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Original article

Application of Failure Mode and Effect Analysis and Cause and Effect analysis for honey production in Tunisia: A Case Study

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Abstract

In Tunisia, apiculture represents a growing strategic sector. In fact, honey production increased from 220 tons in 1970 to 2500 tons in 2020. However, this sector still suffers, as worldwide, from a lack of traceability and a risk of fraud which can impact honey quality. To guarantee food safety, farmers and food processors need to base their efforts on risk analysis. Failure mode and effect analysis (FEMA) is a safety and reliable analysis tool: it allows the identification of failures that could happen on a system and provides their effects and consequences. Conducting risk analysis during honey production would reduce incidents, contribute to risk management associated with the honey human consumption, save costs and improve competitiveness in the market. This research was conducted within a large scale honey production unit (1500 modern beehives) in Nabeul governorate (north-east of Tunisia). FMEA model was applied in conjunction with cause-and-effect analysis for the risk assessment of honey production. Potential failure modes and effects as well as their possible causes were identified in the honey process flow. Criticality of each failure was calculated taking into account risk, frequency and gravity. Qualitative diagnosis during honey process flow revealed 56% of nonconformities, based mainly on failures of implementation of good hygiene and good farming practices. Moreover, highest criticality was attributed to the presence of humid honey frames, honey rehumidification, microbiological contamination, fermentation and ineffectiveness of cleaning. Based on the FMEA analysis, an improvement plan for all stages was suggested with an emphasis on rising employees' awareness and training.

Keywords: Cause-and-effect diagram , FEMA, Honey, Quality, Risk analysis , Safety , Tunisia.

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INTRODUCTION

According to the Codex Standard 12-1981 (2001), honey is defined as "natural sweet substance produced by honeybees from the nectar of blossoms or from secretions of living parts of plants or excretions of plant sucking insects on the living parts of plants, which honeybees collect, transform and combine with specific substances of their own, store and leave in the honey comb to ripen and mature". This natural product is composed mainly by carbohydrates, water and minor components (Bogdanov, 2008 and 2017). Its properties are influenced by honeybee species, floral and geographical origins as well as temperature (Imtiazah et al., 2021). Honey could be used also as a sweetener (Badolatoet al., 2017) especially for its nutritional and health promoting properties (antioxidant, antimicrobial, anti-inflammatory) (Vivek &Supriya, 2018).

The global honey market size was valued at USD 9.21 billion in 2020 (Grand View Research, 2021) and is expected to grow at a substantial growth rate of 7.22% during the forecast period of 2017-2023 (Ahmad and Khairatun, 2021). This rising demand is probably related to the multiple interest of honey and also the rising of consumer's awareness about their diet, particularly after the Covid-19 pandemic. In Tunisia, honey market evolved markedly during the last decade as production increased from 1440 Tons in 2011 to 2500 in 2020 (Ben Salem, 2020). According to the Tunisian Ministry of Agriculture (2020), about 97% of Tunisian honey are produced in modern beehives and only 30 % of producers are beekeeping professionals. Interestingly, this development of honey market could support achievement of Sustainable Development Goals (SGD): Bees, added to honey production, contribute in pollination which may consequently stimulate fruits, nuts, and vegetables production (Bond et al., 2021). Moreover, beekeeping might be an empowering opportunity for rural micro-entrepreneurs in economically challenged areas with limited financial and natural resources as it requires minimal land use and low labor requirement (Runzel et al, 2021). Accordingly, beekeeping may contribute in reducing poverty (SDG1), economy growth (SDG8) while guaranteeing sustainable production (SDG12).

Unfortunately, the increasing demand and commercial value of honey may motivate its falsification and adulteration (Ahmad and Khairatun, 2021). In fact, honey is recognized as one of the most common foods subjected to adulteration (Fakhlaei et al, 2020). Such practices would endanger consumer's health. A survey carried out in 2018 by the Tunisian Ministry of Trade highlighted that 80% of the honey analyzed and marketed in supermarkets and stores in the Ben Arous region (North east Tunisia 36.6306483,10.2100827) are not compliant and are defrauded. Moreover, another study carried out by Tunisian National Institute of Consumption (INC) in 2019 has shown that only 3 honey samples out of 13 were classified as good in terms of quality. In this study quality was assessed through: labeling and physic-chemical parameters (acidity, pH, water content, hydroxyl-methyl-furfural (HMF)).

