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Review

Statistical Process Control (SPC) in the food industry – A systematic review and future research agenda

Sarina Abdul Halim Lim[a,b,*], Jiju Antony[a,1] and Saja Albliwi[a,1]

[a]Dept. Design, Manufacture and Engineering Management, James Weir Building, 75 Montrose Street, Glasgow G1 1XJ, United Kingdom (e-mail: jiju.antony@strath.ac.uk) (e-mail: saja.albliwi@hotmail.co.uk)

[b]Dept. of Food Technology, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia (Tel.: +44 0141415482029, +44 7500200965; e-mails: sarina.abdul-halim-lim@strath.ac.uk; ms.sarinalim86@gmail.com)

This paper presents a systematic review on the reported implementation of Statistical Process Control (SPC) in the food industry. The final selection comprehends 41 articles selected and comprehensively analysed to assess SPC development in the food industry through its motivations, benefits, challenges and limitations. Key outputs indicated from the review include: reduced process variability and conformance to the food regulations are the biggest motivations; resistance to accept SPC is the most cited challenge; lack of statistical knowledge is the most common limitation and the biggest benefits for implementing SPC in the food industry are improved food safety and reduced process variation.

* Corresponding author.
[1] Tel.: +44 0141415482029.

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Introduction

The food industry is known for its highly perishable products, existence of variability in raw material quality, diversity of recipes and processing techniques, seasonality effects, varied harvesting conditions and, typically acquired lower volume of batches (Dora, Kumar, Van Goubergen, Molnar, & Gellynck, 2012; Luning & Marcelis, 2006). However, in recent years, the importance of quality amongst food technologists and food producers has critically grown, mainly due to strict consumer expectations, governmental regulations and fierce market competition. In response to such demands, the food industry began to seek solutions through powerful quality control and quality improvement techniques, namely: food quality management (FQM) practices consisting of goal-oriented decisions and production- and people-based systems to manage quality expectations and delivery (Dora *et al.*, 2012; Luning & Marcelis, 2006). As proposed by the model of FQM functions by Luning and Marcelis (2007), quality control and quality improvement are two interconnected components that greatly impact customer satisfaction in the food industry; thus, the research in this paper presents a detailed discussion on both activities through the application of Statistical Process Control (SPC).

Quality control in the food industry is closely related to technology, sensory (flavour, colour, texture, smell and taste) and physical attributes, safety (microbiological), chemical make-up and nutritional value (Edith & Ochubiojo, 2012). Food poisoning or microbiological outbreaks have been the biggest concern for food producers, governments and consumers have thus moulded consumer behaviour to being more rigid and strictly concerned with the quality of their food (Grigg & Walls, 2007b; Loader & Hobbs, 1999; Luning & Marcelis, 2006). The continuous rejection of finished goods, product scrapping and product recalls have serious financial implications, and put the company's image and public trust at risk (Edith & Ochubiojo, 2012; Loader & Hobbs, 1999; Strugnell, 1992).

In addition to the customer's perception of the quality of a product, the food industry has faced the need to consider critical factors in the production process, the distribution processes and product-market systems as indicators of quality overall (Orr, 1999; Peri, 2006; Trienekens & Zuurbier, 2008). This has introduced and strengthened a trend observed over the last decade among western retailers towards quality certifications such as: Hazard Analysis and Critical Control Points (HACCP), International Organisation for Standardisation (ISO), British Retail Consortium (BRP), European Retail Good Agricultural Practices (EUREP-GAP) and Safe Quality Food (Hubbard, 2003; Trienekens & Zuurbier, 2008).

The variability in food products has challenged food technologists and food scientists for more than 80 years. Accounting for such variability, in the context of food processing and agricultural production, has served to originate some modern statistic approaches as demonstrated by W. S. Gosset. As a technologist and statistician, and through his work within Guinness' breweries, Gosset contributed to the foundation and testing of the statistical application in quality control hypothesis (Dora *et al.*, 2012); which clearly demonstrated that elements of statistical techniques can be successfully applied in the food industry (Grigg, 1998; Grigg & Walls, 2007a; Surak, 1999).

Studies by Banse *et al.* (2008); Dora *et al.* (2012) show a lack of competitiveness in the food industry in Europe when set side-by-side in North America and Australia. Furthermore, compared to other industries such as the automotive, insurance and aerospace the food industry reported the lowest performance based on an assessment against the European Business Excellence Model criteria (Mann, Adebanjo, & Kehoe, 1999). According to a rigorous research by Grigg (1998) such issues are due to the weak quality improvement practice in the food industry today.

The lowest rung in the ladder of food quality control is the usage of inspection mechanisms. These are based on detection of faults or defects at the end of the production line and is, in general terms, an expensive quality control technique since defective products are identified too late in the process (Deming, 1986). An inspection provides only 'defective/non-defective information without providing any insight on the variable; this allows room for alternative techniques such as SPC to investigate variability in food production to prevent product defects from happening earlier in the process. Such characteristics provide SPC a significant advantage over quality control over inspection mechanisms (Paiva, 2013). Furthermore, investigating of the process through SPC allows reductions in variability achieving process stability. Decreased product variability through the SPC implementation follows Deming reaction chain where the variation reduction translates into fewer defects, less rework, decreased cost of poor quality and subsequently allows improvements in product and process quality.

