

## THE FUNCTIONAL PROPERTIES OF FOODS AND FLOURS

Awuchi, Chinaza Godswill<sup>a,b</sup>; Igwe, Victory Somtochukwu<sup>b</sup> and Echeta, Chinelo Kate<sup>b</sup>

<sup>a</sup>Department of Physical Sciences, Kampala International University, Kampala, Uganda.

<sup>b</sup>Department of Food Science and Technology, Federal University of Technology Owerri, Imo State, Nigeria.

### Abstract

The research focused on functional properties of foods and flours; swelling capacity, swelling index, water absorption capacity, oil absorption capacity, emulsion capacity, emulsion stability, foaming capacity, foam stability, gelatinization capacity and temperature, bulk density, dextrinisation, aeration, solubility, and gelation capacity and temperature. Functional properties explain how food ingredients behave during the preparation and cooking, how they impact the finished food products in terms of appearance, texture, structure, and tastes. The functional properties of foods and flours are influenced by the components of the food material, especially the carbohydrates, proteins, fats and oils, moisture, fibre, ash, and other ingredients or food additives added to the food (flour), as well as the structures of these components. Each ingredient used in a food has a specific function, which often impact the functional property of the food. Most of the processes foods undergo initiate the onset of some functional properties. Functional properties are unique quality attributes of foods and food products. Functional properties are among the major quality attributes of foods and flours for infant formulations, preteens, teens, and adult foods.

**Keywords:** Functional properties, swelling, water absorption, oil absorption, emulsion, foaming, gelatinization, bulk density, dextrinisation, aeration, solubility, gelation.

## 1. Introduction

Functional properties are the essential physicochemical properties of foods that reflect the complex interactions between the structures, molecular conformation, compositions, and physicochemical properties of food components with the nature of the environment and conditions in which these are measured and associated (Suresh and Samsher, 2013; Kaur and Singh, 2006; Siddiq et al., 2009). Functional characteristics are required to possibly help to predict and precisely evaluate how new proteins, fat, carbohydrates (starch and sugars), and fibre may behave in specific food systems as well as demonstrate whether or not such can be used to stimulate or replace conventional protein, (Suresh and Samsher, 2013; Kaur and Singh, 2006; Siddiq *et al.*, 2009) fat, carbohydrates (starch and sugars), and fibre.

Functional properties also describes the behavior of ingredients during preparation and cooking, as well as how they affect the finished food products in terms of how it looks, feels and tastes. Functional properties include Swelling capacity, water absorption capacity, oil absorption capacity, Emulsion activity, Emulsion stability, Foam capacity, Foam stability, Gelatinization, Bulk density, Dextrinisation, Preserving, Denaturation, Coagulation, Gluten formation, Jelling, Shortening, Plasticity, Flakiness, Retention of moisture, Aeration, Sensory attributes, among others.

The functional property of a food is characterized by the structure, quality, texture, nutritional value, acceptability, and (or) appearance of the food product. Functional property of a food is often determined by the organoleptic, physical, and/or chemical properties of the food. Further examples of functional properties of foods and flour include solubility, water retention, frothing ability, elasticity, absorptive capacity for fat and foreign particles, emulsification, hydration (water binding), viscosity, cohesion, and adhesion(Suresh and Samsher, 2013).

The functional properties of foods and flours are influenced by the components of the food material, especially the carbohydrates, proteins, fats and oils, moisture, fibre, ash, and other ingredients or food additives added to the food (flour), such as sugar alcohols (Awuchi, 2017; Awuchi and Echeta, 2019), as well as the structures of these components. Mycotoxins such as patulin in grains may also affect the functional properties of flours (Awuchi *et al.*, 2019). Each ingredient used in a food has a specific function, e.g. starch (flour) is mainly used to thicken food mixtures, and also form bulk of foods; sugars add flavour and help with the food browning; eggs can act as an emulsifier, thickener, and foaming agent; Fats and oils play significant roles in food aeration, emulsions, shortening, etc. Functional properties are very critical to the quality of food. Starch is mainly responsible for the gelatinization, browning, dextrinisation, gelation, etc. Protein is mainly responsible for the foaming, browning, emulsification, coagulation, denaturation, etc. Fat is majorly responsible for emulsification, aeration, shortening, among others. Although two or more constituents may have the same influence, and one may also have a minor influence on a functional property.

Most of the processes foods undergo initiate the onset of some functional properties. For example, heating. Starch granules do not dissolve in cold liquid, they rather form a suspension. The starch granules sink to the bottom, if the liquid isn't stirred, and stick together forming lumps. But when heated in a liquid (such as water), starch gradually swell and further gelatinize; at 60°C, the starch granules start to absorb the liquid and swell; by the time the temperature reaches 80°C, the granules would have absorbed 5 times their volume until they burst open, freeing starch into the liquid, initiating gelatinization; gelatinisation is completed as soon as the liquid (water) reaches 100°C. When the paste cools, it gets thicker, setting into gel. When foods containing starch are exposed to dry heat, dextrinization occurs, leading to the

formation of dextrans, which makes the food turn brown and become sweeter. When proteins are subjected to pH extremes, alcohol, heat, or mechanical actions (e.g. whipping or beating), they are irreversibly denatured. Denaturation is a process in which the structure of protein is permanently disrupted, resulting in complete or partial loss of its function. Frying has been reported to affect the refractive index of oils (Awuchi *et al.*, 2018)

The research focused more on the common functional properties of food and the biochemistry, mechanisms, and the physical links between the functional properties of foods and flours and the food components such as starch, protein, fats and oils, moisture, sugars, etc. The research will be valuable to food industries, researchers, food chemists, comestible handlers, flour industries, nutritionists, and policymakers.

## **2. Functional Properties of foods and flours**

### **2.1. Gelatinization capacity and gelatinization temperature**

Gelatinization is a process of breaking down intermolecular bonds of starch molecules in the presence of heat and water, allowing the hydrogen bonding sites (hydroxyl hydrogen and oxygen) to absorb more water. This causes the starch granule to irreversibly dissolve in the water. Water functions as a plasticizer. As soon as starch granules are heated in liquid like water, they absorb the liquid, then swell and rupture, leading to increase in viscosity (stickiness) of the starch. Finally, the mixture is thickened. As required, the mixture must be stirred gradually as it is being heated to prevent the forming of lumps and also helps to ensure thorough and uniform consistency.

