Quality Assurance and Safety of
Crops & Foods

ICC MoniQA

Quality Assurance and Safety of Crops & Foods 2011, **3**, 82–88

ORIGINAL ARTICLE

Opportunities of integrating supply chain quality management and product development with formulation systems in compound feed manufacturing

Andrea Csikai

Centre for Agricultural and Applied Economic Sciences, Institute of Food Processing, Quality Assurance and Microbiology, Faculty of Agricultural and Food Sciences and Environmental Management, University of Debrecen, Debrecen, Hungary

Keywords
feed formulation; ingredient variability; linear programming; stochastic programming; supply chain quality management.

Correspondence
Andrea Csikai, Centre for Agricultural and Applied Economic Sciences, Institute of Food Processing, Quality Assurance and Microbiology, Faculty of Agricultural and Food Sciences and Environmental Management, University of Debrecen, Debrecen, Hungary
Email: andrea.csikai@gmail.com

Received 30 June 2010; revised 26 October 2010; accepted 29 November 2010.

doi:10.1111/j.1757-837X.2011.00093.x

Abstract

Introduction To maximize the performance of the target animal group, market-oriented feed production aims high-quality products by considering variability of ingredient quality attributes in the least cost formulations. Supply chain quality management systems reveal information that formulation can apply to achieve benefits. *Materials and Methods* Feed product had been formulated both with linear and stochastic programming on different probability levels with nutrient averages and the standard deviation of a key nutrient in ingredient batches from two vendors. The information sources of formulation were mapped, as well as the uses of output data. *Results* Data sources of formulation are internal (from feed manufacturer) and external (from vendors). Output data from formulation is mainly used internally, but available also for supply chain quality management. Formulation simulates the implications of raw material variability from suppliers and helps to identify areas of vendor development. *Conclusion* Formulation provides possibility to consider ingredient variability to reach product target on higher probability levels. Integration between supplier quality management and feed formulation brings the benefits of more consistent product quality, lower costs of rations, accuracy in planning, support in ingredient purchasing decisions, better traceability, improvement of supplier performance, and internal quality management processes.

Csikai A (2011). Opportunities of integrating supply chain quality management and product development with formulation systems in compound feed manufacturing. *Quality Assurance and Safety of Crops & Foods*, **3**, 82–88.

Introduction

In 2004 about 5100 companies produced prepared animal feed across 27 EU countries by generating €7.2 billion of added value (European Commission – Eurostat, 2008). The objective of these feed producers is to make safe and nutritious products on the least cost to maximize their profits besides maintaining and continuously improving product quality. Generally their customers look for feed product at the lowest price with the most benefits provided in order to maximize the performance of the animal group. In the turbulent economical and natural environment, feed producers are ought to be able to make quick modifications on their products or even on entire product portfolio that impacts their supplier base. Agricultural products are highly dependent on the environment; therefore food and feed manufacturers continuously compete for acceptable quality ingredients in sufficient quantities. This competition is mainly driven by price although other aspects may also influence market situation.

Recommended approaches for supplier performance assessment, development, and companies' internal quality management are available under the aegis of various quality management systems. In the past decades, methodologies had been developed for managing the quality aspects of supply chains and establishing vertical integration. Practical difficulties appear when a feed producer introduces quality management principles in the supply chain of directly off-farm raw materials with great variability of quality attributes and diverse vendor base.

Feed products can be tailor-made with excellent feed formulation software tools by constraining parameters, so that feed producers are able to formulate even highly complex formulas (including multi-product, -plant, -level, and relational optimizations) effectively. Animal feed rations are frequently re-formulated due to changes of raw material prices, quality attributes (e.g. nutritional values), production changes, or modifications on the product concept, although not all the changes are known with accurate certainty. Every re-formulation changes the product composition, and these changes must be recorded for traceability purposes.

The objective of the study was to highlight opportunities of linking data derived from the supply chain to the different feed formulation methods (with linear and stochastic programming) that drive product quality performance and can influence supply chain quality management (SQM) decisions by quantifying benefits.

