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REVIEW

MYCOTOXINS-CAUSES, PREVENTION AND CONTROL: MATHEMATICAL MODELING STRATEGIES

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ABSTRACT

For many decades ago, planting, harvesting, storing, transporting, distributing, and processing agricultural produce into useful products such as foods and feeds have been plagued by various contaminations and spoilages. Most often, these contaminants are fungi and molds-based microbes producing toxic contaminants that result in severe deterioration of some of the quality characteristics of these agro products. These toxic metabolites are called mycotoxin. Many fungi toxic in food and feed are known to be hazardous to human and animal's health. To prevent the contamination of mycotoxins in foods and feeds, primary, secondary, and tertiary methods are required. Similarly, certain treatments are equally necessary to control the continuous growth of these toxins in the products. This study deals with the review of these various preventive and corrective methods with the view of providing useful insight to the current practices of mitigating the production and contamination of mycotoxins in food and feed products. The study discusses the tendency of an integrated Taguchi model for predicting or studying mycotoxin through the combination of various preventive activities to emerge the optimum preventive procedure.

Keywords: mycotoxins cause, prevention, control, treatment, physical, chemical, quantification, integrated Taguchi-data envelopment analysis, robust parameter procedures

INTRODUCTION

According to **Bennett and Keller (1997)**, mycotoxins are the results of the metabolites formed by fungi and mold. These are those belonging to the species *Aspergillums*, *Penicillium* and *Fusarium*. Mycotoxins are produced in cereal crops, animal feed and forage products either before or during harvesting. They are known to show different chemical types and about 400 mycotoxin fungal metabolites are known to be toxic in nature **(Moss, 1997)**. The fungi contamination of food and feed majorly results in decline in produce yield, value, and mostly importantly economic losses (**Atanda *et al.*, 2010)**. Several hundred diverse mycotoxins have been recognized, but the most usually observed mycotoxins that are constitute a threat to human health and that of livestock are aflatoxins. Human and animal exposure to mycotoxins can happen either directly by eating infected food or indirectly from animals that are fed with infected feed, for instance from milk, meat, and egg **(Abdel-Wahhab *et al.*, 2004)**.

The potential risks of mycotoxin's presence in plants could be controlled or prevented by different methods. This is simply through checking for infected parts of the plant and removing it from the plant, by practicing enhanced cultivation, proper harvesting, and good storage conditions **(Abdel-Wahhabet *et al.*, 2008)**. To prevent crop contamination of fungal from the feed and food, pre- and post-harvest strategies which include annual crop rotation, proper use of pesticides, aeration of the crops effectively after harvesting, storing at a secure humidity level, and providing good protective storage **(Whitaker *et al.*, 2005)**. To understand the menace of mycotoxins, European Union published a list of mycotoxins that are of interest; with those causing major concern for the safety of animal feed and foods **(EU SCAN, 2003)**. The list mentioned Aflatoxin B1 (AFB_1) and Ergot sclerotia (subject to the Commission Regulation (EC) No 1881/20062); Zearalenone (ZEA), Deoxynivalenol (DON), Ochratoxin A (OTA) and Fumonisins (especially Fumonisin B_1, FB_1). The recommended tolerance levels of these mycotoxins have been published in the **Commission Recommendation 2006/576/EC3**. Furthermore, mycophenolic acid, cyclopiazonic acid and moniliform in mycotoxins have been identified as those with high possibility for emerging threats. Unfortunately, their occurrence and toxicological data are still scares, limited, and highly required to combat the menace.

The secondary metabolic products of molds (especially of *Aspergillus*, *Penicillium* and *Fusarium* genera) are called mycotoxins. There are over 300 of such secondary metabolites; however, just around 30 are toxic. Most of these molds producing mycotoxins derive their toxicogenic tendencies at all climatic conditions when attaching to their hosts which could be any solid or liquid in the presence of adequate nutrients and moisture. Mycotoxins are usually referred to as poisonous compounds in foodstuffs created by some fungal type thus posing direct and indirect health threats to human and animal **(Moss, 1997; Scudamore, 2005)**. By direct, mycotoxin contamination occurred through cereal crops and plants. Furthermore, indirect could be by animal feeding contaminated feeds containing mycotoxin residues to animal and human contract it through consumption of contaminated plant and animals' products such as milk, meat, eggs **(Galvano *et al.*, 2005; Scudamore, 2005)**. The fungal species responsible for mycotoxin production mainly belongs to five (5) species namely *Aspergillums*, *Fusarium*, *Claviceps*, *Stachybotrys* and *Penicillium* **(Sweeney and Dobson, 1998; Santin, 2005)**. The environment where pre-harvest and postharvest are conducted is also an essential factor to mycotoxin contamination of grain and oilseed crops **(Anonymous, 2003a)**.

