THE CHEMISTRY OF BAKING

Baking is not usually thought of as a chemical industry, but it relies on the interactions of the various chemicals in flour and the other substances used and thus is chemically based. Usually the properties of the various ingredients are known to the home cook, but not why they behave in that way.

Ingredients

The most common ingredients used in baking are the following:

Flour	This provides most of the bulk of the baked item. For bread baking, the flour should be a wheat flour which is high in gluten (protein) as this is the substance that gives bread its fine texture and supports the ingredients during rising.
Yeast	Yeast is a plant that feeds on starch and sugars, releasing CO_2, alcohol and sugar. The CO_2 bubbles give the dough a light, airy texture.
Fat	Fat gives a softer texture and helps prevent the CO_2 bubbles from escaping from the mixture too soon.
Sugar	Provides a direct food source for the yeast, improving its action.
Vitamin C	Also shortens the time needed for dough to "mature".
Baking soda	Releases CO_2 according to the equation $2NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O$ However, as this also produces a strong base, Na_2CO_3, which has to be neutralised, baking powder is usually used instead.
Baking powder	Baking powder is baking soda with acid added. This neutralises the base and produces more CO_2 according to the following equation: $NaHCO_3 + H^+ \rightarrow Na^+ + H_2O + CO_2$
Egg	Beaten egg white, like fat, helps to retain gas bubbles, while egg alone acts as a binder.
Salt	Salt adds flavour, and strengthens soft fat and sugar mixtures.

Products

These ingredients are used in varying proportions to produce different products. As well as home baking, these include commercial cake mixes and breads. The commercial products and commercially produced raw ingredients are monitored in laboratories to ensure consistent quality, and the New Zealand Institute for Crop and Food Research in Christchurch provides services for monitoring the composition of all wheat grown in New Zealand and all flours produced at flour mills.

INTRODUCTION

There are not many people whose mouths do not begin to water when they are faced with the delicious smell of home cooking, whether it is cakes, biscuits, scones, pikelets or some other "goodies". This delicious smell, and the delicious baking, are produced as a result of the interaction of various chemical and physical processes that can be adjusted by the cook to create a great variety of products. This article considers the chemistry of the common

ingredients used in baking, and looks briefly at the effects of the physical processes of mixing and baking.

COMMON INGREDIENTS

All baking is based around the use of wheat flour (see article), but many other ingredients are also used, each of which has different effects on the final product. The commonest of these (excluding liquids and spices, dried fruits and other "flavourings") are listed here.

Flour

The word flour refers to the powder obtained from grinding a cereal grain. Although other flours (e.g. rye flour) are used in baking, wheat flour is by far the most common and is the only one that will be discussed here. All flours are composed largely from starch and protein, but wheat flour is distinctive in that it has very high levels of a class of proteins known collectively as gluten (8 - 14%). When a dough is made from wheat flour and water, the gluten develops into a thick, cohesive, elastic mass. When placed in an oven, it puffs up to many times it original volume and sets with a light, airy texture. This characteristic enables gluten to provide the structure in baked goods, cakes and bread. In the network of gluten the starch granules are embedded rather like a system of bricks in mortar. The characteristic and general quality of the flour depend on:

- The wheat variety and conditions under which the wheat has grown. This affects the quality and quantity of gluten in the grain.
- The milling process. This determines the degree of separation of the bran and endosperm, as well as the particle size of the flour, an important factor in cake flour.
- Additives and special treatments used by the miller to produce flour mixes with special characteristics. In New Zealand, additives cannot be used in products sold as flour, but they are commonly used by millers to make up pre-mixes for particular applications.

What characteristics are needed for a good cake flour? The best cakes are obtained from a low-protein flour (7-9%) which is soft and gives tender cakes; a clean flour, which is free of bran and wheat germ (i.e. as close as possible to being pure endosperm); a flour with small, even particle size and little starch damage, which will blend easily and give a smooth cake batter. For cakes which contain a higher proportion of sugar than normal, the flour must be chlorinated. Good milling can help to achieve these characteristics, but obviously only if the wheat is already of the appropriate quality.