Literature review

Referring to Grunert *et al*'s. (1996) work, agricultural and food companies need to develop understanding of their markets and apply the knowledge to gain competitive advantage through the application of market-orientation approach. As it had been recognized by Knura *et al.* (2006) the most fundamental change in the agricultural and food production in the last decades was the shift from production to market orientation.

Accordance to Costa and Jongen (2006), the vertical integration of product development and innovation will increase the success opportunity of the new product. The methods for an effective, chain-wide integration of product development activities is an area where considerable improvement could be made.

Customer-focused organizations must understand their suppliers' organization and processes. Alignment of organizational performance goals between the supplier and the customer supports effective risk management. Effective performance measurement and strategy addresses the importance of risk management implied by the large-scale system integration model adopted by many large companies with integrated supply chains (Matthews, 2007).

Gattorna (1998) stated that organizations must bring a multi-enterprise view to their supply chains. They need to be capable of working cooperatively with other organizations in the chain, rather than seeking to outdo them. According to his second principle, organizations must recognize the distinct supply and demand process that must be integrated in order to gain the greatest value. Three key elements have been defined for a holistic strategy framework: (i) Firstly the core processes of the supply and demand chains should be viewed from a broad cross-enterprise advantage point rather than as discrete functions. (ii) Processes that create the link between the supply and demand chains should be integrated (planning, service processes, etc.). (iii) The third point consequently is the supporting infrastructure that makes such integration possible.

Gordon (2008) emphasizes that organizations are under increasing pressure to avoid supplier problems as well as to attract and retain the high-performing strategic suppliers. The process of developing and deploying supplier assessment consists of seven steps. The first one reflects the vertical integration approach stating the need of aligned supplier performance goals with organizational objectives. It is followed by the determination of an evaluation approach. The subsequent steps are the development of a method to collect information about suppliers and the design with the development of a robust assessment system. These preparation steps are followed by the deployment of a supplier performance assessment system where IT may need to develop and link information from disparate systems. In order to establish continuous improvement, giving feedback to suppliers on their performance is essential. The last step is to produce results from measuring supplier performance.

The quality parameters can be divided into intrinsic and extrinsic quality attributes. Intrinsic factors refer to physical product characteristics that can be measured in an objective manner (e.g. nutritional value, appearance, sensory properties). Extrinsic factors are related to the way in which the product was made (e.g. use of pesticides, type of packaging), often they do not have a direct influence on physical product properties but can influence consumers' quality perception (Knura *et al.*, 2006).

Balogh (2008) highlights that the application of statistical methods in inbound quality control helps companies' internal quality management and should be used especially when the information collection and analysis provides mutual benefits both for the supplier and the buyer.

Moe (1998) took the cognizance of the information owned in the food manufacturing chain providing a competitive advantage as it could be sold along with the product. For this reason the desire for the integration of more information in food production sets higher requirements for well-structured traceability systems.

Since the EC/178/2002 regulation, food and feed producers have been obliged to operate traceability systems at least one step forward and backward along the supply chain to ensure food safety. A traceability system transfers information along the participants of the chain, however, it does not ensure the food safety alone. Recently, more publications discussed that the role of traceability went beyond and it had an important function in quality verification.

Golan *et al.* (2004) listed three primary objectives of food companies in using traceability systems: to improve supply management; to facilitate trace back for food safety and quality; to differentiate and market foods with subtle or undetectable quality attributes. Traceability systems can help to isolate the source and extent of safety or quality control problems and to reduce the production and distribution of unsafe or poor-quality products. The better and more precise the tracing system, the faster a producer can identify and resolve food safety or quality problems.

Varga and Csukás (2010) assessed entire chain traceability solutions. They found that these were usually not frequent, only in test phase, or used only for a specific sector of the food chain (e.g. beef). They concluded that every actor of the chain must implement one standard system, develop customized communication interfaces, and adopt integration standards.

