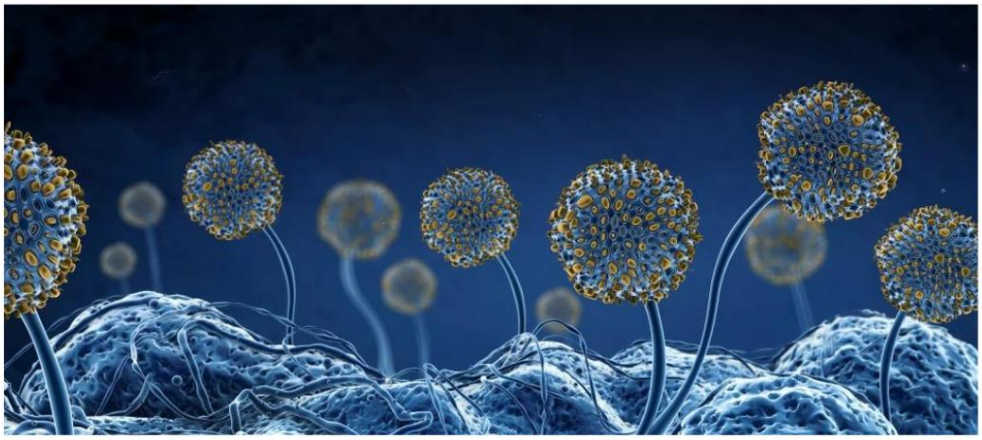
Bachelor thesis

MOULD PREVENTION METHODS OF BREAD MANUFACTURERS

A company comparison



Tess Oostwouder

Mould prevention methods of bread manufacturers

What is the difference in methods of preventing mould growth on bake-off bread between bread manufacturers and how can mould growth be prevented?

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AERES UNIVERSITY OF APPLIED SCIENCES

Preface

You are about to read my thesis on the mould prevention methods of bread manufacturers. This thesis is written for the completion of my fourth year of the Bachelor Biology, Food & Health at Aeres University of Applied Sciences.

I have worked on this thesis for three months during my internship at a meal kit company in the Netherlands. The meal kit company offered me working on the topic of mould causes on bake-off bread products for my Company Project. This thesis is an extension of the Company Project existing of a company comparison between bread manufacturers.
The combination of both working within the Food Safety and Quality Assurance team of the meal kit company and conducting individual research has ensured that I have been able to apply my acquired knowledge in practice.

This thesis is initially intended for Aeres University of Applied Sciences. In addition, it provides interesting information for both industrial bakeries and meal kit companies.

I would like to thank my graduation teacher Marloes van der Horst for guiding me through my graduation year by giving me feedback and tips. Also, I would like to give special thanks to my internship supervisor Milco Meere for assisting me while working on my thesis.

Tess Oostwouder

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Abstract

Microbial spoilage by moulds is a major quality challenge for bread manufacturers. It reduces the product shelf-life generating economic losses and consumers dissatisfaction. In particular, bake-off bread products are susceptible for mould formation. Mould growth is mainly caused by mould aerosols, contaminating the bread in the period after baking and before packaging. Contamination can also occur if the packaging is damaged and oxygen can enter, enhancing mould growth.

Bread manufacturers must use standards that implement food safety and quality systems to prevent hazards like mould contamination. However, bread manufacturers do not use the same standards to prevent mould growth. Therefore, the main purpose of this research was to study the mould prevention methods of bread manufacturers. The following main research question was formulated: *What is the difference in methods of preventing mould growth on bake-off bread between bread manufacturers and how can mould growth be prevented?* A company comparison was made which described the differences and similarities between the prevention methods of four bread manufacturers.

By means of desk research of a meal-kit company, bread products with high error rates on mould could have been generated. Based upon the Relative Error Rate (RER) the following top 5 bread products with most mould complaints was shown: tortilla, brown wheat bread, white wheat bread, Lebanese flatbread and naanbread. Out of the top 5, four suppliers were further investigated on the frequency of mould complaints. One supplier never had a week with RER >0.5%.

During the interviews and audits of the suppliers, prevention methods for mould growth were requested and observed. Most important similarity was found in the way how the bread products are packaged (all apply Flow pack and Modified Atmosphere Packaging (MAP)). The most important difference between the suppliers was found in the residual oxygen limit measured in bread batches, ranging from <0.5% to <3%.

Recommendations to prevent mould contamination for bread manufacturers include a filtered ventilation system (cleanroom) in the cooling and packaging area. Lowering the limit for residual O_2 to a maximum of 0.5% will reduce the chance of mould growth. In addition, a solid primary, secondary and tertiary packaging and a handling training for transport personnel is recommended.

Further research into mould incidents on bread products at the distribution center of the meal-kit company is recommended. Other further research that should be considered includes investigation of transport conditions for causing possible leaks of the bread packages.

Samenvatting

Microbieel bederf door schimmels is een belangrijk kwaliteitsprobleem voor broodfabrikanten. De houdbaarheid wordt korter wat leidt tot economische verliezen en ontevredenheid bij de consument. Met name bake-off broodproducten zijn gevoelig voor schimmelvorming. Schimmelgroei wordt vooral veroorzaakt door schimmelsporen die het brood besmetten in de periode na het bakken en vóór het verpakken. Besmetting kan ook optreden als de verpakking beschadigd is en er zuurstof kan binnendringen wat de schimmelgroei bevordert.

Broodfabrikanten moeten aan bepaalde standaarden voldoen die voedselveiligheids- en kwaliteitssystemen implementeren om gevaren zoals schimmelvorming te voorkomen. Broodfabrikanten hanteren echter niet dezelfde normen om schimmelgroei te voorkomen. Daarom was het hoofddoel van dit onderzoek de schimmelpreventiemethoden van broodfabrikanten te bestuderen. De volgende hoofdonderzoeksvraag werd geformuleerd: *Wat zijn de verschillen in preventie methoden voor schimmelgroei op bake-off brood tussen broodfabrikanten en hoe kan schimmelgroei worden voorkomen?* Hiervoor is een bedrijfsvergelijking uitgevoerd waarin de verschillen en overeenkomsten tussen de preventiemethoden van vier broodfabrikanten zijn beschreven.

Door middel van deskresearch van een maaltijd box leverancier, konden broodproducten met veel schimmelklachten worden gegenereerd. Op basis van de Relatieve Error Rate (RER) werd de volgende top 5 broodproducten met meeste schimmelklachten zichtbaar: bruine tortilla, bruin tarwebrood, wit tarwebrood, Libanees platbrood en naanbrood. Van de top 5 werden vier leveranciers verder onderzocht op de frequentie van schimmelklachten. Eén leverancier had nooit een week met een RER >0,5%.

Tijdens de interviews en audits bij de leveranciers werden de preventiemethoden voor schimmelgroei nagevraagd en geobserveerd. De belangrijkste overeenkomst werd gevonden in de wijze waarop de leveranciers de broodproducten verpakken (allemaal Flowpack en Modified Atmosphere Packaging (MAP)). Het belangrijkste verschil tussen de leveranciers werd gevonden in de limiet voor resterend O_2 (gemeten in iedere brood partij), wat varieerde tussen de <0.5 en <3%.

Aanbevelingen ter voorkoming van schimmelbesmetting voor broodfabrikanten zijn onder meer een gefilterd ventilatiesysteem (cleanroom) in de koel- en verpakkingsruimte. Het verlagen van de limiet voor resterend O_2 naar maximaal 0.5% verminderd de kans op schimmelgroei. Daarnaast is een stevige primaire, secundaire en tertiaire verpakking en een omgangstraining met broodproducten voor transportpersoneel aan te bevelen.

Verder onderzoek naar schimmelincidenten van broodproducten in het distributiecentrum van de maaltijd box leverancier wordt aanbevolen. Ander verder onderzoek dat kan worden overwogen is het onderzoek naar mogelijke lekkages van de broodverpakkingen tijdens transport van brood-leveranciers naar het distributiecentrum.

1. Introduction

Bread products have a high share in the international food market (Axel, Zannini & Arendt, 2017; Kumar, 2018). There is a large variety in types of bread to meet consumers' needs such as convenience, beneficial nutrients, and allergies. According to Gira, a market research firm operating in food sectors, bake-off bread products is one of the strongest growing sectors in the European bakery market (Gira, 2020). Although 71% of bakery product consumption is dominated by fresh baked products, bake-off bread has with 24% a major share in the European bread market and it is expected to grow to 40% by 2025 (Gira, 2020).

Different consumption trends of bread are seen between Eastern and Western European countries (Gira, 2020; Kumar, 2018). Whereas Eastern European countries show a higher production and consumption trend for bake-off bread, Western European countries prefers fresh bread products. In general, European consumers developed a higher demand for nutritious products (high fiber, whole grain, reduced sugar/salt) (Gira, 2020). In addition, consumers developed more consciousness for clean label products with claims such as "without artificial preservatives" or "natural" (Vargas & Simsek, 2021). Despite these market demands, bread manufacturers must still deliver safe and high-quality bread products with an extended shelf life.

A major quality and safety challenge for bread manufacturers is mould growth. Due to the relatively high moisture content of bread and a water activity (a_w) between 0.94-0.97 and pH of about 6, bread is an ideal habitat for moulds to grow (Le Lay, 2016; Melini, V. & Melini, F., 2018; Saranraj, & Sivasakthivelan, 2015). In particular, bread that has been pre-packed (bake-off), cooled or sliced has a higher chance of mould formation. This is because the bread releases moisture to the environment inside the package, which increases the relative humidity inside the package and promotes mould growth (Axel et al., 2017). Special attention should be given during summer months, since the warmer temperatures outside also affects the temperature and humidity level inside the bakery, storage location and during transport (Saranraj & Sivasakthivelan, 2015).

Microbiological spoilage of bread due to mould growth, is a serious food waste concern and causes large economic losses for bread manufacturers and consumers (Melikoglu & Webb, 2013). A consumer research of the Dutch "Voedingscentrum" (Food Center) concluded that Dutch households throw away bread mainly because it is mouldy (29%) (Voedingscentrum, 2021). Beside economic disadvantages, moulds also pose a major hazard for costumer's health due to the fungi that produce mycotoxins. These toxic compounds are present even before moulds are visible on the product (Axel, et al., 2017; Magan, Arroyo & Aldred, 2003). Therefore, the bread industry invested a lot in production- and preservation techniques to ensure the quality and safety of bake-off bread. Numerous techniques are used to prevent moulds to grow, like adding preservatives, chilled storage, freezing, and packaging (Garcia, Bernardi & Copetti, 2019; Galić, Ćurić & Gabrić, 2009). Packaging techniques have been the main choice for bread manufacturers to satisfy the clean-label market demands and extend the shelf life without using preservatives (Gutiérrez, Sánchez, Batlle & Nerín, 2009; Kotsianis, Giannou & Tzia, 2002).

The most common used packaging method by bread manufacturers to control moulds in bake-off bread products is Modified Atmosphere Packaging (MAP) (Gutiérrez et al, 2009; Saranraj, & Sivasakthivelan, 2015). Through altering the proportions of atmospheric gases (CO_2 and N_2) in the packaging of the food product, the shelf life will be extended, and the quality of the product will be maintained during transport to consumers. MAP is commonly used in combination with other packaging techniques such as Active

Packaging (AP) (Muizniece-Brasava et al., 2012; Upasen & Wattanachai, 2018). By using AP, the packaging interacts with the food and environment by absorbing and / or releasing compounds that work effective against oxidation, microbial growth, and moisture migration (Melini, V. & Melini, F., 2018; Muizniece-Brasava et al., 2012). Compounds such as ethanol, have shown to extend the shelf life of bread by spraying it onto the bread surface prior to packaging (Garcia et al., 2019; Suppakul, Miltz, Sonneveld & Bigger, 2003).