Environmental stress during the production of cereal grain and other products consequently reduced the strength requires to characterize and predispose plants to infestation and colonization by toxigenic fungal species. Some of fungal strains are known to produce more than one mycotoxin and a single mycotoxin produces more than one fungal spp. In certain instances, single species could produce multiple mycotoxins **(Devegowda and Murty, 2005; Santin, 2005)**. Environment where that are prone to frequently irregular increase of the temperature and humidity can also affected the colonization of mycotoxin **(Russell *et al.*, 1991)**. During storage of food and feed products, the occurrence of toxigenic fungal contamination is facilitated through some factors related to the prevalent environmental conditions such as moisture, temperature, substrate aeration, oxygen and carbon dioxide concentration, microbial interactions, mechanical injure, great quantity of fungal and pest invasion **(Ominski *et al.*, 1994; Anonymous, 2003a; Santin, 2005)**. High temperature and humidity are the most important factors of mycotoxins fungal colonization and production.

It is usual to categorize toxigenic fungi into "field" (or plant-pathogens) and "storage" (saprophytic/spoilage) organisms **(D'Mello, 2001; Santin, 2005)**. Field fungi are group of fungal species that inhabit seeds while the crop is still in the field and require high moisture conditions (20-21 %). These include species of *Claviceps*, *Neoitphodium*, *Fusarium*, *and Alternaria*. Storage fungi (also called storage molds) are group of fungi that infiltrate grains or seeds during of storage. The group of fungi that invade seeds during storage relatively needs less moisture than field fungi (13-18 %) and in most cases they do not present any serious threat before harvest, and they were those that could grow at moisture contents in equilibrium with relative humidity of 70 to 90% where no free water is present. Storage fungi include species *Aspergillus* and *Penicillium* **(Anonymous, 2003a; D'Mello, 2001; Santin, 2005).** Fungi grow at temperatures between 20 °C and 30 °C. It should be noted that if the grain is at high temperature during time of harvest, high temperature can be maintained for many days or week after harvest unless the storage has regulated room temperature for cooling **(Santin, 2005)**.

Therefore, prevention of mold growth and its mycotoxin production relies on elimination of environmental factors that can favor the growth of mycotoxin. Preventing mycotoxin accumulation in stored grains and oilseeds depends primarily on humidity or moisture control. If the product of feed and foods is too dry to allow fungal growth and it is kept dry, no further deterioration can occur. However, if there is pest activity, moisture migration, condensation, or water

leaks, fungal growth that would be able to bring mycotoxin contamination can happen. Most of the contamination in storage comes from infections that began in the field **(Anonymous, 2003a)**. For the period of collecting and processing food and feed products, adequate care must be ensured to prevent excess damage to protective part and kernels from breaking or bruises to the protective shie of the crop as this may lead to contamination during storage. Moreover, the highest rates of invasion of fungal species are known to be linked with broken and insect-damaged kernels **(Munkvold and Desjardins 1997; Malone *et al.*, 1998b; Anonymous 2003a)**. Urgent attention is advocated to removing contaminated kernels collected in the field, with minimum loss of sound kernels highly recommended **(Sauer *et al.*, 1992; Widstrom 1996; Munkvold and Desjardins 1997; Anonymous 2003a)**.

Pests are known to have contributed immensely to fungal growth due to physical damage of grain barriers, which renders it liable to mold invasion of the exposed endosperm. The biological activity of pests can bring about a raise in both moisture and temperature of the invaded grain. Pests can also carry spores of mold and their fecal materials that can serve as a substrate for mold growth **(Santin, 2005)**. Appropriate grains moisture reduction and well-regulated storage is able to minimize fungal development and mycotoxin infestation after harvesting **(Anonymous 2003a; Santin, 2005)**.