The starch granules pass through three main processes: the granule swelling, the crystal or double helical melting, and the amylose leaching.

- During heating, the molecules of water are first absorbed in the amorphous inter-space of starch, leading to swelling of the starch granules (Jenkins and Donald, 1998), usually happens at approximately 60°C.
- Water then enters through the amorphous regions to the tightly bound areas of the double helical structures of amylopectin of the starch. These crystalline regions do not allow water entering at ambient temperatures. Heat causes such regions to be diffused, the amylose chains start to dissolve, separating into an amorphous form and the size and number of crystalline regions decrease. After this, under the microscope in a polarized light, starch loses its extinction cross and its birefringence (Zobel, 1988).
- Penetration of water therefore increases the randomness in the structure of the starch granule, causing swelling; amylose molecules eventually leach into the surrounding water and the structure of the granule disintegrates.

Gelatinization temperature is the temperature at which the gelatinization of starch takes place. The gelatinization temperature of starch depends on the plant type and amount of water present, pH, salt concentration and types, sugar, protein, and fat in the recipe, as well as the starch derivatization technology used. Some type of unmodified native starches begin swelling at 55 °C, some other types at 85 °C (Hans-Dieter *et al.*, 2004). The gelatinization temperatures of modified starch depend on the degree of cross-linking, acetylation, or acid treatment. Gel temperature can be modified by the genetic manipulation of the starch synthase genes (Robert and Daniel, 2008). Also, gelatinization temperature depends on the amount of the damaged starch granules; will swell faster. Damaged starch granules can be produced, for instance, during the milling process of wheat, drying the starch cake in the starch plant, etc. (Stanley and Linda, 2001). There is inverse correlation between glycemic index and gelatinization

temperature (Robert and Daniel, 2008). High amylose starches require additional energy to break up the bonds to gelatinize into starch molecules.

Starch gelatinization improves and increases the availability of starch for hydrolysis by amylase. Gelatinization of starch is constantly used in cooking and food industries to make starch digestible and also to thicken/bind water in sauce, soup, and roux.

Factors influencing gelatinization are types of starch, stirring, water, temperature, addition (presence) of other ingredients, such as protein, sugar, acids, fat, etc. Starch from different sources differs in the thickening and water-binding ability. Starch with more amylopectin often has higher thickening ability. The root starches are generally more effective than cereal starches. The potato starch is most effective as thickening agent, while wheat starch is the least effective as thickening agent. Sugars compete with starch for water, thus delays gelatinization and raise the final temperature required to achieve gelatinization. Fats and protein delay gelatinization by coating the starch, preventing it from absorbing water, resulting in less granular swelling and leading to reduced viscosity of the starch paste. The hydrophobic and waterproof fat molecules coating the flour components such as starch granules decrease their interaction with water, reduce absorption of water and decrease gelatinization. Acids, such as from vinegar, wine, and lemon juice affect gelatinization. The combination of heat and acid causes the hydrolysis (breakdown) of starch molecules into marginally smaller molecules. The hydrolysis of the starch molecules causes the resulting gelatinized starch paste to be thinner. The acid effect can be minimized by e.g. the acid should be added after gelatinization is completed in order to avoid the thinning caused by acid; secondly, when thickening fruit juice for pie filling, rapid heating rate will minimize the effect of acid on the starch and result in a more thicker product.

When gelatinized starch is allowed to cool for a long enough period (often hours or days), the starch molecules gel (or thicken) and rearrange itself once again to a more crystalline structure, usually expelling water; the process is known as retrogradation. The process of expelling (separating) the water from the gel is called “syneresis”, also spelt “synaeresis”. During cooling, molecules of starch gradually aggregate to form gel. The following molecular associations usually occur: amylose-amylose, amylopectin-amylopectin, and amylose-amylopectin. A mild association among chains comes together with water remaining embedded in the molecule network.

Owing to the strong associations of hydrogen bonding, the longer amylose molecules (and starch that has a higher amylose content) form a stiff gel (Hegenbart, 1996). Molecules of amylopectin with longer branched structure (that makes them more related to amylose), increases the propensity to form strong gels (or thickeners). High amylopectin starches often have stable gels, but softer than the high amylose gels. Retrogradation limits the availability for the occurrence of amylase hydrolysis, which in turn reduces the starch digestibility.

Pregelatinized starch is starch which is cooked and then dried in starch factory in an extruder or on a drum dryer making the starch cold-water-soluble. The spray dryers are often used to obtain low viscous pregelatinized starch powder and dry starch sugars.

Brabender Viscoamylograph is simple technique used to study starch gelation. It is a common technique used in the food industries to determine the swelling capacity, pasting temperature, the extent of retrogradation, and shear/thermal stability. Under controlled conditions, distilled water and starch is heated at constant heating rate in rotating bowl and then cooled. The mixture’s viscosity deflects measuring sensor in the bowl. The deflection is measured as the viscosity in torque over time against temperature and recorded on the computer. Viscoamylograph provides the audience with info on the beginning of gelatinization,

gelatinization temperature, gelatinization maximum, viscosity at the end of cooling, and viscosity during holding.

Differential scanning calorimetry (DSC) is one more method used by industries to evaluate the properties of gelatinized starch. As the water is heated with starch, gelatinization occurs, in an endothermic reaction. The gelatinization initiation is known as the T-onset. The T-peak is the point where the endothermic reaction occurs at maximum. The T-conclusion is when all the granules of starch are fully gelatinized and the curve maintains stability.

## **2.2 Dextrinization**

Dextrinization is the gradual breakdown of molecules of starch to smaller, sweeter-tasting molecules (called dextrans) by dry heat such as toasting or baking. Dextrinization increases the digestibility of starch. Starch is contained in many staple foods and is the most common carbohydrate in human diet. The major sources of starch intake globally are the cereals (rice, maize, wheat, etc.) and the root vegetables (cassava and potatoes). If subjected to dry heat, starch is broken down to form dextrans, also known as pyrodextrans in this context. The break down process is called dextrinization. Pyrodextrans are mostly yellow to brown in color and the dextrinization is partially contributes to the browning of toasted bread (Judith, 2013). Dextrinization gives a golden colour and crisp texture to toasted bread and crust of cakes and biscuits. Dextrans composed completely of glucose units linked together by glycosidic bond; the length of the chain is distinctly shorter than that of starch. Dextrans are more soluble and digestible than starch, and have less thickening ability. Also, dextrans are produced when starch is broken down by the enzymes in saliva.