Most research in SPC is generic and statistically theoretical; hence, there is a limited body of literature on how to operationalise SPC to address the needs of the food industry (Grigg, 1998; Grigg & Walls, 2007a; Pable, Lu, & Auerbach, 2010). Although the literature suggests that there are only a few related articles available on SPC implementation—as a whole, for process control and process improvement in the food industry, there is a sufficient understanding of the importance of control charts over the past decades. Considering the successful implementation and advantages achieved through SPC in industries like the automotive, the reasons for the lack of implementation of this technique in the food industry are rather unclear. Furthermore, food manufacturers adhere to diverse quality control and assurance techniques doomed to fail (Van Der Spiegel, Luning, Ziggers, & Jongen, 2003).

With the aforementioned considerations in mind, this paper aims to consolidate the existing knowledge on the SPC implementation in the food industry by illustrating the SPC development within the industry; critically analysing the motivations, challenges, benefits and limitations of implementing SPC; drawing conclusions and presenting future research avenues.

Methods

SPC was initially popularised in 1950 in the Japanese manufacturing industry by W.E. Deming, who elaborated on the principles developed by W. Shewart in 1920. However, it was not until 1980 that the western manufacturing industry rapidly adopted the technique for their own applications (Srikaeo, Furst, & Ashton, 2005). For this reason, a systematic review bracketed to the literature published between 1980 and 2012 was carried out to investigate the reported and emerging issues of SPC implementation in food industry settings and food production-related organisations. The systematic review is a method of literature review adopting a series of steps to ensure the appropriate rigour and transparency is brought to the process. Tranfield, Denyer, and Smart (2003) suggest that for evidence-based research in management studies, such steps are embedded in four phases: planning, sampling, analysis and reporting.

Planning phase

The planning phase is crucial in depicting the structure and directing the systematic review to meet the research objectives. A useful framework to achieve this is the application of C–I–M–O (context–intervention–mechanism–outcome) (Briner & Denyer, 2012; Denyer & Tranfield, 2009; Rousseau, 2012). This framework determines the relevance of the gathered material, the criteria for evaluation, the research contributions, the research rigour and the communication of the research findings. Then, the review protocol calls for research aims, questions and objectives; research background; inclusion and exclusion criteria; a search and selection strategy; study design and the development of tools for data synthesis and analysis (Tranfield *et al.*, 2003). The protocol is essential to guide the literature review process towards answering the research questions and promotes the transparency, transferability and repeatability of the review and its findings (Boiral, 2012; Booth, Papaioannou, & Sutton, 2012).

Sampling phase

To create the article sample, the authors utilised search strings as inputs in different databases. These search strings included: (statistical process control) or (Six Sigma) or (total quality management) or (quality control) and (food industry) or (food or agriculture* not service) and (statistical process control) (food industry or food or agriculture*) or (Six Sigma) and (food industry OR food OR agriculture*).

As suggested in the previous section, the C–I–M–O framework guided the search process by determining the inclusion criteria for this review. The inclusion criteria included: food manufacturing, SPC, Six Sigma, Total Quality Management (TQM) and Continuous Improvement (CI). Moreover, SPC is considered one of the most powerful techniques in the implementation of TQM (Barker, 1990; Chandra, 1993; Does & Trip, 1997; Tarí, 2005) and Six Sigma (Geoff, 2001; Gutiérrez, Lloréns-Montes, & Sánchez, 2009; Schroeder, Linderman, Liedtke, & Choo, 2008) and as a result, TQM and Six Sigma were considered in the inclusion criterion for this review. That is, if a company/industry applied Six Sigma and TQM, it can be argued that the company would have also used SPC whilst implementing the aforementioned.

Other exclusion criteria are based on the understanding that this review seeks to shed light on the implementation of SPC, the motivations, benefits, challenges and limitations in the food manufacturing industry instead of food-related services. Terms like food service, laboratory trials (context) and technical outputs such as mathematical equations are, consequently, listed in the exclusion criteria. Similarly, Quality Function Deployment (QFD), Just-In-Time (JIT) and lean have been excluded for there is no clear evidence that the usage of SPC underlies these techniques and philosophies.

Finally, database search results usually include all types of sources—conference proceedings, book chapters, leaflets, brochures and website contents and peer-reviewed journals, where standardising the sample guarantees the quality of the information. In this particular study, the review only included journal articles due to the peer-review process in the publication of journal article able to produce quality data. Upon that, the final sample of articles was selected according to the inclusion/exclusion criteria discussed in this section. The sampling process flow is presented in Fig. 1.

Analysis phase

There exist a number of methods for the synthesis of qualitative research. These include: meta-ethnography, thematic analysis/synthesis, grounded theory, content analysis, qualitative meta-analysis, qualitative comparative analysis, qualitative meta summary and narrative synthesis. For the purpose of this review, thematic synthesis was considered the superior choice to identify important recurring themes and the use of structured ways of dealing with data within each theme. Thematic synthesis was conducted on the selected articles by using data extraction forms and QSR Nvivo for coding the extracted data, as it is regarded as the most appropriate software for coding data from full articles (Thomas & Harden, 2008; Thorpe, Holt, Macpherson, & Pittaway, 2005). The extracted data that shaped the finding synthesis, as previously stated are related to the motivations, benefits, challenges and limitations of SPC implementation in the food industry (Boiral, 2012; Medeiros, Cavalli, Salay, & Proença, 2011; Thor *et al*., 2007; Thorpe *et al*., 2005).