Globalization and development of international commerce pushed manufacturer to use several quality tools to achieve customer satisfaction and to competitiveness on market. The quality system uses the quality risk management to improve the ability of companies or farmers to deal with potential risks. Failure Mode and Effect Analysis (FMEA) is a common method used for systematic prevention of errors (Roszak et al, 2014). When it is well integrated it can improve quality performance and conformance. This approach was firstly used in military since 1940s, then in aerospace industry in the 1960s and since FMEA was used in several sectors as automobile, electricity, mechanical, semiconductor industries… (Sharma & Srivastava, 2018). Interestingly, FMEA could be conducted for the whole product, a single component or a structural component of the product and for the whole technological process or any operation (Roszak et al, 2014). Accordingly, different FMEA types were identified: Concept FMEA, Design FMEA and Process FMEA (Sharma & Srivastava, 2018).

To the best of our knowledge no previous work used engineering tool like FMEA and cause and effect diagram in case of honey production. Thus,this work aims to identify and prioritize the main factors affecting honey quality.Thus, it would be possible to identify good hygiene practices needed to be adapted in the context of modern beekeeping production. Consequently, recommend operational actions improving the quality and avoiding adulterations.

Materials and Methods

This research was conducted in a large scale honey production unit (1500 Langhstroth-type, bee hives) based in Nabeul governorate (located in the north-eastern side of Tunisia 36.5514546,10.6079969).This unit produces monofloral (like thyme, eucalyptus, orange and multifloral honey, using a modern production system. This study was conducted from March to June 2021.

A work team has been formed in order to :

- Establish the flow diagram
- Analyze failure modes and identify potential risks at each stage of the process
- Identify the causes and effects of each failure
- Assign a severity level to each risk
- Determine corrective actions to reduce risks levels.

Establishment of the flow diagram

It is important to begin with the description of the main steps of honey production and extraction in order to facilitate the identification of failures and their causes. Working environment, location and installation have been observed and identified.

Analysis of failures, their causes and effects

Brainstorming within the working group was carried out in order to identify as exhaustively as possible the failures (errors or defects that can affect product or cutomer), or risks (potential failure to adhere to specification) encountered and their causes. For each failure mode effects were identified.An effect should affect the performance of the process or the quality of the product (Sharma & Srivastava, 2018). For each identified risk, a degree of frequency and severity was assigned by the work group in order to calculate its criticality index. Severity is determined from the known effects of the risk on the process flow. Indeed, for each risk we have chosen an index from “1” to “5” according to its severity. The frequency of occurrence of risks is determined from observations or from consultation of historical data. Indexes were attributed from "1" to "4" for each risk: rates showed the frequency of occurrence of the risk (Table 1). Once the ratings have been assigned, the criticality matrix was established (Hurtrel et al, 2012).

Table 1. Evaluation criteria of failure severity, occurrence and detection (Hurtrel et al, 2012)

Severity (S)	
1	Minor impact
2	Significant impact
3	Major impact
4	Critical impact
5	Catastrophic impact
Occurrence (O)	
1	Rare (< 1 time per 6 months)
2	Very infrequent (< 1 time per 1 month)
3	Not very frequent (< 1 time per two weeks)
4	Very frequent (< 1 per week)
Detection (D)	
1	High detection Existing checkpoint automatic or manual Detection easy and obvious
2	Partial detection Occasional or periodic manual checkpoint
3	Complicateddetectionmethod

Prioritization of the causes

To a better comprehension of the failure mode and a more effective affective proposal of corrective actions, the potential causes of every failure mode were enumerated. Ishikawa diagram (cause and effect or tree diagram) was drawn after collecting as much information as possible, using a checklist.

Proposal of improvement plans

Based on the most critical failure modes, several risk reduction actions were proposed to improve and sustainably preserve the quality of honey. For detailed event analysis and risk assessment, FMEA model was applied in conjunction with cause-and-effect analysis for the risk assessment of honey production. Risks are rules defined by the factor of severity (S), probability or occurrence (O) and probability of detection (D) (Mzougui& El Felsoufi, 2019).

