Fat Migration

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1. Introduction

There is a strong trend within the chocolate market towards filled products. The consumer has a wide choice of pralines, filled chocolate bars, filled seasonal items, snack bars and baked products with chocolate coating. Such products are particularly vulnerable because of the interaction of filling and chocolate.

During storage some oil from fillings such as nougat, nuts, marzipan, caramel, filling cremes or baking fats migrates into the chocolate shell, but also some cocoa butter migrates into the filling (Figure 1). The components of the fat phase try to achieve a homogenous distribution. Fillings lose their smooth texture, chocolate becomes soft and develops fat bloom. Fat bloom develops from triglycerides, which migrate to the surface where they re-crystallise. The extent of fat migration mainly depends on the proportion and formulation of the filling, storage conditions and the manufacturing process, i.e. the technology for the production of the chocolate shell.

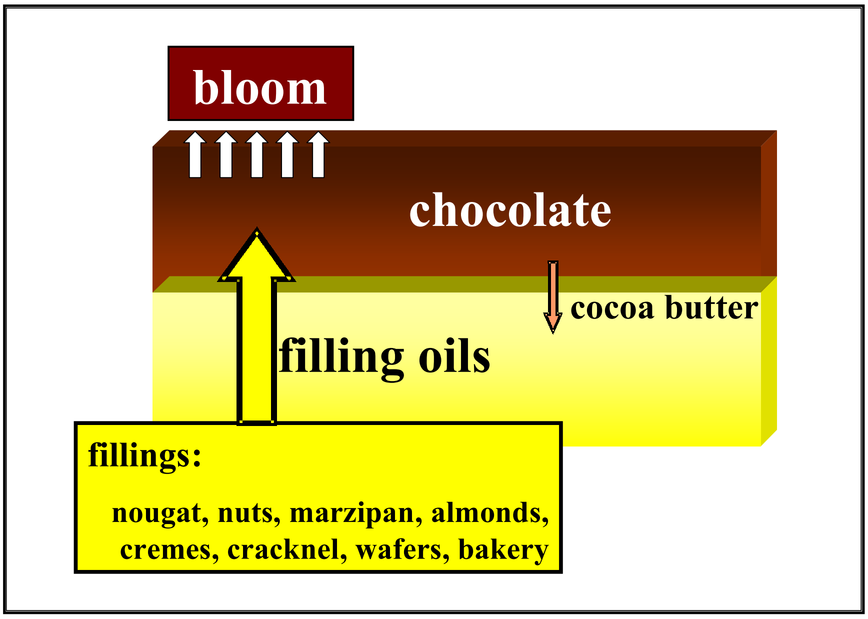

Figure 1: Fat migration in filled chocolate

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2. Mechanism of fat migration

In filled products two fat phases are in direct contact with each other. The triglycerides (TGs) in fillings, which often contain hazelnut or almond oils, are predominately liquid such as triolein (OOO) and other TGs from linoleic and oleic acids (LOO, LLO, POO, SOO). The fat phase in milk chocolate consists of cocoa butter and milk fat and contains high levels of the mostly crystalline triglycerides POS, POP and SOS.

The migration rate of each triglyceride depends on its specific mobility and the concentration gradient. Liquid triglycerides are more mobile than crystalline triglycerides (Figure 2.)

