
| Hardness (N)     | 11.097                   | 9.199  | 18.392 |
| Adhesiveness (N) | -0.230                   | -0.242 | -0.706 |
| Springiness (mm) | 0.169                    | 0.179  | 0.318  |
| Cohesiveness     | 0.126                    | 0.126  | 0.112  |
| Gumminess (N)    | 1.368                    | 1.171  | 2.092  |
| Chewiness (N.mm) | 0.236                    | 0.214  | 0.785  |
| Resilience       | 0.051                    | 0.047  | 0.714  |

\*Means from duplicate experiments

The texture profile analysis (TPA) of the portioned yam cubes (2 cm) cooked under pressure for 20 min is presented in Table 4.1. It can be seen from the data that the middle portion was (i.e. the layer between the outer hemispherical layer and the central hemispherical core) the softest (9.2 N) whereas the core (portion of corm where the stem of the yam plant is attached) was hardest (18.4 N). The difference between the middle and outer layers was rather small (1.9 N). Among other TPA parameters, stickiness/adhesiveness, springiness, chewiness and resilience were perceivably higher in the core portion of the corm. On account of such heterogeneity in the textural (and presumably, colour and flavour) characteristics of the yam corm, the cooked product was judged/evaluated by mashing the cubes into a paste after cooking.

#### **4.1.2 Effect of cooking of yam in acidulated water**

The solubility of oxalates is known to be better in an acid solution as compared to water. In order to solubilise and possibly leach out the oxalates present in yam and thereby reduced the acidity in it, water acidulated to pH

3.0, 3.5 or 4.0 using citric acid was used as the cooking medium for pressure cooking (30 min). However, it was found that there was no perceivable improvement in sensory colour and appearance score (7.25-7.75), body and texture score (7.50), flavour score (6.75-7.25) or acidity score (4.5-5.0) as compared to control i.e. unacidulated water (scores, 7.5, 7.75, 7.25 and 7.75, respectively). A slightly improved colour (reduced darkening) was noticed in instrumentally measured Colourflex lightness (L\*), redness (a\*) and yellowness (b\*) values particularly in case of pH 3.0 and 3.5 (Table 4.2).

**Table 4.2 Effect of pressure cooking (30 min) of yam cubes in acidified water on the Hunter Lab colour attributes of mash**

| Colour Parameters | pH of cooking water |       |       |       |
|-------------------|---------------------|-------|-------|-------|
|                   | Control             | 3.0   | 3.5   | 4.0   |
| L* - value        | 52.68               | 52.95 | 52.81 | 52.64 |
| a*- value         | 5.10                | 4.93  | 4.96  | 4.95  |
| b*- value         | 29.50               | 29.08 | 29.14 | 29.21 |

\*Means from duplicate experiments

Adjusting the pH of cooking water to pH 3.5 by using lactic acid and tartaric acid instead of citric acid also failed to have any favourable impact on the sensory attributes of cooked-yam paste although lactic acid appeared to yield a slightly better result in terms of flavour scores (7.5 vs. 6.5 for citric or tartaric acid and 7.0 for control). Cooking in this case was carried out in an open pan (atmospheric boiling for 30 min).

#### **4.1.3 Effect of coating of raw yam cubes with salt before cooking**

Salt coating of yam cubes was expected to extract the acrid components. So, yam coated with a thin layer of sodium chloride was held for 60, 120 or 180 min before cooking in excess water (1:6) for 30 min in an open pan. The cooked yam paste was, however, found to be too salty, although it was slightly less acrid (score, 5.0-5.5 vs. 4.0 for control).

With a view to reducing the saltiness of salt treated yam, washing with plain water for 60, 120 or 180 seconds was followed after 60 min holding of salt coated yam cubes and before open pan cooking for 30 min. Although washing reduced the saltiness of the cooked yam paste, the product was perceivable

darker (score, 3.0-6.5) and off flavoured (3.0-6.0) in comparison with control (7.5 and 7.0, respectively). There was no perceivable effect of the salt treatment on acidity. Instrumentally measured colour ( $L^*$  and  $b^*$  values vide Table 4.3) corroborated the sensory observation.

**Table 4.3 Effect of washing of salt treated (60 min) yam cubes on the Hunter Lab colour parameters of the resulting cooked paste\***

| Colour parameter | Washing time |       |       |       |
|------------------|--------------|-------|-------|-------|
|                  | Control      | 1 min | 2 min | 3min  |
| $L^*$ - value    | 55.49        | 49.68 | 42.64 | 41.63 |
| $a^*$ - value    | 4.67         | 4.84  | 5.55  | 6.82  |
| $b^*$ - value    | 26.07        | 25.28 | 23.43 | 23.96 |

\*Open-pan (atmospheric) cooking for 30 min

Reduced contact time of salt coated yam (30, 40 or 50 min) followed by washing appreciably reduced the saltiness and improved flavour score (6.0-6.5) as well as colour and appearance score (7.0-7.8), but these attributes were less desirable compared to the control (7.0 and 8.0, respectively). Again the sensorily perceived darkening of the product due to the salt treatment, though to a lesser extent in this case, was again substantiated by colour meter readings (Table 4.4), the lightness ( $L^*$ ) value appreciably decreasing with increasing contact time, but the redness ( $a^*$ ) and yellowness ( $b^*$ ) parameters showing no definite pattern.

**Table 4.4 Hunter lab colour parameters of cooked-yam paste as influenced by the contact time with salt**

| Colour parameter | Contact time |        |       |        |
|------------------|--------------|--------|-------|--------|
|                  | Control      | 30 min | 40min | 50 min |
| $L^*$ - value    | 58.89        | 53.88  | 52.00 | 47.26  |
| $a^*$ - value    | 4.73         | 4.60   | 4.45  | 5.19   |
| $b^*$ - value    | 27.04        | 27.92  | 26.54 | 25.13  |

The acidity of cooked yam paste perceptibly reduced as a result of salt pretreatment whether the contact time was 1-3 hours without washing (score, 5.0-5.5 vs. 4.0 for control), or with washing (4.0-5.5), or it was reduced to 30-50

min (with washing) (score, 5.0-6.0). Body and texture score of the cooked yam paste remained unaffected by the salt treatment. However, since the flavour and appearance of the product were adversely affected, the salt treatment was not considered desirable.

#### 4.1.4 Open pan (atmospheric) cooking vs. Pressure cooking of yam with respect to product properties

Cooking of diced raw yam in an open pan boiling in excess water for 30 or 60 min was compared with pressure cooking for 15 or 30 min. It was observed that the former resulted in a slightly better colour and appearance (score, 7.0-7.5 as against 6.0-7.2 for the later), flavour (7.0 vs. 6.0-6.5) and body and texture (7.5-7.7 vs. 7.2). The improved flavour presumably ascribed more effective 'boiling off' of the volatiles responsible for off flavour in the product. Therefore, cooking in boiling water was preferred.

**Table 4.5 Effect of open-pan cooking time on TPA parameters of yam cubes**

| TPA parameter      | Cooking time (min)* |        |        |        |
|--------------------|---------------------|--------|--------|--------|
|                    | 30                  | 40     | 50     | 60     |
| Hardness (N)       | 38.575              | 32.918 | 28.034 | 29.391 |
| Fracturability (N) | 15.525              | 15.302 | 12.537 | 12.059 |
| Adhesiveness (N)   | -0.091              | -0.533 | -0.171 | -0.245 |
| Springiness (mm)   | 0.784               | 0.695  | 0.702  | 0.657  |
| Cohesiveness       | 0.106               | 0.098  | 0.096  | 0.099  |
| Gumminess (N)      | 4.158               | 3.264  | 2.757  | 3.023  |
| Chewiness (N.mm)   | 3.479               | 2.390  | 2.005  | 2.156  |
| Resilience         | 4.586               | 4.224  | 3.736  | 3.972  |

\*Means from duplicate experiments

While open pan cooking for 30 min was generally found to be effective in giving a fairly acceptable EFY for further use, the effect of cooking time 30-60 min was studied with regard to the TPA and colour flex lab parameters. The data presented in Table 4.5 show that with increasing cooking time the cube hardness declined, the decline being prominent for cooking time up to 50 min (from 38.6 down to 28.0 N). TPA fracturability decreased a little less (from 15.5 to 12.1 N). Other TPA parameters exhibited little or no perceivable impact of the

cooking time. Further, Table 4.6 showed that increasing cooking time (from 30 to 60 min) tendend to darkened the product as evidenced by correspondingly decreasing L\* value (from 57.6-54.9) and increasing a\* and b\* values (from 4.3-5.2 and 27.7-29.4, respectively).

**Table 4.6 Effect of open-pan cooking time on Hunter lab colour parameters of yam paste**

| Hunter Lab colour parameter | Atmospheric cooking time (min) |       |       |       |
|-----------------------------|--------------------------------|-------|-------|-------|
|                             | 30                             | 40    | 50    | 60    |
| L* - value                  | 57.61                          | 56.30 | 55.72 | 54.94 |
| a* - value                  | 4.30                           | 4.84  | 5.15  | 5.24  |
| b* - value                  | 27.66                          | 28.71 | 29.07 | 29.36 |

It thus appeared that pretreatment of raw yam with salt or cooking in acidulated water was not effective in perceivably improving the sensory attributes of the resulting product. Cooking of diced yam in an open pan cooking (in excess boiling water under atmospheric condition) for 30 min was preferable to pressure cooking.

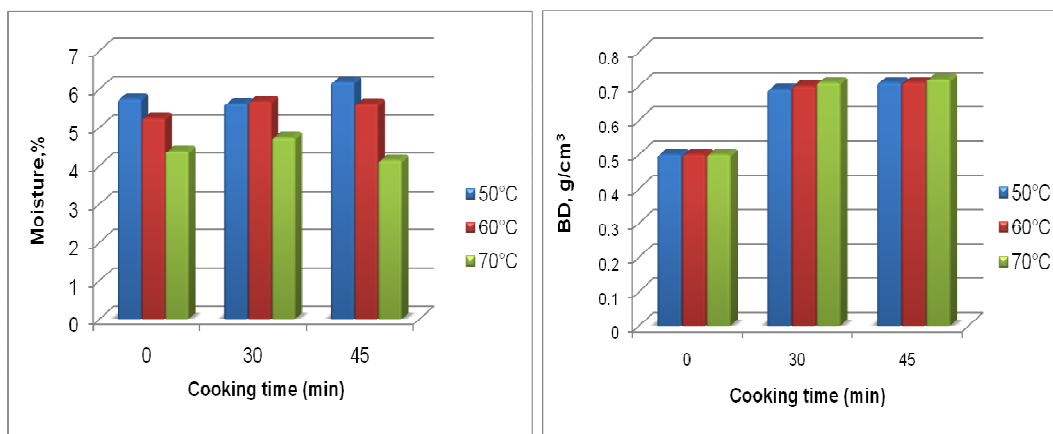
Since peeled fruits and vegetables retain their colour better when dipped in 0.1% potassium metabisulphite, this step was included as a pretreatment of peeled and diced yam prior to cooking.

#### **4.2 EFFECT OF SELECTED COOKING CONDITIONS AND DRYING TEMPERATURE ON THE PROPERTIES OF YAM POWDER**

Yam powder was prepared as shown in Fig 3.1. The effects of various process parameters viz., (a) duration of cooking (0, 30 and 45 min) and (b) drying temperature (50°C, 60°C and 70°C) on the physical and functional properties of the powder were evaluated.

##### **4.2.1 Effect on moisture content**

The effect of cooking time and drying temperature on the moisture content of yam powder is shown in Fig. 4.1. Significant variation ( $p < 0.01$ ) in the moisture content with respect to the drying temperature was observed but the effect of cooking time was not significant (Table 4.7). The moisture content decreased with increasing drying temperature.



**Fig 4.1 Effect of cooking time and drying temperature on moisture and bulk density (BD) of yam powder**

The minimum and maximum moisture contents were recorded as 4.14% and 6.18% in the powders obtained from yam cooked for 45 min and dried at 50°C and 70°C, respectively. The difference in the moisture content could be due to the difference in the drying time.

#### 4.2.2 Effect on bulk density (BD), particle density (PD) and porosity

It was observed (Table 4.7) that the BD, PD and porosity differed significantly different ( $p < 0.01$ ) with the cooking time. BD was significantly different ( $p < 0.05$ ) for different drying temperatures (Fig. 4.1). The BD was found to increase with cooking time from 0.49 to 0.71g/cm<sup>3</sup> and also increase with drying temperature.

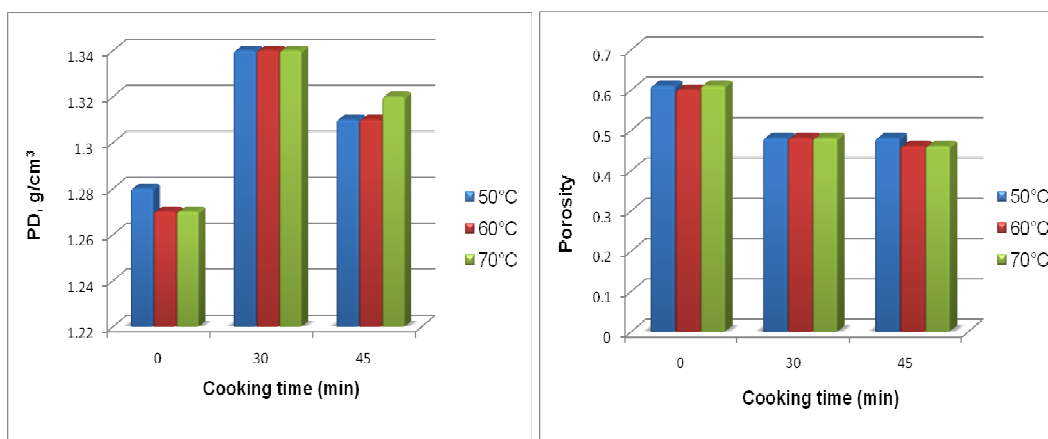
**Table 4.7 ANOVA (F-ratio) for physical and functional properties of Yam powder**

| Attribute | Cooking time           | Drying temperature   | Cooking time × Drying temperature |
|-----------|------------------------|----------------------|-----------------------------------|
| Moisture  | 1.473 <sup>ns</sup>    | 59.995 <sup>**</sup> | 3.394 <sup>ns</sup>               |
| BD        | 3035.400 <sup>**</sup> | 7.800 <sup>*</sup>   | 3.000 <sup>ns</sup>               |
| PD        | 16.987 <sup>**</sup>   | 0.250 <sup>ns</sup>  | 0.289 <sup>ns</sup>               |
| Porosity  | 1314.200 <sup>**</sup> | 1.400 <sup>ns</sup>  | 0.800 <sup>ns</sup>               |

<sup>\*\*</sup>significant at 1% ( $p < 0.01$ ); <sup>\*</sup>significant at 5% ( $p < 0.05$ ); ns-not significant

The BD of raw powders was significantly different ( $p < 0.01$ ) from that of the cooked powders. This was to be expected as cooked powder has a very dense structure resulting from partial or complete gelatinization of the starch granules. The observed effect of cooking time on the bulk density of yam powder

corroborates the results of Tagodoe and Nip (1994) and Njintang and Mbofung. (2006) who reported, respectively, 59% and 29% increase in bulk density of taro flour (0-90min cooking). Bencini (1986) observed an increase in bulk density of chickpea following cooking.



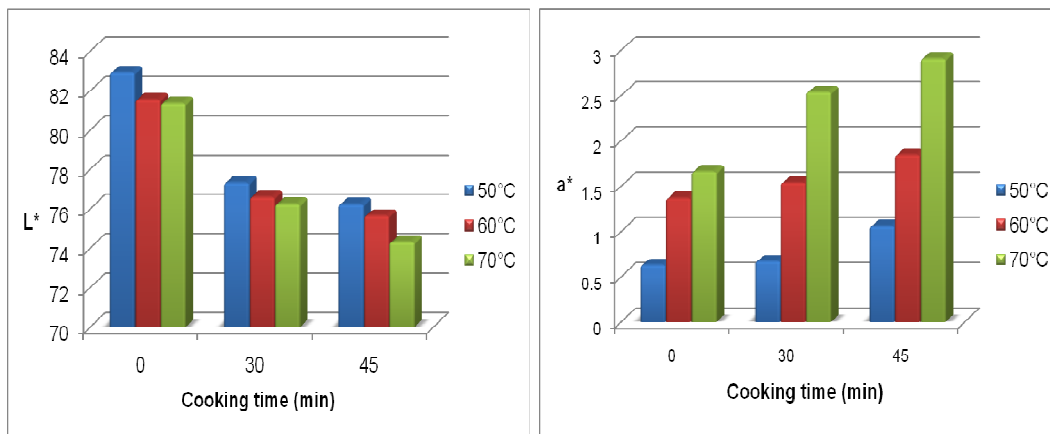
**Fig 4.2 Effect of cooking time and drying temperature on particle density (PD) and porosity of yam powder.**

Bulk density was also observed to increase with the drying temperature but the effect was significant for 30 min cooking only. Similar observations were made in taro slices dried in a convection oven (Njintang & Mbofung, 2006). The particle density of yam flour was also influenced but to a smaller extent (1.26 - 1.34 (g/cm<sup>3</sup>). Raw powders were found to contain less particle density compared to cooked powders (Fig.4.2). Porosity was consistent with the results on bulk density. Raw powders had higher porosity and correspondingly lower bulk density as compared to cooked powders. A similar pattern was observed in the flour of the *Dioscorea* sp. (Hsu *et al.*, 2003).

#### 4.2.3 Effect on colour parameters

The product darkening was primarily non enzymatic browning as indicated by decreasing values of lightness (L\*) and increasing values of the redness (a\*) and, to some extent yellowness (b\*). As shown in Table 4.8, the effect of cooking time and drying temperature on the Hunter Lab lightness (L\*) and redness (b\*) was significant ( $p < 0.01$ ). However, the effect of drying temperature on the whiteness index (WI) was not significant. From the Fig. 4.3, it can be observed that as the cooking time increased (0, 30 and 45 min) the

product increasingly darkened as indicated by L\* value going from 82.92, 81.53 and 81.35 to 76.23, 75.64 and 74.3 at 50°C, 60°C and 70°C, respectively but only a small impact of cooking time was observed beyond 30 min.