Győri *et al.* (2006) reviewed how traceability is established in the feed crop industry of Hungary and found that it is not equally robust at all stages of the food chain. In terms of feed production traceability is established only from the feed manufacturer to the fork. Feed producers have limited influence on the production of crops. The raw materials are monitored on quality at the feed manufacturer. If the batch has nonconformities (e.g. heavy metal, mycotoxin, or GMO contamination), it is rejected. The rejection costs additional money for the vendor and the manufacturer too, if the production is stopped due to missing raw materials. The problem is even bigger if the contamination is detected after the product was made and distributed to customers. The two cornerstones of quality assurance are the process documentation and the analysis of measurement results.

Hoogland *et al.* (1998) summarized why the implementation of quality assurance systems has great importance in agri-food businesses: agricultural products are prone to rapid decay, most of them are seasonally harvested, they have heterogeneous quality parameters depending on cultivar and other variable differences, which cannot be controlled, and the production is made on small scale by large number of farms.

Indeed, the least cost and the most accurate diet could be formulated if the raw materials had limited or no variations at all. Naturally this state will never be reached especially in terms of agricultural products because of reasons mentioned above. Variability of quality attributes of a feed ingredient may occur due to multiple vendors, seasonality, processing variations of the supplier, deviations of laboratory analysis methodologies. Roush (2004) also noted that the reduction of variance to deliver consistent quality finished goods is expected in modern manufacturing industries, however, its ways have not been mentioned.

Usually raw material nutritional analysis and data processing to derive means and standard deviations at most feed mills are done retrospectively (Roush, 2004). By the time the data are available on a raw material batch, the batch probably has been mixed and fed to the animals. Near infrared spectroscopy technology makes real-time data collection available about ingredients.

As a solution for achieving more reliable nutritional composition of the product Nott and Combs (1967) proposed the use of a safety margin for each nutrient by subtracting one-half of a standard deviation from the mean value of the nutrients. In this way the probability of meeting an animal's requirement would be higher.

Black and Hlubik (1980) compared two approaches to the nutrient variability problem: the use of safety factor to nutrient requirements and the second approach that makes the safety factor dependent on variation in nutrient densities of feedstuffs. When two feeds with different coefficient variations (CVs) but the same nutrient averages are considered, the feedstuff with the highest nutrient CV should be discounted relative to the feedstuff with the lowest CV. They suggested that the odds that a constraint is met with depend on the foregone earnings if the requirement is not met against the wasted expenditure if requirements are exceeded.

The variability of nutrients of the feed ingredients has been identified as a major risk in the publication of Roush *et al.* (1996) due to the fact that the diets may not fully deliver sufficient nutrients according to requirements of the animal. The authors argue that nutrient adjustments are appropriate for a linear programme because the variance of nutrients in the formulation algorithm is the square of the standard deviation; therefore the formulation process becomes a nonlinear problem. Nutrient variation as a nonlinear input variable violates the assumptions of uncertainty and linearity for the linear programme, resulting a costly over-formulation of the diet. Stochastic programming is a method that can effectively deal with nutrient variability in the formulation with a measured level of certainty.

Pesti and Miller (1993) states that higher than 50% probability of success can be achieved by adding safety margins to the rations safety margin concept is closely related to stochastic programming.

In a study, carried out also by Roush *et al.* (2007) it has been proven that the linear programme with a safety margin would over-formulate at a higher than requested level of probability and stochastic programming provides more flexibility and accuracy in meeting the requested probability levels. The study showed that the advantage of stochastic programming is in controlling nutrient variation and both of the linear and nonlinear algorithms easily accessible through commonly available Excel spreadsheets for use.

Black and Hlubik (1980) divided the workflow and task around LP into seven parts, they are applicable to a more general feed formulation workflow too: (1) mathematical background, (2) solution methods, (3) development of computer systems to handle LP, (4) system management procedures including database management, (5) data gathering, conversion, and transcription, (6) modelling real world problems, (7) interpretation and presentation of results in management decision making.

Methods and material

A basic pet food product had been formulated using WinFeed (version 2.8) formulation software on 18 parameters, from 10 ingredients on dry matter basis according to a defined set of nutritional constraints. The software tool used is able to carry out formulations both with linear and stochastic methods. Ingredient prices were estimated market prices, however, they were appropriate to indicate their role in least cost formulations.