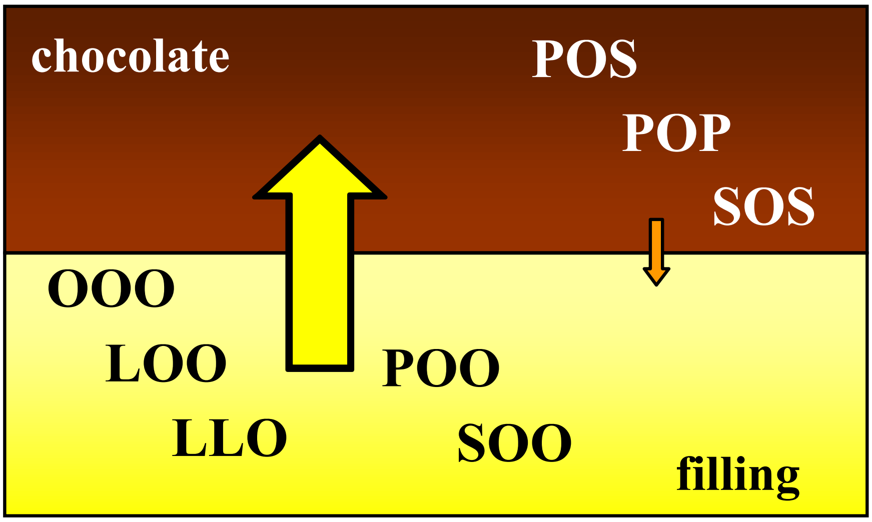

Figure 2: Diffusion of some triglycerides in chocolate and filling. (POS = 1-Palmito-2-oleo-3-stearine, POP, SOS = 1,3-Dipalmito-/ 1,3-Distearo-olein, OOO = Triolein, LOO, POO, SOO = 1-Linolo-/ 1-Palmito-/ 1-Stearo-diolein, LLO = 1,2-Dilinolo-olein.)

In Figure 3 the contents of selected triglycerides in milk chocolate and nougat filling (100 g bar, 60 g chocolate with 32.7% fat, 40 g nougat with 34% fat), fresh and after storage, respectively, are shown. Fresh nougat contains hazelnut oil (Triolein, LOO, LLO, POO) alongside milk fat and cocoa butter (POS, POP, SOS). Fresh chocolate is almost free from nut oil.

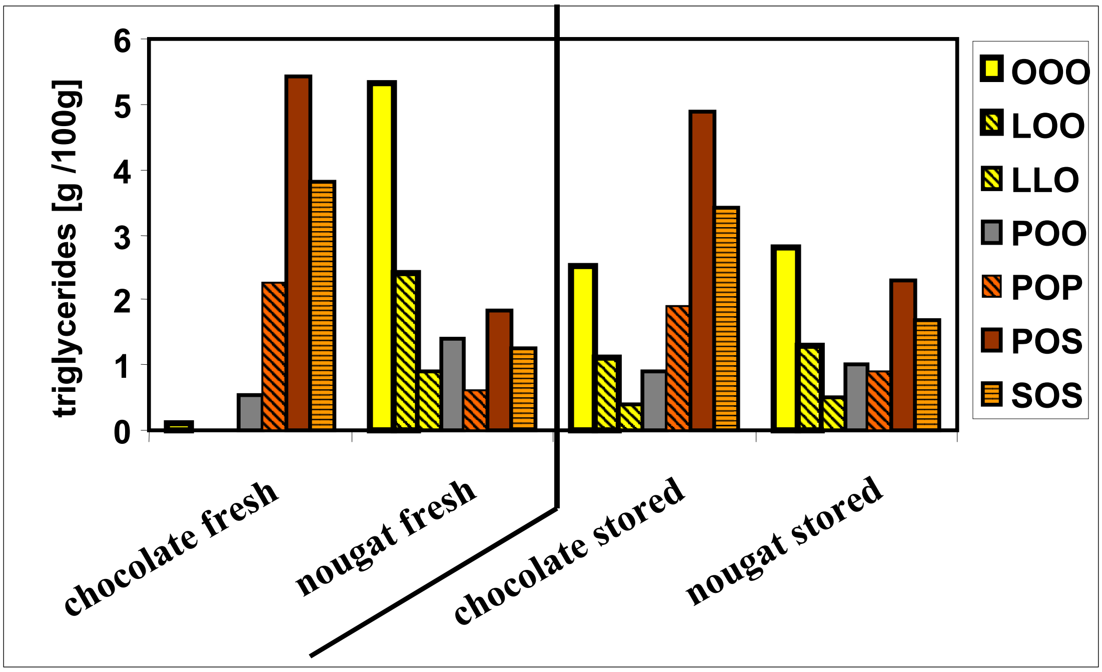

Figure 3: Contents of selected triglycerides in milk chocolate with nougat filling, fresh and after storage (200 days at 20C).

After very long storage over 200 days at 20C the main triglycerides of hazelnut oil (OOO, LOO, LLO) have almost evenly distributed between chocolate and filling, and, therefore, migrated from the filling into the chocolate until saturation. On the other hand, triglycerides of the cocoa butter have only migrated a little into the filling because they are less mobile and their concentration gradient was lower.