The formation of brown crust on the surface of baked potatoes and bread is partly caused by dextrinization. The browning of starchy foods when cooked in dry heat, e.g. brown gravies, sauces, toasting bread, baked goods, etc. is partly caused by dextrinization. Always, browning occurs on the bread surface when toasted. Toasting breaks down the amylose and amylopectin in the starch. The resulting dextrans make toast to have sweeter taste than the original bread itself. The browning of toasted bread and other foods are also results of one or more of the following caramelisation, Maillard reaction, enzymatic browning, etc. Caramelisation and Maillard reaction also contribute to browning in baked foods, such as bread. Browning is a quality attribute of some foods.

## **2.3. Foaming Capacity (FC) and Foam Stability**

The foaming capacity of a food or flour is measured as the amount of interfacial area created by whipping the food or flour. Foam stability is a measured of the time required to lose either 50 percent of the liquid or 50 percent of the volume from the foam (Mauer, 2003). Protein is mainly responsible for foaming. Foaming capacity and stability generally depend on the interfacial film formed by the proteins, which maintains the suspension of air bubbles and slows down the coalescence rate. Egg whites form foams larger in volume than egg yolks due to the unique proteins in the egg white. In fact, when discussing egg products in the food industry, even though the word foam technically refers to any food system where there are entrapped air bubbles, the term tends to be largely exclusive to egg white foams (Cousminer, 2017).

Generally, heating globular protein to accomplish partial denaturation will increase the foaming properties. As the structure gradually unfolds and exposes hydrophobic sites and tails, it may adsorb more rapidly to air–water interfaces and reduce the interfacial tension, thereby

entrapping more air bubbles and increasing the foaming capacity of the food (Mauer, 2003). Extensive heat denaturation of proteins decreases their foaming capability.

Foams are formed by the trapping of pockets of gas in liquid or solid food (Cantat *et al.*, 2013). The head on a glass of beer is example of foam. In most foams, the gas volume is large, with thin liquid or solid films separating the gas regions. Several conditions are required to produce foam: there must be a mechanical work, surface active components that decrease the surface tension, and the foam formation faster than its breakdown. Foams in foods and other materials often disappear with time. To create foam, mechanical work is required to increase the surface area. Good foam capacity and stability are desired attributes for flours intended for use in the production of various baked products such as angel cakes, muffins, *akara*, cookies, etc., and also perform as functional agents in many other food formulations (El-Adawy, 2001). Protein in the dispersion can lower the surface tension at the air-water interface, thus often due to protein which forms continuous cohesive thin film around air bubbles in the foam (Kaushal *et al.*, 2012).

The foam stability (FS) refers to the food ability to stabilize against mechanical and gravitational stresses (Fennema 1996). There is always an inverse relationship between the foaming capacity and the foam stability. Flours with high foaming capacity may form large air bubbles encircled by thinner less flexible protein film. Consequently, this air bubbles may collapse easily and consequently lower the foam stability (Jitngarmkusol *et al.*, 2008).

#### **2.4. Water Absorption Capacity (also Known as Water Hydration or Water Absorption)**

Water absorption capacity (WAC), also called water absorption, is the amount of water (moisture) taken up by food/flour to achieve the desirable consistency and create quality food product. It is the optimum amount of water required to be added to a dough before it becomes excessively sticky to process. Very low or excessive water absorption can negatively affect the quality of food products. Water absorption is often defined by the weight of the food/flour. For instance, 60% water absorption means that 60 lbs of water is used for the hydration of 100 lbs of flour.

*The chemistry:* When water and flour are mixed together, the molecules of water hydrate the gluten-forming proteins glutenin and gliadin, as well as the damaged starch and other ingredients. The process of the hydration is achieved when molecules of starch and protein create hydrophilic interactions and hydrogen bonds with the molecules of water. Particles hydrate via rubbing against each other and contacting molecules of water. Process parameters such as pressure, beating arm, water flow, and type of mixer remove the layer of hydrated surface and expose new layer of the particles to the excess water so the process of water diffusion could continue. Water absorption can influence the following parameters of bread and baking: Proofing, Fracture stress of bread crumb, Loaf volume, Bread yield, Final products attributes, Machinability, Shelf life (Zghal *et al.*, 2001; Pühr and D'Appolonia, 1992; Pyler, 1988)

*How to measure water absorption:* the farinograph is often used and can give an approximate value for the water absorption. First, the test is based on determining the optimum volume of water to achieve a consistent BU (Brabender Unit) value. The volume of water required to make this consistency is the water absorption capacity of a flour. Analysis of the usual farinograph curve produces important quality parameters such as: Optimum mix time (also known as dough development time), the arrival time to first achieve 500 BU, Mixing Tolerance Index, Departure time, Dough stability (Serna-Saldivar, 2010)

*Application:* Water absorption levels often vary from 60–62% in standard white bread formula, 80-90% in the artisan-type Ciabatta formula, and 50–54% in a cookie formula. When developing with sprouted flour, any increase in the enzymatic activity of the flour will increase water absorption capacity and maillard reaction.

*Factors influencing the water absorption capacity of a flour:* the following factors influence the water absorption capacity of a flour;

- **Starch:** Approximately 46% of the total absorbed water is associated with the starch in the flour.
- **Pentosans:** Approximately 23% of total water absorbed is associated with pentosans in the flour.
- **Proteins:** Approximately 31% of total water absorbed is associated with proteins.
- **Vital wheat gluten (VWG):** When added, will increase the water absorption and improve greater stability to the dough (Sumnu and Sahin, 2008).
- **Presence of other water binding ingredients** such as fiber, bran hydrocolloids (gums), eggs, etc.