Risk Priority Number (RPN)corresponds to the product of the occurrence (O), severity (S) and detection (D) of a failure (Equation 1 (Arvanitoyannis &Varzakas, 2009;Mzougui& El Felsoufi, 2019). It is used to classify the items which need additional quality planning.

$$\boldsymbol{RPN} = \boldsymbol{O} \times \boldsymbol{S} \times \boldsymbol{D} \qquad \text{Equation 1}$$

Based on RPN determination, an action strategy was defined based on the classification of risks intoTable 1:

- Minor risk : RPN<12 (Acceptable level no action will be taken)
- Moderate risk: 12<RPN<20 (Risk reduction actions will be taken after processing priority actions)
- High risk: RPN>20 (Priority risk reduction action) (Hurtrel et al., 2012).

RESULTS

Establishment of the flow diagram

To be able to identify the failures and their causes, it is necessary to go through the main honey extraction steps within a large scale honey production unit (Figure 1). Honey production relies on two main steps: pre and post honey-making by bees.

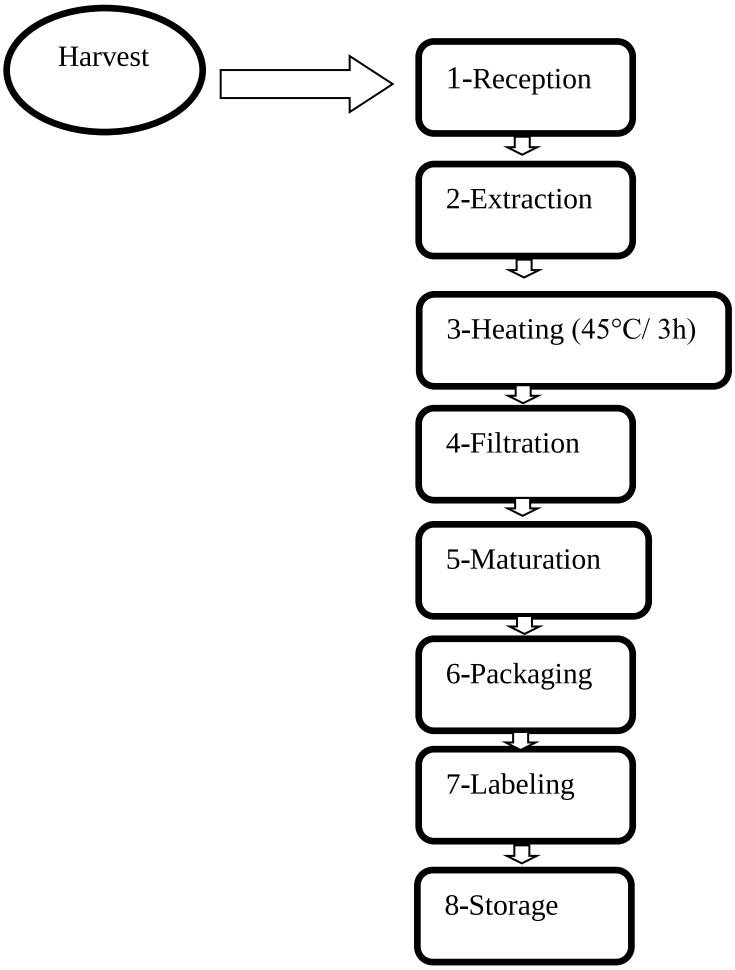

Figure 1. Diagram of honey processing in a large scale honey production unit

Bee hives (around 1500 were placed in different regions in order to guarantee good environmental conditions for bees (mainly adequate temperature). Once honey is ready, hives are transported into production site, in Belli (Nabeul governorate; 36.5514546,10.6079969), for further treatments. Frames are firstly removed in order to uncap the honeycombs. From observations, we noticed that the frames used were old and no control was made (humidity, presence of brood) nor an attention was accorded to where keeping them before extraction. After extraction, honey was heated at 45°C for 3h and filtered using stainless sieves (100 and meshes) to remove foreign objects and debris. The maturation step, consisting in controlling natural fermentation process that follows honey extraction, occurs at 20°C during 5 days. After what, honey is being bottled and stored until commercialization.