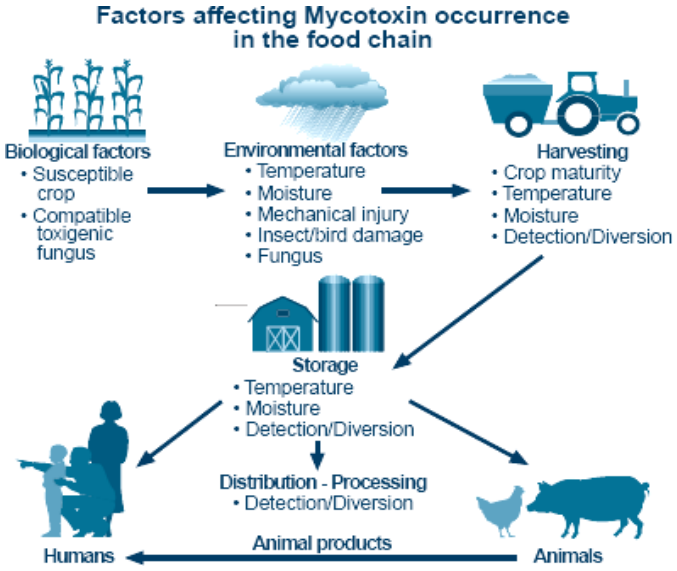

Figure 1 Factors affecting mycotoxin occurrence in the food and feed chain **(Anonymous 2003a**; adapted from **Pestka and Casale 1989)**

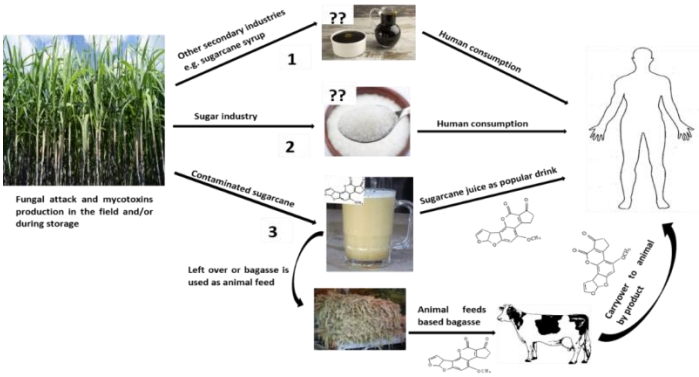

Figure 2 Mycotoxins contamination in sugar cane direct and indirect expose to human being **(Abdel-Wahhab et al., 2008).**

According to **Adegoe (2004)**, more than 300 mycotoxins that have been separated and characterized. These are not limited to the followings: aflatoxins, ochratoxins, deoxynivalenol, zearalenone, fumonisin, patulin**,** trichothecenes and alternariol.

Toxicological syndromes of mycotoxins ingestion are grouped as acute and chronic type toxicity. The acute one generally has short time of onset and clear toxic response, but the chronic toxicity seen by time-consuming and identified diseases which are cancers **(James, 2005)**. In humans particularly the liver and kidneys can be affected **(Bankole and Adebanjo, 2003)**. Aflatoxins have been shown to be involved with and to exaggerate hepatitis B infection, while the fungi fumonisins spices contaminated food have shown to account for esophageal disease in South Africa **(Makaula *et al.*, 1996)**. Similarly, F. *sporitrichoides* and *F. poae* have been identified with alimentary toxic aleukia. Some of the symptoms include esophagealpain, laryngitis, asphyxiation, and vertigo **(Lewis *et al.*, 2005)**. Mycotoxin contamination generates a broad range of harmful effects in animals causing different health problems such as lesions in the mouth, unnecessary enlargement of liver and kidney, pale aspect of liver, immune disorder, dysfunction of nervous system, weakness of bones, reduction in pigmentation, diminish of egg production and egg weight, poorer growth rate to mention a few. These signs depend on the animal species and mycotoxins contamination level **(Abdel-Wahhab *et al.*, 2008)**.

Good Agricultural Practices (GAP) in farming system reduces the contamination of mycotoxin in feed and food products **(Abdel-Wahhab *et al.*, 2013)**. To prevent or reduce of the contamination of animal feed, good practice and activity at farmer level action must be taken before and after harvesting and storage condition must be carefully **(Negashe *et al.*, 2018)**. According to **Abdel *et al.* (2008)**, the first primary prevention is before of the fungal mycotoxin contamination and infestation of the feed and food at the beginning. Primary prevention is the most important for retarding mycotoxin fungal growth in feeds and foods **(Atanda *et al.*, 2013)**. Several procedures can be undertaken. These are planting of anti-fungal plants, timely sowing, harvesting, and weed control, appropriate storage, and transportation, control of insect, moisture, and temperature. Humidity during harvesting is also a main factor for the formation of mycotoxin in feed and food **(Negedu *et al.*, 2011)**. The procedures include (a) planting fungal resistant plants for feed total field control of mycotoxin causing fungi, (b) arranging the proper time of harvest, (c) ensuring proper moisture contents of the feed and food during harvesting, post harvesting and storage condition, administering of fungicides to retard the growth of fungi, (d) managing pest and insects' infestation in storage by using standard insecticides, pesticide and (e) modifying the atmosphere.