Batches ($n > 8$, each ingredient) of the 10 ingredients had been tested for 18 nutrients at the same laboratory to minimize variance related to the analytical methods. Means and standard deviations of the nutrients of each ingredient have been calculated from the analytical results. In order to keep the scenarios for linear and stochastic formulations relatively simple, only one parameter, protein was chosen.

The ingredient, which had the biggest contribution to the protein content of the product, has been identified after the optimization of the ration by linear programming. The standard deviation of protein content of this ingredient had been populated in the software and the formula was re-optimized by stochastic formulation method on 60%, 70%, and 80% probability levels (Iteration A). Other nutritional parameters of each ingredient had been considered as linear factors in the formulations as their standard deviations were not populated in the software tool but kept as 0.

In the following iteration of optimization a scenario was considered when a supplier delivered batches with similar average protein content of the key ingredient but with lower standard deviation. The stochastic formulation cycles had been carried out again on 60%, 70%, and 80% probability levels. The calculated price of the formula in €t^{-1} had been recorded and compared after each iteration.

To find the link between product development, formulation, and SQM, the elements of information flows were listed and grouped per area of use regarding a typical animal feed manufacturing operation. The sources of information required for the formulations had been mapped, as well as the uses of the data that were derived from the formulation.

Results

After the first optimization of the ration by linear programming poultry meal was the ingredient that had the highest contribution (59.85%) to the protein content of the product due to its relatively high protein content and high proportion in the ration (Table 1).

In Iteration A, when the calculated standard deviation of protein content of all poultry meal batches was populated [standard deviation (protein, poultry meal) = 2.36%] in the software tool and the formula was re-optimized by stochastic formulation, the cost of the ration increased from 304.03 to 305.65 € t^{-1} by setting the probability at 60%, 70%, and 80% levels.

In Iteration B, it was simulated how the recipe price changed when the average protein content of the poultry meal was similar but the standard deviation [standard deviation (protein, poultry meal) = 1.22%] was lower due to that batches from only one vendor were taken into account. When the probability levels were changed in the stochastic

Table 1 Formula calculated with linear programming and the relative contribution of ingredients to the product protein level

Ingredients	Ration (%) – LP	Protein content (%)	Contribution to protein content of product (%)
Maize	20.00	7.85	7.35
Wheat	30.16	11.85	16.73
Distillers' grains	5.98	29.09	8.14
Wheat bran	7.26	16.00	5.44
Palatant	5.00	8.53	2.00
Choline supplement	0.79	10.04	0.37
Limestone	1.27	0.00	0.00
Vitamin mineral premix	2.51	1.08	0.13
Pork fat	8.00	0.00	0.00
Corn gluten	0.00	62.30	0.00
Poultry meal	19.03	67.20	59.85

formulation from 60% to 70% and to 80%, the cost of the ration increased (from 304.03 to 304.85€ t^{-1}) in this case too, however, not as much as in Iteration A (Figure 1).

The list of necessary data that were required for the test formulation contains internal information from the feed manufacturer (product constraints, production quantity) and external information from the supply chain (ingredient availability, price and ingredient quality attributes, e.g. the nutrients). The list of data derived from the test formulation contains elements for internal use in the feed production (the ration as the bill of materials, ingredient quantities to purchase) and elements to be used in the interaction with the supply chain (e.g. shadow price, shadow nutrients, desired ingredient quality attributes with expected or tolerable variance, food safety risks in connection with ingredient proportions in the diet) (Figure 2). All of the input elements change across time (ingredient price change, ingredient quality changes, vendor changes, modifications in product concept). A new formulation cycle adjusts the diet to these changes, so that the least cost ration is produced and the other output data may be available for SQM.

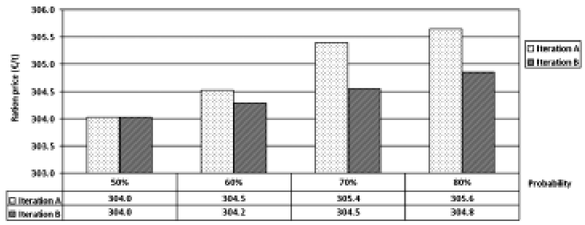

Figure 1 Formula prices in € t^{-1} optimized with linear and stochastic programming (60%, 70%, and 80% probability levels) with calculated mean (67.2%) and standard deviation (2.36%) of poultry meal batches (Iteration A) and a theoretical scenario of a specific supplier's batches with similar mean but lower standard deviation of protein level (1.21%) (Iteration B).