This example illustrates the extent of fat migration. After storage, the weight of chocolate increased by about 4 g (6.7%) and its fat content increased from 32.7% to 36.9%. The filling lost weight and its fat content decreased from 34% to 26.7%. The stored product lost all of its quality with regard to texture, appearance and flavour. After longer storage, the fat phase of the chocolate has a distinctively different composition from that of pure chocolate, which is not an indication of adulteration but technically impossible to prevent.

The kinetic of fat migration follows the law of diffusion as shown in the equation in Figure 4. In its early stage the fat migration is almost proportional to the square root of the storage time; therefore, fresh products are particularly vulnerable. Towards the final stage saturation with an even distribution of triglycerides is achieved. But the acceptable limit regarding quality lies at far lower levels of migrated oil (Figure 4). As can be seen in the equation the migration is in reverse proportion to the thickness of the chocolate shell. Therefore, fat bloom develops predominately where the chocolate shell is thin, often at the bottom of pralines, around enclosed nuts or between the individual pieces of a bar. For the calculation of the diffusion coefficient D the saturation level m_s, which depends on proportion and fat content of the filling, is important.

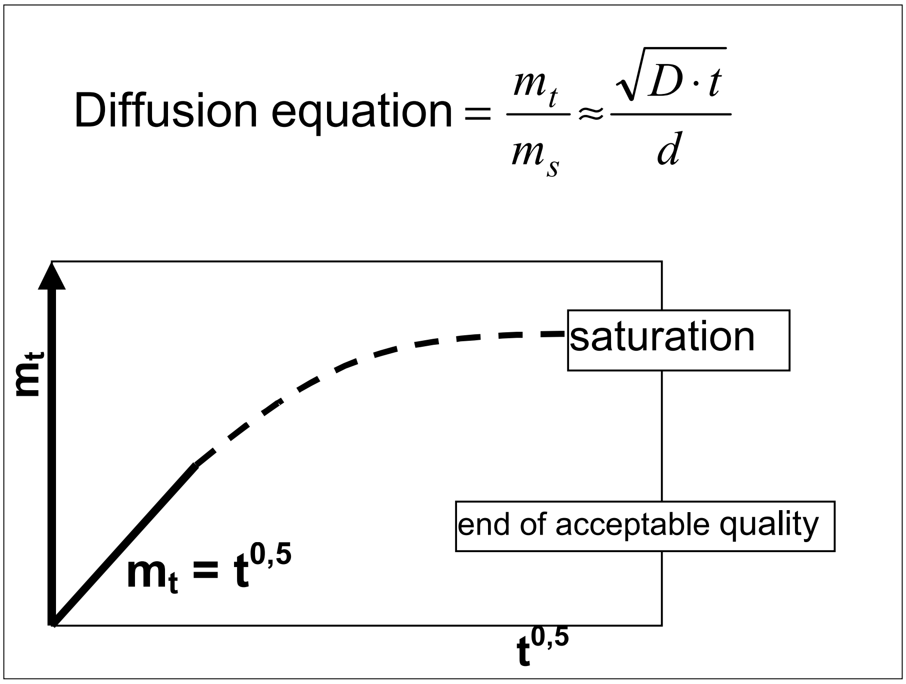

Figure 4: Kinetics of fat migration. (m_t = oil level in chocolate at time t, m_s = oil level at saturation, d = thickness of chocolate shell [cm], t = storage time [s], D = diffusion coefficient [cm^2/s])

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3. Detection of fat migration

Fat migration can be followed with chromatography methods such as HPLC or GC. Chemical analyses are comparatively laborious. More and more physical methods are used because they do not require fat extraction, they are fast, or because they provide important information about the hardness or texture of a product (Table 1).

Table 1. Detection methods for fat migration

Chemical analyses:	Triglycerides (HPLC, GC)
	Fatty acid composition, Iodine value
	Total fat content
Physical methods:	Weighing
	DSC-Thermoanalysis
	Solid fat content (pulsed NMR)
	Magnetic Resonance Imaging (MRI)
	Texture analysis

Pulsed Nuclear Magnetic Resonance (pNMR) is an efficient method of detection. pNMR is used for the determination of the solid fat content of chocolate. Because the solid fat content of chocolate decreases with increasing oil level this can be used as measure of fat migration. The method of Magnetic Resonance Imaging (MRI) has the same principle and shows the three-dimensional oil distribution in a chocolate product, but it is extremely laborious. Filling oil in chocolate can also be quantified and shown in its three-dimensional distribution by DSC-Thermoanalysis.

