Mechanization and Traceability of Agricultural Production: a Challenge for the Future
System Integration and Certification. The Market Demand for Clarity and Transparency—Part 1

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Summary

All parties involved in the food chain increasingly demand from the preceding supplier the proof of quality and safety of the products. The basis for this is an uninterrupted documentation of the product flow and of all process steps over the entire chain, from primary production, via transport, storage, processing, distribution, up to the consumer.
Along this way the product safety has to be monitored by state inspections or by self-organized inspections of producer associations on the basis of national and/or EU regulations. Here often extensive laboratory tests are necessary. Parallel to this the product quality has to be assured by the respective supplier, generally on the basis of contracts that also define quality criteria.
Because of high risks, due to the complexity of production and large volumes of produce, the food industry was the first to establish comprehensive Quality and Safety (QS) Management Systems including Hazard Analysis and Critical Control Points (HACCP) Systems, generally in accordance with ISO 9000 ff.
Industry and trade not only demand from primary producers that they supply large quantities of safe products of defined and constant quality. Increasingly they force farms or farm groups to prove this, e.g. by having their products certified (QS-seals, Bio-seals etc.), or by establishing their own QS-management systems, usually according to ISO 9000 ff., too.
The subsequent labelling of the products is mandatory and allows traceability.
Since quality and food safety depend to a large extent on the way of production, there is a tendency to demand the records of all steps of the production process on the farm as an additional precondition for product certification (Brand-names, QS-or Bio-seals).
Here is a challenge for Agricultural and Biosystems Engineering: to develop new sensors and data processing systems which allow - besides automation - a comprehensive, automated data acquisition and documentation, which makes the production of food even more transparent and thus safer.
1. The food market as seen by the consumer

- **Consumer expectations**

Depending on their social status and educational background, consumers expect

- safe products
- high product quality
- low or reasonable prices
- consideration of sustainability and animal welfare criteria during the production process

with differing priority.

- **Transparency for the consumer**

In **producer-close distribution** such as

- Direct distribution by the producer/farmer, ranging from on-farm sales to the farm's own chain of shops (e.g. milk and meat products),
- Sale via regional distribution chains on the basis of producer associations, e.g. "Franconia Farms",
  (both may include organically and conventionally produced products),
- Distribution directly via the local food craft trades (bakers or butchers),

the personal confidence of the customers in the producer or craft trade is the basis for purchases.

In **producer-distant distribution**, e.g.

- Distribution via the retail trade,

branded products create the basis of trust and confidence.

The packaging secures the product identity and contains essential informations, in particular

- Origin/manufacturer
- Ingredients/conservation agents
- Nutrition facts
- Production or "use-by" date
Producer-distant distribution increasingly is

- Distribution via retail trade chains (e.g. REWE; objective: optimising business management and lower prices):
  They sell branded products too, and to a growing extent house brands (e.g. "Ja!"), which contain the same data on the packaging, but instead of the manufacturer's name state "produced for REWE". Here the origin is frequently no longer traceable, (Fig. 1).

- Distribution via discount chains (e.g. Aldi; objective: further price reduction with low service input):
  Products are generally less well-known brands or "pseudo-brands", which almost plagiarise the brand layout. Both are labelled like branded products.

In particular producer-distant distribution needs labelling in order to inspire confidence among buyers. Labelling is also required by law. For logistic reasons labelling is generally supplemented by bar codes.

- Changes in consumer behaviour
  - Decline of the market share of the retail trade
  - Market share of retail chains and especially of discount chains is increasing
    (shopping at discounters is no longer considered to be discrediting)
  - It is generally expected that all products are labelled as described above

- Food safety is presumed à priori
- Differentiation on the basis of "quality" ("visible" quality, image of the brand, attractiveness of the packaging)
- Increase in the share of organically produced products due to
  1. expected higher nutritional value
  2. expected lower contamination
  3. supposedly better taste
     (with possible poorer appearance being tolerated)
  4. for reasons of organic conviction.