Mould growth is mainly caused by contamination of fungal spores during post baking (Axel et al., 2017). The grains used as raw materials for bread production are highly vulnerable to infections of fungal pathogens in the field or during storage. Even though most fungi are inactivated during baking due to the high temperature, a high count of spores are released in the air as aerosols during the production of bread products (Almeida, Steel & Chang, 2016; Garcia et al., 2019). The spores sediment on the surface of fresh bread products by gravity. Research concluded that bread that has been sliced and packed in a "clean room" (filtered air + extremely hygienic environment) does not become mouldy during the first 20 days (Kwak, 2017). Another important cause of mould growth on bake-off bread is found in packaging leakages, that allows oxygen to enter and enhance mould growth (Axel et al., 2017). The hazard points for increasing of fungal loads on bread products are storage, ingredient mixing, slicing, cooling, packaging, and room storage.

According to Commission Regulation (EC) No 178/2002, every company that prepares or trades food products in Europe is required to implement a system that guarantees food safety (European Commission, 2002). There are several standards that implement food safety and quality systems such as Global Food Safety Initiative (GFSI) and three GSFI-recognised standards: British Retail Consortium (BRC), International Featured Standard (IFS) and Food Safety System Certification 22000 (FSSC 22000). Differences between these standards are seen in the way how the standards are awarded: by a checklist with score result (IFS and BRC) or basic prerequisite program with additional requirements and measures (FSSC 22000). Dutch food manufacturers and traders can also make use of Hygiene Codes, a branch established and officially recognised food safety and quality system. For the Dutch bakery branch, the Hygiene code for Bread and Pastry industry can be of importance (NBC, 2021). It discusses critical steps for the preparation of bread including contamination by hazards (allergens and microbiological growth), machinery and tools, personal hygiene, cleaning and disinfection, temperature control, pest control, storage of raw materials, preparation and storage of finished products and transport. The Dutch Food and Consumer Product Safety Authority (NVWA) regularly assess food companies during inspections and audits. A warning or fine is issued if a food company does not comply with legal hygiene rules.

What all standards has in common is that they implement the 7 principles of Hazard Analysis and Critical Control Points (HACCP). HACCP is a risk-assessment tool which aims to prevent and minimise health risks hazard cause by inadequate control at critical process steps (Luning & Marcelis, 2020). The principles of HACCP describing the hazards (including microbial hazards such as bacteria and moulds), establishing Critical Control Points (CCP's) and standards for these CCP's, designing a control system for monitoring the control points and developing a procedure to rectify any deviations. Food companies can design a self-made HACCP plan or can apply for one of the standards mentioned in the previous section. Therefore, bread manufacturers use different methods to control mould growth. Regarding this, the study of the different methods used by bread manufacturers to control mould growth is of interest.

1.2 Research aim and questions

The aim of this research is to study the mould prevention methods of bread manufacturers and give recommendations on how to prevent mould growth. Additional purpose is preventing food waste, increasing food safety and profit enhancement for both bread manufacturers as consumers. The product of this research is a company comparison, in which the differences and similarities on mould prevention methods between bread manufacturers are sketched. In addition, corresponding opportunities for preventing mould growth for bread manufacturers are given. To reach this aim, the following main research question is formulated:

What is the difference in methods of preventing mould growth on bake-off bread between bread manufacturers and how can mould growth be prevented?

To answer the main research question, four sub-questions are defined:

1. Which bread products are most often affected by mould?
2. What is the frequency of mould incidents on bake-off bread products at the bread manufacturers?
3. Which packaging methods are used by the bread manufacturers?
4. What are the manufacturers currently (hygiene) protocols to prevent mould growth on bake-off bread products?

2. Material & Methods

This chapter will describe the research design and research methods used within this research.

2.1 Research design

Multiple research methods are used to answer the main research question. Descriptive research is used to answer the main research question. This kind of research is useful to identify characteristics and differences between elements, in this case four bread manufacturers. This research starts with conducting a literature study to broaden the knowledge in the field of mould on bake-off bread products. Next, desk research is performed to identify bread products and bread manufacturers that has been affected with mould complaints by making use of Quality software programs and analyzing data of errors in a database program (Tableau). Subsequently, previous internal research is used to define interview questions. Based on this data, qualitative interviews are conducted with quality managers of the four bread manufacturers. Management, products, processes, and techniques that the companies implement are compared making use of the results from these interviews. Based on the information gained during the literature study, desk research and interviews, a comparison between the bread manufacturers and recommendations to prevent mould growth on bake-off bread products are developed.

2.2 Research methods

2.2.1 Literature study

Since this research does not include experiments, literature study is an important part of answering the first and second sub-questions. Several databases are used to gather relevant papers: Google scholar, Greeni, PubMed, and ResearchGate. Using these sources, a wide range of literature is assessed: scientific papers, market reports, company catalogues, and factsheets. In this research, the snowball technique is used in which a key publication serves as a starting point from which the literature list can be used as new sources of information. Additionally, citation searching is used to search for highly recommended and frequently citated publications.

Research describing mould growth on bread that did not include a link to bake-off bread products are mostly excluded, since this current study only focus on bake-off bread products. Research that includes irrelevant bread products (fresh, frozen) are excluded as well. Appendix I shows an overview of the search terms and keywords used during the extension of the literature study. The articles and information are judged on their relevance by reading and analyzing the content. Literature study is finished when all relevant information relating to current bread production methods, causes of mould growth and mould prevention methods and standards were defined.

2.2.2 Desk research

Desk research is conducted by making use of Quality software programs and a database. Quality software programs include Quasydoc and Authenticate. These programs offer international food companies to collect quality management data of product specifications, suppliers, supply chains and improvements to optimize the food safety in accordance with the applicable standards, legal obligations and costumer requirements (Authenticate 2022; Quasydoc, 2021). With database Tableau, errors of all products of the meal-kit company can be showed. Tableau is a visual analytics platform which can be used by companies to explore and manage their data (Tableau, n.d.). For this research, performance errors of suppliers are explored and investigated. Table 1 shows the filters that are used in Tableau to have a detailed overview of errors on bake-off bread products.

Filter 1	Year/week	2020 - 2022
Filter 2	Country	Benelux France
Filter 3	Food category	Bakery
Filter 4	Subcategory	Bread, flat bread, tortilla
Filter 5	Mapped complaint	Mouldy/spoiled/rotten

Table 1. Filters that are used in the database program (Tableau).

By using the filters, graphics of all complaints in the given period are shown. Peaks in errors provided information about which bread products have frequently errors and which none or rare. Within the Quality software programs of the meal-kit company, the manufacturers of the affected bread products could be found. Based on this information, at least one manufacturer with relatively high error rates and one manufacturer with low errors rates are contacted to have an interview plus audit. To have more insight of mould prevention methods of bread manufactures, a total of four bread manufacturers with mould complaints are contacted and investigated.

The Quality programs are used to identify the raw materials of the affected bread products and other relevant information such as packaging methods, minimum shelf life, storage conditions, gas composition, microbiological standards, and food safety and quality management certifications. This information is documented into tables to have an overview of differences and similarities.

Step-by-step plan:

1. Finding top error bread products with mould complaints in Tableau
2. Finding the related suppliers
3. Summarize weeks with peak errors and calculate relative error rate
4. Listing the specifications of the bread products
5. Comparing the bread products of all suppliers
6. Summarize weeks with peak errors and calculate relative error rate

2.2.3 Previous internal research

In previous internal research by Oostwouder, a Fault Tree Analysis (FTA) was developed (Appendix II). A FTA is a top-down approach to identify failures within a system or company that causes a problem. In this case, failures that causes mould growth on bread products are analyzed and displayed in a graphic tool. The FTA provided information to draft questions for the interviews with the bread manufacturers and to develop recommendations for the bread manufacturers.

2.2.4 Qualitative interviews

The companies are chosen based on the mould error rates derived from desk research. Companies with both high error rates and lower error rates are chosen to make a representative comparison. Questions were sent to the company prior to the interviews for at least two weeks (Appendix III), to make sure the respondents have an overview of the topics and could prepare the questions by gathering their protocols and other relevant documentations. The order of the questions was set, but it was allowed to switch between questions and give follow-up questions during the interview. Interviews with the four suppliers are shown in Appendix IV.

Part of the interview were the audits, that followed up the interviews. After thorough hygiene measures and wearing hygiene clothing, the audit took place inside the production facility. Audits were led by the lead auditor of the meal-kit company and assisted by an intern. All the areas of the bakeries were visited; inbound, storage, dough-partition, ovens, cooling, packaging and the expedition hall. In-depth questions were asked during the audit if anything unusual was observed or did not meet the requirements of the meal-kit company. The production site and behavior of the auditees and personnel were observed to have extra insight in their handling and methods that could affect mould growth on bread products. Both the lead auditor and intern noted the answers of the auditees or remarkable observations on paper during the audit. On average, the audits lasted 45 minutes. After the audit the auditors and auditees came together to summarize the audit and mention majors and minors of the audit.

With conducting semi constructed interviews with the quality representatives of the bread manufacturers, information about the same topics could be compared. The objective of the semi-structured interview is to gain information about overall management, products, processes, and techniques of the company, and a deeper insight on mould prevention on their bake-off bread products. Thereby considering that the questions did not provide socially desirable bias. The interview started with a short introduction of the scope and aim of the research and continued with questions about packaging methods, gas composition, packaging processes, preservation (food additives), storage methods, transport, mould prevention and closed with innovation. By addressing these topics, insight is gained into the protocols and methods the companies use to prevent mould on their bread products. Since it was not allowed by the companies to record the interviews, the answers on the questions were directly noted.

All information gathered from the interview and audits were listed in a document (Appendix V). Majors and minors were shared with the relevant company. After all the audits has been conducted, a comparison per question and topic between the companies has been made.

3. Results

This chapter include the answers to the sub-questions. It starts with brief descriptions of the suppliers that are investigated. For the first two sub-questions the results are given based on desk research. The last two sub-questions were mainly answered by the interviews and audits that took place.

3.1 Supplier profiles

Supplier 1
Supplier 1 is a large-scale bakery specialized in producing Mediterranean bread products such as Lebanese flatbread and Mediterranean pastries. They deliver to retailers, catering companies, wholesalers, and ethnic markets throughout Western-Europe.

Supplier 2
Supplier 2 is an international company that produce products such as carriers, puff pastry, crackers, snacks, pastries, and cakes. They develop private labels for their costumers and take care of distribution, marketing, and sales of national and international bakery manufacturers. The key markets for supplier 2 are Western Europe, North America and Canada.

Supplier 3
Supplier 3 is one of the largest franchise formulas in bread, cake and pastries of the Dutch market. In addition, they deliver to retailers, catering companies and meal box providers. They produce bread and pastry products, ranging from baguettes, bread buns and rolls to typical Dutch specialties such as “speculaas koeken” and “gevulde koeken”.

Supplier 4
Company 4 is a medium-sized company with around 25 employees. They only produce pita and naanbread and their customers are from several countries in Europe such as Switzerland, Germany, Belgium, the Netherlands and Scandinavian countries.

Table 2 shows an overview of general information of the suppliers. Differences are seen in the number of employees, the types of bread products that is supplied to the meal-kit company and the diversity of Food Safety certificates. What the suppliers have in common is that they all have Metal detection set as Critical Control Points (CCP) and all suppliers have a Quality Manager on side.