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4. Effect of storage temperature

Fat migration in chocolate is extremely dependent on storage temperature. Chocolate becomes softer with increasing temperature and looses its resistance towards the ingress of oils from the filling. Migration occurs predominately in the liquid fat phase because it requires a mobile phase.

This strong temperature dependency can, for example, be demonstrated by storage trials with nougat-filled milk chocolate bars. In Figure 5 the amount of hazelnut oil in the chocolate coating is shown as a function of storage time and temperature. At the beginning of the storage trial there is always a linear increase over the square root of the storage time as expected according to the laws of diffusion (Equation 1 in Figure 4). At very high storage temperature (26C) the horizontal saturation plateau is reached after about 200 days at which the hazelnut oil is almost evenly distributed between chocolate and filling. At 23C, it can be seen that this plateau is reached after about 400 days. Freshly produced bars contain about 0.8% nut oil in the chocolate because the chocolate shell was only partially solidified during production and could rapidly take up oil after filling with liquid nougat.

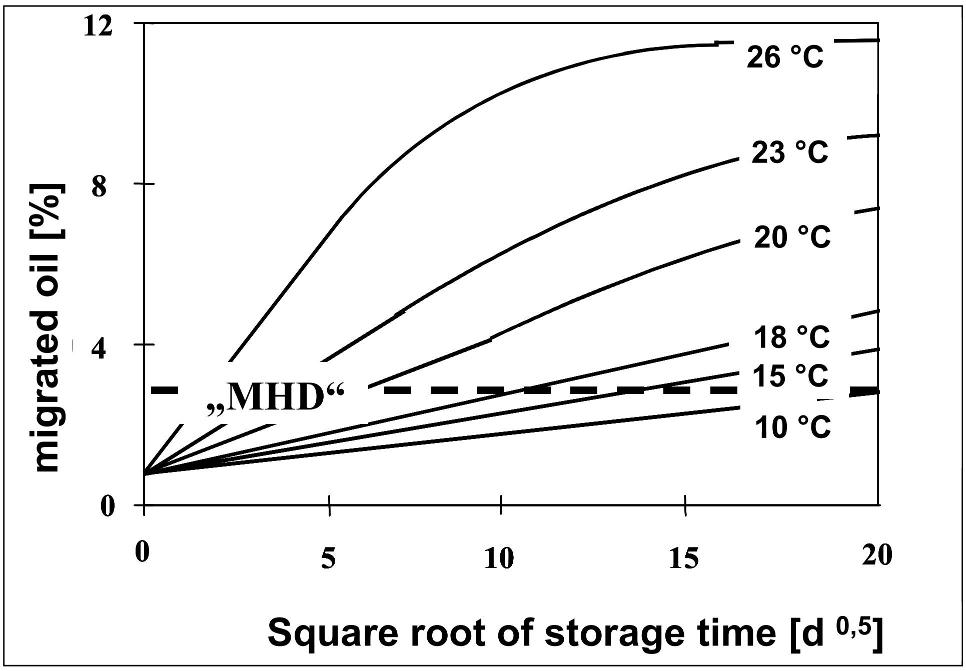

Figure 5: Migrated oil in the chocolate (%/ chocolate) of nougat-filled milk chocolate as a function of storage time and temperature. Horizontal line shows a set limit to describe a maximum shelf-life "MHD" (= Best Before End).

Fat migration, although very slow, can already be seen during storage at 10C. The migration rate at 20C is nearly double that at 10C, and likewise during storage at 26C compared with 20C.

The extent of fat migration can be used for setting the shelf-life of a filled chocolate product. For example, if 3% of migrated hazelnut oil in chocolate was regarded as acceptable maximum for product quality, this condition would be reached at 10C after 400 days (shelf-life), at 15C after 180 days, at 18C after 100 days, at 20C after 36 days, at 23C already after 9 days and at 26C after only 1 day.