Organic products are usually purchased both directly from organic farmers or in organic food shops. However, shopping in the food trade or at discounters, who are also offering organic products to a growing extent, requires consistent labelling of the foods as organic products.

2. The food market as seen by the suppliers

The shift of distribution to large trading chains makes it necessary to offer large quantities of products, processed or unprocessed, with defined and constant quality. The trade and the food industry therefore prefer to buy from large-scale farms, or they force smaller farms to form associations. Parallel with procurement on the home market, the wholesale trade and food industry are increasingly obtaining supplies from international markets, partly at much lower prices. Market liberalisation caters to this trend.

In this way, however, the origin of the primary product becomes increasingly less visible. This means that the trade (especially in the case of unprocessed products) and the food industry have to guarantee the quality and safety. They have to win consumer confidence by credible labelling (Fig. 2).
3. Aspects of food safety and product quality

- **Food safety**
  Safety has long since played a role in the sensitive areas of food and nutrition. In this connection there are extensive legal regulations at national and to a growing extent at EU level, especially in the hygiene sector, e.g. covering
  - meat and meat products
  - milk and dairy products
  - bread cereals, flour, bakery products,
  - fruit and vegetables.

  The product safety is monitored by
  
  - state inspections (e.g. regarding pesticide residues) or
  - self-organised inspections by enterprises or by associations of enterprises (e.g. for milk).

In particular the ingredients and any contamination require very extensive and discriminating laboratory capacities.

It is in the vital interest of both primary producers and processors not to be expelled abruptly from the market due to safety shortfalls. The possible damage in the case of large product quantities is higher and the probability of faults with complex production methods using a variety of material...
flows and process stages is greater. For this reason the food industry developed new instruments for in-house monitoring to avoid risk at a very early stage.

According to U. Nöhle, Messrs. Nestlé, customer requirements for fault-free products led to exceptional efforts by manufacturers to optimise their information management and their process sequences. "The establishment of HACCP Systems (Hazard Analysis and Critical Control Points), hygiene plans, batch tracing possibilities, recall systems and the operation of laboratories in accordance with EN 45001/GLP, embedded in an overall QM system in accordance with ISO 9000 ff., including traceable documentation and archiving, have distinctly increased safety in food production."

However, the industry is interested in more than secure product safety in its own production process. It wants divided responsibility "upstream" and "downstream":

a) "Upstream" it wants to obligate suppliers of (pre-)products to ensure that their products comply with the safety requirements (in accordance with national and EU regulations); in other words the (pre-) products must be free of

- physical contamination (glas, dust etc.)
- chemical contamination (pesticide residues, nitrate, toxins, other chemicals, that enter the products e.g. via the use of sewage sludge or precipitation)
- other specific biological disease pathogens (salmonella, bacteria, prions etc.).

b) "Downstream" it wants to be able to remove products from the market selectively if contamination or spoilage has occurred despite all care, e.g. due to negligence or sabotage, in order to hold in check the damage sustained (loss of product, costs of disposal, loss of image), as well as to be able to claim recoveries if appropriate.

The health authorities are interested in this, too. They are interested, within the context of risk management, in

- removing products from the market,
- finding the party causing the damage,
- if appropriate, initiating criminal proceedings,
- eliminating causes.

This requires traceability from primary production till the "consumer's refrigerator".

The most important instruments here are exact and uninterrupted documentation (declarations, freight documents, laboratory results etc.), which is provided to a growing extent with computer support, and clear labelling of the product.

"Uninterrupted" means documentation via the entire chain:

Primary producer → transport → storage → processing → distributor → counter display.

- **Product quality**

"Quality" means "the sum of similar or same perceptions of a group of persons (consumers/ observers) regarding a specific product or service."

Quality is an essential factor in determining the price obtainable, and food quality and food safety are closely connected.

While faults discovered in food safety and visible spoiling lead to immediate loss of the market, quality defects impair marketing successively.