	Nr. of employees	**Types of bread product supplied**	**Quality department**	**Food Safety Certificate(s)**	**CCP's**
Supplier 1	50	3	Quality Manager, Quality employee	IFS	Metal detection
Supplier 2	10	6	Quality Manager	IFS, BRC, GMP	Metal detection
Supplier 3	50	14	Quality Manager, Product Developer	FSSC 22000, GMP	Metal detection
Supplier 4	25	4	Quality Manager, Junior Quality Manager, Floor Quality Employee	IFS	Metal detection

Table 2. General information of four bread suppliers of the meal-kit company.

3.2 Results sub-question 1

Which bread products are most often affected by mould?

By searching and filtering in database Tableau all bread products (27) that had mould complaints from week 1 of 2021 could be shown (Appendix VI). A top 5 has been drawn up of most affected bread products with moulds complaints (Table 3). The sixth product in line of most affected shows a much lower complaint number and therefore a top 5 was chosen.

It should be noted that numbers are absolute error rates. To have insight how big the incident is, relative error rates (RER) has been calculated by making use of the total order data since 2021 of the affected products. In case the relative error rate would be >0,5% it is considered as a problematic incident.

	Error Count (total)	Order data (total)	Relative error rate (RER) (%)	Ranking based on absolute error rate	Ranking based on RER
1. Lebanese flatbread	1.593	800.572	0.028%	1	4
2. Brown wheat bread	1.085	1.314.528	0.08%	2	2
3. White wheat bread	562	1.696.822	0.03%	3	3
4. Brown tortilla	462	510.87	0.09%	4	1
5. Naanbread	263	1.058.297	0.026%	5	5

Table 3. Top 5 bread products that are most affected by mould complaints from week 1 2021 till week 19 of 2022 (Tableau).

To gain more insight of the RER, accumulated weekly error rates of mould complaints are investigated and shown in Figure 1. The blue line in figure 1 shows the RER on total of bread products. Looking at week 4 of 2022, a RER of 2.361 (0.2361%) is noted. This rate is for 91% caused by mould complaints of Lebanese flatbread. When diving into the order data of the Lebanese flatbread it shows a RER of 0.6%.

Another peak is seen in week 18 of 2022 with a RER of 1.919 (0.1919%). This rate is for 64% caused by mould complaints of Lebanese flatbread and 21% by brown wheat bread. When diving into the order data of these products it shows a RER of 0.3% and 0.2%, respectively.

Week 20 of 2022 also shows a peak with a RER of 1.884 (0.1884%). This rate is for 63% caused by brown wheat bread and shows a RER of 0.7%.

The last week (week 21) of this graph shows the highest peak of this period with a RER of 2.615 (0.2651%). This rate is for 65% caused by brown wheat bread and shows a RER of 0.8%.

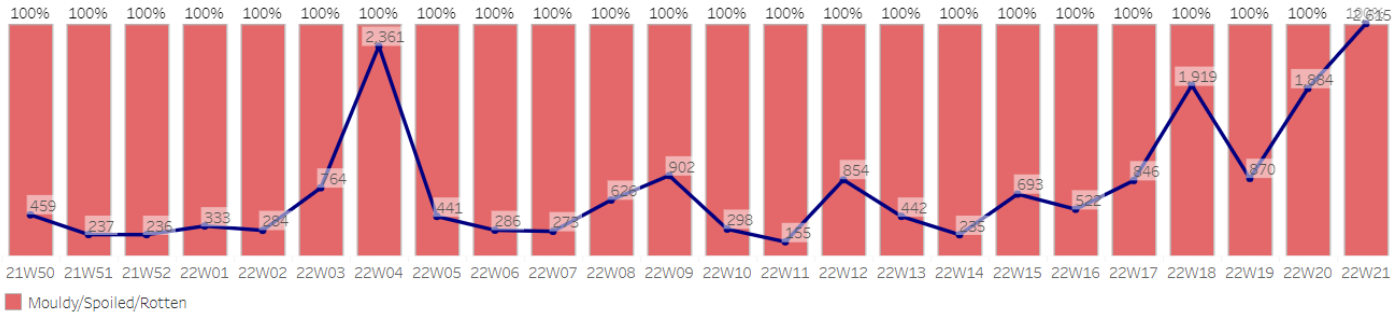

Figure 1: Overview of Relative Error Rate (RER) on mould complaints on total bread products from week 50 2021 till week .. of 2022. The blue line represents the RER.

Figure 1 also shows that the RER of mould complaints is not consistent during the period shown. Although, there is seen an increase of the RER from week 14 (2022) on.

3.3 Results sub-question 2

What is the frequency of mould incidents on bake-off bread products at the bread manufacturers?

The results given on sub-question 1, provided the tools to find the bread manufacturers of the affected bread products. The top 5 most affected bread products with mould complaints (derived from Table 3) are processed in the Quality software programs of the meal-kit company to find the supplier that supplies the affected bread products. In respect of confidentiality, the suppliers are showed as a number (Table 4).

Affected product*	Supplier
Lebanese flatbread	1
Brown tortilla	2
Brown wheat bread	3
Naanbread	4
White wheat bread	3

Table 4. Top 5 affected products and their suppliers (showed as a number in respect of confidentiality).

* *derived from Table 3*

With this information, each supplier is further investigated in database Tableau on weekly absolute and relative error rates since 2021. This database showed several sheets in where mould complaints of the meal-kit company costumers are logged. Each supplier has its own sheet with an overview of mould complaints per week, in total (since 2021) and order data.

Supplier 1 shows 3 peak weeks (>100 complaints) of mould complaints (week 1 of 2021, week 4 of 2022 and week 18 of 2022) (Figure 2). Weeks with more than 100 mould complaints are set as error limit and are further investigated (Table 5).

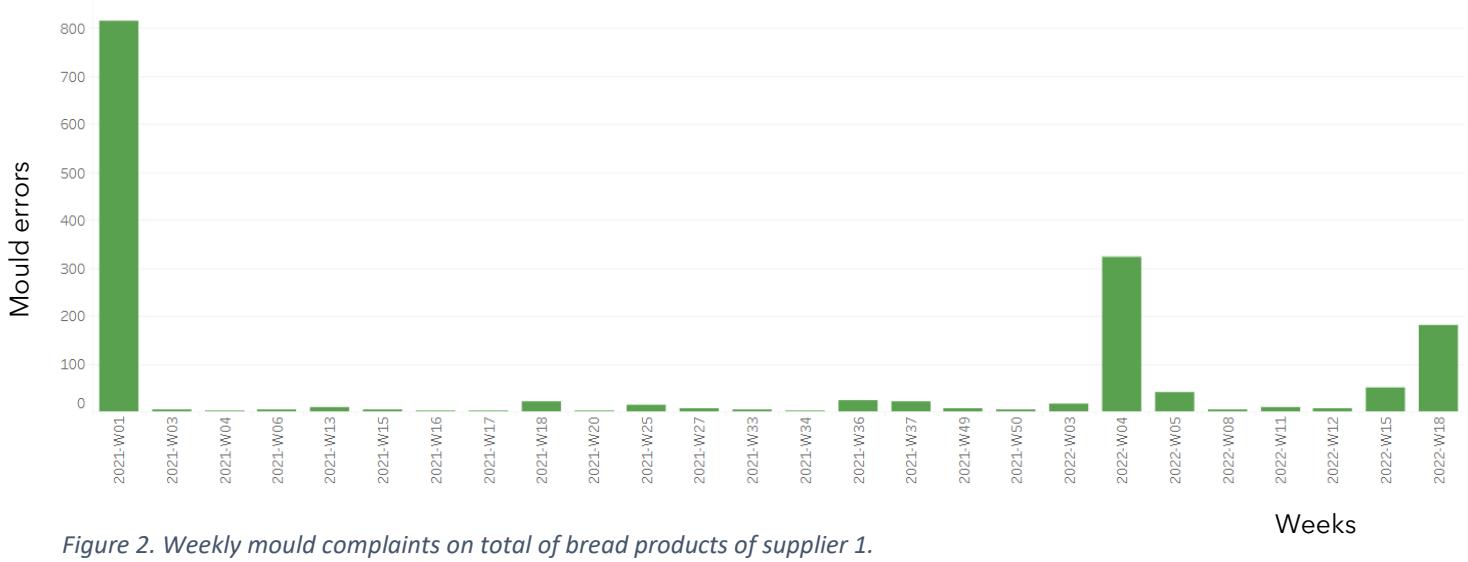

Figure 2. Weekly mould complaints on total of bread products of supplier 1.

Year and week	Total mould complaints	Product	Mould complaints	Order per product	Relative error rate (%)
2021 - Week 01	814	Lebanese flatbread	814	171.908	0.50
2022 - Week 04	324	Lebanese flatbread	324	63.210	0.51
2022 – Week 18	180	Lebanese flatbread	180	83.712	0.21

Table 5. Peak weaks (>100 mould complaints) of mould complaints of supplier 1. Week 1 of 2021 and week 4 of 2022 has an excess on the relative error rate (>0.5%).

Supplier 1 shows two weeks (week 1 of 2021 and week 4 of 2022) where the RER is exceeded (>0.5%). The most affected product of these weeks is Lebanese flatbread. Also, the third peak week (week 18 of 2022) is caused by Lebanese flatbread. The other 2 products, whole wheat flatbread and Turkish bread) supplied by supplier 1 show very low error rates of mould complaints. Whole wheat flatbread has a total absolute error rate of 89 since 2021 and Turkish bread does not show any complaints since 2021.

Supplier 2 shows 6 peak weeks (>60 complaints) of mould complaints (Figure 3). Weeks with more than 60 mould complaints are set as error limit and are further investigated (Table 6).

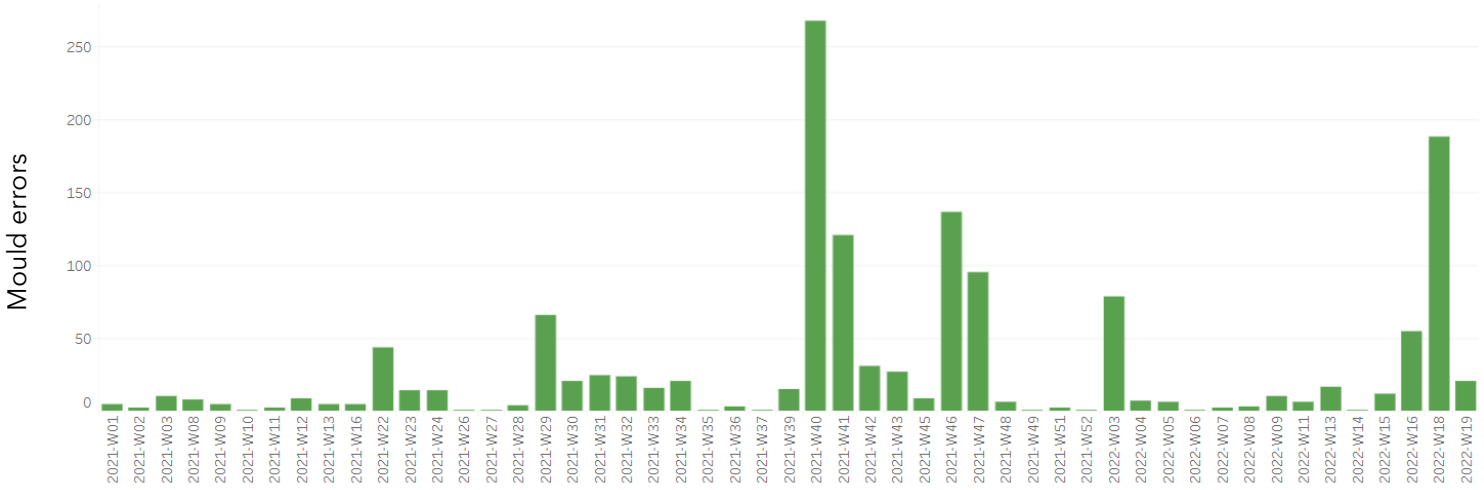

Figure 3. Weekly mould complaints on total of bread products of supplier 2.