Discussion

Feed products and their ingredients can be described with a specific set of parameters that includes measurable nutritional, functional, and food safety attributes. Formulation defines which raw ingredients the product should consist of and in which proportions to achieve the product concept within the constraints. Considering the real and potential

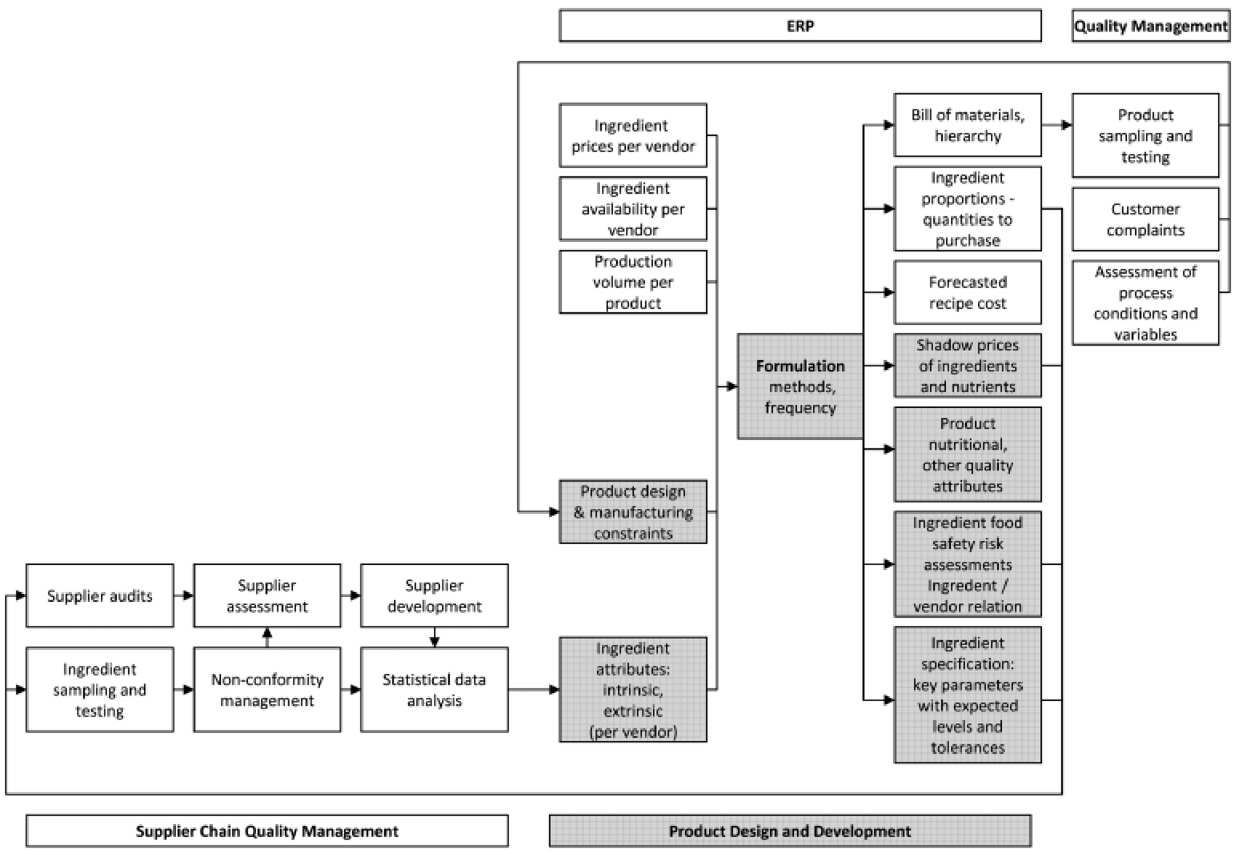

Figure 2 Links between the elements of product design, development, and supplier quality management.