The critical effect of short-term temperature peaks (in this example 26C) as they can occur during transport of chocolate products and inappropriate storage at home becomes clear. For producers of chocolate articles it is of particular interest to set optimum conditions in the warehouse. Although refrigeration at 10C or 15C requires additional energy and costs, it may ensure a significantly improved maintenance of quality than at 18C or 20C storage.

As was expected, the chocolate bars developed fat bloom during the storage trials, at 20 C after about 100 days, at 23C after only 20 days. At 18C, the samples lost their gloss during long storage, but they did not develop fat bloom. After a few days of storage at 26C a slight colour change resulting from oil migration was noticeable, which became extreme after about one month. However, because the lipids that had migrated to the surface could not crystallise at this high storage temperature no fat bloom developed.

The storage trials reveal the close relationship between fat migration and fat bloom. Oil from the filling replaces triglycerides in the chocolate and transports them to the surface where crystallisation is initiated at suitable temperatures. The surface gloss is lost and fat bloom becomes visible. Such fat bloom crystals contain up to 10% triglycerides from filling oils, mostly triolein, besides the main components of cocoa butter (POS, POP, SOS).

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5. Effect of product formulation

Products with a high proportion of filling are particularly susceptible to fat migration because they contain only little chocolate and, hence, have only thin chocolate shells (a low thickness d of the chocolate shell promotes migration m_t (Equation 1 in Figure 4)). A manufacturer would favour a high proportion of filling and a thin chocolate shell because of cost constraints and sensory considerations, but for better stability thicker chocolate shells are recommended. The use of cocoa butter with relatively high solid fat contents is suitable for stabilisation of chocolate shells against migration.

In the filling, the content of liquid oil is decisive. An intensive homogenisation and adsorptive binding of the oils in the filling onto the surface of sugar and milk powder particles are also important for stability. So-called structuring fats have the ability to crystallise as a network that can entrap oils. Emulsifiers that are used for improving the flow properties can have a negative effect on stability because they wet the surface of particles and increase the mobility of the oil phase. Because fillings are generally made with fat blends their compatibility with each other and also on the interface with the shell has to be borne in mind. Incompatible fats, for example lauric fats in the filling and cocoa butter in the chocolate shell, decrease the solid fat content when in direct contact with each other and increase the speed of fat migration.

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6. Effect of manufacturing process

6.1 Cooling

In order to achieve a sufficient resistance against fat migration of a chocolate product besides a good appearance and sensory characteristics the fat phase in the finished chocolate needs to solidify in a dense crystal network. Therefore, the process conditions during pre-crystallisation, moulding and crystallisation in the cooling tunnel are decisive for a good quality.

Because of cost constraints, production rates are being accelerated. To facilitate this, residence times in cooling tunnels are often reduced which can have detrimental consequences, in particular in combination with too low a temperature. In such cases the chocolate shell is only partially crystallised after the cooling tunnel, and after deposition of the filling the high proportion of liquid fat phase in the shell enables a very extensive migration of the filling oil. It is well known that pre-crystallised chocolate mass crystallises fastest and forms a dense crystal lattice in a cooling tunnel at 15C. Above 15C crystallisation slows down because of insufficient supercooling, whereas below 15C it slows down because of decreasing mobility of molecules at increased viscosity. In order to produce chocolate shells which are stable against migration the cooling temperature should not be lower than 10C and the residence time should not be shorter than about 4 minutes.

Figure 6 shows the condition of fresh chocolate after the cooling tunnel using solid fat contents measured by pNMR. At room temperature about 24% of the fat in chocolate always remains liquid. This liquid fat phase consists mainly of the liquid triglycerides of cocoa butter (amongst others POO, SOO, PLS, SLS) and of milk fat. At too short a residence time in the cooling tunnel only about 40% of the fat can crystallise, at slow throughput rates up to 70%. With too short cooling the chocolate contains 60% liquid fat, which enables spontaneous migration during filling. About 36% of the liquid fat can crystallise subsequently, but then, the fat migration is far advanced and can cause development of fat bloom.