Reporting phase

Systematic review is valuable and pose clear advantages over classical narrative reviews. Systematic review reduces the bias that could be introduced by the original research and reports, and by the reviewers during the data collection and sampling phases introducing an element of rigour and transparency to the work presented. This paper uses the IMRaD structure (introduction-methods-results-and-discussion) as such structure provides a clear flow of the article for the readers (Booth *et al*., 2012; Smith, 2000).

Results

The search strategy reported in the method yielded a total of 2008 articles spanning across two domains of studies: the food industry and SPC. Further implementation of the inclusion/exclusion criteria narrowed the sample to 41 articles to be analysed comprehensively. This section exhibits the patterns of publication growth across different food commodities, the evolution of SPC implementation in the food industry and key factors of the motivations, benefits, challenges and limitations of SPC implementation in the food industry.

In recent years, SPC has been integrated with other quality programmes such as Six Sigma, becoming a cornerstone philosophy within the world's leading corporations (Sharma, Gupta, Rathore, & Saini, 2011). Nonetheless, the number of articles in this area of study continues to be relatively low when compared to other process improvement methods and tools (DelliFraine, Langabeer, & Nembhard, 2010); and systematic review of the SPC application in other industries such as healthcare industry has yielded eight times number of articles than those considered for this review (Thor *et al*., 2007).

SPC related publications across food commodities

Since its introduction to the manufacturing industry in the 1950s, the adoption of SPC per sector has varied over time depending on the evolution and maturity of the knowledge available on this technique; then, it is comprehensible that this paper proposes to consider the reported distribution of SPC application across commodities in the food industry over the considered timeline. The aforementioned consideration shows an inconsistent trend of growth of SPC publications in the food industry, and in 1998 reported

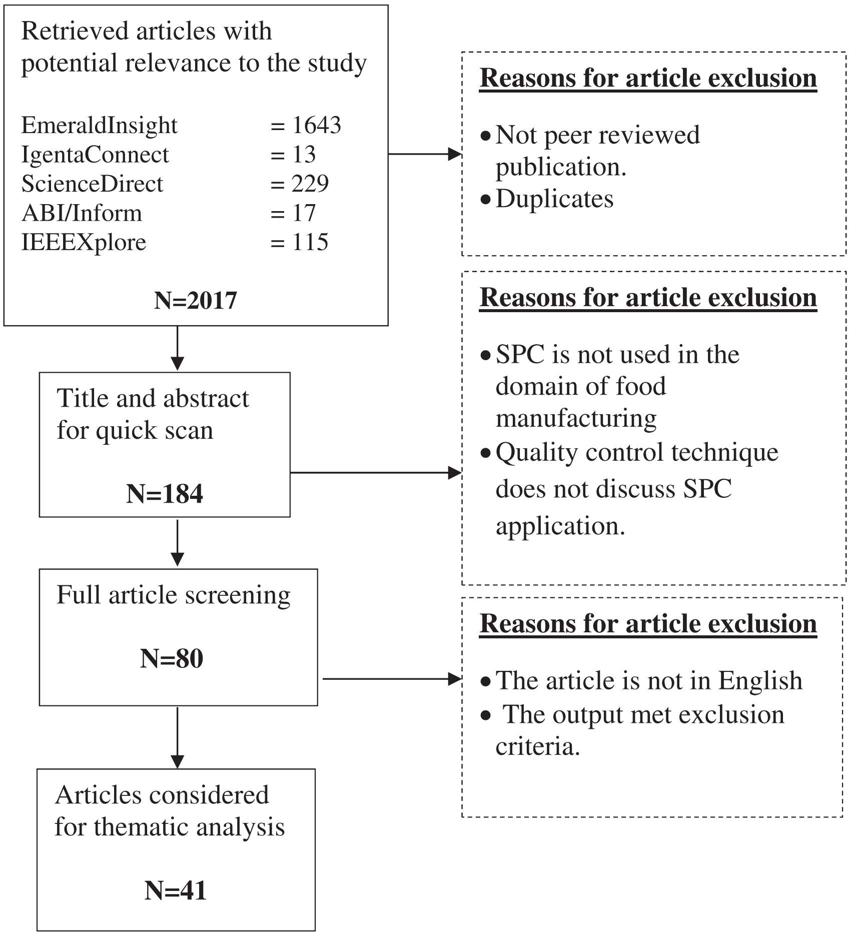

Fig. 1. Process flow for the sampling of articles.

research on SPC implementation reached its summit (Fig. 2).

The publications analysed mostly referred to the bakery industry—bread, pastry goods, cakes, rusks and biscuits (20.31%) and dairy industry—liquid milk, cream, butter, cheese and other milk-derived products (20.31%). This declaration could be explained by the smaller amount and less complex processes in these industries compared to other commodities, enabling the observed wider application of SPC. In the dairy industry, the implementation of SPC is observed as a result of the obligation to comply with strict food safety laws. It was also found that most SPC applications in this industry are integrated with the use of HACCP (Hayes, Scallan, & Wong, 1997; Jacxsens *et al.*, 2011).