**Fig 4.3 Effect of cooking time and drying temperature on lightness (Hunter Lab L\*), redness (Hunter Lab a\*) values of yam powder**

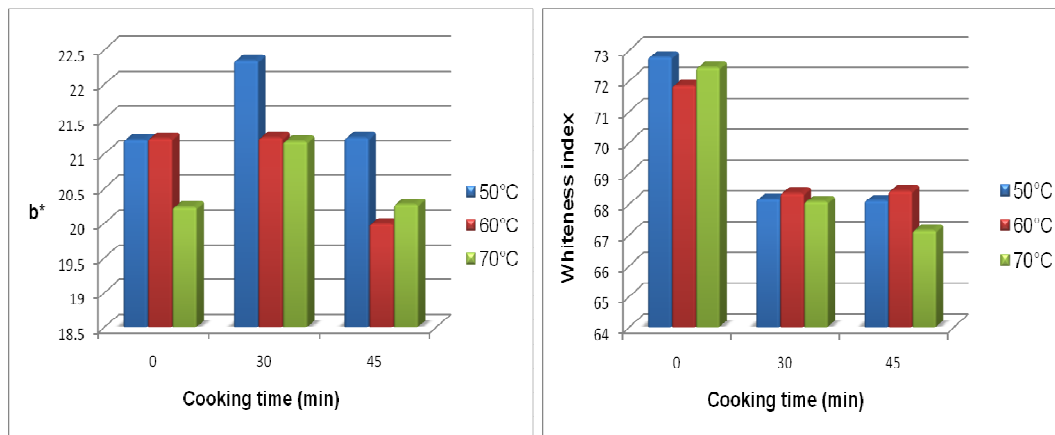
Redness was more pronounced for 30 min and 45 min of cooking as indicated by higher b\* values. Redness increased at all temperatures and cooking conditions studied and the effect was found to be significant ( $p < 0.01$ ). The maximum redness (2.91) of yam powder was for 45 min cooking time and 70°C drying temperature. The raw yam powder obtained at 50°C had minimum

**Table 4.8 ANOVA (F-ratio) for Hunter lab colour parameters of Yam powder**

| Particulars     | Cooking time | Drying temperature  | Cooking time × Drying temperature |
|-----------------|--------------|---------------------|-----------------------------------|
| L*              | 618.328**    | 27.694**            | 2.378 <sup>ns</sup>               |
| a*              | 144.687**    | 717.007**           | 24.814**                          |
| b*              | 8.426**      | 8.020*              | 1.446 <sup>ns</sup>               |
| Whiteness Index | 338.503**    | 2.377 <sup>ns</sup> | 5.160*                            |

\*\*significant at 1% ( $p < 0.01$ ); \*significant at 5% ( $p < 0.05$ ); ns - not significant

redness value of 0.63. It can be seen from Fig. 4.4, that the degree of yellowness (b\*) increased upon cooking for 30 min but decreased upon 45 min cooking at all drying temperatures. No definite pattern was observed in the yellowness of the powders dried at different temperatures.



**Fig 4.4 Effect of cooking time and drying temperature on yellowness (Hunter Lab b\*) and whiteness index (WI) values of yam powder**

Whiteness index (WI) represents the overall whiteness of food products that may indicate the extent of discoloration during the drying process. The WI decreased upon cooking of the product and the effect was pronounced when cooking time increased from 0 to 30 min but no significant difference was observed between 30 and 45 min cooking. Although the WI decreased with increasing drying temperature, the effect was not significant. Increase in browning index of cooked frozen EFY cubes dried at higher temperatures was observed by Sajeev *et al.* (2010). Similar results were obtained in case of taro by Ninjtang and Mbofung (2003).

#### **4.2.4 Effect on functional properties of the yam powder**

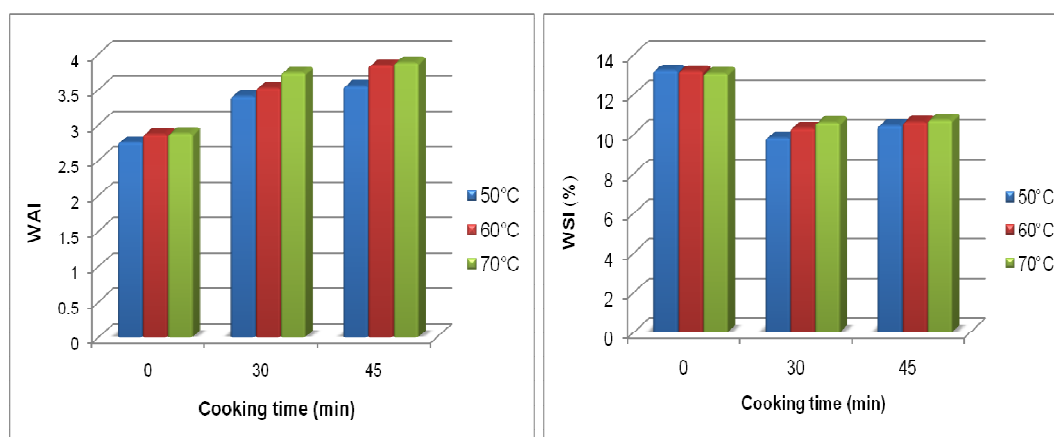
An important functional characteristic of any flour is its water absorption index (WAI). WAI indicates the extent of starch gelatinization. WAI of yam powder was significantly affected ( $p < 0.01$ ) by the cooking time and drying temperature (Table 4.9). With increasing cooking time and drying temperature, increased WAI was observed. Similar observations have been reported for taro flour (Tagodoe & Nip, 1994; Njintang & Mbofung, 2006), winged bean flour (Narayana & Narasinga Rao, 1982) and chickpea flour (Bencini, 1986). Starch granules when heated in water undergo gelatinization accompanied with a disruption of molecular order, which leads to losses of crystallinity and an increase in the ability to bind water (Bemiller & Whistler, 1997).

**Table 4.9 ANOVA (F-ratio) for functional properties of Yam powder**

| Property | Cooking time | Drying temperature  | Cooking time× Drying temperature |
|----------|--------------|---------------------|----------------------------------|
| WAI      | 182.544**    | 9.001**             | 3.180 <sup>ns</sup>              |
| WSI      | 383.230**    | 3.168 <sup>ns</sup> | 2.791 <sup>ns</sup>              |

\*\*significant at 1% (p<0.01); \*significant at 5% (p<0.05); ns-not significant

It was observed that the effect of cooking time on the WAI of cooked-yam powder was different from that of uncooked-yam flour. In this respect no significant effect of drying temperature was observed on the WAI of uncooked yam flour while a significant difference was observed between drying temperature for cooked (45min) yam powder. A similar finding showed that drying temperature had no significant effect on WAI of unprocessed common beans (*Phaseolus vulgaris*), but the effect was significant on the germinated-bean flour (Njintang *et al.*, 2001).



**Fig 4.5 Effect of cooking time and drying temperature on ‘water absorption index’ (WAI) and ‘water solubility index’ (WSI) of yam powder**

The water-solubility index (WSI) reflects the extent of starch degradation (Diosady *et al.*, 1985). In general, the water solubility index of the flours decreased with increase in precooking time. From Fig. 4.5 it is evident that WSI decreased with increasing cooking time, but the increase between 30 min and 45min cooking was not significant. Similar effects of cooking time on WSI have been reported for taro flour (Njintang & Mbofung, 2006), extruded cowpea. With increase in the drying temperature the WSI was increased but the affect was not significant (Table 4.9). Some studies have shown that

increasing extrusion temperature of high starch cereals increased the water solubility index (Mercier & Feillet, 1975; Kirby *et al.*, 1988). On the contrary, fall of WSI at higher drying temperatures have been reported earlier for common bean (Njintang *et al.*, 2001) flour within the temperature range of 60 - 80°C.

#### 4.2.5 Effect on pasting properties

The pasting properties of yam powders were tested using Rapid Visco Analyser (RVA). The shape of the pasting curve differed depending on treatment of the yam. Significant differences were observed, among the powders tested, in their behaviour during heating and cooling in excess of water (Table 4.10).

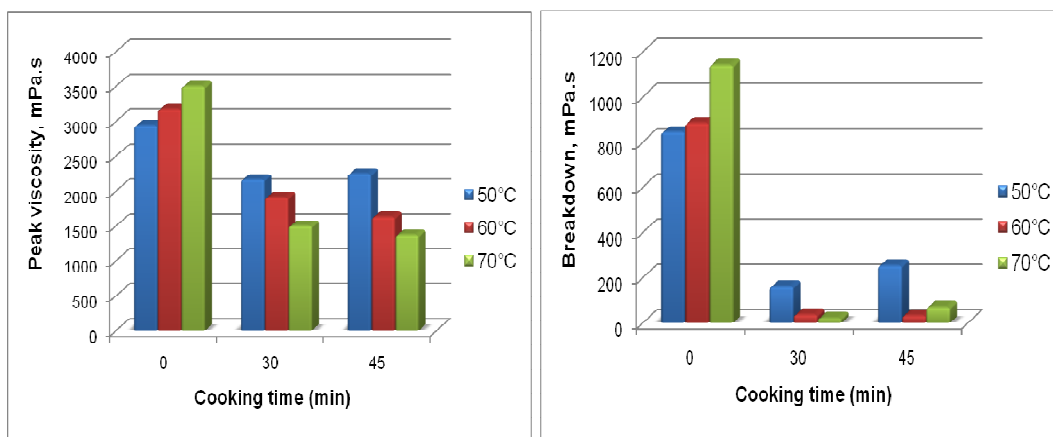
**Table 4.10 ANOVA (F-ratio) for RVA parameters of Yam powder**

| Attribute        | Cooking time        | Drying temperature | Cooking time× Drying temperature |
|------------------|---------------------|--------------------|----------------------------------|
| Peak 1           | 3519.280**          | 151.997**          | 278.876**                        |
| Trough 1         | 493.996**           | 103.835**          | 115.829**                        |
| Breakdown        | 2390.523**          | 28.349**           | 51.673**                         |
| Final Viscosity  | 115.761**           | 48.890**           | 58.442**                         |
| Setback          | 2.386 <sup>ns</sup> | 7.907*             | 10.900**                         |
| Peak Time (min.) | 49.924**            | 16.895**           | 9.315**                          |
| Pasting Temp.    | 5645.905**          | 131.029**          | 10.267**                         |

\*\* significant at 1% (p<0.01); \*significant at 5% (p<0.05); ns-not significant

Peak viscosity indicates the water-binding capacity of the starch or mixture. It is often correlated with final product quality with respect to thickening ability. As the temperature is increased, the starch granules swell and increase the viscosity of the paste until the peak is reached (Adeyemi and Beckley, 1986). From Fig.4.6 it can be observed that with increasing cooking time(0, 30 and 45 min) the peak viscosity of the powders decreased (2942.5mPa.s to 2253.5mPa.s, 3171.5mPa.s to 1633mPa.s and 3502.5mPa.s to 1372mPa.s at 50°C, 60°C and 70°C drying temperatures, respectively) but after 30 min cooking the reduction was not significant. Pre-gelatinization during cooking causing extensive breakdown of starch granules during the RVA run would presumably result in lower viscosities. The interaction of other components and the degree of starch damage during processing could affect the peak viscosity

of powders. In raw powders the peak viscosity increased (2942.5 mPa.s-3502.5 mPa.s) with increasing drying temperature, but in cooked powders the reverse was observed. Higher temperatures had a greater effect on the peak viscosity. The highest peak viscosity (3502.5 mPa.s) was for raw powder dried at 70°C and the lowest (1372 mPa.s) for powder obtained from 45min cooking and at 70°C drying. More starch granules with a high swelling capacity result in a higher peak viscosity.

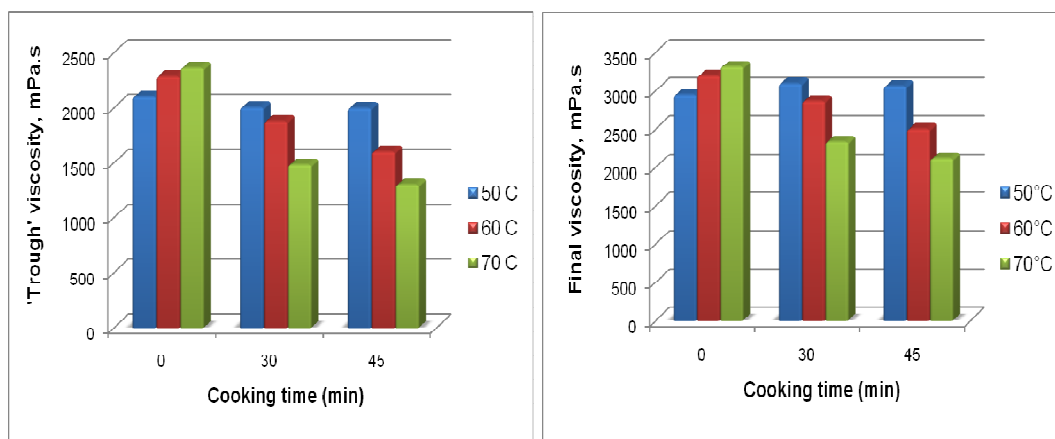


**Fig 4.6 Effect of cooking time and drying temperature on RVA ‘peak viscosity’ and ‘breakdown’ of yam powder**

During the holding period of the viscosity test, the material slurries are subjected to high temperature and mechanical shear stress which further disrupt starch granules in the grains, resulting in amylose leaching out of granules. This period is commonly associated with a decrease in viscosity. It can be seen from Fig.4.6, the raw powders dried at 50°C, 60°C and 70°C had higher breakdown viscosities (845 mPa.s, 886 mPa.s and 1141.5 mPa.s, respectively) as compared to cooked powders (162 mPa.s, 38 mPa.s and 21.5 mPa.s for 30 min cooking and 255 mPa.s, 34 mPa.s and 70 mPa.s at drying temperatures 50°C, 60°C and 70°C). High values of breakdown are associated with high peak viscosities, which in turn, are related to the degree of swelling of the starch granules during heating (Ragae *et al.*, 2006). The ability of starches to withstand heating at high temperature and shear stress is an important factor in many processes. Higher breakdown viscosity indicates that the sample had undergone a higher degree of swelling and subsequent disintegration (Abera & Rakshit, 2003). The cooked powders had lower breakdown viscosities specially

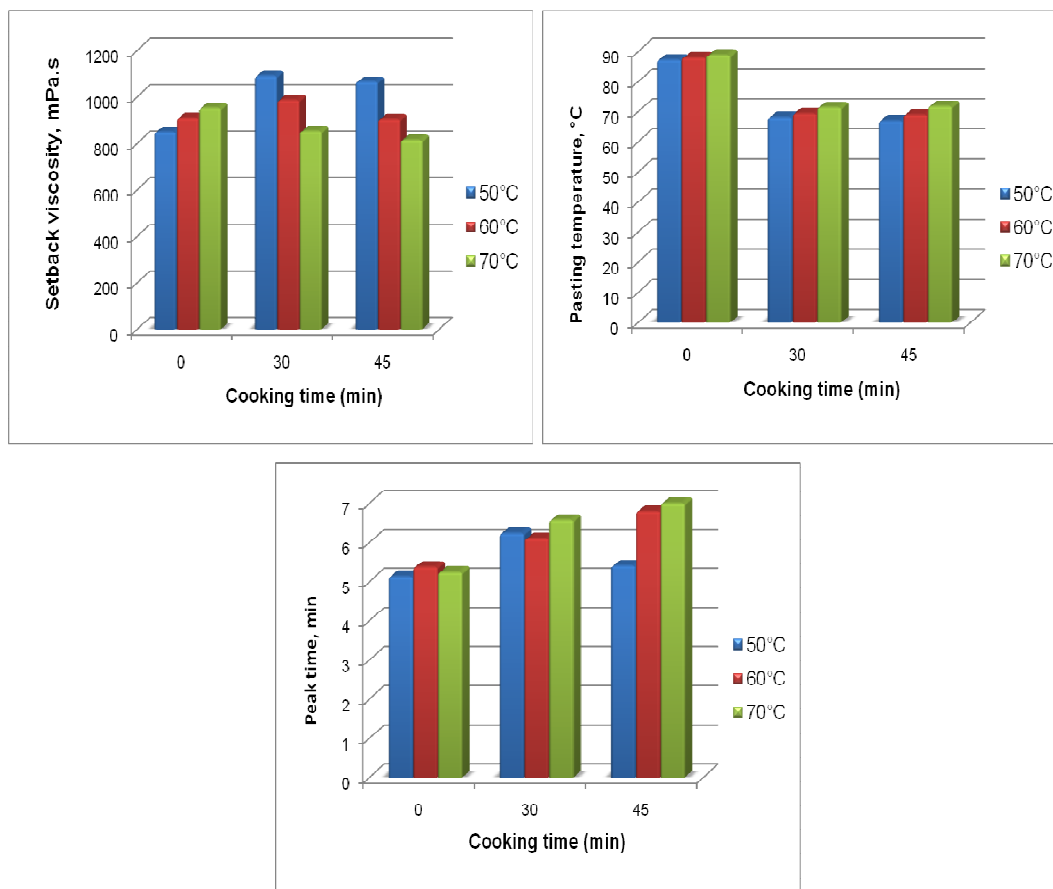
dried at 60°C and 70°C. The lower breakdown viscosities indicate the stability of the paste/gel.

Trough is the viscosity at the end of the holding period at 95°C. Data presented in Fig.4.7 show that with increasing drying temperature the trough was significantly reduced ( $p < 0.01$ ) except in raw powders, where it was increased significantly. The values were appreciably lower for cooked-yam powders. It thus followed a pattern similar to that observed in peak viscosity. The trough viscosity values for raw powders were 2097 mPa.s, 2285.5 mPa.s and 2361 mPa.s, for cooked powder (30min), 2005 mPa.s, 1874mPa.s and 1480 mPa.s and for long-cooked powder (45min) (1998mPa.s, 1599mPa.s and 1302mPa.s) at drying temperatures 50°C, 60°C and 70°C respectively.



**Fig 4.7 Effect of cooking time and drying temperature on RVA 'trough' and 'final viscosity' of yam powder**

Final viscosity is the most commonly used parameter to determine a particular flour/starch quality as it indicates the ability of the material to form a gel after cooking. Final viscosity increased upon cooling which may be due to the aggregation of the amylose molecules. The final viscosity of starch gels is affected by starch retrogradation. From Fig.4.7, it can be seen that the final viscosity of powders followed a similar pattern as that of peak viscosity. It decreased significantly ( $p < 0.01$ ) with an increase in cooking time and drying temperature for cooked powders, whereas for raw powder, it increased with increasing drying temperature. The final viscosity increased from 2945.5 to 3064 mPa.s at 50°C, decreased from 3194 to 2502.5 mPa.s at 60°C and 3313 to 2117 mPa.s at 70°C for cooking time 0, 30 and 45 min cooking respectively.