Yeast

Yeast is made up of many tiny, single-celled plants, which grow by budding, each bud breaking away from the parent cell and forming new buds. The conditions required for growth are warmth (optimum 25-30°C), moisture and food (starch plus a small amount of sugar). Refrigeration slows down the growth so that yeast can be kept for a limited period of time. When the yeast is used, the conditions and the utensils should be kept lukewarm to obtain the best results. As soon as the yeast has been added to the dough or batter, the yeast begins to feed on the starch in the mixture, forming sugar, alcohol and carbon dioxide. The bubbles of CO_2 cause the dough to expand ("rise"). The dough must be "kneaded" thoroughly to distribute the bubbles evenly and then left to rise again, usually to about double its original volume. If the mixture is left too long, acid produced by the oxidation of the alcohol causes the product to taste sour.

Fat

Fat has five major roles in baking as outlined below. How well it will perform each of these functions depends largely on the "slip point" - the temperature at which the fat just begins to melt. In general the slip point should be at least 5°C above the proving temperature of the dough. The roles of fat are as follows:

Shortening

Fat weakens or 'shortens' a dough by weakening its gluten network, resulting in the baked product being softer, breaking easily and having a more tender mouthfeel.

Creaming

Fat can trap air during beating and mixing, producing a batter that consists of masses of tiny air bubbles trapped within droplets of fat. This is very important in cake baking in which it is these air bubbles that expand during baking forming a light, airy structure.

Layering

In puff pastry fats which are soft over a wide temperature range are used. These can be spread between pastry layers and will separate them during cooking giving a layered pastry.

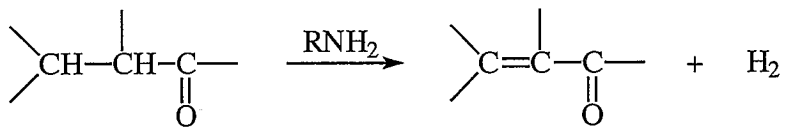
Flavour

Usually the fats used should have a bland flavour to prevent them from changing the flavour of the finished product, but occasionally fats are chosen on the basis of their flavour - e.g. using butter for particular baked goods and lard for meat pie pastry.

In addition, the fat chosen needs to be able to form an emulsion with the other ingredients in the batter or dough.

Sugar

Sugar is most commonly thought of as a sweetener, but in baked goods it is also involved in several other processes. Sugar undergoes a series of complex browning reactions above 160°C, and the products of these form the brown crust of many baked goods. The reactions are known as Maillard reactions, and are essentially amino acid-catalysed caramelisation reactions in which a sugar aldehyde or ketone is converted to an unsaturated aldehyde or ketone:



In addition, 0.5 - 0.75% w/w of sugar increases the rate of fermentation for fermented goods (i.e. breads) by giving the yeast more sugar to work on. In non-fermented goods such as biscuits, large quantities of sugar can be added. This improves the keeping quality of the biscuits as well as sweetening them.

The sugar usually used is pure sucrose as castor sugar, 1A sugar or icing sugar. Occasionally impure forms such as golden syrup, honey and brown sugar are used to give the baking a particular flavour.

Ascorbic acid (vitamin C)
It has been extablished from many experiments that the addition of a small amount (up to 100ppm) of vitamin C also shortens the time needed for the dough to mature. This is because ascorbic acid catalyses the gluten crosslinking reactions to form a more extensible, elastic, strong network.