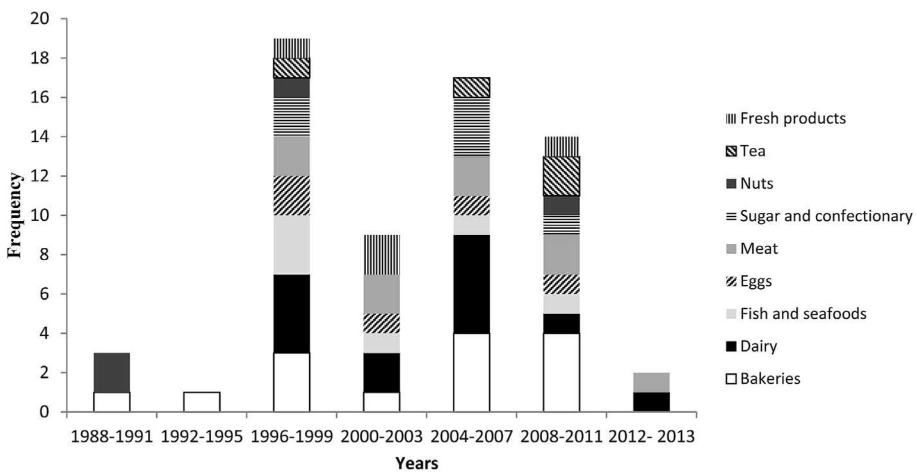

Fig. 2. Growth of SPC publications across food commodities.

Evolution of the SPC implementation in the food industry

The essentials of food quality control can be traced back to around 2500 BC where Egyptian laws had provisions to prevent meat contamination (Edith & Ochubiojo, 2012). Although coined in engineering terminology, the term *quality control* was borrowed by the food industry (Herschdoerfer, 1967) and has been widely used in all types of settings.

The statistical approach to quality control has its origins in the invention of the control chart by W.A. Shewhart for the Bell Telephone Laboratory. However, it was not until the late 1940s when W. Edwards Deming, having adopted Shewhart's work, found that the use of statistical techniques such as control charting, could be beneficially employed in manufacturing industry. This slowly cultivated the usage of statistical quality control in the manufacturing industry.

Pereira and Aspinwall (1991) report that it was not until the mid 1950s that the use of statistical quality control methods in the food industry became significant. One of the first successful applications was the control of container filling processes (Herschdoerfer, 1967; Pereira & Aspinwall, 1993). Until then, most of the applications of statistical quality control took place in the packaging process, where food producers continuously faced problems reducing process variations and detailing accurate net weight. Since then, many efforts to improve filling process control through statistical methods have been made and have led to important savings.

Another important area of study in the 1950s was the use of sampling plans for the raw material inspections. Partial applications of SQC were reported in the USA and UK and by the late 1950s, statistical methods were generally accepted as an important approach for quality control in the food industry (Pereira & Aspinwall, 1991).

In the 1960s, studies on capability analysis were conducted to identify the best machine setting to control weight accuracy and to determine the best time for preventive maintenance to take place. As stated by Pereira and Aspinwall (1991), the food industry began to apply SQC methods in combination with operational research techniques in the so-called Evolutionary Operations (EVOP), opening a window of opportunity to control operations of processes under continuous change and for process improvement. Various applications of quality control techniques changed industries' maintenance priorities, introducing the prevention instead of detection approach. Also, during this period, quality control practices in the food industry started to stress the importance of managerial and training aspects to achieve quality.

The concept of quality assurance spread in the 1970s by food processors and public bodies which it was believed as the best remedy for the quality issues faced by the food industry. One of the major foci, especially in the USA, was the establishment of the Food Products Safety and Consumer Protection Act. By achieving this, an integrated quality system was suggested and Good Manufacturing Practice (GMP) was proposed (Hubbard, 2003; Van Der Spiegel *et al.*, 2003). In 1986, the American Society for Quality Control (ASQC) published the Food Processing Industry Quality Systems Guidelines outlining the basic elements for structuring and evaluating the systems required for food production. Later, Total Quality Control (TQC) was introduced after a long-range research programme conducted in Norway (Pereira & Aspinwall, 1991). During the 1980s, quality management materialised as a better approach to quality control and improvement; highlighting the importance of the management strategies, employee involvement, consumer needs and satisfaction and were highly discussed in many research publications.

Several major food-borne illness outbreaks in the 1990s have resulted in the perception that effective control of food safety should be the most critical activity in food production. Therefore, HACCP and SPC were put in practice in an integrated manner to improve the effectiveness of food quality control systems. Additionally, the utilisation of SPC has facilitated HACCP applications to control and monitor process in real time (Grigg, 1998; Hayes *et al.*, 1997).

Entering the millennium years, quality control studies, especially in the food industry, have diverted its direction to nurturing a statistical thinking mindset in the whole business (Grigg & Walls, 2007a; Hersleth & Bjerke, 2001). However, it is necessary that top management as well as all employees appreciate the advantages of quality improvement initiatives. The culture of continuous improvement and statistical thinking has set a new perspective in the food industry on quality related issues, where quality control and improvement activities are not only useful at the production line but also for the other business units across the organisation. Fig. 3 maps the evolution of SPC in the food industry literature.

In the face of the emerging trends above, the key questions to be answered are: What is the driving force for SPC implementation for the food manufacturing companies? What are the challenges and limitations of SPC implementation in the food industry? What is the future research direction of SPC implementation in the context of the food industry? Thus, the following subsections are structured to address these questions.

SPC implementation in the food industry

In the case of this review, 41% of the sampled articles carried out case studies (Table 1); out of which only three studies applied SPC through the implementation of the Six Sigma methodology. Of the remaining sources, all SPC studies depicted an integration of other quality tools and technique such as Design of Experiment (DOE). Most of the integrated SPC and HACCP cases refer to food safety control and the main issue discussed in these articles concerns the validation of critical control points (CCP).