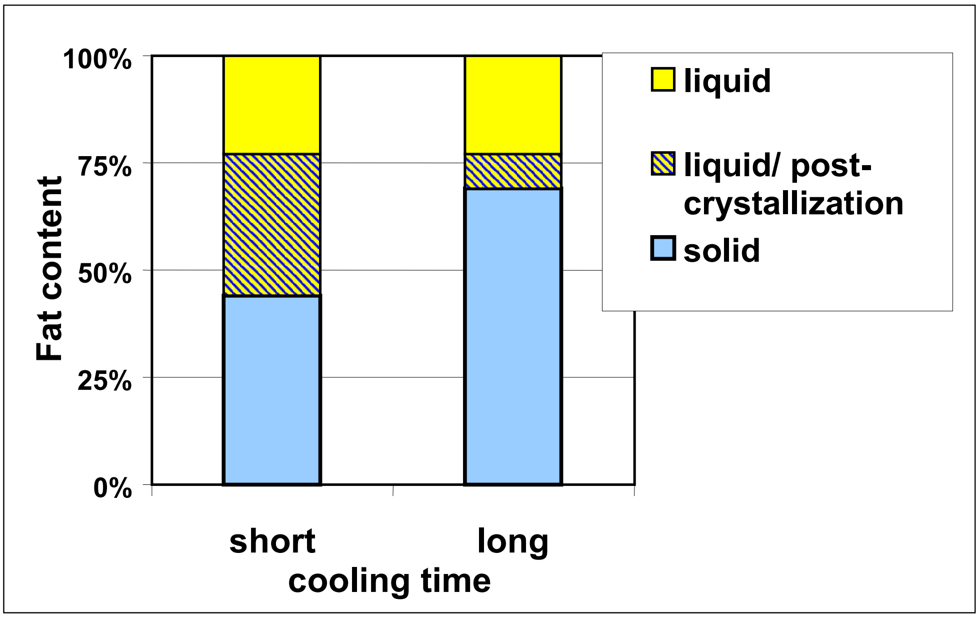

Figure 6: Proportions of crystallised and liquid fat in freshly produced chocolate as a function of cooling time (pNMR-data).

6.2 Moulding

Chocolate shells are traditionally moulded by the following process: the mould, which is filled with liquid chocolate, is turned over to pour out the excessive chocolate leaving behind only a thin film on its wall. After cooling this is obtained as the chocolate shell. Alternative methods used today are cold-stamp, frozen-cone or cold-press moulding. In these methods a pre-determined amount of chocolate is filled into the mould and then pressed against its wall by short insertion of a chilled cone (a few seconds at –25 to 2C) to form the chocolate shell. Because of the shock cooling the chocolate solidifies and retains its shape when the cone is removed. The crystallisation occurs as in the traditional method within a cooling tunnel. A traditionally moulded chocolate shell has thick and thin areas, which are created during the turning-over of the mould, because the centrifugal forces unevenly affect the chocolate that pours out. Cold-pressed chocolate shells have an even wall thickness.

During storage trials, traditionally produced and cold-pressed chocolate shells show similar stability against migration as filled pralines. This is not surprising as the chocolate in both cases was crystallised within a cooling tunnel and could establish the same density and solid fat content, respectively. The short temperature shock during cold-pressing has no detrimental effect. When compared, traditionally moulded pralines develop fat bloom earlier because the migrating filling oil penetrates faster through the thin areas of the shell. Cold-formed shells have the advantage of a uniform average wall thickness and, therefore, exhibit a uniform but retarded fat bloom development.

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7. Summary

Fat migration is an unavoidable problem in pralines and filled chocolate. It leads to structural changes and fat bloom development and, hence, is deciding for the quality loss during storage of filled chocolate.

The application of the equation of diffusion for describing fat migration has made it more reliable to estimate the shelf-life of filled chocolate. Because fat migration shows a linear increase with the square root of storage time fresh products are particularly vulnerable. Therefore, during production it has to be ensured that the chocolate shells have a uniform wall thickness and can sufficiently solidify prior to filling.

The solid fat content of chocolate is of great importance for its stability against migration. The rate of fat migration strongly depends on temperature because with increasing temperature the hardness and resistance of the chocolate are lost. Therefore, chocolate products must be stored in a cool place to retard fat migration and fat bloom development.

The ratio of chocolate to filling must be sufficiently large to ensure a sufficient wall thickness of the chocolate shell. In order to achieve good stability against migration and fat bloom development the oil content of the filling has to be considered, and the oil should be locked by adsorption into the matrix of non-fat constituents.

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