Supplier 2 has one week (week 40 of 2021) with an excess on the RER (0.85%). This is caused by the brown tortilla. Another product that stands out with high RER's is white tortilla (0.46% and 0.30%). Since supplier 2 shows in several weeks more than one product that causes mould complaints, a top 2 is listed for these weeks. In contrast to supplier 1, supplier 2 shows two weeks (week 29 and 41 of 2021) with two different bread products that caused mould complaints.

Year and week	Total mould complaints	Top 2 products mould complaints	Mould complaints	Order per product	Relative error rate (%)
2021 - Week 29	66	Brown tortilla	61	29.946	0.20
		Chapati	5	13.572	0.04
2021 - Week 40	267	Brown tortilla	267	31.563	0.85
2021 - Week 41	121	Bao bread	70	41.942	0.17
		Mini tortillas	48	43.089	0.11
2021 - Week 46	137	White tortilla	137	29.960	0.46
2021 - Week 47	94	White tortilla	94	31.578	0.30
2022 - Week 03	79	Whole wheat tortilla	79	73.806	0.11

Table 6. Peak weaks (>60 complaints) of mould complaints of supplier 2. Week 40 of 2021 has an excess on the relative error rate (>0.5%).

Supplier 3 shows 5 peak weeks (>100 complaints) of mould complaints (Figure 4). Weeks with more than 100 mould complaints are set as error limit and are further investigated.

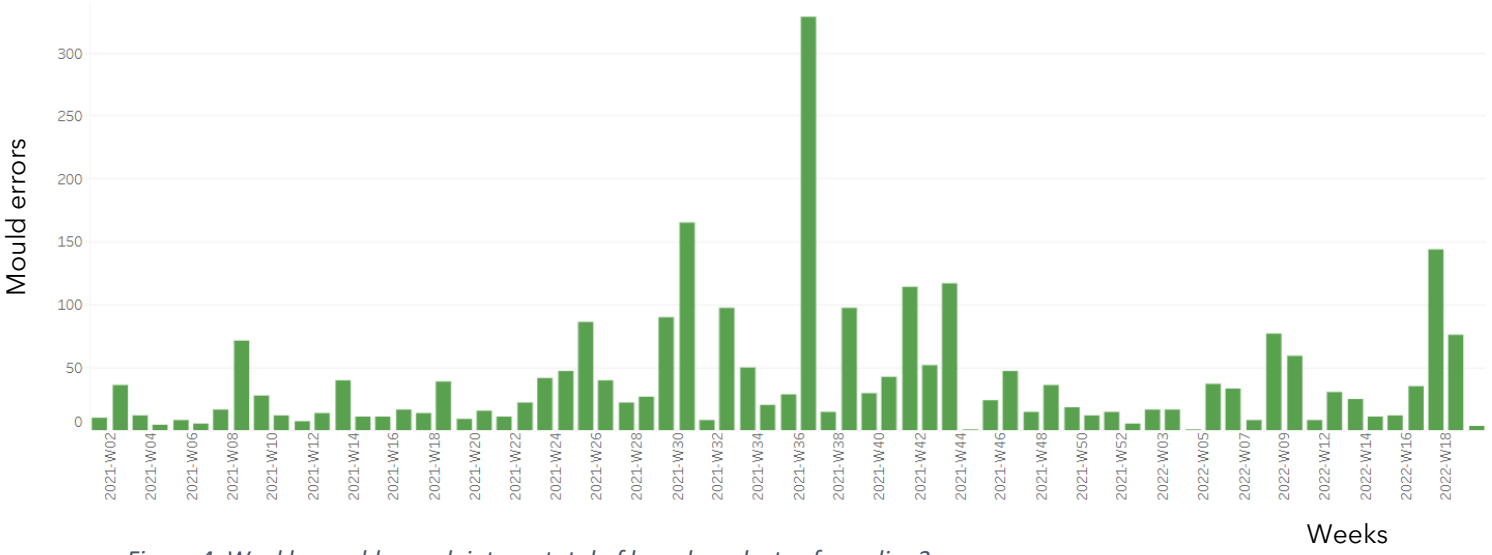

Figure 4. Weekly mould complaints on total of bread products of supplier 3.

Supplier 3 has two weeks (week 30 and 36 of 2021) with an excess on the RER (0.56% and 0.92%) (Table 7). This is caused by two different bread products: brown rose bread and white rose bread, respectively. As seen in the column “Order per product”, these two products have much less order numbers than for example brown wheat bread and white wheat bread. In addition, the brown and white rose bread are not listed in the top 5 most affected bread products with mould complaints.
Since supplier 3 has in every week more than one product that causes mould complaints, a top 3 is listed for these weeks.

Year and week	Total mould complaints	Top 3 products mould complaints	Mould complaints	Order per product	Relative error (%)
2021 - Week 30	165	Brown wheat bread	112	30.516	0.38
		Brown rose bread	36	6.430	0.56
		White wheat bread	9	2.934	0.31
2021 – Week 36	328	Brown wheat bread	220	89.652	0.25
		White rose bread	57	6.180	0.92
		White wheat bread	48	42.838	0.11
2021 – Week 41	114	White rose bread	54	22.520	0.24
		White wheat bread	46	128.526	0.04
		Brown wheat bread	11	23.088	0.05
2021 – Week 43	117	Whole wheat bread	42	32.208	0.13
		Brown bread	41	18.834	0.22
		White wheat bread	31	27.318	0.11
2022 – Week 17	144	White wheat bread	55	30.080	0.18
		Brown wheat bread	40	25.596	0.16
		Sourdough bread	32	10.574	0.30

Table 7. Peak weaks (>100 mould complaints) of mould complaints of supplier 3. Week 30 and 36 of 2021 has an excess on the relative error rate (>0.5%).

Supplier 4 shows 8 peak weeks (>15 complaints) of mould complaints (Figure 5). Weeks with more than 15 mould complaints are set as minimum error limit and are further investigated. Where the other three suppliers have a minimum error limit of respectively >100, >60 and >100, supplier 4 highest peak week is week 20 of 2021 with 33 mould complaints. Remarkable is that supplier 4 has less high mould complaints than the other three suppliers.

Figure 5. Weekly mould complaints on total of bread products of supplier 4.

Supplier 4 does not have any peak weaks with an excess of the RER (Table 8). The product that caused the most complaints (absolute error rate) is Naanbread (complies with table 3). Remarkable is that compared with the other three suppliers, supplier 4 does not have less weekly order numbers per product.

Year and week	Total mould complaints	Top 3 products mould complaints	Mould complaints	Order per product	Relative error (%)
2021 - Week 20	33	Naanbread	33	44.724	0.07
2021 - Week 21	24	Naanbread	24	31.788	0.08
2021 – Week 22	22	Whole wheat pita bread	12	28.728	0.04
		Pita bread	5	46.536	0.01
		Naanbread	5	33.588	0.01
2021 - Week 43	25	Naanbread	25	102.156	0.02
2022 – Week 02	27	Naanbread	27	86.172	0.03
2022 – Week 06	19	Naanbread	17	100.668	0.02
		Whole wheat pita bread	2	7.020	0.02
2022 – Week 09	17	Pita bread	14	42.720	0.03
		Naanbread	3	41.712	0.01
2022 - Week 13	20	Naanbread	20	82.832	0.02

Table 8. Peak weeks (>15 complaints) of mould complaints of supplier 4. No weeks have an excess on the relative error rate (>0.5%).

3.4 Results sub-question 3

Which packaging methods are used by the bread manufacturers?

The Quality software programs of the meal-kit company and the interview questions 1, 2 and 3 (Appendix III) provided information about the packaging methods of the four suppliers. Table 9 shows the packaging method used by the suppliers, if they make use of Modified Atmosphere Packaging (MAP) and the gas composition (CO_2 / N_2) used in the packaging of the bread products. Also, the possession of a leakage detection machine that is used after the packaging process and if they measure the residual O_2 level in packaging samples is shown.

	Packaging method	MAP	Gas composition CO_2 : N_2	Leakage detection	O_2 measurement (<limit%)
Supplier 1	Flow pack	Yes	90:10	Yes	Yes (<1%)
Supplier 2	Flow pack	Yes	80:20	Yes	Yes (<2%)
Supplier 3	Flow pack	Yes	60:40	Yes	Yes (<3%)
Supplier 4	Flow pack	Yes	80:20	Yes	Yes (<0.5%)

Table 9. Packaging methods, Modified Atmosphere Packaging (MAP), gas composition (CO_2 : N_2) and leakage detection machine (yes/no), and O_2 measurement (limit%) information of four bread suppliers.

The suppliers all apply Flow packaging with MAP. A packaging leakage detection machine is present at all suppliers' site, and they measure the residual O_2 on packages of every batch. Differences are seen in the gas composition: suppliers 2 and 4 use the same gas composition (80:20), but suppliers 1 and 3 apply different gas compositions (60:40 and 90:10). Different limits of residual O_2 are found, with supplier 3 having the highest amount limit value (>3%) and supplier 4 the lowest (>0.5%).

3.5 Results sub-question 4

What are the manufacturers currently (hygiene) protocols to prevent mould growth on bake-off bread products?

This section includes the outcomes of the interviews with the suppliers. Answers on the questions 4, 5, 6 and 7 of the interviews (Appendix IV) are documented. In addition, important and/or remarkable observations during the audit at the supplier's sites are described.

The use of additives in the bread products of the suppliers is compared (Table 10). Supplier 2 is the only supplier that applies preservatives (E330 and E282). Supplier 3 also applies additives, but no additives that reduce mould growth. Suppliers 1 and 4 does not use additives to aim for a clean label.

	Additives (yes/no)	**Product**	**Group of Additive**	**E-number**
Supplier 1	No			
Supplier 2	Yes	Brown tortilla	Preservative	Citric acid (E330)
		Chapati	Preservative	Calcium propionate (E282)
Supplier 3	Yes	Brown wheat bread	Doughstrengthener Emulsifiers Thickener	*No effect on reducing mould growth*
		White wheat bread	Doughstrengthener Emulsifiers Thickener	*No effect on reducing mould growth*
Supplier 4	No			

Table 10. Use of additives on products of four bread suppliers.

Questions about temperature conditions and shelf-life information provided a large quantity of data and are summarized in Table B of Appendix VII. Most important difference is that supplier 3 is the only supplier that recommends a refrigerated storage (0 – 7 °C). Remarkable is the short minimum shelf life on delivery on DC of supplier 3 (6 days) compared with the other three suppliers (>30 days). However, the minimum shelf-life after opening is nearly the same between the four suppliers (1 – 3 days).

During the interview, suppliers were asked to their corrective actions after they had a mould incident:

Supplier 1:

- Testing the packaging of the affected products. Leakage in top-foil of two samples were detected after a mould incident in week 20 of 2022.
- Before the high peak of mould complaints of week 1 of 2021, the Lebanese flatbreads were freshly packaged. After that they started to package MAP to lower the mould complaints.
- For some costumers they spray <1 ml ethanol on the surface of the flatbreads prior to packaging. This to disinfect the foil for a longer shelf-life.

Supplier 2:

- The relevant batch code has been blocked, retrieved, and replaced.

Supplier 3:

- Evaluation of the whole baking, packaging, and distribution process of the bread products to find possible failures.
- Start with testing spraying ethanol onto the bread surface (Turkish pide) prior to packaging. Results of this test were negative, since the bread samples had a strong alcohol smell and taste. Because of this, the project has been halted and supplier 3 never supplied bread onto the market.
- The description of the storage advice on the label of the bread products has been adapted from 'keep at room temperature' towards 'keep refrigerated (max. 7 °C)'.
- Considering of applying a cleanroom in the production facility, where the bread products are packed in a sterile room.