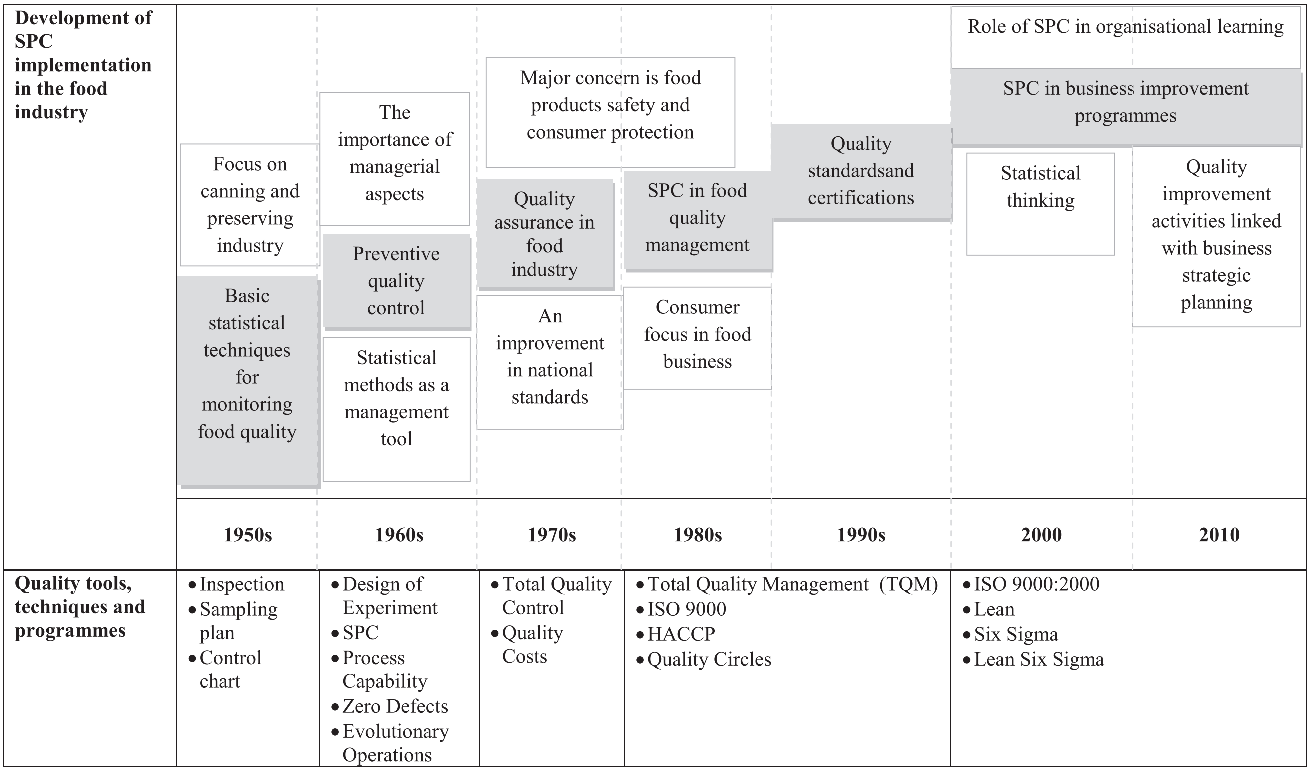

Fig. 3. Development of SPC implementation in the food industry.

From the case studies presented in Table 1, a considerable number of critical parameters involved in the food industry processes were identified. These appertain sensory attributes (i.e. size, weight, texture, colour, height) and safety attributes (i.e. microbial counts). In the same way, for the food industry, SPC implementation prime characteristics of quality include food safety attributes, sensory attributes and packaging attributes of the products. This is supported by information from the seminar of quality control for processed food by the Asian Productivity Organization (APO) where it was reported that a Japanese food quality pre-requisite programme named *Importance of the Quality Control* highlighted the most important criteria in quality control of processed food to be safety and reliability, followed by “deliciousness” and “appropriate price” (Raju, 2005).

Motivations

This review unearthed that the SPC implementation in the food industry is inspired by two categories of motivational factors. Such factors are categorised under proactive (i.e. self-desire by the food producers); and reactive (responds to regulations and threats whereby failure comply may result in adverse effects) (Brannstrom-Stenberg & Deleryd, 1999; Grigg & Walls, 2007a). In fact, the obligation of food producers to comply with food safety and food law and regulations is highly discussed in food control management studies (Jia & Jukes, 2013). Based upon the Pareto 80/20 rule, where 20% (vital few) of the factors influenced 80% of the impact, Fig. 4 depicts the most cited factors (vital few) that motivate food producers to adopt SPC in their facilities

Further analysis of the catalyst elements shows that 67% of the vital few factors consist of proactive factors and the remaining 33% to reactive ones. The most cited motivation for SPC implementation is to reduce process variability, cited by 16.7%, followed by the national legislation demands on assurance of product safety (UK Food Safety Act, 1990), cited by 11.1%, and the correct weight and measurement of the food products (Weight and Measure, 1985, UK).

Benefits and challenges

In contrast to other industries, the lower levels of SPC implementation in the food industry highlighted the importance of assessing the challenges this industry faces and the advantages to be gained despite the challenges. The authors categorised the benefits and challenges of the SPC implementation in the food industry in terms of their nature: managerial, business and operational performance. This categorisation is presented in Table 2, ranked in order of citation frequency.

The review identified that the most cited benefits are reduced process variation (23%), improved food safety control (13%), improved knowledge about the process variation (13%) and cost savings (13%). On the other hand, the most cited challenge is resistance to change (17%),

Table 1. SPC application in the food industry.