Causes analysis

An analysis of the 6Ms was carried out, in order to identify as exhaustively as possible the risks encountered and their causes, and to define their effects subsequently.The Ishikawa diagram (Figure 2) indicated direct and indirect causes that could compromise the quality of honey. The main causes identified affecting honey quality are related mainly to lack of financial sources (low funding, lack of equipment for honey control, lack of rapid control test, insufficient lighting, low worker number, inappropriate separation of work place). At a second level, lack of awareness, information and training (wrong labels, lack of sterilization of containers, inappropriate disinfection, lack of training) were observed. In Tunisia, it is an agricultural sector based mainly on small beekeepers: 80% of Tunisian producers have less than 50 beehives (Tunisian Ministry of Agriculture, 2020).They lack appropriate training and knowledge on improved bee-keeping practices, and adequate supervision by bee-keeping extension services.

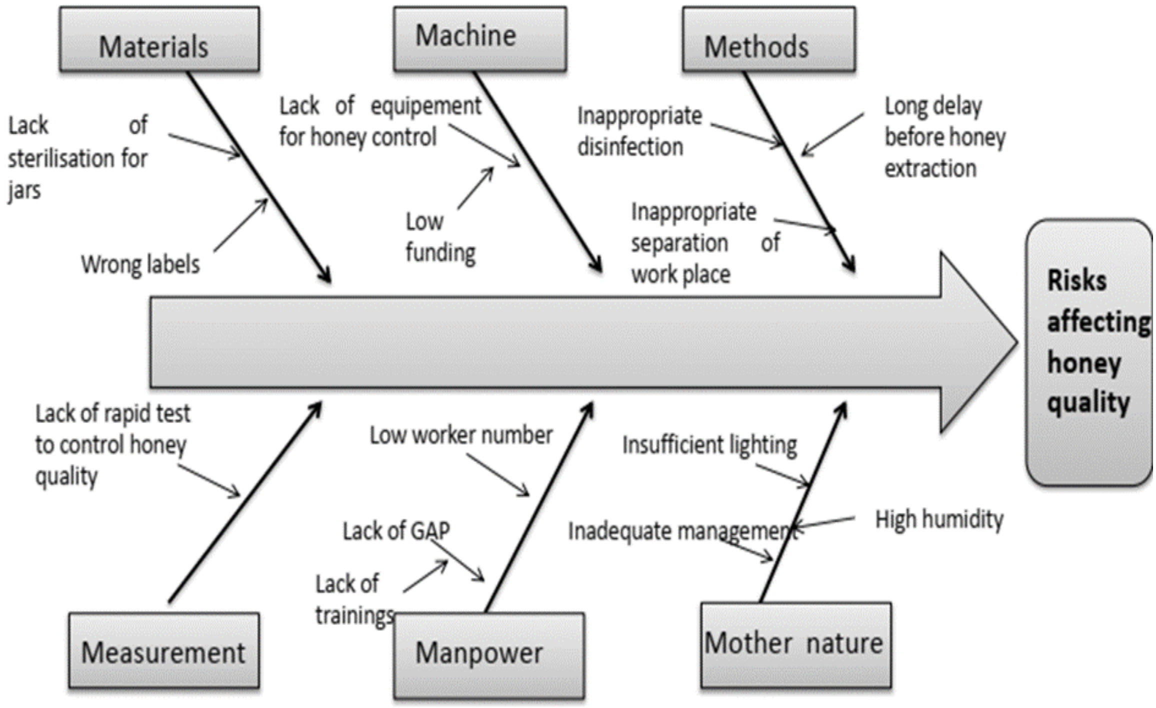

Figure 2. Identification of causes affecting honey quality using Ishikawa diagram.

GAP: Good Agriclutre Practice

Failure mode and effects analysis

According to FMAE rules, every step, operation, practice and method that has or may have an effect on the quality of honey was carefully observed. The main possible failures (Table 2), its effects and its possible causes were identified. Their classification occurred according to the RPN assessment. Many failures have been identified and prioritized according to their RPN.

Qualitative diagnosis during honey process flow revealed 56% of non conformities. These failures have been noted during extracting and storing honey. They are mainly linked to the lack of implementation of good hygienec and farming practices.

The highest criticality was attributed to the presence of humid honey frames and to the microbiological contamination (Table 2). The diagnosis conducted in this study, has indicated fermentation, ineffectiveness of cleaning and excessive heating, possibly affecting physico-chemical and microbiological honey quality. Freshness, heat and storage history of honey can be evaluated by the determination of diastase activity and hydroxymethylfurfural (HMF) (Ulberth, 2016).In the other hand, presence of wax or other biological particles was also observed, potentially affecting organoptic quality. Finally, some other failures can be considered as adulterations like inappropriate labeling.