According to **Kabak *et al.*, (2006)**, harvesting strategies are most significant in the prevention of mycotoxin contamination of foods and feeds. If the attack of some fungi begins in product of feed and food in beginning phase, this secondary prevention level of will be then necessary. The presented toxigenic fungi should be eliminated, or its development be stopped to put off further deterioration and mycotoxin production **(Abdel *et al.*, 2008)**. Actions such as drying the product could be necessary. These secondary prevention methods include (a) discontinuation of the development of contaminated fungi by re-aeration the products of feed and food and (b) elimination of infected seeds from the feed and food. If the feeds and foods are greatly infested by contaminated fungi-mycotoxins, the first and second preventive actions need to be initiated **(Atanda *et al.*, 2013)**. Commonly, agricultural products' contamination of mycotoxin can be banned by means of good pre-harvest and post-harvest management practice **(Kabab *et al.*, 2006)**.

The physical, chemical, and biological control means are usually employed to treat infected plants and crops. However, the action has its own restrictions, since the treated products should be safe from the chemical's contaminants and the essential nutritive value should not be compromised **(Abdel *et al.*, 2008)**. The products of feeds and foods are separated by mechanical means, color categorization of the feed and food, elimination of the small or screenings from the bulk shipments of grains and nuts considerably reduce the mycotoxin content of grains. Gamma irradiation has successfully been used to control ochratoxin levels in animal feeds **(Refai *et al.*, 1996)**. After the crops or plants are harvested, aerated, dried, stored, then and suitable transportation of the products are major importance physical treatment needed thereafter to re-recontamination. The technique should be sure that the removing of toxic substance system can change the contaminants to a non-hazardous derivative without harmful change in the food and feed products. A broad variety of chemicals have been shown to decrease, demolish or inactivate mycotoxins in feed and food **(Samarajeewa *et al.*, 1990)**. The ammonization process uses ammonium hydroxide or gaseous ammonia, both of which are uniformly successful in detoxifying aflatoxins in peanut, cotton, and maize meals **(Piva *et al.*, 1990)**. Major in-roads have been the use of structure difference by natural or bio-control strategies. For instance, growth of non-toxicogenic bio-control fungi, toxigenic strains within field can help in the decreasing of mycotoxins in the crops (Cleveland *et al.*, 2003). The use of microbe-free mycotoxins has been reported by (Murphy *et al.*, 2006) to be shows possible improvement to the treatment of mycotoxins. Fusarium pathogens can be reduced or dropping by using the choice of the production of food and feed cereal plant **(D'Mello and Macdonald, 1998; Baker, 1987)**. Biocontrol is one of the best naturally secure and in some cases is the only choice offered to protect plants in opposition to pathogens **(Heydari, 2010)**.

Existing risk management measures to avoid the direct adverse effects (both acute and chronic) on livestock as well as the indirect effects due to the presence of these toxins in animal products and foods and have been well developed and documented. These includes regulations and recommendations of the tolerable limit of the mycotoxin in foods and feeds, monitoring and enforcing compliance to good production practices by feed and food producers, development of standardized analytical methods to determine the mycotoxin content of a feed lot, developing and encouraging farmers on all the preventive measures and decontamination of mycotoxins contaminated foods and feeds. Many analytical techniques have been designed and applied for determining and predicting mycotoxins in feed and foods. However, most of these known methods have not been thoroughly validated and structured by the European Union of CEN (http://www.cenorm.be). Certain procedures have been standardized for analyzing mycotoxins in human food by the CEN Technical Committee 275 (CEN/TC 275); one protocol **(EN ISO 17375:2006)** has been provided by CEN Committee, the CEN/TC 327 standardized techniques for analyzing mycotoxins in feeds. Standardized procedure such aspr-EN 15791:2009 and ISO 14718:1998with the use of High-Performance Liquid Chromatography (HPLC) has also been sanctioned. Similar HPLC techniques include immune-affinity column clean-up, fluorescence detection and immune-affinity column clean-up, RP-HPLC with fluorescence detection during pre- or post-column determinations (pr EN 16006), OTA estimation by immune-affinity column clean-up and HPLC fluorescence detection (pr EN 16007) just to mention a few.