Articles and country	Commodities (product)	Issues	Quality characteristics	Type of SPC tools	Other quality program	Output: benefits and duration
Knowles, Johnson, and Warwood (2004), -UK	Sugar confectionery (Medicated sweets)	The variation of the sweet size caused reworks, scraps and machine downtime.	• Sweet thickness	• X bar chart • R chart • Histogram • Scatter plot • Ishikawa diagram	• Six Sigma • Taguchi method	Saved £290,000 Improved *Cpk* from 0.5 to 1.6 -12 months
Daniels (2005), -USA	Bakeries (Pie)	Major customer filed complaints on the crust strength and risk of losing the customer.	• Crust strength	• X bar chart • Box plot • Pareto chart	• HACCP • Six Sigma • DOE	Reduced scrap rate 40% Saved £274, 983
Grigg, Daly, and Stewart (1998) -UK	Fish	Product give away and unnecessary Checkweigher rejection	• Package weight	• X bar chart • R chart	• None	Reduced product give away and rejection rate.
Negiz *et al.* (1998) -USA	Dairy	In dairy pasteurisation, if the product temperature drops below 1610 F (15 s holding time), the product must be diverted immediately to comply.	• Temperature	• Hotelling T^2	• None	20% over processing is able to be detected Receive signals for non-compliance.
(Srikaeo & Hourigan, 2002) -Australia	Eggs	There is no evidence of the effectiveness of HACCP elements.	• Temperature • pH • Chlorine level	• Individual chart	• HACCP	The CCP value validated (All control measures are capable to design critical limits except chlorine level). -6 months
Augustin and Minvielle (2008) -France	Meat processing and preserving	The low rate of unsatisfactory batches of *Enterobacteriaceae* and *Pseudomonas* count detection caused doubt on the efficiency of the traditional control scheme.	• Microbial count	• Moving average chart, • Box plot • Histogram	• HACCP	Validates the assumption of microbiological contamination variances is in control (2% variances above the control limit).
Dalgiç, Vardin, and BelibaÄŸli (2011) -Turkey	Meat processing and preserving	There is a demand for more effective quality control technique to assist HACCP implementation.	• Moisture content • pH	• Process mapping • Pareto chart • Scatter plot • Ishikawa diagram • X bar chart • R chart	• TQM • HACCP • ISO 2200 • ISO9000 • FMEA	Stabilise the moisture content (reading approximately 40%). Able to prioritise 5 critical problems. Enable plant operators to take action quickly. -3 months
Rai (2008) -India	Tea	The critical problem faced in tea production is the weight variation in the tea packet (underweight or overweight).	• Weight	• CUSUM • X bar chart	• None	Reduction of out-of-control situation from 66% to 4%

(*continued on next page*)

Table 1 (*continued*)

Articles and country	Commodities (product)	Issues	Quality characteristics	Type of SPC tools	Other quality program	Output: benefits and duration
(Srikaeo *et al.*, 2005) -Australia	Biscuits	Best practice is required for process characterisation either for new process or for when a process has undergone significant engineering change.	• Temperature • Cooking time • Press pressure (in moulder)	• Histogram • X bar chart • R chart	• None	Able to detect the worst line performance; *Cpk* 0.63 < 1.33 (required values) An inadequate measurement system with operators' measurement variations for wheat protein and moisture content contributes 92.21% and 98.84% of total variation respectively. -10 months
Miller and Balch (1991) -USA	Nuts	Downtime for the blend/grinding process caused lost production and more equipment wear-off.	• Colour • Salt content	• Pareto charts • X bar chart • R chart	• None	Reduce 35% blending/grinding downtime and 61% total downtime occurrences. Uniform feed of salt into the grinder Reduce 55% colour variation. -15 months
Hung and Sung (2011) -Taiwan	Bakery	During re-steaming bun process, customers complaints that the product have issues such as shrinkage, foreign material and crack.	• Weight	• Pareto charts • Tree diagram • Process mapping • Ishikawa diagram • X bar chart • R chart	• Six Sigma • GMP • DOE	Decrease the 70% shrinkage rate (defects). -6 months
Hayes *et al.* (1997) -UK	Dairy	There is neither proper trend analysis nor advance warning to out-of-control CP in the Relative Light Units (RLU) – reading for ATP Bioluminescence Technique for food safety purposes.	• RLU reading	• CUSUM • Individual chart	• HACCP	Provide warning in FAIL case as early as Day 51 before the out-of-control on Day 74. Depict better prevention, control system with the integration of SPC and HACCP -3 months
Özdemir and Özilgen (1997) -Turkey	Nuts	Turkey production of hazelnuts worth £312,480,500 faced a quality problem of damage during the cracking process.	• Damaged nuts	• p-charts	• DOE	The quality performance is clear and able to detect the need for equipment readjustment and operational problem (crusher equipment).
Gauri (2003) -India	Bakery	Loss of profit due to manufacturing target is set above the declared packaging weight.	• Thickness • Weight	• Pareto chart • X-moving range chart • Scatter plot	• None	Reductions of 4.6 g average pack weight Reduction of 5.65 S.D Reduction of 10% underweight packet, and 1.2% for overweight Increase 48.6% yield