Baking soda ($NaHCO_3$)
Sodium bicarbonate has the property of releasing CO_2 when it is heated:

$$2NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$$

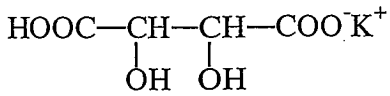
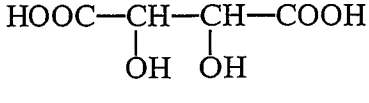
Since the material is relatively cheap and stable to storage, it would seem to be an excellent agent for the production of CO_2. The above equation, however, also illustrates the disadvantages of the material. When used on its own, only half the available CO_2 is released and, more seriously, the sodium carbonate produced is strongly alkaline and gives the baked product a bitter, "soapy" taste and a yellow colour. The digestion of such products also tends to be somewhere between embarassing and traumatic, since the Na_2CO_3 reacts with the HCl in the stomach to produce the other half of the available CO_2. For the above reasons, it must be stressed that sodium bicarbonate is very rarely used on its own, but generally mixed with some acidic material such as cream of tartar, honey, cocoa or golden syrup (e.g. treacle and baking soda are used together in baking gingerbread men). To avoid an imbalance between the acidic and basic materials, i.e. an incorrect pH, baking powder is more commonly used.

Baking powder
Baking powder is essentially a mixture of $NaHCO_3$ and a weak solid acid or acid salt. When the mixture dissolves in water and the temperature is raised, CO_2 is released according to the equation:

$$NaHCO_3 + H^+ \text{(from the acid)} \rightarrow Na^+ + H_2O + CO_2$$

The most common acids used are given in **Table 1**. There are also others which are less important. The N.Z. Food and Drug Regulations list the permitted ingredients and set standards for many foods.

Table 1 - Solid acids used in baking powder

Name	Formula
cream of tartar (potassium hydrogen tartrate)	
tartaric acid	
sodium acid pyrophosphate	$Na_2H_2P_2O_7$
acid calcium phosphate	$CaHPO_4$

The neutralising value (N.V.) is the measure of the number of parts of the acidic material required to neutralise 100 parts of baking soda; e.g. cream of tartar has an N.V. of 200 and

tartaric acid an N.V. of 100. Tartaric acid is more efficient (because only half the weight of tartaric acid is required to neutralise a given amount of baking soda compared with cream of tartar), but it cannot be used alone since it reacts very quickly. This means that a lot of gas is formed initially, but because it does not continue to be formed the gas doesn't hold the cake long enough for it to have the bubbles baked into it and so the cake collapses.

When baking powder is used rather than baking soda alone, the by-products are less alkaline than Na_2CO_3 and thus they have no undesirable effects on the taste of the product. The type of acid used in the baking powder affects the rate of CO_2 production, which in turn affects the product, e.g. a fast rate of CO_2 production is required for doughnuts so that the batter is aerated quickly and will float in the hot oil, ensuring a crisp product[1]. In baking, the rate at which CO_2 is produced and the continuity of CO_2 production are both important. If too much CO_2 is produced initially and the reaction ceases, removal of the cake from the oven will cause the cake to "drop". Some baking powders (e.g. "Sure to Rise") use two different acids to ensure fast initial reaction and continuity.

Baking powder is a very widely used ingredient in cooking and baking such things as buns, fruit loaves, crumpets, pikelets, pastries, cakes, pies, biscuits, omelets, some savouries and some puddings.

Self-raising flour has also become popular in recent years. This is merely a high grade flour to which baking soda and a suitable acid (such as cream of tartar) have already been added, the proportions being equivalent to one raised teaspoon of baking powder to one cup of flour.

Egg

The egg in a mixture usually has one of two functions. Beaten egg white is used, like baking powder, to give the dough a light, airy texture. This is achieved because egg white (albumin) contains lecithin, a protein which lines the outside of the air bubbles created when the egg was beaten and so prevents them from collapsing during baking. In unbeaten whole eggs the lecithin acts as a binder, holding the cake together. In addition eggs can be used as emulsifiers, moisteners (instead of simply adding water) and, nutritionally, as a source of fat and all the essential amino acids. When egg is used as a glaze it also acts as a source of protein for the Maillard reaction (see sugar section above).

Salt

Salt is added to enhance the flavour of cakes and breads and to "toughen up" the soft mixture of fat and sugar.