The best way to control mycotoxin to know the amount of the toxin ingested or that could be ingested by human and animal. This has been done through experimentation and mathematical modeling. The most common experimentation is the in vitro analysis. This procedure involves the analysis of mycotoxin adsorption in the screening of potential mycotoxin detoxifying agents. The idea behind these techniques is that if the detoxifying aid could not adsorb mycotoxin *in vitro*, then such aid has slime or no tendency to detoxify mycotoxin *in vivo*. It is a method used for assessing, identifying, and ranking effective mycotoxin-detoxifying aids as well and the detoxifying conditions and viable mechanism (Diaz and Smith, 2005). Many researchers have adapted and published these experimental applications at different forms such as single-concentration, classical isotherm (those involving binder concentration fixed, toxin concentration increasing) gastro-intestinal tract models, variable loading binding experiments and beyond. These applications are described as follows:

- **Single-concentration methods**
  Under single-concentration method, a known level of mycotoxin is reacted with a known amount of the sample in an aqueous solution. The adsorption of purified toxin solutions in these aqueous media is measured as percent adsorbed (%ads) which the fraction of the toxin bound to the adsorbing aid. This value is determined based on the loading of the adsorbing aid used.
- **Adsorption isotherms**
  According to **Grant and Phillips (1998)** and **Ramos and Hernandez (1996)**, adsorption isotherms have been applied to evaluate mycotoxin-detoxifying aids. This involves plotting mycotoxin adsorbed per unit weight versus constant temperature at stables conditions. It took into consideration the reversibility in the chemical equilibrium of the detoxification process. Freundlich, Langmuir and Hill are frequently used models for interpreting the results.
- **Food matrix method: Modified adsorption isotherms**
  Isotherms could be modified with the view of comparing adsorbed mycotoxins in the presence and absence of a food matrix. This would yield results of whether a matrix-mycotoxin related could affect adsorption efficiency. Here, Freundlich, Langmuir and Hill fitted curves are obtained for mycotoxin adsorbed. A thorough precaution for the efficiency of this method is to ensure that a mycotoxin-free food matrix is used.
- **Gastro-intestinal models: Static and dynamic experiments**
  The purpose of the in-vitro is to assess the efficiency of mycotoxin-detoxifying aids in attaching to the mycotoxins for analysis through simulated gastrointestinal model. This will identify the physiological conditions that are germane such binding. In these static and dynamic in-vitro techniques, gastro-intestinal models are used to examine the efficacy of the detoxifying aids. In the work of **Vekiru *et al.* (2007)**, it was revealed that the efficacy of mycotoxin adsorbing aids is strictly dependent real set of conditions at which it passes through the gastro-intestinal tract.

Retrospectively, mycotoxin production is difficult to be prevented; however, certain prevention activities can be adopted to limit its contamination on food and feeds, bio availability or toxic effects. **Abrunhosa *et al.* (2009)** has revealed vast number of microorganisms that could destroy or reduce several mycotoxins. Biological methods were concluded to be the foremost among all preventive methods. The technique is known for rendering mycotoxins ineffective by bio-transforming the toxin to produce non-toxic metabolites that less harmful when ingested.

Recent revelations confirm the need prioritize modeling mycotoxin in all ramifications **(Battilani, 2016)**. These efforts could be justified due to (i) mycotoxin contamination is vastly becoming a global phenomenon (ii) more chronic health foodborne diseases have increased **(Schatzmayr and Streit, 2013)** (iii) impacts of mycotoxins on agro-products is growing with increased number of compounds and agro-foods worldwide **(Wu and Guclu, 2012; Mitchell *et al*., 2016)**. Freundlich, Langmuir and Hill models have formed the major equations used in many mycotoxins modeling studies. **Grant and Phillips (1998)** had applied modification to these models in the analysis of the various mycotoxin adsorbing aids. The applications of models to mycotoxin prediction have shown positive improvements in my articles published **(Battilani and Logrieco, 2014; Battilani and Leggieri, 2013; 2014; 2015a; 2015b; Skelsey and Newton, 2015; Chauhau *et al.*, 2010; Marin *et al.*, 2012; Garcia *et al.*, 2011; 2013; Aldars-Garcia *et al*, 2015; Medina *et al.*, 2014; Ioannidis *et al.*, 2014; Passamani *et al.*, 2014; Nazari *et al.*, 2016)**. However, efforts to model the attendant threats of mycotoxins in foods and feeds are still scanty and limited. The reasons for this lack in the application of model could be (i) low interest or many researchers in this direction (ii) naivety of the support modeling could render to the efforts to decimate the growth of mycotoxins (iii) lack of adequate trusts in the model itself by researchers and (iv) the complication witness during model development.