*Under- and over-absorption of water in bakery products and other food formulations:* Different bakery products and food formulations require different levels of water absorption or hydration. Each level is usually unique for each kind of food product to achieve a desirable dough consistency, finished product characteristics, and other required quality attributes.

The common problems that may occur during mixing are shown in Table 1 and 2. Both under-absorption and over-absorption of water lead to quality concerns in the both dough and finished product (AIB International, 2018):

**Table 1: Problems of under-absorption of water**

<b>Dough</b>	<b>Finished product</b>
<ul style="list-style-type: none"> <li>• Not enough water to hydrate, moist, and disperse dry ingredients</li> <li>• Stiff and dry</li> <li>• Final development cannot occur</li> <li>• Inadequate pan flow</li> <li>• Proofs slower</li> </ul>	<ul style="list-style-type: none"> <li>• Firm and dense internal structure (crumb)</li> <li>• Low volume</li> <li>• White corner edges</li> <li>• Stales more quickly</li> </ul>

**Table 2: Problems of over-absorption of water**

<b>Dough</b>	<b>Finished product</b>
<ul style="list-style-type: none"> <li>• Extended clean-up time</li> <li>• Wet and sticky</li> <li>• Diminished tolerance to handling (poor machinability)</li> <li>• Prone to over-fermentation</li> </ul>	<ul style="list-style-type: none"> <li>• Open crumb grain with large cells</li> <li>• Poor symmetry</li> <li>• Large volume</li> <li>• Prone to mold</li> </ul>

High WAC value can be attributed to many hydrophilic components contained in foods such as carbohydrate (especially polysaccharides), proteins, especially polar amino acid residues, which have high affinity for water molecules (Sreerama *et al.*, 2012), and other hydrophilic

constituents. Kuntz (1971) reported that lower water absorption in some flours may be because of the less availability of polar amino acids in the flours. The increase in WAC of flour may also be due to the increase in the amylose solubility and leaching, as well as loss of the crystalline structure of starch. High WAC of some composite flours suggests that the combination of different flours can be used in formulation of many foods such as processed cheese, bakery products, sausage, and dough. The flour with high water absorption may have more hydrophilic constituents such as polysaccharides, etc. Protein has both hydrophobic and hydrophilic nature and therefore can interact with the water in foods. In 2010, Butt and Batool reported the observed variation in WAC of different foods/flours can be due to different concentrations of protein, their conformational characteristics, and their degree of interaction with water. Water absorption capacity is a significant functional property required in foods especially those involving dough handling (Iwe *et al.*, 2016). The loose association of amylopectin and amylose in the starch granules and weaker associative forces maintaining the granular structure can have effect on WAC. Water absorption capacity is important in consistency and bulking of products, as well as in baking applications (Iwe *et al.*, 2016).

## 2.5. Oil Absorption Capacity (Oil Absorption)

Oil absorption capacity (OAC), also called water absorption, is the binding of fat by the non-polar side chain of proteins. The Oil absorption capacity is an essential functional property that contributes to enhancing mouth feel while retaining the food products' flavor (Iwe *et al.*, 2016). The rate of oil absorption is very high in foods with high protein content. The oil and water binding capacity of protein in food depend on the intrinsic factors such as protein conformation, amino acid composition, and surface polarity or hydrophobicity (Suresh and Samsher, 2013). The ability of flours to bind with oil makes them useful in food applications where optimal oil absorption is desired, making flours to have potential functional applications in foods such as production of pastries, sausage. The oil absorption capacity also makes the flour suitable in facilitating enhancement in flavor and mouth feel when used in food preparation (Suresh and Samsher, 2013). Due to these properties, the flours with good OAC are used as functional ingredient in foods such as sausages, whipped toppings, angel and sponge cakes, chiffon dessert etc.

*Note: Oil absorption during frying of foods is often not desirable. During frying of foods, oil absorption is a serious concern. The rate of oil absorption is very high in fried foods, especially the foods with high protein content. OAC increases the caloric value of food products. All fried foods absorb some oil usually between 8 to 25% of the weight of the fried food. The temperature of the oil affects the volume of oil absorbed. If the oil is too hot, the exterior of the fried foods becomes burnt before the interior of the food is well cooked—causing undercooking of the interior, unpleasant taste, possible food safety issue, and poor heat penetration. If the oil is too cool, there is increase in frying time, leading to more oil absorption—thus more calories and fat are added to the food. The ideal frying temperature is generally between 162.78°C (325°F) to 190.56°C (375°F). Some frying oils are better choices than others with regards to their saturated versus unsaturated fat contents.*

The possible reason for increase in the OAC of flours is the increase in the presence of non-polar side chain, which may bind the oil hydrocarbon side chains in foods and flours. The flours with high OAC are potentially beneficial in structural interactions in foods especially for improvement of palatability, extension of shelf life, and flavor retention particularly in meat or bakery products where fat absorption is desirable (Suresh *et al.* 2015). The major chemical



component affecting oil absorption capacity is protein which is composed of both hydrophobic and hydrophilic parts. The non-polar side chains of amino acids can form hydrophobic interactions with hydrocarbon chains of lipids (Jitngarmkusol *et al.* 2008). Oil absorbing mechanism often involves capillary interactions in the food matrix which allows the retention of the absorbed oil.

## **2.6. Bulk Density (also known as Volumetric Density or Apparent Density)**

Bulk density, also called volumetric density or apparent density, is defined as the mass of many particles of flour material divided by the total volume they occupy. It is a functional property of flours, powders, fine particles, granules, and other divided solids of foods (or food ingredients). The total volume includes particle volume, internal pore volume, and inter-particle void volume (Buckman and Brady, 1960).

Bulk density may change depending on how the food material is handled; it is not an intrinsic property of a food material. For example, a flour poured into a cylinder will have a certain bulk density; if the cylinder is disturbed, the flour particles will move and commonly settle closer together, leading to a higher bulk density. For this reason, the bulk density of flours is often reported both as "tapped" density and "poured" (or "freely settled") density, where the tapped density refers to the flours' bulk density after a specified compaction process, often involving vibration of the container (The Powder process, 2018). In some instances, the cylinder is continuously tapped until there is no noticeable change in volume of the flour or food powder.