BAKED PRODUCTS

A selection of these ingredients are used for making a variety of baked goods. The flow chart (**Figure 1**) gives some of these and shows how the balance of ingredients used differs. In general, biscuits have the lowest moisture content and use a flour with the least gluten, followed by cakes and then pikelets, waffles and sponges.
The consistency of the cake is also altered by the physical mixing process it undergoes.

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[1]Note that not all donoughts are made using baking powder: many are made using yeast instead.

Some cakes need to be beaten extensively by whipping or creaming of ingredients so that air is incorporated into the mixture, as they don't use yeast, baking powder or baking soda for that purpose. Others, those which contain baking powder or soda, can be beaten too much, as the beating promotes the gas-forming reaction. If they are over-beaten, all the gas will be formed at the beginning and the gas bubbles will not be retained long enough to change the structure of the baked product. This problem can, however, be overcome by using rising agents that only become active when heated.

Cake mixes

In urban communities, the time devoted to cooking has been shortened by the introduction of increasingly popular "convenience" foods such as cake mixes, where most of the "donkey" work has already been done. Cake mixes are essentially a mixture of flour, baking powder and various other ingredients. Their manufacture poses some new and different problems. Since the product must be consistent and easy to use, these problems must be anticipated rather than overcome. Apart from legal Health and Hygiene regulations, manufacturers also comply with strict product specifications and spend much research time and money in developing accurate and simple tests covering the appearance, amount, purity and performance of their products and seek to improve them wherever possible. However, as the products still contain shortening, it is important that the mixes are not kept past their use-by date as this can go rancid.

Commercial bread production

In urban centres the need to produce large amounts of bread, buns, rolls etc. has led to the advent of mechanical dough development production. New combinations of ingredients appropriate to this process have needed to be developed, e.g. flour which has a high tolerance to mixing and higher-producing strains of yeast as 50% more yeast is required. However, these problems have been overcome, and a wide variety of commercial breads are available. These have much more consistent quality than is possible with hand-made bread and better crumb softness, keeping quality and strength.

THE ROLE OF THE LABORATORY

Laboratories are used by commercial manufacturers of baking ingredients, cake mixes and breads as follows.

The activity of baking powder, baking soda and cake mixes is checked by test baking and by testing the amount of CO_2 liberated from a standard sample of the test product. Chittick's method is used for this purpose. This involves adding sulphuric acid to the samples and measuring the amount of CO_2 produced in a gas burette.

Atomic Absorption Spectroscopy is used to determine the concentrations of metal ions present in the product. The main ions which are tested and controlled accurately are sodium, potassium, calcium and phosphorous (as an estimate of acid phosphates). Flame photometers could also be used for this purpose and are used by smaller industries.