Most of the current models only considered the prediction of the toxin base of single factor. For instance, modeling has been done based on crops **(Battilani and Logrieco, 2014; Skelsey and Newton, 2015; Fels-Klerk *et al.*, 2012; Landschoot *et al.*, 2012; Froment *et al.*, 2011; Asselt *et al.*, 2012; Battilani *et al.*, 2013; Chauhau *et al.*, 2010; Battilaniand Leggieri, 2015a). Some are modeled without crops (Marin *et al.*, 2012; Garcia *et al.*, 2011; 2013; Aldars-Garcia *et al.*, 2015)**, empirical models based on environmental and ecological factors **(Landschoot *et al.*, 2012; Van der Fels-Klerx *et al.*, 2010; Leffelaar and Ferrari, 1989)**. Based on meteorological data **(Battilani *et al.*, 2016; Vaugham *et al.*, 2016)** and based on pre- and post-harvest conditions **(Battilani *et al.*, 2015b)**. **Laila *et al.* (2016)** employed a probability-stochastic model to for the growth of and production of aflaxtoxin. Combination of two or more factors into the model prediction and analysis of mycotoxin are limited **(Fels-Klerx *et al.*, 2016)**. **Vaugham *et al.* (2016)** developed a model that predicted mycotoxin from the combination of climate, pathogen and host and cropping systems.

Various means of quantifying mycotoxins through experimentations and mathematical modeling for mycotoxin prediction and estimation have been published. The experimentations are majorly of the in-vitro while most of the models are based on the empirical and mechanistic. The models are usually directed to the determination of the effects of the ecological factors on the fungi infection cycle. This in-vitro data are based mainly on the growth of fungi. Few or none of these models consider the effects of preventive methods on the prediction of the growth of mycotoxin producing fungi. This study intends to emphasize the quantification of mycotoxins are juxtaposed in a modular framework to prevent the production of these mycotoxin producing funguses. Therefore, the main contribution of this study is to apply mathematical modeling discuss how an integrated Taguchi-Data envelopment model can be used to determine the best (optimum) practice (procedure) that could substantially lead to the retardation of the growth these mycotoxin producing fungi. Specifically, the following are anticipated; (i) provision of basic information about mycotoxins, factors responsible for occurrence of mycotoxins, and to give insight to the prevention, treatment, and control of mycotoxins in foods and feeds, (ii) review previous modeling techniques and (iii) Taguchi-Data envelopment model could be developed for the prediction of the optimum practice that could lead to the reduction of the rate of mycotoxin production and contamination in foods and feeds.

MODEL CONCEPTUALIZATION

Few modeling has been carried out on the combination of various preventive techniques, on a mechanistic level, to predict mycotoxin. This is the challenge facing the researchers today and would probably be in the future. This review will now examine the efficacy of an integrated Taguchi-Data envelopment model to adequately combine various preventive techniques to select an optimal procedure that can be used to decimate the growth and production of mycotoxin in feed.

Taguchi robust signal-to-Noise ratio

The old, online traditional methods of quality assurance are based solely and primarily on inspecting products as they are discharged from the production line and rejecting those products that fail to meet up with the specified acceptance range. However, it has been pointed out that no amount of inspection can

improve product's quality attributes and that quality must be built into the product right from conception **(Taguchi *et al.*, 2005)**. Robust parameter design is an engineering procedure that utilizes different strategies for improving performance during product and process design so that quality response can be obtained efficiently and optimally. This off-line quality control procedure idea stemmed up due to the need to enhance the dependability of controllable factors to the effects of the variations in the uncontrollable factors so that the overall quality response is insensitive to the effects of the variations **(Taguchi *et al.*, 2005; Al-Refaie and Al-Tahat, 2011; Adesina and Daneshvar, 2018; Danesvar and Adesina, 2018).**

Factors are classified into two distinct classes of those that are controllable and those are uncontrollable (noise). Taguchi therefore aimed at identifying optimum controllable factor settings (level combination) that minimize process variability. There is the need to understand these classes of process factors. Controllable factors (design or control factors) are those factors that can be easily moderated, adjusted, or controlled by the designer. These are not limited to material choice, cycle time, or operating temperature, process route choice, and type of catalysts used, choice of condition. Uncontrollable factors (noise factors) could be described as forces compelling or causing deviations from production or quality target.