**Fig 4.8 Effect of cooking time and drying temperature on RVA 'setback', 'pasting temperature' and 'peak time' of yam powder**

During cooling, re-association between starch molecules, especially amylose, will result in the formation of a gel structure and, therefore, viscosity will increase to a final viscosity towards the end of the test run. This phase is commonly described as the setback region and is related to retrogradation and reordering of starch molecules. Fig.4.8 shows that the setback was not significantly influenced by the cooking time. However, it increased with increasing drying temperature in raw-yam powder but decreased in cooked yam powders, the interaction between cooking time and drying temperature being significant ( $p < 0.01$ ). The set back values were increased from 848-1065 mPa.s at 50°C, decreased from 908-903 mPa.s at 60°C and 952-815 mPa.s at 70°C with increasing cooking time 0, 30 and 45min respectively. Low setback value (815 mPa.s) was observed in powder made from 45min cooking time and 70°C drying temperature. The low setback values indicate low rate of starch retrogradation and syneresis.

Pasting temperature of the powders decreased significantly when yam was cooked. The pasting temperatures were much higher 87.25°C, 87.79°C and 88.87°C for raw powders as compared to 68.12°C, 69.40°C and 71.4°C for 30min cooked-yam powder and 67.05°C, 69.0°C 71.82°C for 45min cooked-yam powder obtained at drying temperatures 50°C, 60°C and 70°C, respectively. Cooking of the yam led to per-gelatinization which might have reduced pasting temperature.

Peak time of the powders was significantly affected by the cooking time and drying temperature (Table 4.10). From the Fig.4.8, it can be seen that with increased cooking time the peak time was increased and the drying temperature had little effect on the peak time except for raw powder dried at 50°C. Because of some extent of gelatinization during cooking could cause the higher peak time for cooked powders.

#### **4.3 ASSESSMENT OF YAM POWDER FOR ITS COMPATIBILITY IN MILK**

In order to assess the compatibility of yam powders obtained under different conditions, each powder was added to milk @ 2.5% and heated to 75°C for 5 min and cooled to 5°C. The yam-milk mix samples were analyzed for physical (Hunter colour parameters) and sensory attributes (flavour and mouthfeel) on a 10 cm linear scale (0-100) (*Appendix*).

##### **4.3.1 Effect on colour**

As shown in Table 4.11, Hunter lab L\*, a\*, b\* values as well as of the yam-milk mix were significantly ( $p < 0.01$ ) affected with cooking time and drying temperature of yam, the interaction between the factors being significant for L\*, a\* ( $p < 0.01$ ) and b\* ( $p < 0.05$ ). The effect of drying temperature was significant only at 45 min cooking time (Table 4.12). The Hunter lab L\* values were reduced up to 30 min cooking time and further the effect was not significant. Higher lightness values were observed in mix added with raw powder. Among the mixes added with cooked powders higher lightness values viz. 79.73 and 79.90 were observed for 30 min cooking/60°C drying and 45 min cooking/ 50°C drying, respectively.

The redness (Hunter a\*) value of the yam-milk mix was drastically increased with increasing cooking time but the effect was not significant at 50°C, and increased with increasing the drying temperature in mixes added

with cooked yam powder. But the effect was not significant for mixes added with raw flour. The yellowness (Hunter b\*) value of the mixes added with cooked powders decreased with increased drying temperature of yam. The raw powders had lower yellowness values compared to the cooked powders.

The whiteness index (WI) of the mixes decreased significantly ( $p < 0.01$ ) with cooking time but the drying temperature had no perceivable impact. The impact of cooking time after 30 min on WI was not significant. Higher WI (76.21, 75.32 and 76.26) were observed for mixes added with raw powder dried at 50°C, 60°C and 70°C respectively.

**Table 4.11 ANOVA (F-ratio) for the physical and sensory attributes of Yam-milk mix**

| Colour parameters  | Cooking time        | Drying temperature  | Cooking time × Drying temperature |
|--------------------|---------------------|---------------------|-----------------------------------|
| L* - value         | 115.266**           | 25.975**            | 14.204**                          |
| a* - value         | 329.069**           | 382.604**           | 25.244**                          |
| b* - value         | 10.083**            | 9.137**             | 4.761*                            |
| Whiteness index    | 55.829**            | 2.626 <sup>ns</sup> | 1.784 <sup>ns</sup>               |
| Apparent Viscosity | 307.395**           | 11.236**            | 3.717*                            |
| Flavour            | 2.029 <sup>ns</sup> | 4.481*              | 3.283 <sup>ns</sup>               |
| Mouthfeel          | 0.370 <sup>ns</sup> | 3.637 <sup>ns</sup> | 2.086 <sup>ns</sup>               |

\*\* significant at 1% level ( $p < 0.01$ ); \*significant at 5% ( $p < 0.05$ ); ns-not significant

#### 4.3.2 Effect on apparent viscosity

The apparent viscosity of the yam-milk mix varied significantly with the yam-cooking time and drying temperature used in powder preparation. As the milk was heated 75°C which is lower than the pasting temperature of the raw powders, the apparent viscosity of the mixes added with raw powders was minimum. The apparent viscosity of the mixes added with cooked powders was corroborated with the RVA peak and final viscosities of the powders. High apparent viscosities (7.0, 6.65 and 6.35 mPa.s) was observed for mixes added with powders made from 30 min-cooked yam and dried at 50°C, 60°C and 70°C respectively.

**Table 4.12 Effect of yam powders made by using different cooking times and drying temperatures on the physical and sensory attributes of Yam-milk mix**

| Parameter   | Cooking Time (min) | Drying temperature#        |                            |                            |
|---|--------------------|----------------------------|----------------------------|----------------------------|
|   |                    | 50 <sup>0</sup> C          | 60 <sup>0</sup> C          | 70 <sup>0</sup> C          |
| L*  | 0                  | 81.96 <sup>aY</sup> ±0.19  | 80.44 <sup>aY</sup> ±0.53  | 81.50 <sup>aZ</sup> ±0.17  |
|   | 30                 | 79.46 <sup>aX</sup> ±0.21  | 79.73 <sup>aX</sup> ±0.08  | 79.08 <sup>aY</sup> ±0.01  |
|   | 45                 | 79.90 <sup>bX</sup> ±0.82  | 76.17 <sup>aX</sup> ±0.51  | 76.22 <sup>aX</sup> ±0.64  |
| a*  | 0                  | -5.30 <sup>aX</sup> ±0.07  | -4.93 <sup>aX</sup> ±0.09  | -3.18 <sup>bX</sup> ±0.12  |
|   | 30                 | -4.00 <sup>aY</sup> ±0.19  | -3.64 <sup>aY</sup> ±0.18  | -1.88 <sup>bY</sup> ±0.16  |
|   | 45                 | -4.00 <sup>aY</sup> ±0.22  | -1.69 <sup>bZ</sup> ±0.23  | -0.58 <sup>cZ</sup> ±0.09  |
| b*  | 0                  | 14.58 <sup>aX</sup> ±0.31  | 14.22 <sup>aX</sup> ±0.16  | 14.53 <sup>aX</sup> ±0.06  |
|   | 30                 | 16.15 <sup>aXY</sup> ±0.99 | 16.12 <sup>aX</sup> ±0.64  | 15.23 <sup>aX</sup> ±0.13  |
|   | 45                 | 16.73 <sup>bY</sup> ±0.88  | 14.36 <sup>aX</sup> ±0.48  | 13.78 <sup>aX</sup> ±0.35  |
| Whiteness index   | 0                  | 76.21 <sup>aY</sup> ±0.36  | 75.32 <sup>aY</sup> ±0.31  | 76.26 <sup>aY</sup> ±0.11  |
|   | 30                 | 73.56 <sup>aX</sup> ±0.74  | 73.84 <sup>aXY</sup> ±0.35 | 74.05 <sup>aX</sup> ±0.07  |
|   | 45                 | 73.54 <sup>aX</sup> ±1.21  | 72.12 <sup>aX</sup> ±0.21  | 72.51 <sup>aX</sup> ±0.38  |
| Apparent viscosity (mPa.s) (shear rate, 132 s <sup>-1</sup> ) | 0                  | 2.90 <sup>aX</sup> ±0.28   | 2.85 <sup>aX</sup> ±0.35   | 2.80 <sup>aX</sup> ±0.28   |
|   | 30                 | 7.00 <sup>aY</sup> ±0.28   | 6.65 <sup>aY</sup> ±0.21   | 6.35 <sup>aY</sup> ±0.21   |
|   | 45                 | 7.25 <sup>bY</sup> ±0.35   | 6.15 <sup>abY</sup> ±0.35  | 5.60 <sup>aY</sup> ±0.28   |
| Flavour   | 0                  | 69.00 <sup>aX</sup> ±8.49  | 70.00 <sup>aX</sup> ±1.41  | 71.00 <sup>aX</sup> ±0.00  |
|   | 30                 | 40.00 <sup>aX</sup> ±7.07  | 79.00 <sup>bX</sup> ±7.07  | 68.50 <sup>abX</sup> ±9.19 |
|   | 45                 | 72.50 <sup>aX</sup> ±9.9   | 79.50 <sup>aX</sup> ±7.78  | 66.00 <sup>aX</sup> ±2.83  |
| Mouthfeel   | 0                  | 71.50 <sup>aX</sup> ±0.70  | 70.00 <sup>aX</sup> ±8.49  | 66.5 <sup>aX</sup> ±0.71   |
|   | 30                 | 67.50 <sup>aX</sup> ±7.78  | 75.50 <sup>aX</sup> ±3.54  | 71.00 <sup>aX</sup> ±1.41  |
|   | 45                 | 78.00 <sup>aX</sup> ±2.82  | 77.50 <sup>aX</sup> ±3.54  | 60.50 <sup>aX</sup> ±4.95  |

# Means ±SD (n=2).

Means with same superscripts do not differ significantly (p>0.05); a,b,c refer to rows and X,Y,Z to columns.

### 4.3.2 Effect on sensory attributes

#### 4.3.2.1 Flavour score

The prepared yam-milk mixes prepared from yam powder obtained under different processing conditions was assessed using a 100- point linear scale (0- 'most bland' and 100- 'intense (off) flavour') for flavour. The scores

recorded were significantly different ( $p < 0.05$ ) among the mixes added with powders dried at different temperatures. But the effect of cooking time for yam had no significant effect on the mixes (Table 4.11). With increasing the yam-drying temperature the mix flavour scores tended to decrease. Maximum flavour scores (79.0 and 79.5) were registered for mixes added with powders obtained from respectively 30 and 45min cooked-yam by drying at 60°C (Table 4.12).

#### 4.3.2.2 Mouthfeel score

It can be seen from Table 4.11, that there was no significant effect of cooking time or the drying temperature on the mouthfeel of yam-milk mix. Relatively high mouthfeel scores were recorded for mix from yam cooked for 30 min and dried at 60°C (75.5) and that from 45-min cooked yam dried at 50°C (78.0) and 60°C (77.5).

Based on the sensory and mouthfeel scores of the mix, yam powder prepared by 30-min cooking and 60°C drying was found best suited to add in milk to prepare a yam-milk mix with good sensory attributes. Further, the selected powder (vide sec. 4.2.4) had third most RVA peak and final viscosity among the cooked powders, the major properties which determines the thickening in milk. Also, the powder had the low breakdown viscosity which indicates stability of the mix under refrigeration conditions. Therefore, further experiments were carried out using yam powder obtained by 30-min cooking and tray drying at 60°C. The proximate composition of the selected yam powder in comparison with raw yam is presented in Table 4.13.

**Table 4.13 Proximate composition\* of the raw yam and the cooked yam powder (30-min cooking and 60°C drying)**

| Constituent (%) | Raw yam    | Cooked yam powder |
|-----------------|------------|-------------------|
| Moisture        | 78.28±0.09 | 5.30±0.01         |
| Protein         | 1.45±0.06  | 6.81±0.06         |
| Fat             | 0.06±0.01  | 0.34±0.01         |
| Starch          | 17.56±0.03 | 78.12±0.10        |
| Fibre           | 1.20±0.01  | 5.86±0.03         |
| Ash             | 1.33±0.01  | 3.40±0.01         |

\*mean±SE, (n=3)

#### 4.4 EFFECTS OF YAM SOLIDS LEVEL AND TOTAL MILK SOLIDS ON THICKENING AND OTHER PROPERTIES OF YAM-MILK MIX

Using the selected yam powder i.e. one obtained from 30-min cooked yam dried at 60°C in a tray dryer, the properties of the yam-powder milk mixtures as influenced by the levels of yam solids and milk solids were studied in an RSM (response surface methodology) mode. The RSM experiment was designed incorporating the yam-solids range of 0.5 - 2.0% and total milk-solids range of 10 - 14% (Table 4.14).

**Table 4.14 Coded and actual levels of yam solids and total milk solids in yam-milk mix**

| Factor               | Coded level | Axial point | Factorial point | Centre coordinate | Factorial point | Axial point |
|----------------------|-------------|-------------|-----------------|-------------------|-----------------|-------------|
|                      |             | -1.413      | -1              | 0                 | +1              | +1.413      |
| A: Yam Solids        |             | 0.19        | 0.5             | 1.25              | 2               | 2.31        |
| B: Total milk solids |             | 9.17        | 10              | 12                | 14              | 14.82       |

The two-factor combinations in 13 experiments based on the Central Composite Rotatable Design (CCRD) are given in Table 4.15.

**Table 4.15 The Central Composite Rotatable Design (CCRD) comprising of thirteen experiments including two independent variables: Yam solids and Total milk solids**

| Standard Order | Block   | Factor 1   | Factor 2          | Coefficient assessed by |
|----------------|---------|------------|-------------------|-------------------------|
|                |         | Yam Solids | Total milk solids |                         |
| 1              | Block 1 | 0.19       | 12                | Axial                   |
| 2              | Block 1 | 0.5        | 14                | Factorial               |
| 3              | Block 1 | 1.25       | 12                | Center                  |
| 4              | Block 1 | 2.00       | 10                | Factorial               |
| 5              | Block 1 | 1.25       | 14.82             | Axial                   |
| 6              | Block 1 | 1.25       | 12                | Center                  |
| 7              | Block 1 | 2.31       | 12                | Axial                   |
| 8              | Block 1 | 2.00       | 14                | Factorial               |
| 9              | Block 1 | 1.25       | 12                | Center                  |
| 10             | Block 1 | 1.25       | 12                | Center                  |
| 11             | Block 1 | 1.25       | 9.17              | Axial                   |
| 12             | Block 1 | 1.25       | 12                | Center                  |
| 13             | Block 1 | 0.5        | 10                | Factorial               |

The responses generated in terms of physicochemical properties, colour characteristics, and sensory attributes are discussed below.

#### 4.4.1 Physico-chemical properties of yam-milk mix as influenced by levels of yam solids and milk solids

##### 4.4.1.1 Apparent viscosity

The apparent viscosity of yam-milk mix ranged between 5.9-12.9 (Table 4.16). A minimum apparent viscosity of 5.9 was found in the mix with yam solids 0.19% and total milk solids of 12%, and the maximum apparent viscosity with the corresponding values of 2.39% yam solids and 12% TMS.

**Table 4.16 Physico-chemical properties of yam-milk mix as influenced by levels of yam solids and milk solids**

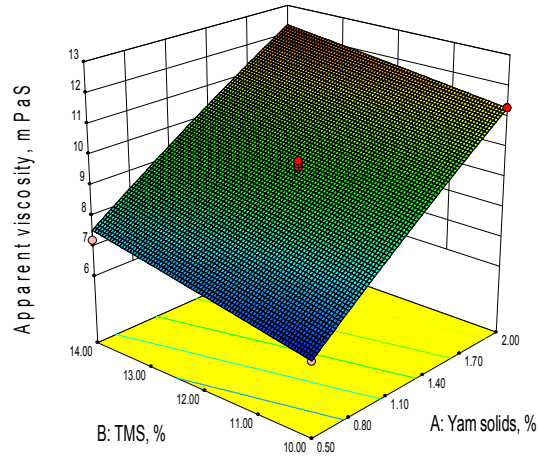
| Run | Yam solids (%) | Total milk solids(%) | Apparent viscosity (mPa.s) | Sediment (ml) | Acidity (%) | pH   | HCT (130°C) |
|-----|----------------|----------------------|----------------------------|---------------|-------------|------|-------------|
| 1   | 0.19           | 12.00                | 5.9                        | 0.15          | 0.18        | 6.73 | 49.51       |
| 2   | 0.50           | 14.00                | 7.2                        | 0.30          | 0.18        | 6.70 | 34.03       |
| 3   | 1.25           | 12.00                | 9.4                        | 0.70          | 0.19        | 6.73 | 28.11       |
| 4   | 2.00           | 10.00                | 11.3                       | 1.00          | 0.18        | 6.86 | 28.51       |
| 5   | 1.25           | 14.82                | 10.7                       | 0.70          | 0.17        | 6.75 | 15.40       |
| 6   | 1.25           | 12.00                | 9.5                        | 0.60          | 0.18        | 6.79 | 30.15       |
| 7   | 2.31           | 12.00                | 12.9                       | 0.90          | 0.20        | 6.71 | 3.14        |
| 8   | 2.00           | 14.00                | 12.0                       | 0.85          | 0.18        | 6.71 | 4.31        |
| 9   | 1.25           | 12.00                | 9.7                        | 0.70          | 0.18        | 6.79 | 32.21       |
| 10  | 1.25           | 12.00                | 9.1                        | 0.70          | 0.18        | 6.8  | 31.03       |
| 11  | 1.25           | 9.17                 | 8.5                        | 0.70          | 0.16        | 6.87 | 40.21       |
| 12  | 1.25           | 12.00                | 9.6                        | 0.70          | 0.18        | 6.75 | 30.21       |
| 13  | 0.50           | 10.00                | 6.1                        | 0.20          | 0.16        | 6.80 | 50.52       |