Supplier 4:

- extra checks at every production step.
- Increasing CO_2 amount during summer months up to 90% (June-July-August) to prevent damage of the packaging.

Important extra information the supplier provided considering mould growth are listed below.

Supplier 1:

- Citation QA Manager: *"mouldy packs are always an indicator for damaged packs".*
- Every half hour a package is checked for gas ratio.
- Lebanese flatbread is going with a temperature of ± 27°C into packaging. Statement of QA Manager: "*The entire production and packaging process, also the recipe, gives the product the quality, taste and softness. Any change in this standardized and historically evolved process will change the product sustainably. If the process will change and allow the product to cool not in the packaging, but in a cooling tunnel, then the product will dry out".*
- The Turkish flatbread has a thicker packaging (130 µm) than Lebanese flatbread (52 µm). Turkish flatbread has showed no mould complaints.
- Supplier 1 has a filtered ventilation system in the proofing, cooling and packaging area. However, the outside and inside doors were open, affecting the clean air atmosphere of the bakery.

- Several steps in the process that involves mould prevention are indicated with a control point (CP) in their hazard analysis, such as temperature control (<20°C) in the cooling area, contamination with micro-organisms by personnel at mixing, proofing and packaging and by overpressure in the cooling area. Also, a temperature range of 12 °C – 25 °C is controlled in their "cleanroom". They call it a cleanroom, but it is not completely closed and therefore not sterile.

Supplier 2:

- Citation of QA Manager: *"mould can be caused by the absence of a preservative, by the fact that the packaging was not properly sealed or by the fact that the gas composition of the packaging was not correct".*

Supplier 3:

- If there is a mould complaint from one customer, they also notice mould complaints from other customers.
- During warm days with a high humidity ('dogs days') there are noticed more mould complaints (also from their own brand products) than colder days with less high humidity. Corrective actions on this are a shorter storage period on production site.
- The presence of chalk fungus is a point of attention.
- Some bags with raw materials (flour) where not closed, therefore mould aerosols present in the raw material have the ability to spread through the air.

Supplier 4:

- Another costumer of supplier 4 does have a preservative in the pita bread (Calcium Propionate, E282).
- Naanbread is going with a temperature of ± 27°C into packaging. The cooling of naanbread is more difficult.
- Control samples of all batches are tested after 17 weeks.
- Citation of QA Manager about temperature shifts: *"moulds need O_2 to grow, so a temperature shift which leads to a high moisture level inside the packaging cannot be the cause of mould growth. The only possible reason is the presence of micro leakages, since O_2 can enter the packaging".*
- A roof window in the baking area was open, moulds from outside could enter the bakery facility.

3.6 Summary results

Table 11 provides an overview of the most important results of the company comparison.

	Supplier 1	**Supplier 2**	**Supplier 3**	**Supplier 4**
Gas ratio (CO_2:N_2)	90:10	80:20	60:40	80*:20
Limit residual O_2	<1%	<2%	<3%	<0.5%
Preservatives	No	Yes	No	No
Filtered ventilation system	Yes	No	No	No
Ethanol spray	Yes	No	No**	No

Table 11. Most important results of the company comparison. Remarkable results are indicated in blue.
** increase CO_2 content up top 90% during summer months*
*** conducted tests with ethanol spray but where not successful because of the strong alcohol smell and taste*

Remarkable results are indicated in blue and will be further elaborated. Supplier 4 shows the lowest limit for residual O_2 in the packaging. Supplier 2 is the only supplier that applies preservatives into its bread products (E330 and E282). Supplier 1 is the only supplier that has a filtered ventilation system on site and applies an ethanol spray on the surface of bread products prior to packaging to prolong a mould-free shelf-life.

4.Discussion

This chapter will start with a short description of the research aim and research methods and will continue with the reflection on the research process. Results are interpreted and limitations and possible implications of the research are discussed per sub-question. In addition, the validity of the research is argued.
Aim of this research was to study the mould prevention methods of bread manufacturers and give recommendations on how to prevent mould growth. The methods used for this research included literature study, desk research, previous internal research and qualitative interviews.

4.1 Reflection research process

Within this research, four bread manufacturers were interviewed and investigated. However, it was not possible to plan an audit at supplier 2 in the research period, due to the full schedule of the Quality Manager of the supplier. From the audits at the other three suppliers, the information gathered by the interviews and desk research could be confirmed or contradicted. If an audit had been possible at supplier 2, more information in addition to the digital interview would have been available and a more full-fledged company comparison could be made.

Next, this research is limited to bread manufacturers that supplies to the meal-kit company. Therefore, it is representative for this research, but an extended data range could be accomplished when data of more suppliers would have been available. Despite the limit of four bread suppliers, the final recommendations of this research are applicable for every bread manufacturer that produce bake-off bread products.

4.2 Discussion sub-question 1

Which bread products are most often affected by mould?

The result of this sub-question shows a top 5 out of the total of 27 bread products that have received mould complaints since 2021. As mentioned in chapter 4.2, the sixth product in line of most affected bread products shows a much lower number of complaint and therefore a top 5 was chosen. The 27 bread products of all suppliers are not very similar and ranging from pitabread, naanbread, whole wheat bread, tortillas and flatbread. However, the products are similar looking at the necessary ingredients (flour, water, yeast and salt) and manufacturing process of the products. Therefore, the top 5 is a representative ranking.

It is assumed that the database system, Tableau, used to search for a top 5 most affected bread products showed the right valuable data. However, it was noticed that one datapoint was not correctly logged (at the wrong supplier). Other possibly unnoticed mis-logged data may have influenced the results of this research.

It should be also mentioned that the mould complaints within this research is limited to customer complaints (customers of the meal-kit company). However, it is known that mould issues also occur at the distribution center of the meal kit company. Unfortunately, these data were not properly logged and therefore not taken into consideration for this research.

Looking at the consistency of the research method used for answering sub-question 1, a different top 5 could be presented after a period of time (for instance year 2022). Factors such as the addition of new suppliers, removal of old suppliers, product or process improvement at the supplier's site can present another ranking or new products in the top 5.

4.3 Discussion sub-question 2

What is the frequency of mould incidents on bake-off bread products at the bread manufacturers?

The results from sub-question 1 provided the information needed for sub-question 2, 3 and 4.
There was sufficient information supplied by database Tableau and the Quality software programs of the meal-kit company to compare the mould error rates. An extensive comparison based on total complaints, RER's and peak weeks could be made between the four suppliers.

A higher error rate was expected during summer months (June-July-Augusts) since literature states that during these months the growth conditions for moulds are ideal. However, the results on sub-question 2 does not show a comparable trend. Sometimes even higher mould error rates were seen in autumn and winter months.

4.4 Discussion sub-question 3

Which packaging methods are used by the bread manufacturers?

The results of sub-question 3 have a high reliability because the packaging information found in the Quality software programs of the meal-kit company has been observed and confirmed during the audits on the supplier's site. Except for supplier 2 the information could not be confirmed during an audit. A digital interview was conducted with this supplier. All necessary packaging information for the company comparison could be gathered, but possible important observations at the supplier's packaging site are therefore not included in this research.

The visit at supplier 4 was the bakery for only Turkish bread. It was expected that also the Lebanese flatbread was manufactured at this site. The supplier assured that the process of the Lebanese flatbread is the same as the Turkish bread, but possible differences that have influenced the results cannot be ruled out.

4.4 Discussion sub-question 4

What are the manufacturers currently (hygiene) protocols to prevent mould growth on bake-off bread products?

Results of the interview questions 4, 5, 6 and 7 were successful. Even though the questions were formulated openly (to aim for extensive answers), many similar answers were given by the suppliers and therefore clear comparison patterns could be made. Questions were based on a thorough literature study and previous internal research. An interview schedule is used (with fixed questions in a fixed order) and the interviews were conducted after the observation round through the bakery facility. Interviews were conducted after the observation round which prevented the interviewees from giving socially desirable

answers. As a result, it can be argued there has been measured what needed to be measured and that (ecological) validity is ensured.

As mentioned in 5.3, there was no visit at the site of supplier 2. All necessary information focused on prevention protocols for the company comparison could be gathered, but possible important observations at the supplier's site are not included in this research.

The prevention methods of the suppliers are compared, and two results are in contrast of what is found in literature. First, supplier 2 is the only supplier that applies preservatives in his products but does not show lower mould complaints. This contrasts with what is found in literature about preservatives, which states that preservatives have a reducing effect on mould growth. Secondly, after the adaptation of the storage advice into 'keep refrigerated (max. 7 °C)' on the products of supplier 3 after the high peak of mould complaints in week 36 of 2021, A reduction in complaints was not observed thereafter. This contrasts with what is found in literature that states that a refrigerated storage reduces mould growth.

5. Conclusion and recommendations

The aim of this research was to study mould prevention methods of bread manufacturers and give recommendations on how to prevent mould growth. The following research question was designed to reach this aim: *what is the difference in methods of preventing mould growth on bake-off bread between bread manufacturers and how can mould growth be prevented?* This chapter describes the answer to this question in a set of sub questions. Based upon these conclusions, recommendations are given next which should prevent mould growth, lowering costumer mould complaints and reducing food waste.

5.1 Conclusions

Sub question 1: *Which bread products are most often affected by mould?*

Evaluation of the data gained during the desk research showed a top 5 most affected bread products of the meal-kit company based on absolute error data:

1. Lebanese flatbread (total complaints of 1.593)
2. Brown wheat bread (total complaints of 1.085)
3. White wheat bread (total complaints of 562)
4. Brown tortilla (total complaints of 462)
5. Naanbread (total complaints of 263)

Relative error rates (RER) have been calculated to have insight in how big the moulds incidents were and showed a different top 5:

1. Brown tortilla (0.09%)
2. Brown wheat bread (0.08%)
3. White wheat bread (0.03%)
4. Lebanese flatbread (0.028%)
5. Naanbread (0.026%)

Sub-question 2: *What is the frequency of mould incidents on bake-off bread products at the bread manufacturers?*

There is no correlation found in frequency of mould complaints between the four suppliers, although it was expected that the frequency was related to the seasonal periods of the year. Especially during summer months higher error rates were expected because mould growth benefits from higher environmental temperatures.
To identify which company has the highest rate of mould complaints, the RER of mould complaints of the four suppliers were compared. Supplier 4 scored best by having zero RER weeks >0.5%. Supplier 3 scored lowest by having four weeks with a RER >0.5%.

Sub-question 3: *Which packaging methods are used by the bread manufacturers?*

During the interviews and audits, prevention methods for mould growth were requested and observed. All suppliers apply Modified Atmosphere Packaging (MAP) but in different gas ratios (60:40, 80:20 and 90:10). Supplier 4 increases the CO_2 ratio during summer to prevent the packaging from damage. Another similarity was observed in the possession of a leakage detection machine and O_2 measurement on bread samples of every batch. However, the suppliers have different limits of residual O_2, with supplier 3 having the highest limit value (<3%) and supplier 4 the lowest (<0.5%). The lower error rates of supplier 4 can be explained by the stricter limit value since a lower residual oxygen level in the packaging reduces the chance of mould growth.

Sub question 4: *What are the manufacturers currently (hygiene) protocols to prevent mould growth on bake-off bread products?*

The bread manufacturers current (hygiene) protocols to prevent mould growth includes the following:

- Spraying ethanol on the surface of bread prior to packaging (supplier 1)
- Filtered ventilation system in the cooling and packaging area (supplier 1)
- Use of preservatives (supplier 2)
- A refrigerated storage (supplier 3)
- Increasing CO_2 ratio during summer months up to 90% (supplier 4).