The variation in bulk density of foods could be as due to the variation in starch content of the foods. The higher the starch content the more likely the increase in bulk density. Also, bulk density depends on factors such as geometry, method of measurement, particle size, surface properties, and solid density of the materials and can be improved when the particles are smaller, properly tapped/vibrated, compactible, and with a suitable packaging material (Iwe *et al.*, 2016). Bulk density reflects the relative volume or capacity of the required packaging material. The higher the bulk density of the flour, the denser the packaging material required for packaging. It indicates the porosity of a food product which impacts the design of the package and can be used in determining the type of the required packaging material (Iwe *et al.*, 2016). Recent studies suggest that bulk density of flours may be influenced by the initial moisture content of flours. High bulk density of flours suggests their suitability for application in food preparations. On the other hand, low bulk density would be useful in the formulation of complementary foods (Suresh and Samsher, 2013). Starch forms the main structure and bulk of many food products e.g. in biscuits, bread, cakes, and pastries.

## **2.7. Swelling Capacity (Swelling Index)**

The swelling index (SI), also known as swelling capacity (SC), is the volume in milliliter taken up by the swelling of one gram (1 g) of food material under specific conditions. Its determination is based upon the water addition or addition of a swelling agent as indicated in the test procedure for every individual food material (whole, pulverized, or cut). The swelling capacity is the measure of the starch ability to absorb water and swell, and also reflects the extent of associative forces in the starch granules. Swelling capacity (index) is considered a quality measure in some food products such as bakery products. It is an indication of the non-covalent bonding between the molecules of starch granules and also one of the factors of the  $\alpha$ -amylose and amylopectin ratios (Iwe *et al.*, 2016). The swelling capacity (index) of flours are influenced by the particle size, species variety and method of processing or unit operations (Suresh and Samsher, 2013).

High starch content increases swelling capacity (index) of foods and flours, especially in starch with higher amount of the branched amylopectin. Starch is made up of amylose (linear chain) and amylopectin (branched chains), both are chains of glucose units. Starch is found in very small packets known as granules. The amount and proportion of amylose and amylopectin found in starch vary according to the plant source. This explains why different flours from different (plant) sources and species have different swelling capacities.

## 2.8. Emulsion Capacity (Emulsion Stability)

An emulsion is a combination or mixture of two or more liquids which are normally immiscible (unblendable or unmixable). Emulsions are part of general class of two-phase food systems of matter called colloids. Though the terms *emulsion* and *colloid* are sometimes interchangeably used, *emulsion* should be used when the two phases, continuous and dispersed, are liquids. In emulsion, one liquid (called the dispersed phase) is dispersed in the other phase (called the continuous phase). The examples of emulsions in food system include salad dressing, vinaigrettes, and homogenized milk. Two major types of emulsion are water in oil and oil in water emulsions. Milk is an emulsion of oil and water, together with other components (Harper, 2019). Milk is considered as an emulsion of oil in water.

The emulsifying capacity, also called emulsion capacity (EC), of foods is associated with the amount of oil, non-polar amino acids residues on the surface of protein, water, and other components in the food. An increased number of non-polar amino acids residues on the surface of protein will reduce the energy barrier to adsorptions which depends on the protein structure. Emulsion stability (ES) is the ability of emulsion system of foods to resist the changes and alterations in its physicochemical properties over time. Many mechanisms such as flocculation, coalescence, creaming, etc., cause the breakdown of emulsion.

Two or more liquids can form different types of emulsions. For example, oil and water can form, firstly, an emulsion of oil-in-water, in which the oil is the dispersed phase, and the continuous phase is water; one example of this is the lipoproteins used by all the complex living organisms. Secondly, they can form an emulsion of water-in-oil, in which the dispersed phase is water and the continuous phase is oil. Also, multiple emulsions are possible, including an oil-in-water-in-oil emulsion and water-in-oil-in-water emulsion (Khan *et al.*, 2006), though rare, but possible. Being liquids, emulsions do not exhibit static internal structure. The dispersion medium (the droplets dispersed in the continuous phase) is often assumed to be statistically distributed.

*The appearance and properties:* The droplets may be liquid-crystalline, amorphous, or any mixture thereof. Diameters of the droplets creating the *dispersed phase* often range from about 10 nm–100  $\mu\text{m}$ ; i.e., the droplets may exceed the regular limits for colloidal particles size. An emulsion is termed water in oil (w/o) if water or an aqueous solution is the dispersed phase and an organic liquid (an "oil") is the continuous phase and is termed an oil in water (o/w) emulsion if an organic material is the dispersed phase and water or aqueous solution is the continuous phase. A water-in-oil emulsion is sometimes known as an inverse emulsion. The term "inverse emulsion" can be misleading, incorrectly suggesting that the emulsion has the properties opposite to those of an emulsion. Therefore, its use is not recommended (Slomkowski *et al.*, 2011).

As already stated, emulsions contain both dispersed and continuous phases, with the boundary between these phases called the "interface" (Loi *et al.*, 2018). Emulsions have a tendency to have cloudy appearance because the several phase interfaces scatter light or radiation as it passes through the emulsions. Emulsion appears white when all light is equally scattered. If the emulsion is sufficiently dilute, low-wavelength (higher-frequency) light will be more scattered,

and the emulsion appears bluer – this is known as the "Tyndall effect". If the emulsion is sufficiently concentrated, the colour would be distorted toward relatively longer wavelengths, and appears more yellow. The phenomenon can be easily observed when comparing skimmed milk with little fat to cream with a much higher milk fat concentration. One typical example would be a mixture of oil and water.

Two special classes of emulsions – nanoemulsions, with droplet sizes below 100 nm, and microemulsions – appear translucent (Mason *et al.*, 2006). This property is due to light waves that are scattered by the emulsion droplets if their sizes exceed approximately one-quarter (1/4) of wavelength of the incident light. As the visible spectrum of light is made of wavelengths between 390 nm and 750 nm, if droplet sizes in the emulsion are below approximately 100 nm, the light may penetrate through the emulsion without scattering (Leong *et al.*, 2009). Due to their similarity and resemblance in appearance, microemulsions and translucent nanoemulsions are often confused. Unlike microemulsions which are spontaneously formed by solubilizing the oil molecules with a mixture of surfactants, co-solvents, and co-surfactants, translucent nanoemulsions require a specialized equipment to produce (Mason *et al.*, 2006). The required concentration of surfactant in a microemulsion is, however, many times higher than that of surfactant concentration required in a translucent nanoemulsion, and significantly exceeds the dispersed phase concentration. Because of several undesirable side-effects caused by the surfactants, their presence is prohibitive or disadvantageous in many food applications. Additionally, the stability of a microemulsion is often compromised easily by heating, by changing pH levels, or by dilution.