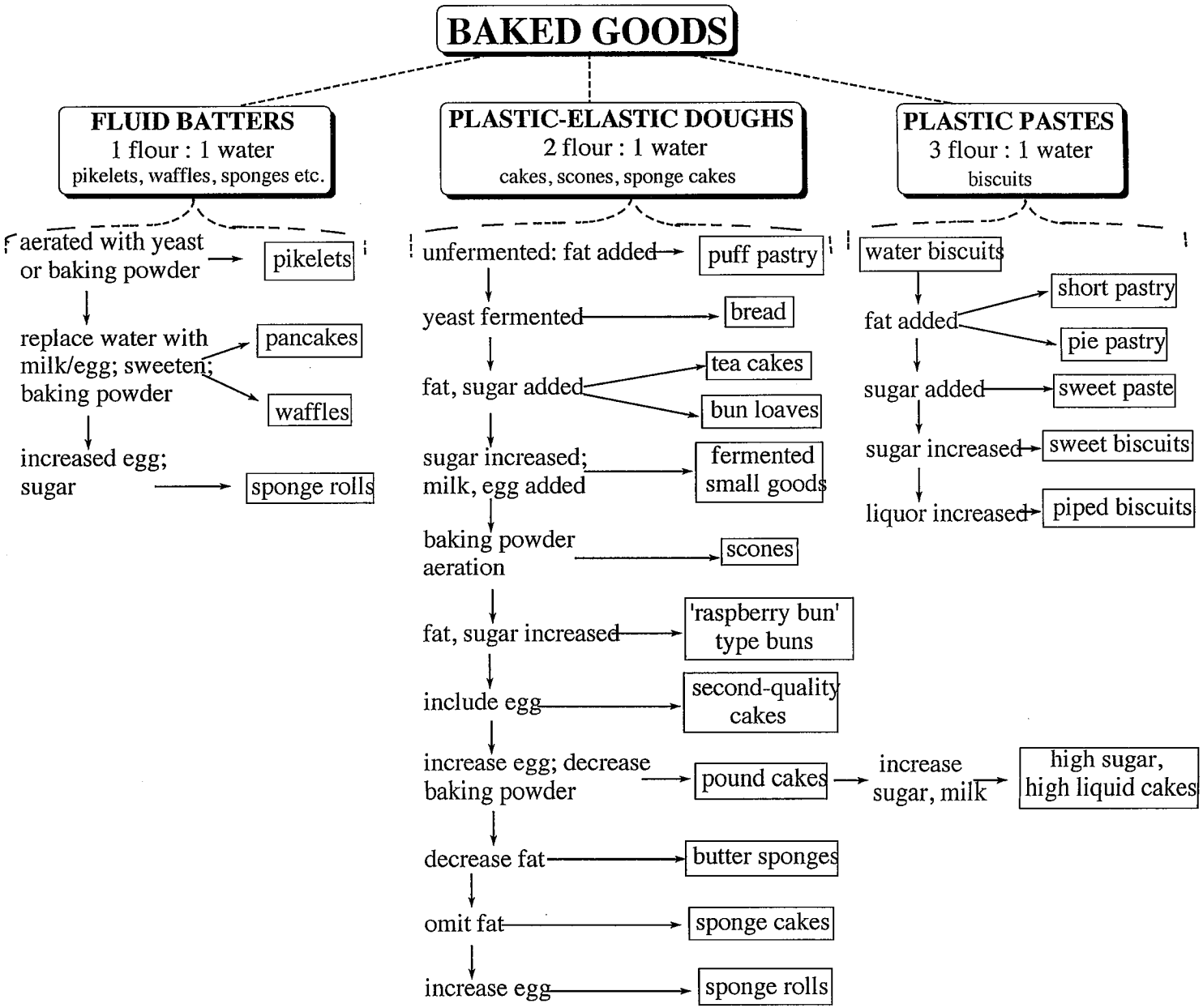

Figure 1 - Varying compositions of different bajed goods

In addition the Grain Foods Research Unit of the New Zealand Institute for Crop and Food Research carry out a variety of tests on wheat to determine its quality. These include:

- falling number determination — a measure of the presence of an enzyme, -amylase, which indicates the proportion of sprouted wheat,
- test baking — in which samples of flour and bread are baked using standard formulae to determine their potential to make high quality breads,
- tests of protein, fibre, fat, carbohydrate and mineral composition.

Based on this information flour manufacturers can blend flours appropriately to produce a consistent product.

It will be obvious from the article that a chemist employed in this industry will always be challenged by the variability of the raw materials and the applicability of the product possibilities. Changing tastes and fashions demand the constant development of new and different products. Changing Health and Hygiene regulations also demand improvement in products and manufacturing processes. The chemist also has to work towards cost reduction, especially in times when the costs of the raw materials are increasing so quickly or when raw materials become unavailable due to shipping delays or shortage of import licence. The chemist then has to become very versatile at making quick but good substitutions of raw materials which are available at short notice or from he local market, while still maintaining the quality of the product and without increasing the cost if all these are possible.

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- Humphrey-Taylor, Virginia; *New Zealand Institute for Crop and Food Research Resource sheets*
- Campbell, Annette and Humphrey-Taylor, Virginia; *The Science behind Breadmaking* [Online]; Available http://www.crop.cri.nz/foodinfo/millbake/science.htm