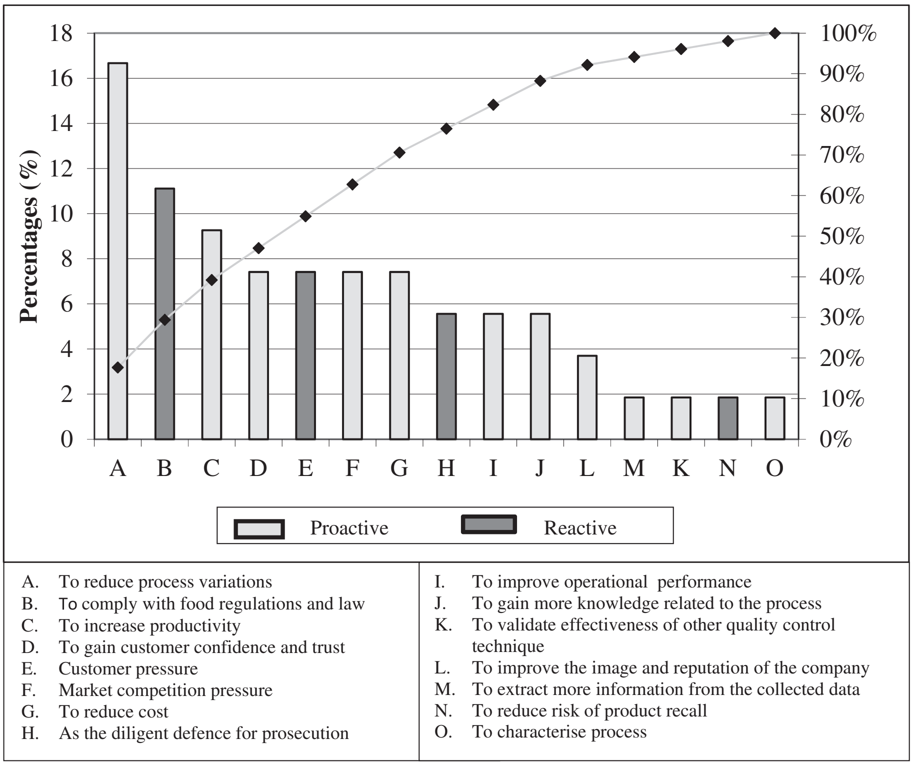

Fig. 4. Motivations of SPC implementation in the food industry.

lack of sufficient statistical knowledge (17%) and lack of management support (15%).

Limitations

There are several factors that may limit food companies from gaining full advantage of SPC implementation in their organisations. Based on the Pareto analysis in Fig. 5, out of six factors, three are the most common limitations. These are the lack of statistical thinking (ST) (30.8%), lack of usable and practical SPC guidelines for the food industry (23%), and SPC perceived as too advanced for the use of food companies (23%). The top three factors deduced from the results depicted operational factors are limiting the implementation of SPC, instead of technical aspects of SPC.

Discussions

This review aims to consolidate the existing knowledge on SPC implementation providing a starting point for researchers and practitioners seeking to implement SPC in the food industry setting. Table 1 illustrates that SPC implementation has taken place in the food industry across various food commodities and countries; however, from the empirical study suggested that its integration with other quality tools and technique would provide better results. For example, typically, DOE is used in early phases of food product development prior the SPC implementation to identify factors affecting the elaboration of the finished product and in the later stages, but in SPC implementation, DOE is used for feedback action to reduce variation in the production process. Without any out-of-control feedback action, SPC can only be applied as a process control technique, not as a process improvement technique (Xie & Goh, 1999).

The major difference between the implementation of SPC as a stand-alone technique and SPC through Six Sigma is expressed in the measurement units to assess the implementation impact. That is, Six Sigma cases render a clear saving cost as the success of the projects is linked to the business bottom-line (Zu, Robbins, & Fredendall, 2010) and, since a business or financial bottom-line is considered a good measurement of quality improvement impact and clear calibration of progress (Goh, 2002), Six Sigma implementation could be considered superior to SPC. In contrast, performance measurement indicating the success of SPC implementation in the food industry is vaguely addressed and current literature, mostly refers to the use of C_{pk}, percentages of waste and defects, and customer satisfaction as measures for performance. In the food industry, customer satisfaction is measured through surveys by using the Likert scale; however, this scale is not standardised and it is difficult to measure the real impact of the implementation towards the business performance.

Motivations of SPC implementation in the food industry

The motivation section examined the reasons for the uptake of SPC in the food industry. The results of this review

Table 2. Benefits and challenges.

Authors	Benefits	Authors	Challenges
Bidder (1990); Daniels (2005); Hung and Sung (2011)	**Managerial** • Improved process knowledge and understanding • Improved decision-making process. • Gained more information from the data.	Alsaleh (2007); Beardsell and Dale (1999); Bidder (1990); Hersleth and Bjerke (2001); Hung and Sung (2011); Jha, Michela, and Noori (1999); Matsuno (1995); Rohitratana and Boon-itt (2001); Sanigar (1990); Scott *et al.* (2009); Srikaeo *et al.* (2005); Surak (1999)	**Managerial** • Resistance to change • Employees lack of statistical knowledge • Lack of management support • Lack of interest • Lack of empowerment culture • Lack of experience • Lack of in-house expertise • Lack of trained staff • Lack of feedback and continuous learning
Alsaleh (2007); Augustin and Minvielle (2008); Hayes *et al.* (1997); Holt and Henson (2000); Narinder, Aastveit, and Naes (2005); Negiz *et al.* (1998); Orr (1999); Srikaeo and Hourigan (2002); Van Der Spiegel, Luning, Boer, Ziggers, and Jongen (2005)	**Business** • Improved food safety control • Cost savings • Improved customer satisfaction • Increased customer trust • Improved image of the company • Reduced product recall	Grigg (1998); Grigg and Walls (2007b)	**Business** • Lack of reported business benefits
Grigg and Walls (2007b), Grigg (1998); Ittzes (2001); Özdemir and Özilgen (1997); Pable *et al.* (2010); Knowles *et al.* (2004); Cinar and Schlesser (2005); Mataragas *et al.*, (2012); (Kosebalaban) Tokatli *et al.*, (2005); Psomas and Fotopoulos (2010); Alsaleh (2007)	**Operational** • Reduced variations • Reduced defects • Predicted process behaviour • Saved time • Increased productivity • Reduced product 'giveaway'	Gauri (2003); Grigg and Walls (2007b); Hersleth and Bjerke (2001)	**Operational** • Poor measurement systems • Lack of guidelines and manuals • Lack of systematic systems for data collection