**Quality in fruit and vegetables**

is usually perceived by our senses, e.g. in the case of fresh vegetables or fruit via

- Size, form, colour
- Consistence, "freshness"
- Odour
- Taste

Corresponding quality criteria are agreed between the producer and the customer (trade or processor), and should be based as far as possible on objective (measurable) assessment criteria. The ingredients (acids, sugar, esters etc.) determining taste and odour, and the dietetic ingredients (vitamins etc.) must be determined by laboratory examinations.

In addition, a separate examination for food safety is conducted.

There are very specific national and EU regulations regarding fresh products, too, e.g. concerning

- Trade categories
- Data on varieties and origin
These date must be given on the corresponding labelling on the packaging or in the display (Fig. 3). Transport packaging, e.g. fruit cases or cartons, serve here not only to protect the products, but also to secure their identity. They are marked with the appropriate labelling.

Fig. 3: Labelling in the case of fruit

Quality in potatoes

Another example is presented by potatoes, that are usually packed in nets on the basis of variety, size, colour, and cooking behaviour. Here the labelling is provided on tags. Since these data partly concern "internal quality features", both storage warehouses and packing units require exact information also from the producer.

This means that for both potatoes and fruit and vegetables, there is a growing demand for traceability right back to the individual field or plantation.

Quality of bulk products

A third example is formed by bulk products, especially cereals. Here, large bulk quantities have to be “labelled”.

The intended use is of major importance, e.g. as bread cereal or brewer's grain. The examination criteria are then the baking quality or the brewing quality. This depends not only on the variety, but also on the composition of the ingredients, especially of proteins, and this in turn is determined e.g.
by the nitrogen fertilising. This means that the buyers or processors (mills) also require comprehensive documentation from the primary producer/farmer. Under certain circumstances processors even provide the primary producers with concrete advice regarding production measures, within the framework of cropping contracts.

Additionally safety examinations are directed especially at pesticide residues, toxins, mould infestation or ergot.

4. Quality and Safety Management and Certification

- Quality and Safety Management

Since quality and safety are influenced by the way of primary production, grain mills, breweries and feed concentrate mills require comprehensive documentation from the primary producer (farmer), too. Furthermore, they have detailed requirements for each link of the production chain:

(Farm production) → drying/cleaning → transport → storage → transport → processing/packing → transport → trade or processor

The overall aim is to ensure that the final product satisfies the necessary criteria regarding Quality and Safety

There is a tendency of moving away from stand-alone solutions in quality and safety management for each link of the chain towards integrated quality and safety (QS) management systems. This obligates the individual partners to create respective structures, to harmonise these, and to implement measures that serve the common goal "QS".

The foundation of this is agreed documentation which is based on documents, process data and - if required - samples to verify the different steps of the whole process.

- Certification

Subsequently the quality and safety of the products must be certified and labelled in order to achieve marketing advantages! (Fig. 4)
The certifying institution can be
- the bulk buyer (e.g. the grain mill, the food industry or the feed plant). The branded product is here the guarantee for the customer/consumer (flour, bread),
- a number of farms or enterprises in form of a quality producer community (quality eggs production),
- an institution especially created for this purpose, e.g. an executing organisation of a "quality seal" (Fig 5).

5. Integration of the quality of the production process into quality assurance systems

- Interest of the buyers

As already mentioned at various points, product safety and product quality depend directly on the nature of primary production (residues, ingredients, suitability for processing etc.). In this respect, buyers increasingly demand from producers evidence concerning the quality of production (seed used, fertilising programme, consideration of waiting periods after pesticide
treatment etc.), in addition to measurable data concerning the product (e.g. moisture, protein content, residues).
This is intended on the one hand to rule out certain undesirable substance in or on the products, and on the other hand to guarantee quality-determining ingredients.

- **Interest of the public**

However, documentation of the production process has further objectives:

a) to provide to a critical public evidence of sustainable, environmentally sound management including the consideration of animal welfare aspects
b) to provide data for applications for subsidies or to avoid sanctions, especially in connection with national or EU legislation.

Within the framework of this paper we shall only look at point a):

The minimum that the public expects of agriculture is that it observes the "rules of good management practice" and uses the "best available technology".
Since these factors are generally not visible on the product itself, they must be declared credibly by the producer by means of a description of the production process. This then enters the quality guarantee via the brand or a quality seal.