Common emulsions in foods are inherently unstable and, as a result, do not tend to form freely and spontaneously. Energy input – through homogenizing, shaking, stirring, or exposure to power ultrasound (Kentish *et al.*, 2008) – is often required to form a relatively more stable emulsion. With time, emulsions usually tend to revert to the previous stable state of the phases in the food comprising the emulsion. A typical example is seen in the separation of oil and vinegar components of the vinaigrette, an unstable emulsion that rapidly separate unless shaken nearly continuously. There are significant exceptions to this rule – translucent nanoemulsions are kinetically stable, while microemulsions are thermodynamically stable (Mason *et al.*, 2006).

Whether an emulsion of water and oil turns into an oil-in-water emulsion or a water-in-oil emulsion depends on the type of emulsifier (surfactant) present and the volume fraction of both phases. Generally, the Bancroft rule applies. Emulsifying particles and emulsifiers tend to promote the dispersion of the food phases in which they are not well dissolved. For example, protein dissolves better in water than it does in oil, and as a result tend to form oil-in-water emulsions (i.e., protein promotes the dispersion of droplets of oil throughout the continuous phase of water).

Geometric structure of a food emulsion mixture of two lyophobic liquid foods with large concentration of the secondary constituent is fractal: the particles of food emulsions unavoidably form the dynamic inhomogeneous structures on small scale of length. The geometry of these dynamic inhomogeneous structures is fractal. Size of elementary irregularities is governed by universal function which relies on the volume of the components. These irregularities fractal dimension of is 2.5 (Ozhovan, 1993).

#### *Instability (Emulsion stability)*

Emulsion stability of foods is to the ability of a food emulsion to resist any change in its properties over time (McClements, 2004). The types of instability that exist in food (flour) emulsions include sedimentation, coalescence, flocculation, Ostwald ripening, and creaming.

When there is attractive force between the food emulsion droplets, flocculation occurs, leading to the formation of flocs, such as bunches of grapes. The process can be desirable, if controlled in its amount, to tune the physical properties of food emulsions such as their flow behaviour (Fuhrmann *et al.*, 2019). Coalescence occurs when the food emulsion droplets bump into each other, resulting in their combination to form a bigger droplet, increasing the average droplet size with time. Food emulsions undergo creaming, when the droplets surge to top of the emulsion under buoyancy influence, or under the influence of a centripetal force induced when centrifuge is used (McClements, 2004). Creaming is a common in dairy and non-dairy beverages such as milk, soy milk, coffee milk, almond milk, and usually does not change droplet size (Loi *et al.*, 2019). Sedimentation in food emulsions is the opposite of creaming and often observed in water-in-oil emulsions (Loi *et al.*, 2018). Sedimentation occurs when a dispersed phase is denser than a continuous phase, pulling the denser globules towards the bottom of the food emulsion by means of gravitational forces. Like creaming, sedimentation follows Stoke's law.

Appropriate surface active agent (surfactant) may increase the kinetic stability of a food emulsion so that the droplets sizes do not significantly change with time. Like a suspension, the emulsion stability can be studied as zeta potential, which indicates repulsion between particles or droplets. If the dispersion and size of droplets do not change with time, the food emulsion is said to be stable (McClements, 2007), e.g., oil-in-water emulsions with monoglycerides, diglycerides, and milk protein as surfactant indicated stable oil droplet size at 25°C, over 28 days storage (Loi *et al.*, 2019). The stability of food emulsions can be characterized by the use of techniques such as focused beam reflectance measurement, light scattering, rheology, and centrifugation. Each method has its unique advantages as well as its disadvantages (Dowding *et al.*, 2001).

*Accelerating methods for the prediction of shelf life:* The kinetic process of destabilization may be rather long; up to many months or years for some food products (Dickinson, 1993). Often the food formulator must accelerate this process so as to test products in reasonable time during food product design and development. Thermal methods are the most normally used – these consist of increasing the temperature of the food emulsion to accelerate destabilization (if below the critical temperatures for phase inversion or for chemical degradation) (Masmoudi *et al.*, 2005). Temperature does not only affect the viscosity but also affects the interfacial tension in case of non-ionic surfactants or, on an extensive scope, interactions between the droplets within the system. The storing of an emulsion at high temperatures allows the simulation of the realistic conditions for a food product, but also accelerates the destabilization processes over 200 times. The mechanical methods of acceleration, including centrifugation, agitation, and vibration, can also be used. These mechanical methods are almost often empirical, without a sound and clear scientific basis.

*Emulsifiers (Emulsifying agents or Emulgents):* A food emulsifier (also called a food emulgent) is a substance that stabilizes a food emulsion by increasing the kinetic stability of the food emulsion. One class of food emulsifiers is known as surfactants or surface active agents. Emulsifiers are compounds that typically have a non-polar (i.e. lipophilic or hydrophobic) part and a polar or hydrophilic (water-soluble) part. Due to this, emulsifiers tend to be more or less soluble either in oil or in water. Emulsifiers which are more soluble in oil (and conversely, less soluble in water) will generally form water-in-oil emulsions, while emulsifiers that are more soluble in water, and less soluble in oil, will form oil-in-water emulsions (Cassiday, 2014).

Examples of food emulsifiers are:

- Mustard – where a variety of the chemicals in the mucilage surrounding the hull of the seed act as emulsifiers
- Egg yolk – in which the major emulsifying agent is lecithin.
- Soy lecithin is another emulsifier as well as thickener
- Sodium phosphates
- Mono- and diglycerides – common emulsifier found in various food products such as coffee creamers, ice-creams, cakes, spreads, breads
- Pickering stabilization – uses particles under some circumstances
- Sodium stearoyllactylate
- Simple cellulose – particulate emulsifier derived from the plant material using only water
- Diacetyl tartaric acid esters of the monoglycerides and the diglycerides (called DATEM) – an emulsifier primarily used in baking

Many different emulsifiers are often used in pharmaceutical industries to prepare emulsions such as creams, drugs, etc. Common examples include polysorbate 20, cetareth 20, and emulsifying wax (Anne-Marie, 2008).