**Table 4.17 Regression coefficients and ANOVA of fitted quadratic model for physico-chemical properties of yam-milk mix**

| Partial Coefficients | Apparent viscosity   | Sediment                 | Acidity       | pH                       | HCT                 |
|----------------------|----------------------|--------------------------|---------------|--------------------------|---------------------|
| Intercept            | 9.46                 | 0.68                     | 0.18          | 6.77                     | 30.34               |
| A-Yam solids         | 2.49**               | 0.30**                   | 5.557E-003**  | 5.214E-003 <sup>ns</sup> | -14.66**            |
| B-Total milk solids  | 0.61 **              | -6.25E-003 <sup>ns</sup> | 3.789E-003*   | -0.052**                 | -9.47**             |
| A <sup>2</sup>       | -0.12 <sup>ns</sup>  | -0.084**                 | 3.163E-003*   | -0.025 <sup>ns</sup>     | -1.44 <sup>ns</sup> |
| B <sup>2</sup>       | -0.017 <sup>ns</sup> | 3.75E-003 <sup>ns</sup>  | -8.337E-003** | 0.020 <sup>ns</sup>      | -0.70 <sup>ns</sup> |
| AB                   | -0.10 <sup>ns</sup>  | -0.063 <sup>ns</sup>     | -4.25E-003 *  | -0.013 <sup>ns</sup>     | -1.93 <sup>ns</sup> |
| R <sup>2</sup>       | 0.99                 | 0.97                     | 0.93          | 0.84                     | 0.98                |
| Model F value        | 109.49**             | 55.41**                  | 17.53**       | 7.62**                   | 73.13**             |
| Adequate precision   | 33.39                | 24.32                    | 15.43         | 9.22                     | 27.34               |
| Lack of Fit          | ns                   | ns                       | ns            | ns                       | ns                  |

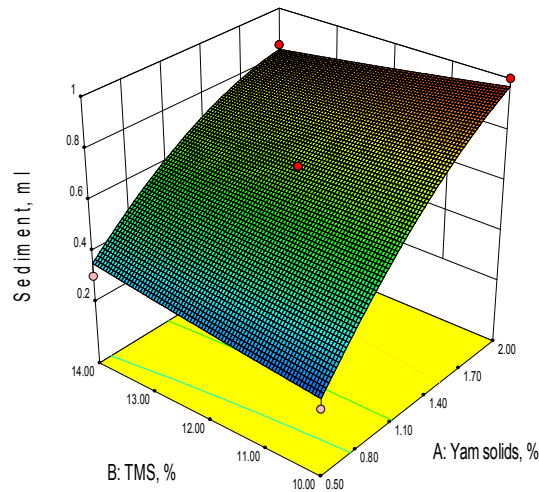
\*\* Highly significant (p < 0.01); \* Significant (p < 0.05); ns not-significant (p > 0.05)

Design-Expert® Software  
 Factor Coding: Actual  
 Apparent viscosity, mPaS  
 ● Design points above predicted value  
 ○ Design points below predicted value  
 12.9  
 6.9  
 X1 = A: Yam solids, %  
 X2 = B: TMS, %



**Fig 4.9 Response surface relating to apparent viscosity as influenced by yam solids and TMS in yam-milk mix**

Design-Expert® Software  
 Factor Coding: Actual  
 Sediment, ml  
 ● Design points above predicted value  
 ○ Design points below predicted value  
 0.15  
 X1 = A: Yam solids, %  
 X2 = B: TMS, %



**Fig 4.10 Response surface relating to sediment as influenced by yam solids and TMS in yam-milk mix**

The regression analysis of data presented in Table (4.17) shows that the coefficient of determination ( $R^2$ ) for the quadratic model was 0.99 and the “lack of fit”, which measures the fitness of the model obtained was not significant indicating that the model is sufficiently accurate for predicting the apparent viscosity of yam-milk mix made with any combination of the factors level within the range evaluated. The adequate precision was found to be 33.39 appreciably higher than the minimum desirable 4 (for high prediction ability). Further the statistical analysis indicated that the model fitted the observed data well, the model F value being 109.49 ( $P < 0.01$ ).

The coefficient estimates of apparent viscosity of yam-milk mix showed that the yam solids and milk solids concentration had positive significant ( $P < 0.01$ ) effect at linear level which means that with increasing concentrations of yam and milk solids the apparent viscosity increased linearly but the effect of increase of yam solid on apparent viscosity was more pronounced (Fig 4.9). The interaction between the two variables was non-significant. The apparent viscosity of yam-milk mix formulation could be predicted by the equation (for actual values of the variables) given below:

$$\text{Apparent viscosity, mPa.s} = -0.32557 + 4.63880 * A + 0.49529 * B - 0.066667 * A * B - 0.20889 * A^2 - 4.37500E-003 * B^2$$

#### 4.4.1.2 Sediment

The range of the sediment value of yam-milk mix from 0.15 (yam solids 0.19% and TMS 12%) to 1.00 (yam solids 2% and TMS 10%) (Table 4.16). The coefficient estimates for the sediment model (Table 4.17) show that yam solids concentration had significant ( $P < 0.01$ ) positive effect on the sediment value of yam-milk mix, whereas the effect of TMS concentration was found to be non-significant. Thus, with the increasing yam solids level sedimentation increased, the rate of increase falling at the higher values of yam solid within the range evaluated (Fig. 4.10). However the interaction between the yam solids and TMS was non-significant. The regression analysis presented in Table 4.17 further reveals that the coefficient of determination ( $R^2$ ) was 0.97 ( $p < 0.01$ ) and the lack of fit test of the model was not significant indicating that the model is sufficiently accurate for predicting sedimentation behaviour of the yam-milk mix

based on yam solids and TMS concentration. The model fitted the data well (F value, 55.41). The adequate precision was high enough 24.32. The sediment value of yam-milk mix formulation could be predicted by the equation (for actual factors) given below:

$$\text{Sediment, ml} = - 0.50736 + 1.27400 * A + 0.026458 * B - 0.041667 * A * B - 0.14889 * A^2 + 9.37500E - 004 * B^2$$

#### 4.4.1.3 Acidity

The acidity of yam-milk mix ranged between 0.16-2.0 %LA. The highest acidity was obtained for the formulation with yam solids of 2.31 % and TMS of 12%. The least acidity was recorded for the mix corresponding to yam solids 0.5 and TMS 10%.

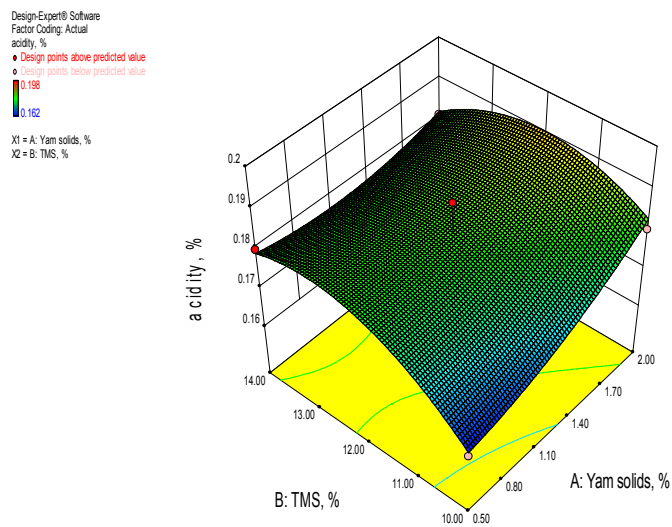
The regression analysis of data presented in Table 4.17 reveals that the coefficient of determination ( $R^2$ ) was 0.93 and the “lack of fit” test was not significant indicating that the model is sufficiently reliable for predicting the acidity of yam-milk mix made with any combination of the factors level within the range evaluated. The adequate precision was found to be 15.43, appreciably higher than the minimum desirable 4 (for high prediction ability). Further statistical analysis indicated that the model fitted the data well, the model F value being 17.53 ( $P < 0.01$ ). The coefficients of the linear terms of the model indicated that the yam solids ( $P < 0.01$ ) as well as TMS ( $p < 0.05$ ) had a positive on the acidity. However, the positive and negative quadratic coefficients for yam solids ( $p < 0.05$ ) and TMS ( $p < 0.01$ ), respectively, together with negative interaction effect ( $p < 0.05$ ) implied that with increasing TMS beyond a certain level had the opposite (decreasing) effect on acidity particularly at higher levels of yam solids, and the effect of yam solids in relative to TMS was nearly the opposite (Fig. 4.11). The mix acidity could be predicted by the equation (for actual values or variables) given below:

$$\text{Acidity, \%} = - 0.18406 + 0.027354 * A + 0.055461 * B - 2.83333E-003 * A * B + 5.62222E-003 * A^2 - 2.08437E-003 * B^2$$

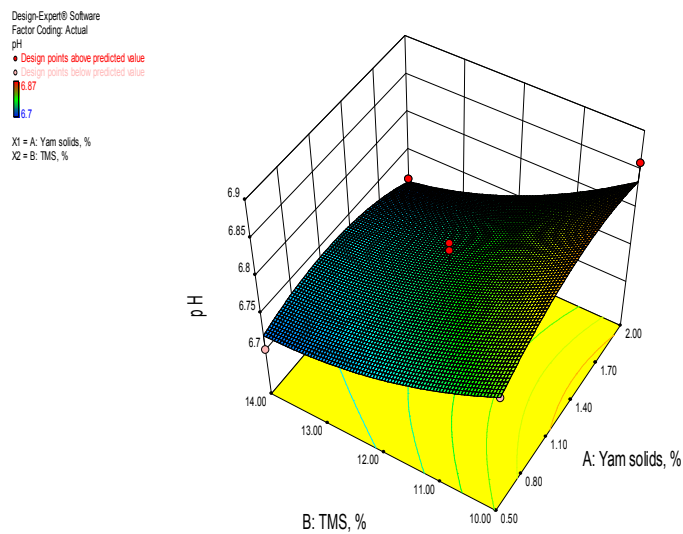
#### 4.4.1.4 pH

The pH of the yam-milk mix ranged between 6.7- 6.86 (Table 4.16). The response surface for pH (Fig. 4.12) exhibited nearly inverse pattern as compare

to that for acidity. The coefficient estimates for the model (Table 4.17) showed that TMS level had negative significant effect ( $p < 0.01$ ) on the pH of mix which means that with increase in TMS level of mix, the pH value decreased at linear level while with increase in yam solids level the pH value increased though the effect was found to be non-significant (Fig 4.12). The quadratic levels and the interaction between the two variables were non-significant.



**Fig 4.11 Response surface relating to acidity as influenced by yam solids and TMS in yam-milk mix**



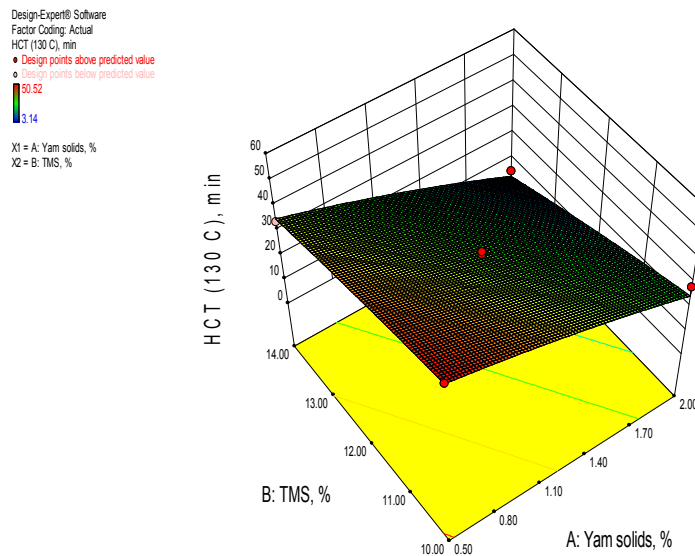
**Fig 4.12 Response surface relating to pH as influenced by yam solids and TMS in yam-milk mix**

The regression analysis of data presented in Table 4.17 reveals that the coefficient of determination ( $R^2$ ) was 0.84 and the lack of fit test was non-significant. The adequate precision was 9.22 appreciably higher than the minimum desirable (for high prediction ability). Further, the model fitted the data well (F value, 7.62) suggesting a high degree of reliability ( $P < 0.01$ ). The pH could be predicted by the equation (for actual factors) given below:

$$\text{pH} = +7.58910 + 0.21973 * A - 0.13356 * B - 8.33333\text{E-}003 * A * B - 0.045111 * A^2 + 4.90625\text{E-}003 * B^2$$

#### 4.4.1.5 Heat coagulation time (HCT at 130°C)

The HCT of yam-milk mix ranged between 3.14-50.52 min (Table 4.16). The maximum HCT was obtained for the formulation with yam solids level of 0.5% and TMS concentration of 10%, whereas the minimum HCT was obtained for the formulation with the corresponding values of 2.31 and 12%.



**Fig 4.13 Response surface relating HCT-130°C as influenced by yam solids and TMS in yam-milk mix**

The regression analysis of data presented in Table 4.17 reveals that the coefficient of determination ( $R^2$ ) was 0.98 and the “lack of fit” test was not significant indicating that the model is sufficiently accurate for predicting the HCT of yam-milk mix made with any combination of the factors level within the range evaluated. The adequate precision was found to be 27.34 appreciably

higher than the minimum desirable viz., 4. Further statistical analysis indicated that the model fitted the data well, the model F value being 73.13). As can be seen from Fig. 4.13, the effects of yam solids and TMS on HCT were negatively significant in linear term ( $p \leq 0.01$ ) (Table 4.17) though the effect was more pronounced for yam solids (Fig 4.13). Decrease in HCT with increase in yam solids could be attributed to the corresponding increase in the starch content, which had destabilizing effect on milk. The quadratic term and the interactions between the two variables were non-significant thereby suggesting that there was largely a linear dependence of the HCT on the yam solids and TMS. The HCT of yam-milk mix could be predicted by the equation (for actual values or variables) given below:

$$\text{HCT (130}^\circ\text{C), min} = + 63.17239 + 2.26493 * A + 1.06496 * B - 1.28500 * A * B - 2.55844 * A^2 - 0.17478 * B^2$$

#### **4.4.2 Hunter Lab colour parameters of yam-milk mix as influenced by levels of yam solids and milk solids**

The yam-milk mix was analyzed for instrumental colour parameters lightness ( $L^*$ ), redness ( $a^*$ ) and yellowness ( $b^*$ ) values as influenced by the yam solids and TMS levels. The model F values for the colour parameters were higher for  $L^*$  and  $b^*$  than the  $F_{\text{tab}}$  while for  $a^*$  it was lower than  $F_{\text{tab}}$  which indicates the the model for  $a^*$  is not significant.

The coefficient of determination ( $R^2$ ) was 0.87 and 0.80 for  $L^*$  and  $b^*$  (Table 4.19) values, respectively. The non-significant lack of fit for  $L^*$  and  $b^*$  suggests that the quadratic model could be used to predict the effect of the components of the yam-milk mix on its colour. The  $L^*$  value indicating lightness (or whiteness) of yam-milk mix varied from 81.12 to 86.27. The lowest  $L^*$  value was obtained when 2.31 yam solids and 12% TMS were used in the mix. Yam solids and TMS levels of 0.5 and 14% resulted in the maximum  $L^*$  value of the product (Table 4.18). The linear terms for yam solids had significant negative effect ( $p \leq 0.01$ ) on lightness value of mix while the effect of the TMS was found to be non-significant at linear level. The quadratic term and the interaction between the two variables were non-significant thereby suggesting that there was largely a linear dependence of the  $L^*$  value on the yam solids level.

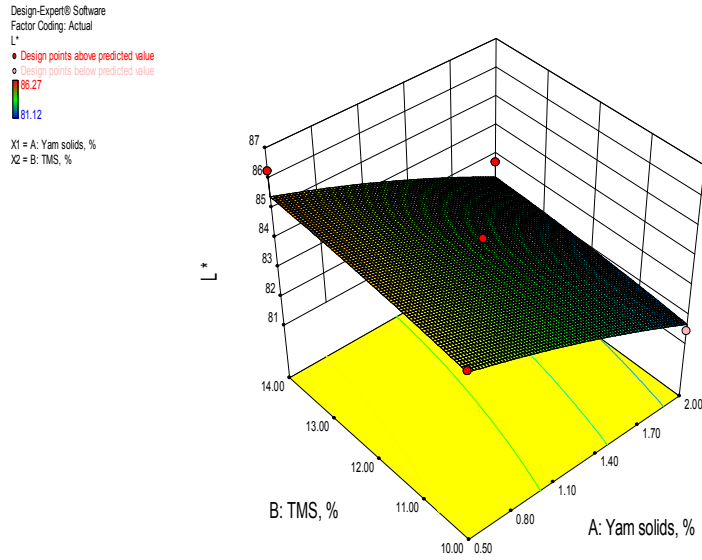
**Table 4.18 Effect of the Yam solids and Total milk solids level on colour characteristics of yam-milk mix (RSM Experiment)**

| Run | Yam solids (%) | Total milk solids (%) | L*    | a*    | b*    |
|-----|----------------|-----------------------|-------|-------|-------|
| 1   | 0.19           | 12                    | 85.25 | -2.19 | 5.71  |
| 2   | 0.5            | 14                    | 86.27 | -1.79 | 8.84  |
| 3   | 1.25           | 12                    | 83.44 | -1.43 | 9.58  |
| 4   | 2              | 10                    | 81.45 | -2.21 | 10.82 |
| 5   | 1.25           | 14.82                 | 83.19 | -1.09 | 9.38  |
| 6   | 1.25           | 12                    | 84.38 | -2.8  | 9.93  |
| 7   | 2.31           | 12                    | 81.12 | -1.29 | 10.22 |
| 8   | 2              | 14                    | 82.76 | -1.94 | 9.61  |
| 9   | 1.25           | 12                    | 84.36 | -2.84 | 10.02 |
| 10  | 1.25           | 12                    | 83.4  | -1.95 | 8.42  |
| 11  | 1.25           | 9.17                  | 83.51 | -2.18 | 9.08  |
| 12  | 1.25           | 12                    | 83.47 | -2.69 | 11.46 |
| 13  | 0.5            | 10                    | 84.91 | -2.73 | 6.91  |