A group of the population that is particularly critical as regards organic aspects makes additional demands on top of this:

- specific maintenance of soil fertility (e.g. minimum or conservation tillage),
- matter or nutrient cycles on the farm (including avoidance of mineral fertilisers),
- avoidance of chemical pesticides (substituted by biological or mechanical plant protection measures and special crop rotation etc.),
- animal welfare oriented management (no cages, more space for each individual animal etc.),
- no use of genetically modified organisms (plants and animals),
- reduction of energy consumption etc.

Farmers who want to produce and sell products in accordance with these criteria have to keep strictly to the rules of corresponding institutions. These are organic farming associations that certify the farms after inspection and a transition phase (generally 2 years). Both the farm and the products are labelled accordingly (e.g. by "Bioland" or "Demeter" - seals); or the new EU Ecological

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Regulation is used as a basis for certification; labelling is then carried out with the new "EU Bio-seal" (Fig. 6).

Fig 6: "EU Bio-seal" for organic production/products

6. Conclusions

Management

- Since consumers increasingly demand food safety and high product quality and environmentally sound production in line with animal welfare, integrated management systems for quality and safety (QS) are indispensable.

- These comprise complete documentation of all substance flows through all process stages including transport and storage, and the performance of checks on food safety and on quality factors at all critical points of the entire process, right through to the display in the retail trade.

- These measures end with labelling of the product and a guarantee of quality and safety via the brand, via QS symbols of various kinds, or via the retail trade chain.

- The more complex the final product, e.g. deep-frozen dishes, the higher the demands related to the QS management.

- This results in a trend to obligate the suppliers more strongly. Evidence is increasingly demanded that suppliers have their own effective quality and safety management systems. In the case of large product flows and hence high risks, it is therefore required that suppliers be certified in accordance with DIN, EN, ISO 9000 ff.
• Suppliers who cannot produce evidence of this are ousted from large markets in the medium term.

Technical aspects

• In addition to management aspects there are also technical aspects concerning quality assurance and food safety:
  a) suitable software and hardware for the necessary management systems including documentation (IT)
  b) fast, precise and low-cost testing techniques (laboratory technology)
  c) new sensors and process computers for on-line process control regarding quality and safety and for data capture
     - for stationary plants, e.g. in the post-harvest sector and in the food industry
     - for tracking products from the producer to the point of sale
     - for process.

Specific requirements on agricultural machinery

• For geo-referenced data acquisition during primary production on the farm DGPS is already common practice. The data processing is carried out in a first stage via GIS. These elements form the technical basis for "precision farming (crop) " (Fig. 7).

• Equivalent technologies are being developed for the livestock production sector, including an appropriate BUS. The preconditions for "precision livestock farming" have been created with the electronic animal identification system - at least for "large" productive livestock like cattle.

• What is lacking is a comprehensive interlinking of IT-supported plant production and livestock production in a farm management system that includes the documentation of all data which are determining food safety and quality.

• Second, new sensors or sensor/ process computer combinations have to be developed that, as far as possible, allow the recording of additional safety and quality-relevant factors on-line, e.g. on-line moisture content measurement, protein determination, toxin surveying etc.
• The same applies by analogy for livestock production, where new sensor techniques are in demand for animal-physiological parameters and for questions of behaviour, as well as for quality parameters of the products (milk). There are already several promising approaches.

Fig. 7: "Pendulum-meter" for assessing the crop density in front of the tractor / spreader for real-time precision fertilization; geo-referenced documentation via DGPS

• Dynamic development can be observed in the field of tracking products from producer to buyer, for example: "active labelling" via sensor/data logger combinations or radio transmission of data for transport surveillance (temperature recording),

• or the application of new sensors, e.g. the "artificial nose" for early recognition of spoiling, also with radio-remote transmission etc.

• One essential aspect of all above mentioned potential agricultural engineering solutions is the standardization of signals and signal transmission. This has to be solved as soon as possible.