quality attributes of the ingredients, formulation provides the size of the impact due to the proportion of the raw material in the ration. The deviations from expected level might cause impacts on the animal's performance and health. The simulation carried out showed that in case of the protein level of the product the key contributor was the poultry meal. In the same way, ingredient proportions are needed to assess any quality parameter objectively (including feed safety risks too) and this information is available from formulation. SQM programmes should measure, control, and improve these quality attribute/ingredient/supplier combinations and formulation can quantify the cost benefits of doing it. In Iteration B, the use of a material from a supplier with lower standard deviation (maybe due to better process control) brings benefits to the feed manufacturer.

For accurate formulations actual raw material analytical data are to be used after statistical analysis. As the case study showed, linear programming provides the lowest price, however, the probability of the case that the product meets the product specification is 50%. Where higher probability is required, stochastic formulation can provide solution. Ingredients with lower standard deviation enable the manufacturing of more consistent products at lower ration prices, however, the increase of the probability of stochastic formulation results in more expensive rations. Formulation tools combine all the information to define which product parameter is impacted by what ingredients the most. Consequently, the nutritionist may decide if higher than 50% probability is needed for that specific parameter, standard deviation of the parameter can be taken into account in the software tool. The store of information about quality attribute/ingredient/supplier combinations should be able to manage, statistically process, report, and transfer actual quality data of the batches in a timely manner into the formulation tool. The accurate data set are the foundation of formulation, supplier performance measurements, and it also supports traceability. Every time when diets are re-formulated due to input data changes, a dynamic system would enable producers to adjust their SQM actions according to the recent product portfolio and the composition of products resulting in more conforming products to specifications.

The following dimensions of benefits have been identified that can be delivered by an integrated formulation and SQM system:

- Consistency of product quality and food safety: dynamic reaction to raw material changes, reformulation of diets, and possibility of formulation on various probability levels.
- Time: setting the frequency of formulation, frequency of ingredient deliveries and sampling, quicker realization of new products, more flexible re-optimizations.
- Accuracy in production planning: ingredient demand and logistics planning.
- Raw material purchasing: ingredient demand planning according to diet composition, how much of a material would be needed if it was available at certain price or in different quality (shadow prices, nutrients).
- Supplier quality assurance: audits and incoming ingredient control focusing on key quality parameters at the right frequency, better information for vendor comparison and selection.
- Financial benefits: least-cost diets, better negotiation positions at suppliers due to better understanding of ingredient quality required.
- Traceability and quality management: ingredient batches, supplier information, formulas, more effective changes control, and documentation.
- Operation management: help in logistic questions related to ingredients (segregation per quality, quantity demand).

Conclusions

Performance of vendor of primer agricultural products is mainly measured on a few quality and food safety attributes of the material with the consideration that the variation of the product highly depends on natural circumstances and environment. The more processing a food ingredient goes through, the more opportunities occur to segregate raw material batches per quality grade and control the processing to gain consistency. If the effectiveness of the vendor assurance programme fails of delivering the specified ingredient quality consistently, the feed producer might face significant impacts on the product and potentially on its market position too in negative way. The question has been raised if there was a way to share resources and information between supplier and feed manufacturer more effectively, so that market orientation cascades down from formulation to SQM.

Today data management, SQM, formulation, and product manufacturing at most of the cases exits as standalone applications from very simple (e.g. Excel spreadsheets) to highly complex systems with software tools using sophisticated mathematical algorithms. These elements do not always have direct links to each other. The benefits and advantages generated from the individual processes rarely penetrate vertically and horizontally the invisible borders of formulation, internal quality management, and SQM. The flexible selection of right-for-purpose formulation method (linear or stochastic programming) supported by easily accessible and statistically processable supplier quality information, enables the proper determination of frequencies of re-formulations, supplier audits, raw material analysis, etc.