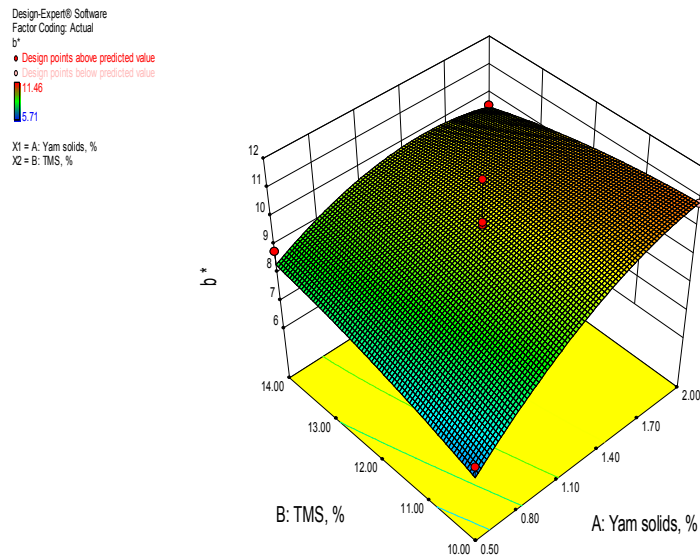
**Table 4.19 Regression coefficients and ANOVA of fitted quadratic model for colour characteristics of yam-milk mix**

| Partial Coefficients | L*                   | a*                  | b*                  |
|----------------------|----------------------|---------------------|---------------------|
| Intercept            | 83.81                | -2.34               | 9.88                |
| A-Yam solids         | -1.60**              | 0.21 <sup>ns</sup>  | 1.38**              |
| B-Total milk solids  | 0.28 <sup>ns</sup>   | 0.34 <sup>ns</sup>  | 0.14 <sup>ns</sup>  |
| A <sup>2</sup>       | -0.17 <sup>ns</sup>  | 0.18 <sup>ns</sup>  | -0.85 *             |
| B <sup>2</sup>       | -0.085 <sup>ns</sup> | 0.23 <sup>ns</sup>  | -0.21 <sup>ns</sup> |
| AB                   | -0.012 <sup>ns</sup> | -0.17 <sup>ns</sup> | -0.79 <sup>ns</sup> |
| R <sup>2</sup>       | 0.873                | 0.474               | 0.806               |
| Model F Value        | 9.65*                | 1.27 <sup>ns</sup>  | 5.84*               |
| Adequate precision   | 10.02                | 3.34                | 7.65                |
| Lack of Fit          | ns                   | ns                  | ns                  |

\*\* Highly significant ( $p \leq 0.01$ ); \* Significant ( $0.01 < p \leq 0.05$ ); ns- non significant



**Fig 4.14: Response surface relating Hunter lab L\* value as influenced by yam solids and TMS in yam-milk mix**



**Fig 4.15 Response surface relating to Hunter b\* value as influenced by yam solids and TMS in yam-milk mix**

The lightness of the product is basically a surface characteristic and it depends on the substances that reflects or absorbs light. The addition of yam solids decreased the whiteness of mix. The Hunter L\* value of yam-milk mix could be predicted by the equation (for actual factors) given below:

$$\text{Hunter Lab L* value} = +81.16553 - 1.29067 * A + 0.65901 * B - 8.33333E-003 * A * B - 0.29778 * A^2 - 0.021250 * B^2$$

The yellowness (Hunter b\*) value of the yam-milk mix was in the range of 5.71 to 11.46. The mix containing 0.19% yam solids and 12% TMS concentration exhibited the minimum b\* value and 1.25% yam solids and 12% TMS showed maximum b\* value (Table 4.18). The b\* value appeared to be independent of the TMS level. However, the yam solid level significantly influenced the b\* value, the linear term having positive coefficient (P<0.01) and the quadratic term had a negative coefficient (P<0.05) (Table 4.19). Thus the response surface showed Hunter lab b\* value tended to decline or level off with increasing yam solids level after an initial increasing trend (Fig 4.15). The Hunter b\* value of yam-milk mix could be predicted by the equation (for actual factors) given below:

$$\text{Hunter lab b* value} = -11.19021 + 11.88579 * A + 2.01043 * B - 0.52333 * A * B - 1.50511 * A^2 - 0.053531 * B^2$$

#### **4.4.3 Sensory attributes of yam-milk mix as influenced by the levels of yam solids and total milk solids (TMS)**

Sensory attributes, namely sediment, colour, consistency, Flavor, mouthfeel and overall acceptability of the yam-milk mix were monitored as responses to variations in yam solids and TMS in the RSM experiment. The results are given in Table 4.20

##### **4.4.3.1 Sediment**

The sediment of yam-milk mix ranged between 24.4 and 54.75 (Table 4.20). The maximum score was registered for the mix made using 2% yam solid and 10% TMS. The minimum score was obtained for 1.25% yam solid and 10% TMS concentration. The sediment score was found to be essentially a linear function of the yam solids as with increasing level of

**Table 4.20 Effect of the Yam solids and Total milk solids (TMS) levels on sensory characteristics of yam-milk mix (RSM Experiment)**

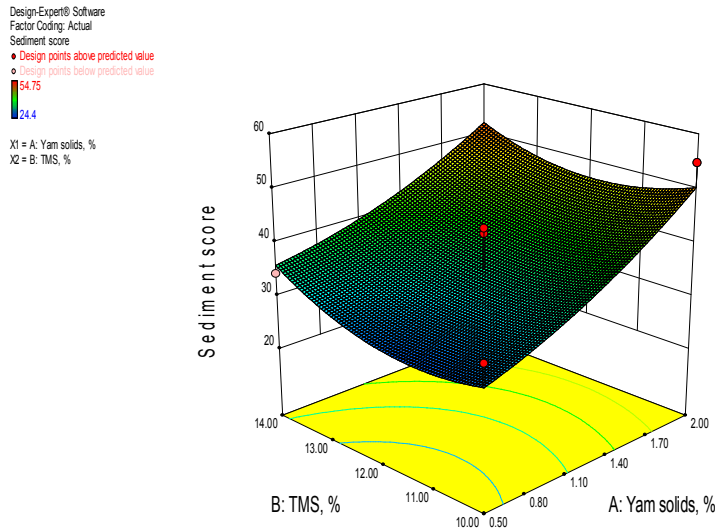
| Run | Yam solids (%) | TMS (%) | Sensory rating* |        |             |         |           |                       |  |
|-----|----------------|---------|-----------------|--------|-------------|---------|-----------|-----------------------|--|
|     |                |         | Sediment        | Colour | Consistency | Flavour | Mouthfeel | Overall Acceptability |  |
| 1   | 0.19           | 12      | 25.2            | 93.7   | 29.3        | 90.6    | 95.6      | 81.1                  |  |
| 2   | 0.50           | 14      | 34.3            | 93.2   | 36.2        | 87.3    | 95.9      | 83.0                  |  |
| 3   | 1.25           | 12      | 24.4            | 86.6   | 32.7        | 74.8    | 91.9      | 76.7                  |  |
| 4   | 2.00           | 10      | 54.75           | 82.0   | 40.5        | 70.3    | 86.3      | 71.2                  |  |
| 5   | 1.25           | 14.82   | 49.8            | 81.0   | 41.0        | 73.8    | 92.5      | 74.7                  |  |
| 6   | 1.25           | 12      | 33.7            | 81.2   | 35.3        | 70.6    | 96.2      | 70.8                  |  |
| 7   | 2.31           | 12      | 51.5            | 76.0   | 41.4        | 66.6    | 84.0      | 67.1                  |  |
| 8   | 2.00           | 14      | 51.0            | 72.7   | 42.7        | 71.3    | 80.0      | 69.4                  |  |
| 9   | 1.25           | 12      | 33.5            | 82.7   | 34.1        | 71.5    | 96.3      | 70.1                  |  |
| 10  | 1.25           | 12      | 41.8            | 84.0   | 38.7        | 80.83   | 87.8      | 75.0                  |  |
| 11  | 1.25           | 9.18    | 35.3            | 85.1   | 29.3        | 88.5    | 94.6      | 80.3                  |  |
| 12  | 1.25           | 12      | 42.8            | 82.0   | 36.8        | 79.9    | 89.3      | 76.4                  |  |
| 13  | 0.50           | 10      | 33.0            | 96.0   | 19.4        | 87.0    | 94.7      | 77.8                  |  |

\*on a 100-point linear scale (0-minimum, 100-maximum)

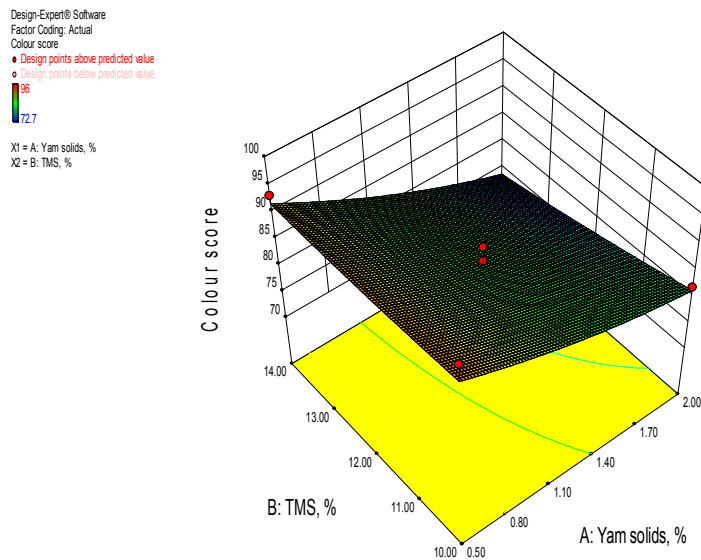
**Table 4.21 Regression coefficients and ANOVA of fitted quadratic model for sensory characteristics of yam-milk mix**

| Partial Coefficients | Sediment            | Colour              | Consistency         | Flavour             | Mouthfeel           | Overall Acceptability |
|----------------------|---------------------|---------------------|---------------------|---------------------|---------------------|-----------------------|
| Intercept            | 35.24               | 83.30               | 35.52               | 75.53               | 92.30               | 73.8                  |
| A-Yam solids         | 9.46**              | -7.44**             | 5.59**              | -8.33**             | -5.09**             | -5.00**               |
| B-Total milk solids  | 2.26 <sup>ns</sup>  | -2.24*              | 4.44**              | -2.44 <sup>ns</sup> | -1.01 <sup>ns</sup> | -0.56 <sup>ns</sup>   |
| A <sup>2</sup>       | 2.26 <sup>ns</sup>  | 1.28 <sup>ns</sup>  | -0.22 <sup>ns</sup> | 1.31 <sup>ns</sup>  | -1.86 <sup>ns</sup> | 0.037 <sup>ns</sup>   |
| B <sup>2</sup>       | 4.36 <sup>ns</sup>  | 0.38 <sup>ns</sup>  | -0.32 <sup>ns</sup> | 2.59 <sup>ns</sup>  | 0.012 <sup>ns</sup> | 1.74 <sup>ns</sup>    |
| AB                   | -1.26 <sup>ns</sup> | -1.63 <sup>ns</sup> | -3.65*              | 0.17 <sup>ns</sup>  | -1.88 <sup>ns</sup> | -1.75 <sup>ns</sup>   |
| R <sup>2</sup>       | 0.750               | 0.923               | 0.93                | 0.812               | 0.76                | 0.809                 |
| Model F Value        | 4.20*               | 16.76**             | 17.54**             | 6.08*               | 4.39*               | 5.93*                 |
| Adeq. precision      | 5.96                | 13.62               | 13.90               | 7.60                | 6.50                | 7.80                  |
| Lack of Fit          | ns                  | ns                  | ns                  | ns                  | ns                  | ns                    |

\*\* Highly significant (p < 0.01); \* Significant (p < 0.05); ns- not significant



**Fig 4.16 Response surface relating to sediment score as influenced by yam solids and TMS in yam-milk mix**



**Fig 4.17 Response surface relating to colour score as influenced by yam solids and TMS in yam-milk mix**

yam solids the sedimentation increased significantly ( $P < 0.01$ ) (Fig. 4.16). Neither the TMS concentration at linear and quadratic terms nor the interaction effect between the two variables significantly influenced the sediment score (Table 4.21). The  $R^2$  value was 0.75 and lack of fit was non-significant and model F value indicates that this model was significant. The sediment score of yam-milk mix formulation could be predicted by the following equation (for actual factors) given below:

$$\text{Sediment score} = + 156.47887 + 12.67119 * A - 23.96816 * B - 0.84167 * A * B + 4.01444 * A^2 + 1.08953 * B^2$$

#### 4.4.3.2 Colour

The colour of yam-milk mix ranged between 72.7 and 96 (Table 4.20). The maximum score was registered for the mix made using 0.5% yam solid and 10% TMS. The minimum score was obtained for 2% yam solid and 14% TMS concentration. The colour and appearance score of the mix was positively significant for both yam solids ( $P < 0.01$ ) and TMS levels ( $P < 0.05$ ), which means with increase in the concentration of yam solids the colour and appearance score increased (Fig. 4.17). The quadratic term and the interactions between the two variables were non-significant thereby suggesting that there was essentially a linear dependence of the colour on yam solids and TMS (Table 4.21). The  $R^2$  value was 0.92 and lack of fit was non-significant and model F value indicates that this model was significant. The colour score of yam-milk mix could be predicted by the following equation (for actual factors) given below:

$$\text{Colour score} = + 110.16015 - 2.61637 * A - 2.05198 * B - 1.08333 * A * B + 2.27778 * A^2 + 0.095312 * B^2$$

#### 4.4.3.3 Consistency

The consistency of yam-milk mix ranged between 19.4-42.7 (Table 4.20). The maximum score was registered for the mix made using 2% yam solids and 14% TMS. The minimum score was obtained for 0.5% yam solid and 10% TMS concentration.

The regression analysis of data presented in Table 4.21 reveals that the coefficient of determination ( $R^2$ ) was 0.93 and the “lack of fit” test which

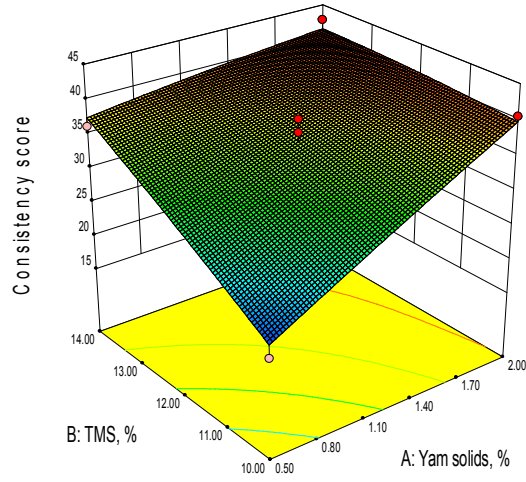
measures the fitness of the model obtained was not significant indicating that the model is sufficiently accurate for predicting the consistency of the yam-milk mix made with any combination of the factors level within the range evaluated. The adequate precision was found to be 13.90 appreciably higher than the minimum desirable viz., 4. Further statistical analysis indicated that the model fitted the data well, the model F value being 17.54). As can be seen from Fig. 4.18, the effects of yam solid and TMS level on consistency were similar to those observed for apparent viscosity. However in the case of consistency rating only the linear terms and interaction term ( $p < 0.05$ ) were significant. Thus with increasing yam solids the consistency (intensity) rating increased linearly, the increase being much greater at lower levels of TMS. Similarly, the effect of TMS on consistency was linear and much more pronounced at lower levels of yam solids as compared to higher levels (Fig. 4.18) which means the maximum consistency was obtained at the higher concentration of the two variables within the range evaluated (Table 4.21). The quadratic effects between the two variables were non-significant. The consistency of yam-milk mix could be predicted by the equation (for actual values or variables) given below:

$$\text{Consistency score} = -49.18278 + 37.64089 * A + 7.19831 * B - 2.43333 * A * B - 0.39556 * A^2 - 0.080625 * B^2$$

#### 4.4.3.4 Flavour

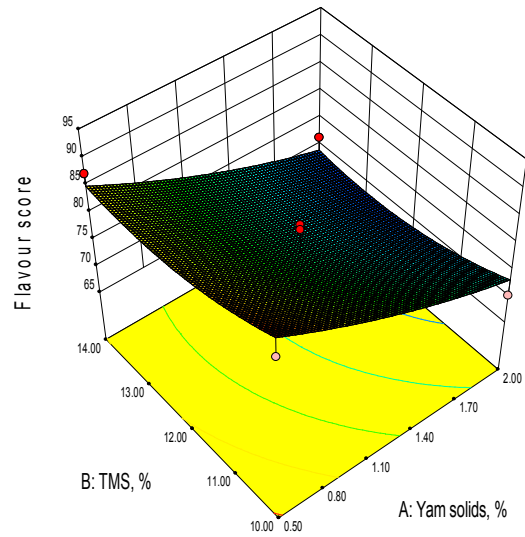
The flavour intensity rating of yam-milk mix ranged between 66.6 and 90.6 (Table 4.20). The maximum score was registered for the mix made using 0.19% yam solids and 12% TMS. The minimum score was obtained for 2.31% yam solids and 12% TMS concentration. It can be further seen from the Table 4.21 that the negative coefficient of the linear terms of the quadratic regression equation were significant ( $p \leq 0.01$ ) for yam solids which means that an increasing concentration of yam solids decreased the flavour score (Fig. 4.19). Interestingly, TMS also showed a negative (though non-significant) relationship with flavour of the mixture, thereby suggesting rather a lack of compatibility between milk and yam at least in the absence of any added flavouring. The quadratic and interaction terms for both the factors were non-significant.

Design-Expert® Software  
 Factor Coding: Actual  
 Consistency score  
 ● Design points above predicted value  
 ○ Design points below predicted value  
 42.7  
 19.4  
 X1 = A: Yam solids, %  
 X2 = B: TMS, %



**Fig 4.18 Response surface relating to consistency score as influenced by yam solids and TMS in yam-milk mix**

Design-Expert® Software  
 Factor Coding: Actual  
 Flavour score  
 ● Design points above predicted value  
 ○ Design points below predicted value  
 90.6  
 66.6  
 X1 = A: Yam solids, %  
 X2 = B: TMS, %



**Fig 4.19 Response surface relating to flavour score as influenced by yam solids and TMS in yam-milk mix**

The  $R^2$  value was 0.812, lack of fit was non-significant and model F value indicated that the model was highly significant ( $p \leq 0.05$ ). The flavour of yam-milk mix could be predicted by the equation (for actual factors) given below:

$$\text{Flavour score} = +202.55272 - 18.33797 * A - 16.88589 * B + 0.11667 * A * B + 2.33244 * A^2 + 0.64675 * B^2$$

#### 4.4.3.5 Mouthfeel

The mouthfeel score of yam-milk mix formulation ranged between 80-96.3 (Table 4.20). The maximum score was registered for the mix made using 1.25% yam solid and 12% TMS. The minimum score was obtained for 2% yam solids and 14% TMS concentration.