It can be subdivided into three categories namely external, internal, and unit-to-unit noise factors. External noise factors are those that arose due to the exposure or variation in condition of use. Internal noise factors are due to production variations while unit-to-unit are because of deterioration or variation with time of use. Noise factors are difficult or almost impossible to control and could be expensive when attempted to control or eliminate them. Taguchi proposed three steps technique for developing good quality products and processes. These are system design, parameter design and tolerance design. Experiment must be carried out to implement parameter and tolerance designs. Here various mycotoxin preventive activities could be grouped into the orthogonal array and with a response of mycotoxin level, optimum prevention procedure would emerge. Signal-to-Noise ratio of the robust parameter; Larger-The-Better (LTB), Smaller-The-Better (STB), and Nominal-The-Better (NTB) of each orthogonal array would be determined by Equations (1-3).

$$\mathrm{SN} = -10\log\left(\frac{1}{\mathrm{n}}\sum_{\mathrm{i=1}}^{\mathrm{n}}\frac{1}{\mathrm{y_{ij}^2}}\right) \quad (1)$$

$$\mathrm{SN} = -10\log\left(\frac{1}{\mathrm{n}}\sum_{\mathrm{i=1}}^{\mathrm{n}}\mathrm{y_{ij}^2}\right) \quad (2)$$

$$\mathrm{SN} = -10\log\left(\frac{\bar{\mathrm{y}}_{\mathrm{ij}}^2}{\mathrm{s_{ij}^2}}\right) \quad (3)$$

Revamped Data Envelopment Analysis (DEA)

In general, DEA have been referred to as a fractional mathematical programming technique solely responsible for evaluating the efficiency or performance of homogeneous decision making units (DMU) with multiple inputs and outputs system. **Rocha *et al.* (2016)** described data envelopment analysis (DEA) as a linear programming technique used for determining the relative performance of a set of competing DMUs whenever multiple inputs and outputs makes the comparison cumbersome. It is a non-parametric technique for measuring technical efficiency of various systems. By technical efficiency, we mean the degree of industry technology level that the production process of a production unit reaches. This can be determined from two perspectives (i) input and (ii) output. From input aspect under the input condition defined for the system, the technical efficiency is measured by the degree of output maximization and for output perspective under the output condition defined; the technical efficiency is measured by input minimization. In both cases, technical efficiency can be estimated quantitatively as a ratio of output to input. Each set of mycotoxin factor combination would form the DMUs.

There are many models in DEA, variable return to scale (VRS) model could be adapted into the suggested integrated model. VRS model in Equation (4) and (5) below would be leveraged to determine the optimum mycotoxin preventive procedure.

$$\begin{aligned} &Max \ \textstyle\sum_{r=1}^{s} u_r y_{ro} + u_o \\ &S.t. \ \textstyle\sum_{i=1}^{m} v_i x_{io} = 1 \\ &\textstyle\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} + u_o \le 0 \\ &u_r \ge 0 \quad r = 1, \dots s \\ &v_i \ge 0 \quad i = 1, \dots m \\ &u_o \ free \end{aligned} \quad (4)$$

$$\begin{aligned} &Min \ \textstyle\sum_{i=1}^{m} v_i x_{io} + v_o \\ &S.t. \ \textstyle\sum_{r=1}^{s} u_r y_{ro} = 1 \\ &\textstyle\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} + u_o \le 0 \\ &u_r \ge 0 \quad r = 1, \dots s \\ &v_i \ge 0 \quad i = 1, \dots m \\ &u_o \ free \end{aligned} \quad (5)$$

Taguchi-data envelopment modeling approach

This robust parameter procedure could be achieved in four phases: data collection and generation, responses evaluation by any of the experiments mentioned before, efficiency determination using DEA model, optimization to determine and select optimum preventive level combination that can reduce the growth and contamination of mycotoxin in foods and feeds.