The gap occurs between the diet formulation and SQM when the producer does not have adequate and sufficient information about the suppliers to predict deviations or when the supplier development focuses on raw material attributes that are less relevant from the overall diet composition point of view. It is a valid question to consider that either the feed producer pays the price of higher recipe costs, less reliable product performance, or a certain amount is invested in SQM programme, however, the information to give an answer, in theory, could be managed in integrated, real-time basis. With the right formulation tool supported by a SQM system, there is a possibility to simulate the economical and quality benefits of purchasing decisions that enhances more consistent products for customers.

References

Balogh A. (2008) Az átvételi mintavétel új területei. *Minőség és megbízhatóság*, **5**, 268–276.

Black J.R., Hlubik J. (1980) Basics of computerized linear programs for ration formulation. Symposium: computer programs for dairy cattle feeding and management: past, present, and future. *Journal of Dairy Science*, **63**, 1366–1378.

Costa A.I.A., Jongen W.M.F. (2006) New insights into consumer-led food product development. *Trends in Food Science and Technology*, **17**, 457–465.

European Commission – Eurostat. (2008) European Business: facts and figures – 2007 edition. Available at http://epp.eurostat.ec.europa.eu/portal/page/portal/product_details/publication?p_product_code=KS-BW-07-001 [Last accessed 21 August 2009].

Gattorna J. (1998). *Strategic Supply Chain Alignment: Best Practice in Supply Chain Management*. Gower Publishing, Farham, UK: pp. 94–97.

Golan E., Krissoff B., Kuchler F. (2004) Food traceability: one ingredient in a safe and efficient food supply. *USDA Economic Research Service, Amber Waves*, **2**, 14–21. Available at http://www.ers.usda.gov/AmberWaves/April04/Features/FoodTraceability.htm.

Gordon S. (2008) Supply chain management – seven steps to measure supplier performance. *Minőség és megbízhatóság*, **6**, 332–336.

Grunert K.G., Baadsgaard A., Larsen H.H., Madsen T.K. (1996). *Market Orientation in Food and Agriculture*. Kluwer Academic Publishers, Norwell, USA: pp. 3–18.

Győri Z., Mitlasovszky I., Kerekes B., Sólyom J., Németh Z.S. (2006) Farmtól az asztalig – a takarmánynövények termesztésére és nyomonkövethetőségére kialakítandó minőségbiztosítás. *Minőség és megbízhatóság*, **4**, 196–205.

Hoogland J.P., Jellema A., Jongen W.M.F. (1998) Quality assurance systems. In: *Innovation of Food Production Systems* eds Jongen W.M.F., Meulenberg M.T.G. pp. 139–158, Wageningen Academic Publishers, Wageningen, the Netherlands.

Knura S., Gymnich S., Rembialkowska E., Petersen B. (2006) Agri-food production chain. In: *Safety in the Agri-Food Chain* eds Luning P.A., Devlieghere F., Verhé R. pp. 19–65, Wageningen Academic Publishers, Wageningen, the Netherlands.

Matthews C.R. (2007) Supply chain management – linking the supply chain to TQM. *Minőség és megbízhatóság*, **2**, 115–119.

Moe T. (1998) Perspectives on traceability in food manufacture. *Trends in Food Science and Technology*, **9**, 211–214.

Nott H., Combs G.F. (1967) Data processing feed ingredient composition data. *Feedstuffs*, **39**, 21–22.

Pesti G.M., Miller B.R. (1993). *Animal Feed Formulation: Economics and Computer Applications*. Chapman & Hall, New York: pp. 1–35.

Roush W.B. (2004) Stochastic programming: addressing risk due to variability. *Aqua Feeds: Formulation and Beyond*, **1**, 6–8.

Roush W.B., Cravener T.L., Zhang F. (1996) Computer formulation observations and caveats. *Journal of Applied Poultry Research*, **5**, 116–125.

Roush W.B., Purswell J., Branton S.L. (2007) An adjustable nutrient margin of safety comparison using linear and stochastic programming in an Excel spreadsheet. *Journal of Applied Poultry Research*, **16**, 514–520.

Varga M., Csukás B. (2010) On the way toward the sector spanning agrifood process traceability. *Journal of Agricultural Informatics*, **1**, 8–18.