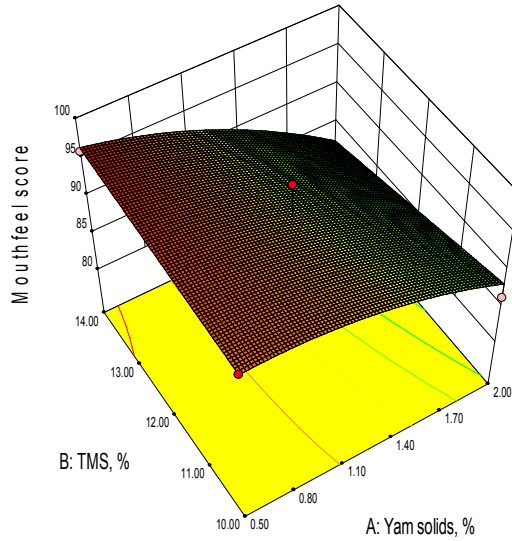
$R^2$  value for the model was 0.76, lack of fit was non-significant and the model F value indicated that the model was significant ( $P < 0.05$ ) (Table 4.21). The linear terms for yam solids and TMS level on yam-milk mix were negatively significant ( $P < 0.01$ ). But the effect of quadratic terms and interaction between these two factors on mouthfeel was non-significant. With only the yam solids factor (linear coefficient) being significant, the mouthfeel response surface was somewhat similar to that for the flavour rating but the nature of curvature was different, the flavour surface being slightly convex downward and the mouthfeel surface slightly convex upward. The mouthfeel score of yam-milk mix could be predicted by the equation (for actual factors) given below:

$$\text{Mouthfeel score} = +83.35896 + 16.49363 * A + 0.98313 * B - 1.25000 * A * B - 3.31111 * A^2 + 3.12500E-003 * B^2$$

#### 4.4.3.6 Overall acceptability

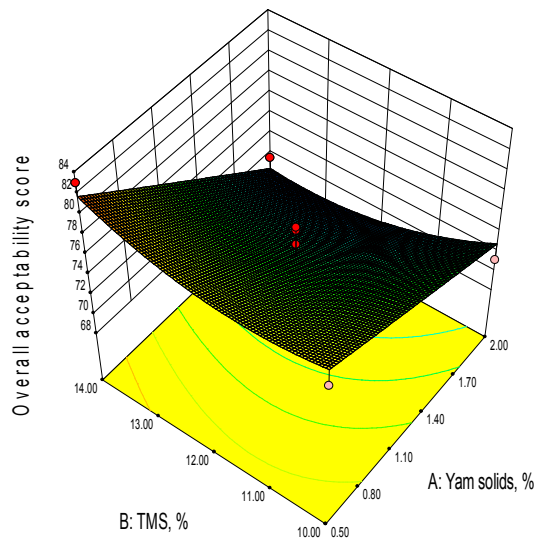
The overall acceptability score of yam-milk mix ranged from 67.1-83.0 (Table 4.20). The maximum score was registered for the mix made using 0.5% yam solid and 14% TMS. The minimum score was obtained for 2.31% yam solids and 12% TMS concentration. Table 4.21 reveals that the  $R^2$  value of overall acceptability score model was 0.78 and lack of fit non-significant. Thus the model was highly significant ( $F, P \leq 0.01$ ). Adequate precision of 7.8 further

Design-Expert® Software  
 Factor Coding: Actual  
 Mouthfeel score  
 ● Design points above predicted value  
 ○ Design points below predicted value  
 96.3  
 80  
 X1 = A: Yam solids, %  
 X2 = B: TMS, %



**Fig 4.20 Response surface relating to mouthfeel score as influenced by yam solids and TMS in yam-milk mix**

Design-Expert® Software  
 Factor Coding: Actual  
 Overall acceptability score  
 ● Design points above predicted value  
 ○ Design points below predicted value  
 83  
 67.1  
 X1 = A: Yam solids, %  
 X2 = B: TMS, %



**Fig 4.21 Response surface relating to overall acceptability score as influenced by yam solids and TMS in yam-milk mix**

indicates that model's prediction ability was high (Table 4.21). The effect of yam solids level on the overall acceptability was significant ( $P < 0.01$ ). Fig. 4.20 indicates that as yam solids level increased, the overall acceptability scores perceptibly declined, the effect being small at lower TMS levels but pronounced at higher TMS levels. Similarly, though non-significant, TMS had little impact on overall acceptability at lower levels of yam solids, it tended to depress the acceptability rating at higher yam solids levels (Fig. 4.21). The quadratic parameters of the model were non-significant. The overall acceptability score of yam-milk mix could be predicted by the equation (for actual factors) given below:

$$\begin{aligned} \text{Overall acceptability score} = & +130.67699 + 7.16684 * A - 9.24914 * B - 1.16667 \\ & * A * B + 0.066667 * A^2 + 0.43437 * B^2 \end{aligned}$$

#### 4.4.4 Optimization of yam-milk mix

Optimization of the levels of yam solids and total milk solids (TMS) with a view to working out the combination representing the maximum thickening effect of yam solids, was attempted using CCRD response surface design software (Design Expert version: 8.0.1.0.) setting the constraints as shown in Table 4.22. The two optimized solutions found with 0.75 and 0.68 desirability with different goals set are given in Table 4.23).

**Table 4.22 Goals set for constraints to optimize the yam-milk mix**

| <b>Constraints</b>          | <b>Goal set for yam-milk mix</b> | <b>Lower limit</b> | <b>Upper limit</b> |
|-----------------------------|----------------------------------|--------------------|--------------------|
| L*                          | In range                         | 81.12              | 86.27              |
| a*                          | In range                         | -2.84              | -1.09              |
| b*                          | In range                         | 5.71               | 11.46              |
| Apparent viscosity, mPas    | Maximize/ In range               | 5.90               | 12.90              |
| Sediment, ml                | In range                         | 0.15               | 1.00               |
| acidity, %                  | In range                         | 0.162              | 0.198              |
| pH                          | In range                         | 6.70               | 6.87               |
| HCT (130°C), min            | Maximize/In range                | 3.14               | 50.52              |
| Colour score                | In range/ Maximize               | 72.70              | 96.00              |
| Consistency score           | Maximize                         | 19.40              | 42.70              |
| Flavour score               | In range/ Maximize               | 66.60              | 90.60              |
| Mouthfeel score             | In range/ Maximize               | 80.00              | 96.30              |
| Sediment score              | In range/ Maximize               | 24.40              | 54.75              |
| Overall acceptability score | In range/ Maximize               | 67.10              | 83.00              |

**Table 4.23 Optimized solutions of yam-milk mix from the RSM analysis**

| Solution No.1               | Goal     | Yam Solids (%)              | TMS (%)  | Desirability | Solution No.2            | Goal     | Yam Solids (%) | TMS (%) | Desirability |
|-----------------------------|----------|-----------------------------|----------|--------------|--------------------------|----------|----------------|---------|--------------|
| L*                          | In range | 0.5                         | 14       | 0.75         | L*                       | In range | 2              | 10      | 0.68         |
| a*                          | In range |                             |          |              | a*                       | In range |                |         |              |
| b*                          | In range |                             |          |              | b*                       | In range |                |         |              |
| Apparent viscosity, mPas    | In range |                             |          |              | Apparent viscosity, mPas | Maximize |                |         |              |
| Sediment, ml                | In range |                             |          |              | Sediment, ml             | In range |                |         |              |
| Acidity, %                  | In range |                             |          |              | Acidity, %               | In range |                |         |              |
| Ph                          | In range |                             |          |              | Ph                       | In range |                |         |              |
| HCT (130°C), min            | In range |                             |          |              | HCT (130°C), min         | Maximize |                |         |              |
| Colour score                | Maximize |                             |          |              | Colour score             | In range |                |         |              |
| Consistency score           | Maximize |                             |          |              | Consistency score        | Maximize |                |         |              |
| Flavour score               | Maximize |                             |          |              | Flavour score            | In range |                |         |              |
| Mouthfeel score             | Maximize |                             |          |              | Mouthfeel score          | In range |                |         |              |
| Sediment score              | Maximize |                             |          |              | Sediment score           | In range |                |         |              |
| Overall acceptability score | Maximize | Overall acceptability score | In range |              |                          |          |                |         |              |

The solutions obtained as a result of numerical optimization was verified by using the values of yam solids and total milk solids concentration to prepare yam-milk mix and comparing the same with the predicted values in respect of physico-chemical properties and sensory characteristics of the resulting yam-milk mix.

The results obtained are presented in Table 4.24. The observed values and the predicted values were subjected to t-test. The t-test indicated that there was no significant difference between the predicted and observed values.

**Table 4.24 Predicted and observed values for optimized yam-milk mix**

| Parameter                   | Solution 1*     |              |                     | Solution 2*     |              |                     |
|-----------------------------|-----------------|--------------|---------------------|-----------------|--------------|---------------------|
|                             | Predicted value | Actual value | t <sub>0.05</sub>   | Predicted value | Actual value | t <sub>0.05</sub>   |
| L*                          | 85.45           | 85.31        | 1.33 <sup>ns</sup>  | 81.70           | 81.85        | -1.15 <sup>ns</sup> |
| a*                          | -1.62           | 2.18         | -3.82*              | -1.90           | -1.92        | 0.75 <sup>ns</sup>  |
| b*                          | 8.37            | 8.22         | 1.28 <sup>ns</sup>  | 10.85           | 10.84        | 1.00 <sup>ns</sup>  |
| Apparent viscosity, mPas    | 7.55            | 7.30         | 2.50 <sup>ns</sup>  | 11.30           | 11.15        | 2.80 <sup>ns</sup>  |
| Sediment, ml                | 0.35            | 0.30         | 0 <sup>ns</sup>     | 0.97            | 1.00         | 0.40 <sup>ns</sup>  |
| acidity, %                  | 0.18            | 0.17         | 1.00 <sup>ns</sup>  | 0.18            | 0.18         | 1.00 <sup>ns</sup>  |
| pH                          | 6.72            | 6.73         | -1.00 <sup>ns</sup> | 6.84            | 6.83         | 1.00 <sup>ns</sup>  |
| HCT (130°C), min            | 35.32           | 35.12        | 2.22 <sup>ns</sup>  | 24.94           | 23.26        | 0.74 <sup>ns</sup>  |
| Colour score                | 91.79           | 90.62        | 2.36 <sup>ns</sup>  | 81.38           | 82.58        | -2.06 <sup>ns</sup> |
| Consistency score           | 37.48           | 36.50        | 1.94 <sup>ns</sup>  | 39.77           | 39.14        | 0.19 <sup>ns</sup>  |
| Flavour score               | 85.14           | 85.08        | 0.09 <sup>ns</sup>  | 73.36           | 71.92        | 0.49 <sup>ns</sup>  |
| Mouthfeel score             | 96.40           | 95.75        | 0.37 <sup>ns</sup>  | 88.25           | 87.79        | 1.20 <sup>ns</sup>  |
| Sediment score              | 35.92           | 32.42        | 1.35 <sup>ns</sup>  | 50.32           | 50.25        | 0.20 <sup>ns</sup>  |
| Overall acceptability score | 81.76           | 82.09        | -0.16 <sup>ns</sup> | 72.89           | 73.67        | -1.54 <sup>ns</sup> |

\* significant at 5% (p< 0.05); ns-not significant

This indicated that the model predictions were reliable and therefore, the optimized product formulation could be taken as the best available from the RSM experiment.

**Table 4.25 Proximate composition of optimized yam-milk mix\***

| <b>Constituent (%)</b> | <b>Mix 1</b> | <b>Mix 2</b> |
|------------------------|--------------|--------------|
| Total solids           | 14.78±0.03   | 12.49±0.02   |
| Fat                    | 2.08±0.02    | 1.48±0.02    |
| Protein                | 4.66±0.01    | 3.40±0.01    |
| Lactose                | 6.56±0.02    | 5.24±0.04    |
| Starch                 | 0.5±0.02     | 1.50±0.03    |
| Crude fibre            | 0.02±0.01    | 0.10±0.01    |
| Ash                    | 0.96±0.01    | 0.77±0.01    |

\*mean±SE, (n=2).

It thus appeared that if maximum sensory scores (high flavour and mouthfeel, 85 and 96, respectively) were to be realized in the yam-milk mix, the necessary levels of yam solids and TMS would be 0.5 and 14%, respectively (Table 4. 23) with corresponding moderate consistency score (37) and moderate viscosity (7.3 mPa.s) (Table 4.24). If maximum viscosity and also maximum heat stability (HCT) are desired, the yam solids and TMS levels would be 2.0 and 10.0%, respectively (Table 4.23), the corresponding flavour and mouthfeel scores would be 72 and 88, respectively. The proximate composition of these two formulations given in Table 4.25 shows that such mixes would contain low fat (1.5-2.1%) and good amount of protein (3.4-4.8). Thus, although yam solids could potentially provide a good thickening effect in milk, its adverse effect on flavour and heat stability would allow only a small level of yam solids in the yam-milk mix formulation, with moderate viscosity.

# *CHAPTER - 5*

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## **Summary and Conclusions**

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## **5. SUMMARY AND CONCLUSIONS**

Starches play a variety of roles in food processing. They are extensively used in food products such as jellies, sauces, custards and desserts. They are used as thickening agents in food systems with other ingredients, such as milk in custard. Elephant foot yam, commonly known as Jimmikand/ Ol/ Suran and used as vegetable, *chutney*, pickle, etc. in different parts of the country is rich in starch as well as health principles. As addition of elephant foot yam (EFY) to milk is expected to have a thickening effect, its use as an ingredient in milk-based products such as dairy desserts would potentially enhance the importance of the latter as value-added products or health foods. Hence, the present project was undertaken to examine the properties of yam-added milk. The principal objective was to investigate the effects of different processing (pre-cooking) variables, and the levels of yam solids and total milk solids on the physico-chemical characteristics of the yam-milk mix.

Relevant literature was reviewed as presented in Chapter 2. The materials and methods used in the investigation have been described in Chapter 3. The results obtained in the present study as presented and discussed in the Chapter 4 are summarized below.

### **5.1 PRELIMINARY STUDIES ON THE SENSORY ATTRIBUTES OF EFY**

To select suitable processing conditions for elephant foot yam, different cooking treatments viz., pressure cooking for different times, cooking in acidulated water, salt coating before cooking, etc. were studied. However, these treatments did not show any perceivable improvement in the sensory attributes, flavour and mouthfeel/acridity in particular, of the yam. Pressure cooking for 15 min or 30 min was compared with open-pan cooking in excess water for 30 min or 60 min. Open-pan cooking showed better sensory attributes, especially flavor, and instrumentally measured colour of the EFY. Therefore, open-pan cooking for minimum of 30 min was selected for further experiments with regard to tray drying of yam and use of the yam powder as a thickener in milk.

## **5.2 EFFECT OF COOKING TIME AND DRYING TEMPERATURE OF ELEPHANT FOOT YAM ON PROPERTIES OF YAM-MILK MIX**

Elephant foot yam diced into 2-cm cubes was cooked in an open pan for different cooking times (0, 30 and 45 min) and then the resulting cubes were mashed and dried at different temperatures (50°C, 60°C and 70°C). The resultant powders (9 different lots) were evaluated for their physical and functional properties. The gelatinization results obtained from Rapid Visco Analyzer (RVA) revealed that the raw-yam powders obtained at drying temperatures of 50°C, 60°C and 70°C had high final viscosity (2945.5, 3194 and 3313 mPa.s, respectively) and breakdown viscosity (845, 886 and 1141.5 mPa.s). The 30 min cooked-yam powders had medium final viscosity (3097, 2862 and 2331.5 mPa.s) and low breakdown viscosity (162, 38 and 21.5 mPa.s) dried at 50°C, 60°C and 70°C respectively. High final viscosities for a good thickening effect and low breakdown viscosities for a stable mix are required.

Further, an attempt was made to compare the EFY powders, obtained under different processing conditions, for their compatibility in milk in order to select one set of conditions so as to be able to use the selected conditions to process yam into a form that would serve as stock material for use in milk or milk system. The yam-milk mix was prepared by using yam powder and evaluated for its physical and sensory properties. The flavour score (79.5 and 79.0) on a 100-point linear scale was high for powders obtained from 30 min-cooked and 45 min-cooked EFY which that was dried at 60°C. Accordingly, the powder, which was obtained at 60°C after 30 min pre-cooking, was used in further studies.

## **5.3 EFFECTS OF YAM SOLIDS AND TOTAL MILK SOLIDS LEVELS ON PROPERTIES OF YAM-MILK MIX**

An Response Surface Methodology (RSM) experiment was conducted two variables viz., yam solids level (0.5 – 2.0%) and total milk solids (TMS) level (10 – 14%). Thirteen lots of yam-milk mix were prepared as per Central Composite Rotatable Design and examined for their physico-chemical properties and sensory attributes. The data were analyzed using Design Expert software.

The effects of the yam solids on the apparent viscosity, sediment, titratable acidity, and heat coagulation time (HCT-130°C) were highly significant. With increasing yam solids, apparent viscosity (shear rate, 132 s<sup>-1</sup>), sediment and acidity increased whereas HCT decreased, the HCT decrease being drastic at higher levels of yam solids. The effects of total milk solids on the apparent viscosity, pH, and HCT were significant. With increasing total milk solids (TMS), the apparent viscosity and acidity increased, and pH and HCT decreased. The apparent viscosity and HCT of the mix were in the range of 5.9 -12.9 mPa.s, and 3.14 – 49.51 min, respectively. The sediment increased with increasing yam-solids level and it was in the range 0.15 – 1.0 ml. With increasing yam solids, the lightness (L\*) value of the milk-yam mix decreased and the yellowness (b\*) increased significantly.

The sensory consistency scores and sediment scores increased and the flavour, mouthfeel and overall acceptability scores decreased with the increasing level of yam solids. With increasing TMS, consistency scores increased especially for lower levels of yam solids, but it had no effect on the flavour, mouthfeel and overall acceptability of the mix. The quadratic effect and the interaction effect were non-significant. The colour, consistency, flavour, mouthfeel and overall acceptability scores of the mix were in the range of 72.7 - 96.0, 19.4 - 42.7, 66.6 - 90.6, 80 - 96.3 and 67.1 - 83.0 respectively.