Table 2. Failure Modes and RPN values

Failure Mode	**S**	**O**	**D**	**RPN**
Rehumidification of honey	5	4	3	60
Microbiological contamination	5	4	3	60
Lack of specific disinfection and cleaning plan	5	4	2	40
Presence of brood in the frames	5	3	2	30
Use of old equipments (brood)	4	3	2	24
Inappropriate labeling	2	4	3	24
Fermentation	5	4	1	20
Presence of wax or other biological particles	3	2	3	18
Excessive heating	4	4	1	16
Storage temperature not monitored	5	1	3	15

Proposal for improvement plans

The FMAE team has defined an action strategy based on calculated RPM. Corrective and preventive actions were discussed and proposed per identified risk, as shown in Table 3. In order to eliminate or reduce the effects of failure modes, acting on criticalities, several actions on gravity, frequency, and detection should be done. These preventive measures refer, overwhelmingly, to best practices, frequent analyses and personalawareness and training (Table 3).

Table 3. Integrated FMEA Preventive actions

Failure Mode	Ways of control	Corrective actions
Honey humidification and fermentation	Control measures used and supervision	Collect mature honey (at least three-quarters of the frame should be encrusted) Ventilate the extraction and packaging rooms Implement Good Farming practices
Microbiological contamination	Control measures used and supervision	Implement Good Farming practices Training and awareness of workers Use appropriate and clean equipments
Lack of cleaning plan	Control measures used and supervision	Implement of Good Hygiene Practices
Presence of chemical hazards	Chemical analyzes	Verify compliance with standards by chemical analyzes
Inappropriate labeling	Visual control	Provide appropriate Labeling
Presence of wax or other biological particles	Visual control	Perform the filtration properly using suitable filters
Excessive heating	Temperature control	Do not heat the honey or do not exceed 40 ° C

DISCUSSION

The findings have pointed out failures or risks problems related to hygiene and good farming and manufacturing practices in a Tunisian honey production unit. The application of these improvement plans will allow the beekeeper to guarantee the final product quality and subsequently prevent any unexpected non-compliance. To do this, it is recommended to implement, as priority, least expensive and long-term effect solutions, in particular for:

Workers: Each person working in direct contact with honey should maintain adequate personnel cleanliness and should have been aware of and trained to safe food handling practices. Awareness-raising strategy should be established using sheets containing the main practices to avoid and critical limits of honey to be respected. Cleaning plan indicating the date, the products used and the cleaning frequency should be displayed.

Infrastructure: the area around and near the honey house should be in condition to protect against microbiological and chemical contaminations. The structure must facilitate maintenance, equipment cleaning and storage. Ventilation should be provided to avoid humidity. Rearrangement of the extraction site, so as to avoid frequent crossing of flows.

Extraction and storage: low pH and fermented honeys must then be identified.

Labeling: specific model of a labeling sheet contain the mandatory information (Name, best before date, origin, batch number, etc.) should be designed.

To be successful, it is necessary to regularly update this FMEA because of new potential failure modes and consequently to develop corresponding control plans. Main expected benefits of setting up these plans for the beekeeper would be not only the improvement of honey quality and safety, but also a reduction in cost of production and an increased productivity.

Tunisian honey market evolved markedly during the last decade as production increased. FMEA approach should beconducted in other honey production units, to highlight recurring problems in this sector. It would help managers and decision makers to focus on the formulation of effective risk mitigation strategies. These recurring issues would also be considered by Tunisian policy makers and regulators to make better policies forsolving them with priority considerations. In addition to these recommendations, strategic work should be undertaken on the value chain in order to protect this sector against frauds.

Conclusion

The present study aimed to applying the FMEA methodology to a large scale honey production unit. Qualitative diagnosis during honey process flow revealed 56% of nonconformities, based mainly on failures of implementation of good hygiene and good farming practices. Moreover, highest criticality was attributed to presence of humid honey frames, honey rehumidification, microbiological contamination, fermentation and ineffectiveness of cleaning. The Ishikawa diagram was used to explain and alidate the conclusions drawn from the risk assessment and FMEA.Based on the FMEA analysis, an improvement plan for all stages was suggested with an emphasis on rising employees' awareness and training. In conclusion, this study has pointed out the importance of implementing an efficient systematic control system for risk management in the honey industry.

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