It should be noted however that no lower mould error rates have been observed after supplier 3 changed the storage temperature advice. This could be due to costumers not following the advice of a refrigerated storage. Also, the mould error rates of supplier 2 are not lower than other suppliers while using preservatives. To conclude, the filtered ventilation system of supplier 1 was negatively affected by open outside and inside doors of the bakery which contribute to higher mould aerosols in the air environment.

Research question: *What is the difference in methods of preventing mould growth on bake-off bread between bread manufacturers and how can mould growth be prevented?*

By desk research, interviews and audits at the suppliers' site, a company comparison could be made. A few similarities are found in the prevention methods of mould growth of the bread suppliers. First, all suppliers package their bread products using flow pack and apply MAP. At the end of the packaging line, they all have a packaging leakage detection machine. They also measure the residual O_2 on bread samples of every batch.
Differences were found in the gas ratios of the MAP packaging (60:40, 80:20 and 90:10) and supplier 4 is the only supplier that increases the CO_2 ratio during summer up to 90% to prevent the packaging from damage. The suppliers do not apply the same residual O_2 limits, with supplier 3 having the highest critical limit value (<3%) and supplier 4 the lowest (<0.5%). The lower error rates of supplier 4 can be explained by the stricter limit value, because the lower the residual oxygen in the packaging, the less chance on mould growth.
Another difference is found in the use of preservatives, whereas only supplier 2 applies preservatives (E330 and E282) into its products. Remarkable is that this supplier does not show lower mould complaints compared to the other three suppliers. Supplier 3 is the only supplier that advice refrigerated storages at the costumer's home but has not showed lower mould complaints after implementing. Last important difference is found at the bakery of supplier 1, which is the only supplier with a filtered ventilation system.

However, during the audit the outside- and inside doors were open which negatively affect the air environment.
Minor differences between the companies were observed in the recommended storage temperature after opening, minimum shelf-life on delivery and minimum shelf-life after opening.
The answer on how mould growth can be prevented will be elaborated in paragraphs 5.2 and 5.3.

5.2 Recommendations for bread manufacturers

Numerous strategies can help the bread industry to control the problem of mould spoilage and extending the shelf-life of bread products for the long term. One of the most effective methods of dealing with mould growth is to start at the beginning of the contamination process: mould aerosols. By implementing a ventilation system that allows filtered air inside the bakery facility, a positive pressure (cleanroom) can be created. A cleanroom is especially recommended from the moment after oven up to the packaging process because the bread is most vulnerable to mould contamination by aerosols in this timeframe.

Recommendations which are relatively easier to implement with respect to a ventilation system include an effective sanitization of the facilities environment to prevent contamination by machinery and/or personnel. Lowering the critical limit of residual O_2 to <0.5% will lower the chance of mould growth. Also spraying small amounts of ethanol (<1 ml) on the surface of breads prior to packaging can be taken into consideration for achieving a prolonged shelf-life.

Recommendations for latter stages in the bread production can be given in the packaging and transport step. To prevent leaks in packages, a proper leakage detection should be on site as well as a functioning gas flushing and sealing machine. It should be also considered to implement a thicker foil for bread packaging, since this can prevent leakages if the packaging is exposed to damage. In addition, it is important to ensure packages leak-free by carefully handling it during transport. A solid secondary and tertiary packaging and handling training for transport personnel is recommended.

The results of this study have shown that bread manufacturers can use several methods to prevent mould growth. After implementation of recommendations mentioned in this sub-section, it should be checked if these methods have effect on reducing the costumer mould complaints.

5.3 Recommendations for further research

Based on the current research some recommendations for further research can be made. First of all, data of mould incidents on the distribution center of the meal-kit company should be included in further research. This is necessary to obtain a broader picture of the mould problem. With this, research into packaging leakage and refrigerated storage is recommended to investigate whether refrigerated storage can reduce mould growth if the packaging has possible leaks. Second, further research into how consumers storage their bread products is recommended. This to find out if refrigerated storage advice is followed by consumers or if they use other storage conditions that affects mould growth.

Supplier 2 is the only supplier within this research that applies preservatives into its products as mentioned on section 6.1. However, this supplier does not show lower mould complaints than the other

three suppliers. Further research on the effectiveness of preservatives on mould growth is therefore recommended.

A final recommendation can be made for research into mould species. Since a higher mould error rate was expected during summer months but no trend was seen in the weekly error rates of the suppliers, further research on the growth preferences of different species of mould is recommended. This will provide better insight to what their growth preferences are, and which specific preventive actions could be taken.

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Appendix I – Literature Search Strategy

Search strategies and databases:

- Google scholar
- Greeni
- PubMed
- ResearchGate
- Academia
- Tableau

Inclusion and exclusion criteria:

- National and international sources
- Scientific and non-scientific references
- English and Dutch literature only
- Literature used that dated only after 2000

Search terms sub-question 1 and 2:

- Bakery products
- Bread moulds
- Bread spoilage
- Flatbread mould
- Middle Eastern bread mould
- Mould complaints
- Tortilla mould
- Wheat bread mould

Search terms sub-question 3:

- Bread packaging
- Flow packaging
- Gas composition bread products
- Modified Atmosphere Packaging*
- Residual oxygen bake-off bread

Search terms sub-question 4:

- Bake-off bread temperature
- Biopreservatives bread
- Bread preservatives
- Bread high moisture
- Shelf-life bake-off bread
- Storage temperature bread

Appendix II – Fault Tree Analysis (FTA)

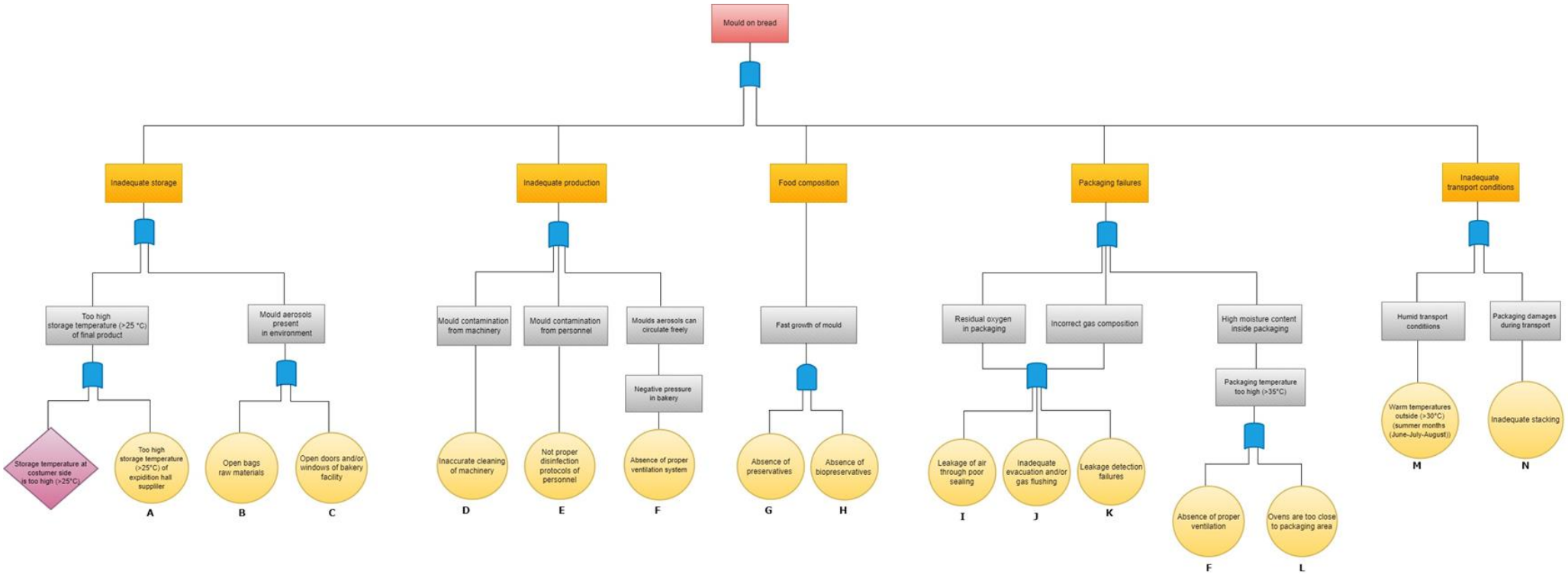
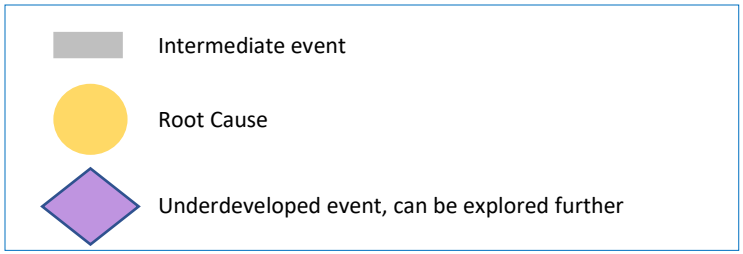
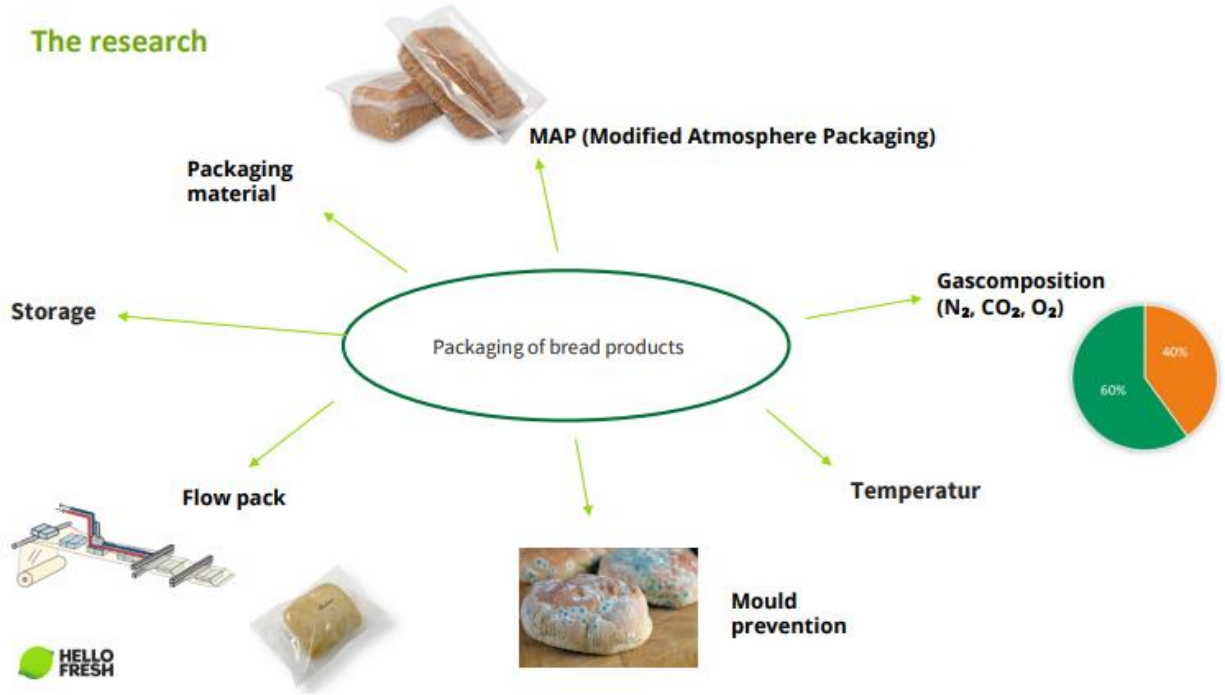


Figure A. Fault Tree Analysis (FTA) of moulds on bread products. 14 Root Causes (yellow round circles) are displayed (Oostwouder, 2022).