#### **5.4 OPTIMIZATION OF YAM SOLIDS AND TOTAL MILK SOLIDS**

Optimization of the yam solids and total milk solids (TMS) was tried with two goal-sets viz., (1) maximizing sensory scores and (2) maximizing apparent viscosity, HCT and consistency score. The best solutions were obtained for goal '1' suggested the use of 0.5% yam solids and 14% TMS in the mix ,and for goal '2', 2% yam solids and 10% TMS. Solution '1' yielded higher sensory scores and HCT of the resulting yam-milk mix in comparison to the mix based on solution '2', as it contained lower level of yam solids. However, mix '2' had a higher apparent viscosity (11.2 mPa.s) as compared to mix '1' (7.3 mPa.s).

It can be concluded that pre-cooking of elephant foot yam in boiling water for 30 min followed by tray drying at 60°C yielded a yam powder which was fairly compatible with milk. When used at different levels in milk containing

varying TMS, increasing yam solids increased the viscosity and consistency score, but decreased the heat stability and flavor and acceptability scores. Thus 0.5% yam solids resulted in a moderate thickening effect in milk without much adversely affecting the HCT or sensory status of the mix, whereas 2% EFY solids yielded a yam-milk mix with appreciable thickening effect but perceivably reduced HCT and sensory scores. The regression equations developed for the two variables with respect to various properties of the milk-yam mix would allow choosing the right levels of yam solids and TMS so as to have the desired properties in the mix within the limits of the concentrations studied in the present investigation.

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# **Bibliography**

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## BIBLIOGRAPHY

- Abera, S., and Rakshit, S. K. (2003) Comparison of physicochemical and functional properties Cassava starch extracted from fresh root and dry chips. *Starch/Starke*. **55**: 287–296.
- Abu-Jdayil, B., Mohameed, H. and Eassa, A. (2004) Rheology of wheat starch–milk–sugar systems: effect of starch concentration, sugar type and concentration, and milk fat content. *Journal of Food Engineering*. **64**: 207–212.
- Acharya, S. M., Misra, R. S. and Neduncheziyan, M. (2005) Some value added products from *Amorphophallus* tubers. *Proceedings NSRTC-2*. pp.61-64.
- Adeyemi, I.A. and Beckley, O (1986). Effect of Period of Maize Fermentation and Souring on Chemical Properties and Amylograph Pasting Viscosity of Ogi. *Journal of Cereal Science*. **4**, 9.
- Ahmad, F. B. and Williams, P. A. (1999) Effect of sugars on the thermal and rheological properties of sago starch. *Biopolymers*. **50**:401–412.
- Akissoe, N., Hounhouigan, J., Mestres, C. and Nago, M. (2003) How blanching and drying affect the colour and functional characteristics of yam (*Dioscorea cayenensis-rotundata*) flour. *Food Chemistry*. **82**: 257-264.
- Albihn, P. and Savage, G. P. (2001a) The bioavailability of oxalate from oca (*Oxalis tuberosa*). *The Journal of Urology*. **166**:420–422.
- Anderson, R. A., Conway, H. F., Pfeifer, V. F., & Griffin, E. L. (1969) Gelatinization of corn grits by roll- and extrusion-cooking. *Cereal Science Today*, **14**(1), 4–7, 11–12.
- Antai, S. P. and Obong, U. S. (1992) The effect of fermentation on the nutrient status and some toxic components of *Icacinia manni*. *Plants Food for Human Nutrition*. **42**: 219-224.
- AOAC. (1995) Official methods of analysis (16th ed.). Washington, DC, USA: Association of Official Analysis Chemists (AOAC).
- AOAC. (2000) Official methods of analysis (17th ed.). Washington, DC, USA: Association of Official Analysis Chemists (AOAC).

- Asha, K. I. and Nair, M. C. (2002) Ethnic knowledge system on wild *Dioscorea* (yams) by the Kanikkars of Southern Western Ghats, Kerala. *Indian Journal of Plant Genetic Research*. **15**: 146-149.
- Atwel, W. A., Hood, L. F., Lineback, D. R., Varriaio-Marston, E., and Zobel, H. F. (1988) The Terminology and Methodology Associated with Basic Starch Phenomena. *Cereal foods world* **33**: 306-331.
- Aviara, N. A., Igbeka, J. C. and Nwokocha, L. M. (2010) Physicochemical properties of sorghum (*Sorghum Bicolor* l. Moench) starch as affected by drying temperature. *Agric Eng Int: CIGR Journal*. **12(2)**: 85-94.
- Ayernor, G. S. (1985) The Yam (*Dioscorea*) Starches. In: Advances in Yam research. 1<sup>st</sup> ed. Godson Osuji. Anambra State University of Technology Publishers. Nigeria. pp.79-88.
- Baloch, A. K., Buckale, K. A. and Edwards, R. A. (1981) Effect of chemical treatments on the stability of dehydrated carrot. *Pakistan journal of scientific and industrial research*. **24**: 203-211
- Banks, S. J. (1963) *The Endeavour Journal of Joseph Banks 1768-1771*. eds. Beaglehole, J. C., Angus and Robertson. 2<sup>nd</sup> edn., Vol. 2. Sydney, Australia. pp.85
- Basnat Ram. (2008) Role of Amorphophallus in food and nutrition security for human kind in Uttar Pradesh. In Palaniswami, M.S. et al. ed., National Seminar on *Amorphophallus*: innovative technologies, July 19-20, 2008, Patna, Bihar- abstract book, status papers and extended summary. pp.47
- Belitz, H. D. and Grosch, W. (1999) *Food Chemistry*, 2<sup>nd</sup> edn. Springer, Berlin.
- BeMiller, J. N., & Whistler, R. L. (1997) Carbohydrate. In R. Fennema Owen (Ed.), *Food chemistry* (pp. 157–223). Ohio State: Columbus.
- Bencini, M. C. (1986). Functional properties of drum-dried chickpea flours. *Journal of Food Science*. **51**: 1521–1526.
- Bertolini, A. C., Creamer, L. K., Eppink, M., and Boland, M. (2005) Some rheological properties of sodium caseinate-starch gels. *Journal of Agricultural and Food Chemistry*. **53(6)**: 2248-2254.

- Bhandari, M. R. and Kawabata, J. (2006) Cooking effects on oxalate, phytate, trypsin and  $\alpha$ -amylase inhibitors of wild yam tubers of Nepal. *Journal of Food Composition and Analysis*. **19**: 524–530.
- Borah, P., Saikia, J. and Narzary, B. D. (2008) Status of elephant foot yam cultivation in Assam. In Palaniswami, M.S. *et al.*, ed., National Seminar on *Amorphophallus*: innovative technologies, July 19-20, 2008, Patna, Bihar-abstract book, status papers and extended summary. pp. 55-57
- Bradbury, J. H. and Holloway, W. D. (1988) *Chemistry of tropical root crops: significance for nutrition and agriculture in the pacific*. ACIAR Monograph No. 6, Canberra.
- Carpenter, J. R. and Steinke, W. E. (1983) Animal feed. In: Wang, J. K. ed., Taro: a review of *Colocasia esculenta* and its potentials. University of Hawaii Press, Honolulu, Hawaii, USA. pp. 269-300.
- Chai, W. and Liebman, M. (2005). Effect of different cooking methods on vegetable oxalate content. *Journal of Agriculture and Food Chemistry*. **53**: 3027-3030.
- Chamberlain, E. K., Rao, M. A. and Cohe, C. (1999) Shear thinning and antithixotropic behavior of a heated cross-linked waxy maize starch dispersion. *International Journal of Food Properties*. **2**: 63–77.
- Chattopadhyay, A., Saha, P., Pal, S., Bhattacharya, A. and Sen, H. (2010) Quantitative and qualitative aspects of elephant foot yam. *International Journal of Vegetable Science*. **16**:73-84.
- Chawla, A. K. and Balachandran, R. (1994) Studies on yoghurt buffalo milk: effect of different solids not fat content on chemical, rheological and sensory characteristics. *Indian Journal of Dairy Science*. **47**: 762–765.
- Cheer, R. L. and Lelivre, J. (1983) *Journal of Applied Polymer Science*. **28**: 1829-1836.
- Chinachoti, P., White, V. A., Lo, L. and Stengle, T. R. (1991) *Cereal Chemistry*. **68**: 238-244.
- Colonna, P., Leloup, V. and Buleon, A. (1992) Limiting factors of starch hydrolysis. *Eur. J. Clin. Nutr.* **46** (2): S51-S62.

- CTCRI. (2010). CTCRI News. Vol. **27(4)** Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, India.
- Davies, D. T., & White, J. C. D. (1966) The stability of milk proteins to heat. 1. Subjective measurements of heat stability of milk. *Journal of Dairy Research*. **33**: 67–81.
- De, S., Dey, Y. N. and Ghosh, A. K. (2010) Anti-inflammatory activity of methanolic extract of *Amorphophallus paeoniifolius* and its possible mechanism. *International Journal of Pharma and Biosciences*. **1(3)**: 1-8
- Descamps, O., Langevin, P. and Combs, D. H. (1986) Physical effect of starch/carrageenan interactions in water and milk. *Food Technology*, **40**: 81–88.
- Dincer, I. (1998). Moisture transfer analysis during drying of slab woods. *Heat and Mass Transfer*, **34**: 317–320.
- Diosady, L. L., Patton, D., Rosen, N., & Rubin, L. J. (1985) Degradation of wheat starch in a single screw extruder: mechano-kinetic breakdown of cooked starch. *Journal of Food Science*. **50**: 1697–1706.
- Doublier, J. and Durand, S. (2008). A rheological characterization of semi-solid dairy systems *Food Chemistry* **108**: 1169–1175.
- Doublier, J. L., Marzin, C., Visdeloup, S. and Lefebvre, J. (1994) Effect of sodium caseinate on the pasting behaviour of starch from different origins. *Carbohydrate Polymers*. **25(3)**: 228-229.
- El-Garawany, G. A. and Abd El Salam, M. H. (2005) Preparation and rheological properties of a dairy dessert based on whey protein/potato starch. *Food Chemistry*. **91**: 261–267.
- Eliasson, A. C. and Gudmundsson, M. (1996) Starch: Physicochemical and functional properties, Chapter 10, In: *Carbohydrates in Food*, A.C. Eliasson, (ed.). Marcel Dekker Inc., pp. 431-503.
- Englberger, L., Aalbersberg, W., Ravi, P., Bonnin, M., Marks, G. C., Fitzgerald, M. H. and Elymore, J. (2003) Further analysis on Micronesia banana, taro, breadfruit and other foods for provitamin A carotenoids and minerals. *Journal of Food Composition and Analysis*. **16**: 216–236.

- Gallant, D. J., Bewa, H., Buy, Q. H., Bouchet, B., Szylit, O. and Saely, L. (1982) Ultrastructural and nutritional aspects of some tropical tuber crops. *Starch/Starke*. **34**: 255-262.
- Hansen, L. M., Setser, S. C. and Paukstelis, J. V. (1989) *Cereal Chemistry*, **66**: 411-415.
- Hedrick, U. P. and Nair, R. V. (1993) *Indian Medicinal Plants 1*. 2nd Edn. Orient Longman: 118-122.
- Hodge, S. and Osman, M. (1976) *Food Chemistry*. Marcel Dekker, New York, USA.
- Hoover, R. (2001). Composition, molecular structure and physicochemical properties of tuber and root starches. *Carbohydrate polymers*. **45**: 253-267.
- Hoover, R. and Hadziyev, D. (1981) The effect of monoglycerides on amylose complexing during a potato granule process. *Starch/Stärke*. **33**: 346-355.
- Hsu, C. L., Chen, W., Weng, Y. M. and Tseng, C. Y. (2003) Chemical composition, physical properties, and antioxidant activities of yam flours as affected by different drying methods. *Food Chemistry*. **83**: 85–92.
- Huang, A. S. and Hollyer, J. Manufacturing of acidity free raw flour from Araceae tubers. Patent number- 5,464,646. Date of patent November 7, 1995.
- Huang, A. S., Lam, S. Y., Nakayama, T. M. and Hui Lin. (1994) Microbiological chemical changes in poi stored at 20°C. *Journal of Agriculture and Food Chemistry*. **42**: 45-48.
- Indian Standard. (1981) *Hand book of food analysis: Dairy products* (IS: 18, Part XI), Manak Bhawan, New Delhi.
- Indian Standard. (1984). *Hand book of food analysis: Edible starches and starch products* (IS: 18, Part III), Manak Bhawan, New Delhi.
- Iwuoha, C. I. and Kalu, F. A. (1995) Calcium oxalate and physico-chemical properties of cocoyam (*Colocasia esculenta* and *Xanthosoma sagittifolium*) tuber flours as affected by processing. *Food chemistry*. **54**: 61-66.
- Janick, J. (1981) *Plant science: an introduction to world crops* (3rd ed.). W.H. Freeman and Co., San Francisco, CA, USA.

- Jimoh, K. O., Olurin, T. O. and Aina, J. A. (2009) Effect of drying methods on the rheological characteristics and colour of yam flours. *African journal of biotechnology*. **8(10)**: 2325-2328.
- Judprasong, K., Charoenkaiikul, S., Sungpang, P., Vasanachitt, K., and Nakjamanong, Y. (2006) Total and soluble oxalate contents in Thai vegetables, cereal grains and legume seeds and their changes after cooking. *Journal of Food Composition and Analysis*.**19**: 340-347.
- Kay, D. E. (1987) In Rev. Gooding, E. G. B. *Crop and Product Digest no.2 Root crops* ed.2 Tropical Development and Research Institute, London.**15**. pp.380
- Kay, D.E. (1973) Root crops. Tropical Products Institute, London, U.K. Crops and Products Digest 2.
- Keating, R.C. (2003) Anatomy of the Monocotyledons. IX. Acoraceae and Araceae. Series eds. Gregory, M. and Cutler, D. F. Oxford University Press, Oxford, UK.
- Keating, R.C. (2004) Systematic occurrence of raphide crystals in Araceae. *Annals of the Missouri Botanical Garden*. **91**: 495–504.
- Keogh, M. K. and O’Kennedy, B. T. (1998) Rheology of stirred yogurt as affected by added milk fat, protein and hydrocolloids. *Journal of Food Science*. **63(1)**: 108-112.
- Khan, A., Rahman, M. and Islam, M. S. (2008) Antibacterial, antifungal and cytotoxic activities of Amblyone isolated from *Amorphophallus campanulatus*. *Indian J Pharmacol*. **40(1)**: 41-44.
- Kim, N. Y., Joon, S. J. and Jang, S. M. (1993) Effect of blanching on the chemical properties of different kinds of spinach. *J Korean Soc Food Sci*. **9**: 204-209.
- Kirby, A. R., Ollett, A. L., Parker, R., & Smith, A. C. (1988) An experimental study of screw configuration effects in the twin screw extrusion cooking of maize flour grots. *Journal of Food Engineering*. **8**: 247–272.
- Kirtikar, K. R. and Basu, B. D. (1994) Indian Medicinal Plants, Dehra Dun Publisher Ltd. India. Vol. 4, 2nd ed. pp. 2609-2610.

- Kirtikar, K.R., Basu, B.D. (1935) Indian Medicinal Plants, vols. 1–4. Lalit Mohan Basu, Allahabad, India.
- Kohyama, K. and Nishinari, K. (1991) *Journal of Agricultural Food Chemistry*. **39**: 1406-1410.
- Kostman, T. A. and Franceschi, V. R. (2000) Cell and calcium oxalate crystal growth is coordinated to achieve high-capacity calcium regulation in plants. *Protoplasma*. **214**: 166–179.
- Kumar, S., Nath, V. and Das, B. (2004) Priorities of Horticulture Development in Jharkhand. In Sarkar, A.K. ed., *Sustainable development of horticultural crops*, Proceedings of State level Workshop held from September, 27-October, 1, 2004. SAMETI, Ranchi, Jharkand.
- Lagarrigue, S. and Alvarez, G. (2001) The rheology of starch dispersions at high temperatures and high shear rates: a review. *Journal of Food Engineering*. **50**: 189–202.
- Lai, V. M.-F. and Lii, C. Y. (2004) Role of saccharides in texturization and functional properties of foodstuffs. In P. Tomasik (Ed.), *Chemical and functional properties of food saccharides* (pp. 159–179). Boca Raton: CRC Press
- Leach, H. W. (1965). Gelatinization of starch. In: *Starch: Chemistry and Technology*. Whistler, R. L. and Paschall, E. F. (eds.). Academic Press. New York, USA. pp. 289-307.
- Lebot, V. (2009) Tropical root and tuber crops: cassava, sweet potato, yams and aroids. In Atherton, J. and Rees, A. eds., *Crop Production Science in Horticulture series*. CABI, Oxford
- Lelievre, J. and Husbands, J. (1989) *Starke*. **41**: 236-238.
- Lewicki, P. P. (2006) Design of hot air drying for better foods. *Trends in Food Science and Technology*. **17**: 153–163.
- Liu, Q. (2005) Understanding starches and their role in foods. In *food carbohydrates chemistry, physical properties and application*. Taylor & Francis Group, LLC. pp. 347
- Mais, A. and Brennan, C. S. (2008) Characterization of flour, starch and fibre obtained from sweet potato (Kumara) tubers and their utilization in biscuit

- production. *International journal of food science and technology*. **43**: 373-379
- Matser, A. T. and Steeneken, P. A. M. (1997) Rheological properties of highly cross-linked waxy maize starch in aqueous suspensions of skim milk components. Effects of the concentration of starch and skim milk components. *Carbohydrate Polymers*. **32**: 297-305.
- Mayo, S. J., Bogner, J. and Boyce, P. C. (1997) The genera of Araceae. Kew Publishing, Kew, London.
- Mehdi, G. D., Vijayanand, P., Kulkarni, S. G. and Ramana, K. V. R. (2007) Effect of different pretreatment and dehydration methods on quality characteristics and storage stability of tomato powder. *Food science and technology*. **40**: 1832-1840.
- Mercier, C., & Feillet, P. (1975) Modification of carbohydrate components by extrusion cooking of cereal products. *Cereal Chemistry*. **52**: 283–297.
- Montesinos-Herrero, C., Cottell, D. C., O’Riordana, E. D. and O’Sullivan, M. (2006) Partial replacement of fat by functional fibre in imitation cheese: effects on rheology and microstructure. *International Dairy Journal*. **16(8)**: 910-919.
- Moorthy, S. N. (2002) Physicochemical and functional properties of tropical tuber starches: A review. *Starch/Starke*. **54**: 559-592.
- Moorthy, S. N., Unnikrishnan, M. and Lakshmi, K. R. (1994) Physicochemical properties of some accessions of *Amorphophallus paeoniifolius*. *Tropical Science*. **34**: 371-376.
- Morris, E. R. (1990) Mixed polymer gels. In P. Harris (Ed.), *Food gels* (pp. 291). London: Elsevier Applied Science
- Mounsey, J. S. and O’Riordan, E. D. (2001) Characteristics of imitation cheese containing native starches. *Journal of Food Science*. **66(4)**: 586-591.
- Mounsey, J. S. and O’Riordan, E. D. (2008c) Influence of pre-gelatinised maize starch on the rheology, microstructure and processing of imitation cheese. *Journal of Food Engineering*. **84(1)**: 57-64.