Sometimes the inner phase itself may act as an emulsifier in food products, and the result is often a nanoemulsion, wherein the inner state disperses into droplets of nano-size within the outer phase. A common example of this phenomenon, called the "ouzo effect", occurs when water is poured into strong alcoholic anise-based beverage, like ouzo, raki, pastis, absinthe, or arak. The anisolic compounds, soluble in ethanol, will then form nano-size droplets, emulsifying within the water. Resulting color of the drink is milky white and opaque.

*Mechanisms of food emulsification:* Many different chemical and physical mechanisms and processes can be involved in the food emulsification process:

- Viscosity modification – emulsifying agents like tragacanth and acacia, which are hydrocolloids, as well as glycerine, polyethylene glycol (PEG), and other polymers like carboxymethyl cellulose (CMC), all increase viscosity of the medium, which then helps create and maintain suspension of the globules of dispersed phase.
- Surface tension theory – this theory states that emulsification takes place by the reduction of interfacial tensions between two phases.
- Repulsion theory – according to this theory, the emulsifying agent creates film over one phase that forms globules, which then repel each other. The repulsive force makes them remain suspended in the dispersion medium.

#### *Applications and uses of emulsion in food*

Oil-in-water emulsions are more common in food products:

- Mayonnaise and Hollandaise sauces are oil-in-water emulsions stabilized with either egg yolk lecithin, or other types of food additives, like sodium stearoyllactylate
- Crema (foam) in espresso – brewed coffee (coffee oil in water), unstable emulsion
- Vinaigrette is an emulsion of vegetable oil in vinegar; an unstable emulsion results if prepared using only oil and vinegar without an emulsifier
- Homogenized milk is the emulsion of milk fat in water (oil in water emulsion), with milk proteins as the emulsifier

Water-in-oil emulsions are often less common in food, but still in existent:

- Margarine
- Butter is emulsion of water in butterfat

Other foods can be turned into another food product similar to emulsions, e.g. meat emulsion is a suspension of meat in a liquid. The suspension is similar to true emulsions.

## 2.9. Solubility

In food system, solubility is the property of solid, liquid or gaseous food (chemical) substances known as solute to dissolve in liquid, gaseous, or solid solvent. A substance solubility fundamentally depends on the chemical and physical properties of the solvent and solute as well as on pressure, pH, temperature, and presence of other chemicals of the solution. The extent of the solubility of a food (flour) substance in a specific solvent is commonly measured as the saturation concentration, in which addition of more solute does not increase concentration of the solution and rather starts to precipitate the excess quantity of solute. The presence of lipids reduce water absorption capacity of foods (flours) which can lead to reduced swelling capacity and consequently reduced solubility (Opong *et al.*, 2015) High solubility of food can show high digestibility of the food which may indicate excellent use for infant formula and food. On the other hand, insolubility is the inability of a food to dissolve in a liquid, gaseous, or solid solvent. Flour solubility is the amount of the flour that dissolves into solution, usually with water as solvent. Flour solubility is one of the functional properties usually determined during the development and testing of a new flour or flour composite. It is required that the solubility of new foods or their components is determined as a functional property.

Solubility in foods is a chemical and functional property referring to the ability of a given food substance to dissolve in a solvent, usually water or oil. It is measured and determined in terms of the maximum quantity of solute dissolved in a given solvent at equilibrium. The resultant solution is known as a saturated solution. The smaller the size of a food particle is, the quicker it dissolves, though there are several factors to add to this before generalizing. In all cases solubility usually depends on the physical conditions (such as pressure, concentration, and temperature) and the entropy and enthalpy directly relating to the solutes and solvents in consideration. By far water is the most common solvent in food and is a solvent for a wide range of organic substances (such as protein, sugars, water soluble vitamins, most phytochemicals, etc.), inorganic substances (such as NaCl, NaOH, etc.) and most ionic compounds. Solubility can be stated in many units of concentration such as mass (solute) per volume (solvent), molarity, mole fraction, molality, mole ratio, and other units (IUPAC, 2006).

There are wide ranges of the extent of solubility, from infinitely soluble (without limit, fully miscible) (Clugston and Fleming, 2000) such as ethyl alcohol in water, to poorly soluble, e.g. silver chloride in water. Insoluble is often used to refer to poorly or very poorly soluble substances. Also, some other descriptive terms are used to qualify the solubility extent for a given food application. Specifically food substances are classified insoluble when their solubility is below 0.1 g per 100 mL of the solvent (Rogers and Stovall, 2000). Solubility occurs under dynamic equilibrium, meaning that solubility results from the opposing and simultaneous processes of dissolution and phase joining. Pressure, concentration, temperature, and the polarity of a solvent are the main factors which affect the solubility of flour and food components. The solubility of food substances is useful and advantageous when separating mixtures.

## 2.10. Gelation Capacity (Gelation property)

Gelation Capacity, also called gel transition property or gelation property, is the formation of a gel from a food system with biopolymers (Oliveira and Reis, 2008; Ahmed, 2015) such as

starch, protein, etc. Branched polymers can form links (chemical associations) between the chains, which result in progressively larger biopolymers. As this linking continues, larger branched biopolymers are obtained and, at some extent of the reaction, the links between the biopolymers result in formation of single macroscopic molecule. At this point in the reaction, which is known as gel point, the food system loses fluidity and the viscosity becomes very large. The gel point, or onset of gelation, is accompanied by a rapid increase in viscosity (Oadian, 2004). This infinite sized biopolymer is called the network or gel, and does not dissolve in the solvent, although can swell in it (Chanda, 2006). Gelation characteristic is an important functional property of food components such as starch, protein, etc. as food additive or material, and is directly related to its texture and its viscoelasticity.