Appendix III – Interview questions



Packaging methods

1. Which packagingmethod(s) do you apply on the bread products for HelloFresh?
   - Why have you chosen this method(s)?
   - Have you experienced any changes in packaging methods?
   - Are other methods used for other customers?

Gas composition

2. What are the gas ratios in your products? Is there a difference between types of bread products?

- On what are these gas ratios based?

Packaging process

3. What is the packaging process look like after the breads have been baked?

Preservation

4. Do you use preservatives to influence the shelf life of bread? If so, do you use minimum and maximum limits?

- Have tests been conducted to see which values are optimal?

Storage

5. What is the temperature condition at the production site until it is transported?

Transport

6. How does the transport proces look like after packaging the bread products? How many days untill the bread reach our distributioncenter?

Mould

7. What are your (packaging) strategies for preventing mould on bread?

- Have you ever had mould incidents? If so, what were your corrective actions?

Innovation

8. Are you working on (packaging) innovations?

Appendix IV - Interviews

1. What packaging method(s) do you use on bread products for the meal-kit company?

Supplier 1: We apply on every product MAP packaging.

Have you experienced any changes in packaging methods?

First, we had no MAP packaging for the Lebanese flatbread, but after mould complaints we implemented the MAP also for this product. We were aiming for fresh products because our costumers want that. But we had to many mould complaints and short shel-life problems that we decided to also implement the MAP for the Lebanese flatbread.

Are other methods used for other customers?

No, for all our costumers we use MAP packaging. Some costumers do want to have the ethanol spray on the surface on the bread.

Where is ethanol used for?

We use the ethanol to prolong the shelf-life on the bread. A super small amount is sprayed on the top of the bread prior to packaging.

Do you also use this for the products on the meal-kit company?

No, we don't use it for you, because previously you didn't want to apply it. If that change, we can apply it already at the new production batch. Just let us know.

Supplier 2: flowpack and vacuum pack (MAP) for all products and every costumer. We started with

Supplier 3: Flowpack with MAP packaging on bread products. For sweet products we don't use MAP packaging because of the high sugar content it has a long shelf-life.

Are other methods used for other customers?

For our own brand we don't use MAP packaging because these breads are freshly sold at Dutch markets. When selling it we advise the costumer how to store their bread, especially for our low-carb bread because this product contains a lot of water. We advise them to store them in the fridge and consume it within 3 days or slice it and put it in the freezer. But we don't sell this product to you.

Supplier 4: We use MAP packaging for the pita and naanbread and already doing this for 40 years.

Are other methods used for other customers?

For every costumer we apply MAP packaging. We do use different sealing methods, according to packaging image what to costumer wants. But the technique is the same.

2. What are the gas ratios in your products? Is there a difference between types of bread products?

Supplier 1: We apply 90% CO_2 and 10% N_2 for our flatbreads and other Mediterranean bread products

On what are these gas ratios based?

The ratios are based on internal research. We use this ratio for already 20 years.

Supplier 2: 80% CO_2 and 20% N_2 this are the average ratio, we use for different products different ratios.

On what are these gas ratios based?

The gas ratio is based on the products its specification. We look to the ingredients, sugar content, if there are additives in it to measure if it needs more CO_2 or can use less CO_2

Supplier 3: For every bread product we use 60% CO_2 and 40% N_2

On what are these gas ratios based?

The ratios are based on the advice of the gas supplier. We never changed this ratio

Supplier 4: Normally we use 80% CO_2 and 20% N_2, but during summer months we increase the amount of CO_2 up to 90%

Why you increase it?

Because we have seen by internal research that during warm summer days the quality of our products are deteriorating. For example, high moisture content, broken bread and bubbles on our breads. We have seen by increasing the CO_2 content the shelf-life is more stable and the packages are more resistant to damages.

3. What is the packaging process like after the bread has been baked?

Supplier 1: The breads are cooled in a cooling area (max. 25 °C) for 1 hour, then continue to the packaging line and packed with MAP. This flow all goes sterile because the treadmill is covered by a metal shield. Some breads are sprayed with ethanol to prolong shelf-life, but not the ones for the meal-kit company. After packaging, we check residual oxygen on a few samples of every batch.

And how long are the products stored in your facility prior to transport?

After the products are packed, the packs are stacked and are picked up by an external transporter the same day for delivery.

Supplier 2: The breads are cooled in facility air and packed with flowpack, vacuumpack and/or MAP packaging. All of this is daily monitored by our Packaging Manager on site. The packages are stacked on pallets and stays for a few days until it gets picked up by a truck to the distribution centre.

Supplier 3: The breads are slowly cooled on the treadmill that runs through the entire production hall. The bread stays a for a maximum of 24 hours in our storage room before it goes on the packaging line. That depends on the type of product and the order rate. After this the products are packed at one of our two packaging lines.

Are there differences in the two packaging lines?

Yes, one line is used for bigger products, such as whole bread loaves and thick baguettes. This treadmill is wider than the other packaging line, that is used for smaller bread, like the whole wheat bread and white wheat bread we sell to you.

Is also the gasflushing different between the two lines?

No both have the same system and apply 60% CO_2 and 40% N_2.

Supplier 4: After the pita- or naanbreads coming out of the oven, they go on a treadmill to cool down. When the bread has reached a temperature of approximately 25 °C they are ready to be packaged. We have 1 packaging line for the pita bread and 2 lines for the naanbread.

How you measure the temperature of the cooled breads?

In the middle and end of the treadmill there are sensors that monitor the temperature. When the Quality Manager sees a too high temperature of above 27°C the treadmill is stopped so the breads have longer time to cool down.

Why you have this maximum temperature?

When the breads are packed higher than 27°C the pack will have moisture inside, this is not appealing to our customers, and it can enhance mould growth when packaging leakages are present.

4. Do you use preservatives to influence the shelf life of bread? If so, do you use minimum and maximum limits?

Supplier 1: We don't use any additives to aim for a clean label. The MAP packaging ensures the prolonged shelf-life so we don't need additives.

Supplier 2: Yes, E330 for the brown tortilla and E282 for the Chapati. For other bread products we also use preservatives to have a prolonged shelf-life.

Have you tested the optimal value?

We tested the optimal value per product, and we use 1%.

Have you seen improvents by applying different values?

Yes, but mould can be caused by more things than only the absence of preservatives, for example by the fact that the packaging was not properly sealed or by the fact that the gas composition of the packaging was not correct.

Supplier 3: We apply additives into our bread products to reach a specific taste and/or texture like doughstrengtheners, emulsifiers and thickeners. But we don't use preservatives into the bread products of the meal-kit company because that were the regulations set up with Procurement.

Supplier 4: Our Swedish costumer wants to have calcium propionate in their pita bread for a sourer taste. For the meal-kit company we don't use preservatives to aim a clean label.

Is calcium propionate only used for a sourer taste?

Yes, mainly for the taste, in Sweden costumers are less focused on clean labels than in The Netherlands. It was not the intention to use calcium propionate by increase the shelf-life without mould formation. But it is a nice addition of course.

5. Under what kind of (temperature) conditions do you keep the bread at the production location until it is transported?

Supplier 1: After packaging the products they are sealed on big pallets and are picked up the same day by our external transporter. This is all room temperature, because of the MAP packaging.

Do you monitor the temperature at the production location?

We monitor the temperature at the cooling and packaging area but not at the storage area. Because it stays there for a short time.

Supplier 2: All our packaged products are stored at room temperature (18 – 25 °C). At our production site, but also at the store site of the distributer the products are stored in ambient temperature.

Do you monitor the temperature at the production location?

No, because bread is not seen as a high-risk products so it's not necessary.

Supplier 3: We keep the packaged bread products for a few days in our expedition hall until it gets picked up by our transporter. The temperature in this hall is not logged, so its room temperature.

Supplier 4: It depends per products how long its stored at our site, but on average the products stay here for 5 days.

Is the expedition hall temperature monitored?

The expedition hall is room temperature and not monitored.

6. Under what kind of (temperature) conditions will the bread be transported to the distribution centre of the meal-kit company?

Supplier 1: an external transport company picks up our products and send it directly to your distribution centres. The Turkish bread goes to Schiedam and store it a bit longer. Lebanese flatbread goes to Bleijswijk and is not stored longer.

Do you know the temperature conditions of the truck?

I know that it is not monitored. But the truck arrives at the distribution centres within 4 hours.

Supplier 2: everything is transported in ambient temperatures and not monitored.

Supplier 3: We don't know exactly the temperature of the transport, because it is an external transport company that deliver our products. But we know it is room temperature.

Do you know if the temperature is logged by the transport company?

No, it is not logged.

Supplier 4: Everything is room temperature, so also the transport.

Do you know if the temperature is logged by the transport company?

No, it is not monitored.

7. What are your (packaging) strategies to prevent mould on bread?

Supplier 1: Mouldy packs are always an indicator for damaged packs. After the high mould complaints beginning of this year on the Lebanese flatbread, we decided to apply MAP packaging. When we receive know mould complaints of our customers, we ask for the affected products and investigated them on leakages. 100% of the affected products has leakages or micro-leakages.

Do you apply different corrective actions with other customers?

As mentioned before we apply ethanol spray on products of some of our customers. But not every customer wants that. We recommend applying it for a longer shelf-life. And we receive less mould complaints of these costumers.

Supplier 2: When receiving mould complaints, we check the recipe list or our products and apply changes if necessary. Also, we block the affected batch and replace it with a new one.

Supplier 3: We have every week meetings with the Quality team and talk about complaints. Also mould complaints are discussed here.

What are your corrective actions when receiving mould complaints?

We did experiments with applying ethanol spray on the breads, but even with the smallest amount we tasted and smell alcohol. So, we never entered this on the market.

And what are you doing currently when receiving mould complaints?

When we receive now mould complaints, we do a root cause analysis and let our costumer know what the cause is of the mould formation, if we can find out. Lastly, we found out that the mould was probably due to infected flour that we put on the surface of the bread, to not have a sticky bread against the packaging. Now we are looking for a new flour supplier.

Supplier 4: We don't have mould complaints often with other costumers, that's why we are surprised by the graph you showed us with the mould complaints.

How come you don't have many mould complaints with other costumers?

We don't know that because we don't do any different production method for the other costumers. Mould problems are very important for us. We know from our costumer from Sweden it checks every batch on mould. But we know that moulds need O_2 to grow, so a temperature shift which leads to a high

moisture level inside the packaging cannot be the cause of mould growth. The only possible reason is the presence of micro leakages, since O_2 can enter the packaging.

8. Are you working on (packaging) innovations?

Supplier 1: Currently not, but we just finished an innovation on thicker packaging on the Turkish flatbread. We apply quite a thick plastic wrap because this is more resistance to damage.

Why do you only apply it on the Turkish bread and not for instance Lebanese flatbread?

Because thicker foil is more expensive, so some customers are not interested in that. Beside that, we trust in our current process. The entire production and packaging process, also the recipe, gives the product the quality, taste and softness. Any change in this standardized and historically evolved process will change the product sustainably. If the process will change and allow the product to cool not in the packaging, but in a cooling tunnel, then the product will dry out.

Supplier 2: We are not working on innovations, but always seeking for the best recipe and often adapt this to reach the best quality for our products.

Can you give an example of this adaptations within the recipe?

Yes, last month we applied new additives in our new product carrot bread.

Were these additives preservatives?

No, this were natural colorants, to have a bit more brighten orange color.