- Mounsey, J. S. and O’Riordan, E. D. (2008d) Modification of imitation cheese structure and rheology using pre-gelatinised starches. *European Food Research and Technology*. **226(5)**: 1039-1046.
- Moy, J. H., Shadbolt, B., Stoewsand, G. S. and Nakayama, T. O. M. (1979) The acidity factor in taro processing. *Journal of Food Processing and Preservation*. **3**: 139-144.
- Muir, D. D., Hunter, E. A. and West, I. G. (1991) Optimization of the properties of dried skim milk for use in white sauce suitable for use with frozen products. *Journal of the Society of Dairy Technology*. **44**: 20–23.
- Murthy, G. N, Bhagavan, B. V. K., Ramanandam, G., Babu Ratan, P., Madhava Rao, D., Reddy, R. V. S. K. and Suryanarayana Reddy, P. (2008) *Amorphophallus* (var. *Gajendra*) in Andhra Pradesh. In Palaniswami, M.S. *et al.*, ed., National Seminar on *Amorphophallus*: innovative technologies, July 19-20, 2008, Patna, Bihar-abstract book, status papers and extended summary. pp.51-54.
- Narayana, K., & Narasinga Rao, M. S. (1982) Functional properties of raw and processed winged bean (*Psodocarpus tetragonolobus*) flours. *Journal of Food Science*. **47**: 1534–1538.
- Nayak, S. K., Makrariya, A., Singh, R. R. B., Patel, A. A., Sindhu, G. S., and Patil, G. R. and Priyanka Tomar. (2004) Heat stability and flow behaviour of buffalo milk added with corn starch. *Food Hydrocolloids*. **18**: 379–386.
- Nayouf, M., Loisel, C. and Doublier, J. L. (2003) Effect of thermomechanical treatment on the rheological properties of crosslinked waxy corn starch. *Journal of Food Engineering*. **59**: 209-219.
- Newport Scientific (1998) Applications manual for the Rapid visco™ analyzer Using thermocline for windows. Newport Scientific Pty Ltd., 1/2 Apollo Street, Warriewood NSW 2102, Australia. pp. 2-26.
- Njintang, N. Y., Mbofung, C. M. F., & Waldron, K. W. (2001) In vitro protein digestibility and physicochemical properties of dry red bean flour (*Phaseolus vulgaris*) flour: Effect of processing and incorporation of

- soybean and cowpea flour. *Journal of Agricultural and Food Chemistry*. **49**: 2465–2471.
- Njintang, Y. N. and Mbofung, C. M. F. (2003) Development of taro (*Colocasia esculenta* (L.) Schott) flour as an ingredient of food processing: effect of gelatinization and drying temperature on the dehydration kinetics and colour of flour. *Journal of food engineering*. **58**: 259-265.
- Njintang, Y. N. and Mbofung, C. M. F. (2006) Effect of precooking time and drying temperature on the physico-chemical characteristics and in-vitro carbohydrate digestibility of taro flour. *LWT*. **39**: 684–691.
- Noisuwan, A., Hemar, Y., Bronlund, J. E., Wilkinson, B. and Williams, M. A. K. (2007) Viscosity, swelling and starch leaching during the early stages of pasting of normal and waxy rice starch suspensions containing different milk protein ingredients. *Starch-Stärke*. **59(8)**: 379-387.
- Oh, H. E., Anema, S. G., Wong, M., Pinder, D. N. and Hemar, Y. (2007) Effect of potato starch addition on the acid gelation of milk. *International Dairy Journal*. **17**: 808-815.
- O'Hair, S. (1990) Tropical Root and Tuber Crops. In: *Advances in new crops*, J. Janick and J. E. Simon (eds.). Timber Press, Portland, U. S. A. pp. 424-428.
- Paull, R. E., Tang, C. S., Gross, K. and Uruu, G. (1999) The nature of the taro acidity factor. *Postharvest Biology and Technology*. **16**: 71–78.
- Perry, P. A. and Donald, A. M. (2002) The effect of sugars on the gelatinisation of starch. *Carbohydrate Polymers*. **49**: 155–165.
- Pomeranz, Y. (1991) Carbohydrates: starch. In: *Functional Properties of Food Components*. 2nd ed. Academic Press, San Diego, CA, pp. 24–77
- Quinteros, A., Farre, R. and Lagarda, M. J. (2003) Effect of cooking on oxalate content of pulses using an enzymatic procedure. *International Journal of Food Sciences and Nutrition*. **54**: 373–377.
- Ragae, S., El-Sayed, M. and Abdel-Aal. (2006) Pasting properties of starch and protein in selected cereals and quality of their food products. *Food Chemistry*. **95**: 9–18.

- Ramalingam, R., Bindu K. H., Madhavi, B. B., Nath, A. R. and Banji, D. (2010) Phytochemical and anthelmintic evaluation of corm of *Amorphophallus campanulatus*. *International Journal of Pharma and Biosciences*. **1(2)**: 1-9.
- Ravi, V., Ked, J. and Balagopalan, C. (1996) Review on Tropical Root and Tuber. In: *Critical Reviews .Food Science and Nutrition*. **36(7)**: 360-730.
- Rickard, J. E., Asoako, M. and Blanshard, J. W. V. (1991) The Physicochemical properties of cassava starch. *Tropical Science*. **31**: 189-207.
- Rodriguez-Sosa, E. J., Parsi-Ros, O. and Gonzalez, M. A. (1981) Effect of pH on pasting properties of Habanero yam starch. *J. Agric. Univ. Puerto Rico*. **65**: 154-159.
- Ross, Y. H. (1992) Transitions and Transformations in Food systems. In D. R. Heldman, & D. B. Lund (Eds.), *Handbook of food engineering* (pp. 145–197). New York: Marcel Dekker, Inc
- Sajeev, M. S., Sheriff, J. T. and Jyothi, A. N. (2010) Process technology for the production of dehydrated quick cooking tubers. Annual report 2009-2010. pp. 76-78. Central Tuber Crops Research Institute, Trivandrum, Kerala, India.
- Sakai, W. S., Hanson, M. and Jones, R. C. (1972) Raphides with barbs and grooves in *Xanthosoma sagittifolium* (Araceae). *Science*. **178**: 114–115.
- Sankaran, M., Singh, N. P., Chander Dutt, Santhosh, B., Nedunchezian, M. and Ngachan, S. V. (2008b) Morphological and proximate composition of *Amorphophallus muelleri* Blume. *Indian Journal of Root Crops*. **34(1)**
- Savage, G. P., Vanhanen, L., Mason, S. M. and Ross, A. B. (2000) Effect of cooking on the soluble and insoluble oxalate content of some New Zealand foods. *Journal of Food Composition and Analysis*. **13**: 201–206.
- Savage, H. L. and Osman, E. M. (1978) *Cereal Chemistry*. **55**: 447-454.
- Sefa-Dedeh, S. and Agyir-Sackey, E. K. (2004) Chemical composition and the effect of processing on oxalate content of cocoyam *Xanthosoma sagittifolium* and *Colocasia esculenta* cormels. *Food Chemistry*. **85**: 479–487.
- Sengupta, S., Chowdhary, B. M., Singh, B. N. and Ray R. N. (2008) Status of elephant foot yam cultivation in Jharkhand. In Palaniswami, M. S. *et al.*

- ed., National Seminar on *Amorphophallus*: innovative technologies, July 19-20, 2008, Patna, Bihar-abstract book, status papers and extended summary. pp.30-34
- Seow, C. C. and Teo, C. H. (1996) Staling of starch-based products: a comparative study by firmness and pulsed NMR measurements. *Starch/Stärke*. **48**(3): 90-93.
- Severini, C., Baiano, A., Teresa, D. P., Carbone, B. F. and Derossi, A.(2005) Combined treatments of blanching and dehydration: study on potato cubes. *Journal of food engineering*. **68**: 289–296.
- Sharma, S. K. (1998) Medicinal Plants Used in Ayurveda. National Academy of Ayurveda, Ministry of Health and Family Welfare, Govt. of India, New Delhi, India.
- Shastry, R. A, Mhadevan, K. M., Habbu, P. V., Joshi, H. and Das, S. K. (2008) *Natural Products*. **4**(1): 55-56.
- Sheen, L. Y. (1990) Studies of microcapsules of essential oils of basil, garlic, and ginger. PhD dissertation, Graduate Institute of Food Science, National Chung-Shin University, Taiwan.
- Sikora, M., Kowalski, S., Tomasik, P. and Sady, M. (2007) Rheological and sensory properties of dessert sauces thickened by starch–xanthan gum combinations. *Journal of Food Engineering*. **79**: 1144–1151.
- Singh, J., Gupta, C. R., Deo Shankar and Patel, D. (2008) Status of *Amorphophallus* in Chhattisgarh. In Palaniswami, M.S. et al. ed., National Seminar on *Amorphophallus*: innovative technologies, July 19-20, 2008, Patna, Bihar-abstract book, status papers and extended summary. pp.51-54
- Singh, N., Singh, J., Kaur, L., Sodhi, N. S. and Gill, B. S. (2003) Morphological, thermal and rheological properties of starches from different botanical sources: A review. *Food Chemistry*, **81**, 219–231.
- Singh, P. P., Singh, C. P., Chaudhary, B. C. and Singh, J. R. P. (2008) Status of elephant foot yam cultivation in Bihar. In Palaniswami, M.S. et al. ed., National Seminar on *Amorphophallus*: innovative technologies, July 19-20,

- 2008, Patna, Bihar-abstract book, status papers and extended summary. pp.19-24
- Spies, R. D. and Hoseneey, R. C. (1982) *Cereal Chemistry*. **59**: 128-131.
- Srichuwong, S., Sunarti, T. C., Mishima, T., Isono, N. and Hisamatsu, M. (2005) Starches from different botanical sources II: Contribution of starch structure to swelling and pasting properties. *Carbohydrate polymers*, **62**: 25–34.
- Sundaresan, S. (2005) Acridity of edible aroids. Technical bulletin series: 38. CTCRI. Thiruvananthapuram, Kerala, India
- Sundaresan, S. and Nambisan, B. (2008) Acridity of *Amorphophallus* and the processing methods for its application. In Palaniswami, M.S. et al. ed., National Seminar on *Amorphophallus*: innovative technologies, July 19-20, 2008, Patna, Bihar-abstract book, status papers and extended summary. pp. 194-195
- Tagodoe, A., & Nip, W. K. (1994) Functional properties of raw and precooked taro (*Colocasia esculenta*) flours. *International Journal of Food Science and Technology*. **29**: 457–462.
- Tarrega, A., Velez-Ruiz , J. F. and Costell, E. (2005) Influence of milk on the rheological behaviour of cross-linked waxy maize and tapioca starch dispersions. *Food Research International*. **38**: 759–768.
- Tecante, A. and Doublier, J. L. (1999) Steady flow and viscoelastic behavior of crosslinked waxy cornstarch-k-carrageenan pastes and gels. *Carbohydrate Polymers*. **40**: 221–231.
- Terry, E. R., Akoroda, M. O. and Arene, O. B. (1986) Tropical root crops- Root crops and the African food crisis. Proceedings of the third triennial symposium of the International Society for Tropical Root Crops- Africa branch. Owerri, Nigeria. 17-23 August. pp. 9.
- Thebaudin, J. Y., Lefebvre, A. C., & Doublier, J. L. (1998) Rheology of starch pastes from starches of different origins: applications to starch-based sauces. *Lebensmittel Wissenschaft und Technologie*, **31**: 354–360.

- Toma, R. B., Tabekhia, M. M. and Williams, J. D. (1979) Phytate and oxalate contents in sesame seed (*Sesamum indicum L.*) *Nutr Reports Int.* **20**:25-31
- Tziboula, A. and Muir, D. D. (1993a) Effect of starches on the heat stability of milk. *International Journal of Food Science and Technology.* **28**: 13–24.
- Tziboula, A. and Muir, D. D. (1993b) Milk protein–carbohydrate interactions. *International Dairy Journal.* **3**: 209–223.
- Utomo, J. S., Cheman., Y. B., Rahman, R.A. and Sadd., M. S. (2008) The effect of shape, blanching methods and flour on characteristics of restructure sweet potato stick. *International journal of food science and technology.***43**: 1896-1900.
- van de Velde, F., van Riel, J. and Tromp, R. H. (2002) Visualisation of starch granule morphologies using confocal scanning laser microscopy (CSLM). *Journal of the Science of Food and Agriculture.* **82(13)**:1528–1536.
- van de Velde, F., Weinbreck, F., Edelman, M. W., van der Linden, E. and Tromp, R. H. (2003) Visualisation of biopolymer mixtures using confocal scanning laser microscopy (CSLM) and covalent labeling techniques. *Colloids and Surfaces B-Biointerfaces.* **31(1–4)**: 159–168.
- Ve'lez-Ruiz, J. F. and Barbosa-Ca'novas, G. V. (1997) Rheological properties of selected dairy products. *Critical Reviews of Food Science and Nutrition.* **37**: 311–359.
- Verbeken, D., Baela, K., Thasb, O. and Dewettincka, K. (2006) Interactions between k-carrageenan, milk proteins and modified starch in sterilized dairy desserts. *International Dairy Journal.* **16**: 482–488.
- Verbeken, D., Thas, O. and Dewettincka K. (2004) Textural properties of gelled dairy desserts containing k-carrageenan and starch. *Food Hydrocolloids* **18**: 817–823.
- Vu Dang, H., Loisel, C., Desrumaux, A. and Doublier, J. L. (2009) Rheology and microstructure of cross-linked waxy maize starch/whey protein suspensions. *Food Hydrocolloids.* **23(7)**: 1678-1686.

- Wanasundera, J. P. D. and Ravindran, G. (1992) Effects of cooking on the nutrient and antinutrient content of yam tubers (*Dioscorea alata* and *Dioscorea esculenta*). *Food Chemistry*. **45**: 247-250.
- Wankhede, D. B. and Sajjan, S. U. (1981) Isolation and physico-chemical properties of starch extracted from yam, elephant (*Amorphophallus campanulatus*). *Starch/Starke*. **33(5)**: 153-157.
- Watanabe, T. (1981) Traditional techniques in Japan for food preservation by freezing, thawing and drying. In *Water activity: influences on food quality*. L. B. Rockland and G. F. Stewart eds. Academic Press, New York, U. S. A. pp. 733-742
- Wiley, R. C. (1994) *Minimally Processed Refrigerated Fruits & Vegetables*, New York, Chapman and Hall
- Willett, J. L., Jasberg, B. K. and Swanson, C. L. (1995) Rheology of thermoplastic starch: effects of temperature, moisture content, and additives on melt viscosity. *Polymer Engineering and Science*. **35**: 202–210.
- Williams, R. P. W., Glagovskaia, O. and Augustin, M. A. (2003) Properties of stirred yogurts with added starch: effects of alterations in fermentation conditions. *Australian Journal of Dairy Technology*. **58(3)**: 228-232.
- Wischmann, B., Norsker, M. and Adler-Nissen, J. (2002) Food product models developed to evaluate starch as food ingredient. *Nahrung/ Food*. **46**: 167–173.
- Yesodharan, K. and Sujana, K. A. (2007) Wild edible plants traditionally used by the tribes in the Parambikulam Wildlife Sanctuary, Kerala, India. *Natural Product Radiance*. **6(1)**: 74-80.

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# Appendix

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**Score card for sensory evaluation of Elephant foot yam**

Please rate the samples for sensory attributes according to the 9-point hedonic scale.

**HEDONIC SCALE**

|                            |   |
|----------------------------|---|
| Liked extremely            | 9 |
| Liked very much            | 8 |
| Liked moderately           | 7 |
| Liked slightly             | 6 |
| Neither liked nor disliked | 5 |
| Disliked slightly          | 4 |
| Disliked moderately        | 3 |
| Disliked very much         | 2 |
| Disliked extremely         | 1 |

| Characteristics       | Sample No. |   |   |   |
|-----------------------|------------|---|---|---|
|                       | 1          | 2 | 3 | 4 |
| Colour and Appearance |            |   |   |   |
| Body and Texture      |            |   |   |   |
| Flavour               |            |   |   |   |
| Acridity/Irritation   |            |   |   |   |
| Overall Acceptability |            |   |   |   |

REMARKS:

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Signature:  
 Name: ( )

### Sensory evaluation card for Yam-milk mix as a dessert base

[Please evaluate the given samples for colour (*degree of whiteness*), flavour (*degree of blandness*), mouthfeel (*degree of smoothness*), consistency (*degree of thickness*) and overall acceptability using the respective linear scales given below. Kindly make a “vertical mark” along the scale and give sample number to indicate the attribute intensity.]

- 1) First, pour out the sample into a beaker and look for the **Sediment**

Nil                      Slight                      Definite                      Pronounced                      Extremely heavy

- 2) Next, mix the sample by pouring back into the sample container and stir it. Judge its **colour** and **consistency (viscosity)**

**a. Colour**

Absolutely white      Light yellow (creamish white)      Moderately dark (yellow)      Definitely dark (yellowish brown)      Extremely dark (brown)

**b. Consistency (Viscosity)**

Very Thin (like skim milk)      Thin (like milk)      Slightly thick (like thin cream)      Moderately thick (like SCM)      Definitely thick (honey like)

- 3) Finally, take a sip of the sample and judge its flavour and mouth feel

**a. Flavour**

Bland                      Slightly off flavour                      Moderate off flavour                      Definite off flavour                      Intense off flavour

**b. Mouthfeel**

Extremely smooth                      Slightly grainy                      Moderately grainy                      Definitely grainy                      Extremely grainy

- 4) **Overall acceptability**

Dislike very much                      Dislike moderately                      Neither like nor dislike                      like moderately                      like very much

Signature