Gelation links the macromolecular chains to result in formation of a branched polymeric structure with solubility that depends upon the chemical properties of the starting materials. The food mixture containing the soluble branched polymer and water is called a “sol.” The increasing dimension of the structure leads to decreases in the solubility of the polymer. This infinite polymer is called the “network” or the “gel,” and it is made up of many finite branched polymers. Transition from a food system with finite branched biopolymer to infinite molecules is called “gelation” or “sol–gel transition,” and the critical point where the gel first appears is known as the “gel point.” Good gelling characteristics can be credited to the presence of carbohydrates (especially starch) (Ammar *et al.*, 2016) and proteins. Also, the presence of carbohydrates reduces the thermodynamic affinity of protein for aqueous solution and also magnifies the degree of interactions between the molecules of protein, hence, improving the gelling capacity (Ammar *et al.*, 2016). Gelation can occur either by chemical cross linking or by physical linking in food (flour). It is essential to predict the onset of gelation (gel point), since it is the process is irreversible and dramatically changes the food system properties.

### **2.11. Aeration**

Aeration, also called aeration or aerification, is a process by which air is circulated (distributed) through, dissolved in, or mixed with food substances (Wayback Machine, 2011). It is the process wherein air is absorbed into the food. Aeration is done on foods to improve the water/nutrients infiltration, consistency, etc. The process allows the incorporation of air into food ingredients to create more volume and/or make them lighter. For example, the sifting of flour adds air and removes lumps making the resulting flour, as well as the food dish using the flour, become lighter in consistency and texture. In the tasting of wine, a range of methods can be used to aerate wine and draw out the aromas including the use of decanter to increase the exposure to air, swirl wine in the glass, or the use of a specialized wine aerator. The cider from Asturias is emptied into the glass from height of approximately 1 m (*el escanciado*) to increase the aeration. Some food formulations, especially in baking, depend on aeration to give proper structure to food products. Flour with good aeration properties usually gives food products with good texture, structure, and consistency.

Aeration can be accomplished in many ways including chemical (baking soda), physical (lamination or steam), biological (yeast), mechanical (methods of mixing some ingredients or the batter through beating or whipping), or a combination of at least two of these methods. Each one is designed to introduce gas, such as air, to a liquid or viscous food (solution). For example, in baking, cake batter as emulsion requires good aeration so as not to become very sloppy or thin. Dough viscosity can have effect on processing, machinability, and the end product texture and appearance (Pyler and Gorton, 2010). Fats and oils, protein, etc. play important roles in food aeration. In cake varieties including white, yellow, and pound cakes, if

the cake must have proper volume, texture, and grain, the baker must incorporate considerable quantities of air into the batter (Pylar and Gorton, 2010).

*The chemistry of aeration (Eggs as excellent aeration agents for baking and other food applications):* When air is incorporated into liquid or viscous food solution, the solution entraps the air bubbles, forming foam. If protein stabilizes the foam, it leavens the food, increasing the height and reducing the density of the food (Zayas, 1997). Eggs are excellent aeration agents. Eggs supply aeration in baking applications through mechanical method of aeration (whipping or beating), with the viscosity of all products of egg ideal for incorporating air during the process of whipping or beating. As the beating or whipping progresses, air bubbles reduce in size and increase in number, and surrounded by the egg proteins. The liquid products of egg have low air-liquid interfacial tensions, as a result when eggs are whipped or beaten, the proteins unfold, or simply, they denature. This exposes the two oppositely charged ends of the molecules of protein: the hydrophilic or water loving end, and the hydrophobic, or water hating end. The proteins line up between the water and air, securing the air bubbles with hydrophilic end and pointing hydrophobic end in the other direction. In baking, the proteins bond with each other, resulting in the formation of a delicate, yet reinforced network (American Egg Board, 2012). Unlike any other natural food ingredient, egg whites create the largest possible food foam, about six to eight times greater in volume and capacity than non-whipped, non-aerated liquid egg white (Cousminer, 2017). This foaming capacity of egg white finds wide uses in multiple baking applications, especially angel food cake, which depends on the aerating capacity of egg white for its characteristic appearance, texture, height, and cell structure (Munday *et al.*, 2017a). Many confections, such as nougat candies, depend on proper aeration for texture, height, and appearance, which can suffer if egg white is removed (Munday *et al.*, 2017b). Increasing the acidity of egg whites will help to stabilize the foam through loosening the structure of protein, keeping the foam stable and elastic enough to trap air bubbles, and allowing their to expansion when heated, leading to better volume. In some applications and uses, whole eggs and egg yolks increase the food volume through the aeration process, including some dairy desserts (such as ice custard and cream) and baked goods.

### 3. Conclusion

Functional properties describes the behavior of ingredients during preparation and cooking, as well as how they affect finished food products in terms of how it feels, looks, tastes. Functional properties include: Swelling capacity, water absorption capacity, oil absorption capacity, Emulsion capacity and stability, Foam capacity and stability, Gelatinization capacity and temperature, Bulk density, Dextrinisation, Plasticity, Aeration, Sensory attributes, among others. The food property is characterized by the structure, acceptability, quality, and/or nutritional value of a food product. A functional property of food (flour) is determined by organoleptic, physical, and/or chemical properties of a food. The functional properties of foods and flours are influenced by the components of the food material, especially the carbohydrates, proteins, fats and oils, moisture, fibre, ash, and other ingredients or food additives added to the food (flour), as well as the structures of these components. Every single ingredient used in a food has a specific function, which often impact the functional property of the food. Most of the processes foods undergo initiate the onset of some functional properties. For example, starch particles do not dissolve in cold liquid, they form a suspension. If the liquid isn't stirred, the starch granules sink to the bottom, stick together and form lumps. At 60°C, the starch granules begin to absorb the liquid and swell. At 80°C, the granules will have absorbed 5x their volume until they burst open, releasing starch into the liquid. Gelatinisation is completely achieved when the liquid reaches 100°C. When the sauce cools, it gets even thicker, setting into a gel. Dextrinization occurs when foods containing starch are subject to dry heat, leading to the formation of dextrans, which turns the food brown and becomes sweeter. When proteins are



subjected to heat, pH extremes, alcohol or mechanical actions (e.g. beating or whipping), they undergo denaturation. Functional properties are unique quality attributes of foods and food products.

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