Phase A (Data generation and collection)

The major aim of this phase is to gather data for signal-to-noise ratio estimation using the orthogonal array. This phase would consist of five steps:

- Step 1 (identifying controllable factors):
- Step 2 (selecting adequate orthogonal array):
- Step 3: Conducting the experiment, literature data (neural network could be used to predict some factor levels as well)
- Step 4: estimation signal-to-noise ratios for responses from experimental data
- Step 5: Normalized signal-to-noise-ratio estimation NSNs

Phase B (Data prediction using BP-NN)

This phase is necessary when all the data needed for the prediction and estimation could not be obtained from the experiment carried. BP-NN neural network can be used to predict the values of the factors levels combinations beyond those obtained through the experimented in phase A. This phase could also be achieved in three steps as follow:

- Step 1 (neural network topology and architecture selection).
- Step 2 (selection of the training and the testing data sets).
- Step 3 (factor levels and corresponding signal-to-noise ratio prediction).

Phase C (determination of efficiency of DMUs using modified DEA)

An analysis will be done to evaluate the efficiency frontier of each factor level combination.

Phase D Optimization to select optimum DMU

To optimize and select optimum DMU, DEA penalization model of the efficient DMUs obtained at Phase C above is estimated.

This integrated procedure is schematically presented in Figure 4. It is believed that this integrated model has high propensity to interrogate all the analytical methods with other mathematical model to optimally determine a way that would lead to the decimation of mycotoxins production and contamination. The inclusion of a perceptron neural network model is for the purpose of predicting from experimental or literature results, the factors combination, and responses. This would save the researcher enormous time and resources that usually dissipated and wasted on experimentations. However, this model is not intended as a substitute to experimentation but rather a better complement to optimizing the search for the optimum result. Furthermore time, money and resources are intended to be saved with the utilization of this model.

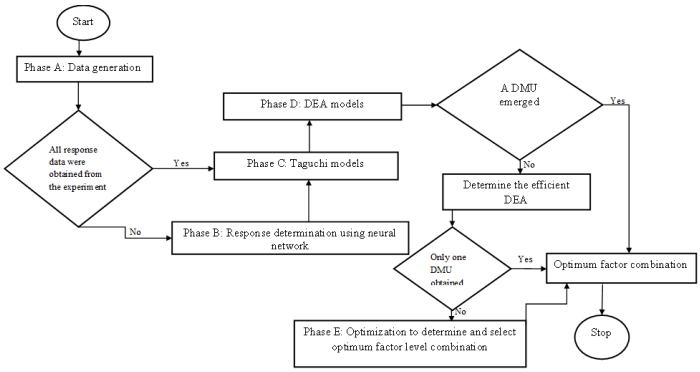

Figure 3 Mycotoxin Taguchi-Data Envelopment prediction model framework

CONCLUSION

Numerous valuable habits for the prevention and management of harmful fungi and the hazardous mycotoxins in feeds and foods have been discussed. A lot of issues responsible for the formation of mycotoxins in feed and food in different ways have been revealed. They are planting crops that are a not resistant to fungi invasion, fitness of fungal substrate, comfort of the temperature climate, moisture for mycotoxins, injured product seeds of food and feed due the activities of small invertebrate and arthropod animals, poor farming systems and

agricultural techniques, pre- and post-harvesting techniques, storage methods transportation conditions and food processing.

Mycotoxin treatments and control in feed and food can be done through any of primary, secondary, and tertiary actions, good agronomic and agricultural practices, and detoxification. Currently, biological-breed plants of fungal resistant hybrids are selected for planting to avoid the production and contamination of the produce by mycotoxin of fungi or other microbial origins. Producers and suppliers now must understand how to handle pre- and post-harvest issues. They should be aware and be knowledgeable of the causes of mycotoxin production and contamination. Drying of commodities of food and feed after post-harvest is the most important preventive and corrective actions for mycotoxin contamination. The use of chemical is an appropriate dosage which does not pose dangers to health has been advocated and another way of controlling the growth of mycotoxin in products. The over-all anticipated outcome of the integrated model explained is the selection of an optimum preventive procedure for reducing mycotoxins in crops, foods, and feeds.

The reviews therefore recommend the prediction of the mycotoxin and its control from the combination of all the preventive strategies (primary, secondary, and tertiary). More so all the means of quantifying mycotoxin should be incorporated into an optimum procedure for predicting, quantifying, preventing and detoxifying mycotoxins in foods and feeds. The suggested integrated Taguchi-data envelopment model has a great propensity through the integration of various robust steps, to produce results adequately and optimally.

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