Supplier 3: Not perse on packaging, but more on recipe. Beginning of this year we added on all our bread product rye flour, to lower the pH of the product. Beside the taste is more appreciated by our customers, the shelf-life is also increased with 2 days.

Supplier 4: since week 8 we have a new packing machine for the naanbread. Now the naanbread is fully automated, also the gasflushing goes automatically.

And for the packaging itself?

For the packaging itself we don't have any plans. Maybe that will come later when we enter our new facility about a few years. We would like to improve on sustainability and looking at trends in the bread packaging market. Maybe we will apply more sustainable sources of plastic in the future.

Appendix V – Audit notes

Audit Supplier 1 21-06-2022 (Cologne - DE)

Structure company	
Names and function	General manager & owner Managing Partner QA Manager on site QA assistant Sales
Supplier 1	Several production sites: Cologne = Turkish flatbread and demi-baguette Bochum = Lebanese flatbread
General	IFS certified Checking everything twice a day Supplying German supermarkets under own label but also private label Supplying meal-kit company since 2015. First delivered fresh products (beginning 2021, high peak 800). From then on delivered MAP. Only Lebanese flatbread did not have MAP yet, the others did. First look at whether there is leakage. Owner says there is a small chance that it is due to transport, because it is packed very well. But doesn't know exactly what can happen during transport. Transport by de Vries.
Traceability	
Product and date	Turkish flatbread SKU: BAK-77-001766-1-110984-beneluxfr Production date: 16/05/2022 Shelflife: 22/06/2022
Leveranciersbeoordeling	Questionaire, all suppliers are IFS certified
Registraties (inbound) **temperatuur** **controle vd wagen** **lotcode / THT registratie**	
Grondstoffen gebruik	
Verpakking food safe	Comply to legal obligations (topfoil and bottom foil)
Vervolg producten **transport door wie? zijn die gecertificeerd?**	De Vries Turkish bread goes first to schiedam. Lebanese go directly to klappolder and prismalaan
Basisvoorwaarden	
Pest control	Weekly check
Inkomende goederen	

Training personeel	Training check of MIT Responsible of packaging line. Trainings are: metal detection, covid 19 hygiene measures, HACCP, Food Defence and Food Fraud
Schoonmaak **- swabs van open area**	Cleaning is done every Saturday. Turkish bread runs 24 hours a day. Internal people clean (3 people). Some parts on the line are cleaned every day. Only alcohol used. No chlorine
Interne audits	They check according to IFS 7. Every month they check a number of points.
HACCP	
Allergenen (label, schoonmaak, cross contamination) **In pand: noten, melk, ei**	2 allergens present (sesame and gluten)
Temperatuurbeheersing	Packing room temperature and cooling room are indicated. Around 30 °C degrees for packaging and 25 ° for cooling. No temperature limit for storage.
Recalls gehad via trade activiteiten	
Chemische gevaren	
Microbiologie (Analyse rapporten inzien) (Schimmels, entero, aeroob kiemgetal)	External lab. External lab. It is tested 6 days after shelf life. They only say if it is under the limit, not exactly how much. They test 1 product per year. This is requested by the customer. Other customers test more times a year
CCP (critical limit, monitoring, corrective actions)	Only CCP is metal detection on the packaging lines
CCP 1 metaaldetectie	Packaging lines
Specs en Labels	
Spec beheer	
Authenticate	Everything (3) is approved
Labeling process	
Overige topics	
	Outside and inside doors were open (they do this to reduce CO2 in the room because it affects metal detection). This increases the risk of vermin. Ilyas indicates that the doors should be closed, but staff leaves them open all the time. Area of demi-baguette is out-dated (floor and wall have holes) Packaging line had a bottle of cola under the crates Ventilation in ceiling of demi-baguette oven was very dirty (lots of dust). Could contaminate the fresh bread from the oven as there was no screen over it as there was with the Turkish bread

Audit Supplier 3 09-05-2022 (NL)

Meal-kit company: Marissa, Tess Oostwouder
Supplier 3: Quality Manager, Sales Manager, Quality Control

Changes Supplier 3
- Commodities Act; all products have already been adapted. to 1 raw material
- Process parameters set, temperature measurement of proofing cabinet, oven temperature etc.
- Smart bakery system in final stage

Quality evaluation:
- Blue plastic is off the line or when cutting the bags (raw material)
Due to reduction of plastic material now going to paper bags. Only plastic bags for raw materials with higher fat content.

- Nitrogen tanks put down. 2 silos. Still needs to be fine-tuned, realised last month (therefore maybe more mould complaints in week 17?).

- Last year decided to keep products in fridge after high peak week 36 (2021).
- When they get complaints, they keep some products separate and store them in different places.
- Weekly complaints are analyzed and presented at supplier 3

Production round
- Cheese bag open
- Sacks of flour open?
- Old labels (chicken fillet?) on crates
- The butter packed in cardboard boxes (1 box was open)

Packaging
- Went from 42 mu to 37 mu (thinner film)
- Testing at 32 MU, but THT starts to fluctuate then.
- First, all rolls were in a plastic container, now 80% loose.
- Large packages are still put in a tray (3 or 4 articles)

Project with ethanol packaging has been stopped. Turkish midi pidi. Sample taken. Never came on the market.

Research questions
All packaging is flowpacked. Biscuits, sugar bread also flowpack but without gas.
Always flowpacked, since this month switched to bunker instead of loose cartridges.
Everything is baked for 80%.

All 60% CO_2 - 40% N_2 at meal-kit company and other customers. The gas supplier advised this. Never had different gas compositions.

Every Tuesday deliver to the meal-kit company. Bread rolls, conditioned room temperature at DC.

No preservatives in products, because aiming clean label/

Temperature sensors in dough preparation
At packaging line not monitored
In truck also Stable room temperature

Dog days = moulds, also own products. Air pressure. Rainy, high humidity. Also see them in own products indoors. Short stock.

Kh lowered 130% was not achievable by linseed . Now it is. Products with a lot of water. The market is also advised to keep it in the fridge.

No air filter in the bakery.

Actions were after mould complaints
- Alcohol
- Process evaluated
- Label kept in fridge

Same weeks with mould complaints, other customers also notice there are mould complaints.

Thinking about a clean room. They want to pack where it is produced. Creating shorter lines.

Chalk fungus is a yeast and a point of attention

Audit Supplier 4 17-05-2022

Structure company	
Names and function	CEO Quality Manager Junior Quality Manager
Supplier 4	- Moving to new premises around 2026 - Now old building. 3 production lines. 1 for naan bread and 2 for pita breads - 5 or 6 days a week (24 hours)
Algemene werkzaamheden	
Traceability	
Product and date	Product: Naanbrood (2x120g) SKU BAK-10-002238-1 Delivered: 26-04-2022 - Prismalaan West THT 19-07-2022. Lot 16 L3 E (week 16, line 3 and friday) 91 cases ordered. 79010.
Leveranciersbeoordeling	Yeast check - below 7 degrees it must come in. Supplier has IFS certificate until 3 July. Questionnaire completed in 2020.
Verpakking food safe	Combitherm XX 18 foil bottom film → declaration. Wipack is BRC certified until 01/04/2022
Vervolg producten • **transport door wie? zijn die gecertificeerd?**	Transport by external company
Basisvoorwaarden	
Pest control	The door to the exhibition is roughly always open, QA has pest control once a week.
Training personeel	Records are kept in the specification system. Everyone receives HACCP training.
HACCP	
Allergenen (label, schoonmaak, cross contamination) **In pand: noten, melk, ei**	Only allergen Gluten present
Temperatuurbeheersing	Temperature of packed bread is monitored
Recalls gehad via trade activiteiten	
Chemische gevaren	
Microbiologie (Analyse rapporten inzien) (Schimmels, entero, aeroob kiemgetal)	Every other month each product is tested (n=1). BBD 2 samples Acrylamide testing: (2x per year) Last was December 2021 End of THT they test for: Aerobic germ, entero, E. coli, lactic acid bacteria, yeasts & moulds, listeria, salmonella
Shelf life test	Samples of each batch are kept for 17 weeks for quality testing.
CCP (critical limit, monitoring, corrective actions)	The only CCP is metal detection on the packaging line. (Leakage detection is qccp)

CCP 1 metaaldetectie	After packaging line
Specs en Labels	
Spec beheer	Own specification system containing all suppliers, specifications, and personnel data
Authenticate	4 specs (Naan bread, naan bread with garlic and coriander, wholemeal pita bread and white pita bread)
Labeling process	Labels can easily be changed, if it is reported in time
Overige topics	
	• Skylight opened in production hall to cool bakery. • Stairs over treadmill with unpacked pita breads • After alarm (2x) hands were not disinfected by staff in packaging hall • Leakage in labelling room • No visitor registration • Disinfection device for the packaging hall did not work • Plastic around the proving cabinet is made • Open door in the expo hall

Appendix VI - Bread manufacturers and their affected products

Supplier 1	Company 2	Company 3	Company 4
Brown wheat bread	Lebanese flatbread	Naan bread	Brown tortilla
White wheat bread	Whole wheat flatbread	Pita bread	White tortilla
White rose bread		Whole wheat pita bread	Mini tortillas
Beer bread		Naan bread with herbs	Bao bun
Brown bread			Carrot bread
Turkish pide			
Mini-hamburger bun			
Sourdough bread			
Hamburger bun			
Brown rose bread			
Baguette			
Demi-baguette			

Tabel A. Four companies with their affected products. The products first listed are the ones with the most complaints since 2021 (Tableau).

Appendix VII – Temperature and shelf-life information of bread products

Table B shows an overview of the temperature and shelf-life information of the bread products that had mould complaints. Each supplier is indicated by a color to have a clear overview. All four suppliers transport / deliver at room temperature (±18 – 22 °C). Supplier 3 is the only supplier that recommends a refrigerated storage (0 – 7 °C). Differences are observed in the recommended storage temperature after opening between the suppliers and between products of the same suppliers. Supplier 1 recommends a refrigerated storage temperature (0 – 7 °C) after opening for Lebanese flatbread and Whole wheat flatbread, while Turkish bread has a higher and wider temperature range (0 – 25 °C) on this topic. Also, the two bread products of supplier 2 have different recommendations for storage temperatures after opening: brown tortilla 0 – 25 °C and chapati 0 – 4 °C. Supplier 3 and 4 has the same recommendations for storage temperatures after opening for their products (refrigerated, max. 7 °C). To conclude, the minimum shelf-life on delivery at the DC and the minimum shelf-life after opening is the same for the four bread products of supplier 3 and the two bread products of supplier 4.

Remarkable is the short minimum shelf life on delivery on DC of supplier 3 (6 days) compared with the other three suppliers (>30 days). However, the minimum shelf-life after opening is nearly the same between the four suppliers (1 – 3 days).

Supplier	**1**	**1**	**2**	**2**	**3**	**4**
Bread product	Lebanese flatbread, Whole wheat flatbread	Turkish bread	Brown tortilla	Chapati	Brown wheat bread, White wheat bread, White rose bread, Brown rose bread	Naanbread, Pita bread
Transport / delivery temperature (°C)	18 – 22 °C	18 – 22 °C	20 °C	20 °C	20 °C	20 °C
Storage temperature (range) (°C)	0 – 25 °C	0 – 25 °C	0 – 25 °C	0 – 25 °C	0 – 7 °C	20 °C
Recommended storage temperature after opening (°C)	0 – 7 °C	0 – 25 °C	0 – 25 °C	0 – 4 °C	0 – 7 °C	5 – 7 °C
Minimum shelf life on delivery DC (days)	35	30	80	45	6	81
Minimum shelf life after opening (days)	1 - 2	1	3	3	1	2 - 3

Table B. Temperature and shelf-life information of bread products of four supplier that had mould complaints.