strongly suggest that most of the food companies implement SPC on their own free will—to experience a greater extent of advantages; but when implemented as a defence mechanism against audits and to abide food law, it is more likely to provide only short-term improvements and restricted further long-term success (Brannstrom-Stenberg & Deleryd 1999; Cheng & Dawson, 1998). Furthermore, the companies that were forced to implement SPC

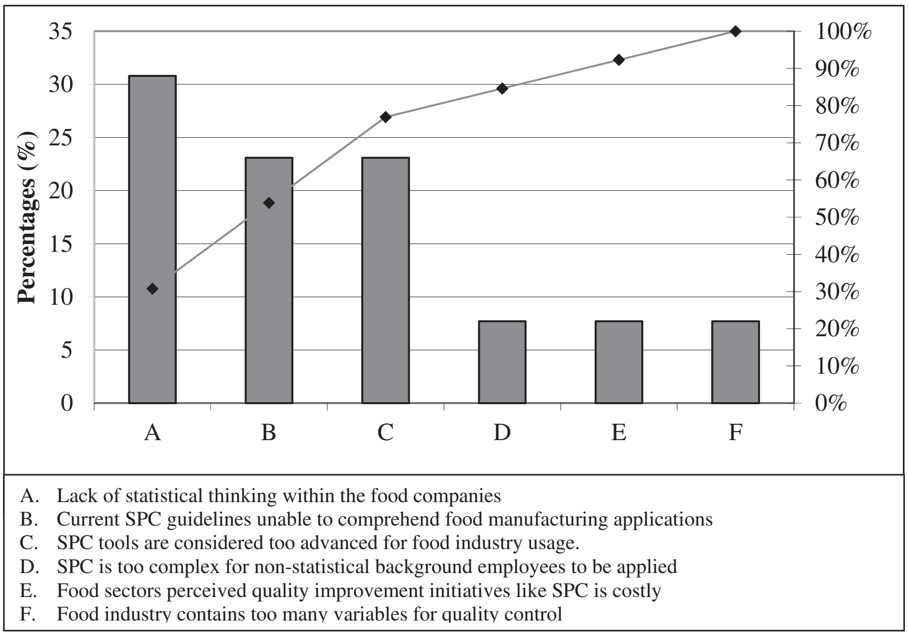

Fig. 5. Limitations of SPC implementation in the food industry.

commonly missed their opportunity to gain greater benefits such as understanding process behaviour, identifying process trends and subsequently defying process improvement opportunities (Dale, van der Wiele, & van Iwaarden, 2007).

The result from this review contrasts with a survey study on the application of lean in the food industry, where food safety is the main focus and less on process improvement (Dora, Kumar, Van Goubergen, Molnar, & Gellynck, 2013). Nonetheless, the results of this review are in synchrony with the result of a survey of the motivations of continuous improvement practice in the Canadian food industry (Scott, Wilcock, & Kanetkar, 2009). It can be said that uniformity of products is the target of most of food producers and reducing variation is the most effective solution for such goal (Surak, 1999).

The food manufacturing industry continuously struggles to maintain their process performance within the restrictions of their low profit margins; in other words, the work has to be right first time, every time (Dudbridge, 2011). The implementation of SPC would help overcome such struggles, providing a profound understanding of the sources of product variability. In return, identifying the influence of the variations on product properties could also aid the lessening customer complaints.

Since introduced by governments, food laws and regulations are highly overseen and mandatory for compliance and are mostly circulated by food safety officers (Grigg, 1998; Grigg & Williams, 2000; Surak, 1999). This has influenced the motivating factors for the implementation quality management techniques. In fact, Psomas and Fotopoulos (2010) indicate that TQM implementation in the food industry took place due to the escalating demands of the consumers and the government in regards to food quality and safety. For example, since January 2006, all Greek food companies are obliged by the legislation to implement food safety and hygiene management procedures.

Finally, this review disclosed that although the SPC implementation in the food industry mainly relates to food safety, the adoption of SPC implementation in these recent years is also due to great interest in process and quality improvement opportunities.

Benefits and challenges of SPC implementation in the food industry

The low rates of SPC implementation in the food industry have led to the speculation of its effectiveness in this industry. Despite the challenges of its implementation, this review has listed the evidence SPC applicability in this industry. Table 2 shows some of the benefits that could counterbalance the challenges faced. Some characteristics of the food production systems, such as high variability of product features, the small batch production techniques and the data in the area are appropriate at least for short-run SPC. In spite of being known as a powerful technique for variability control, SPC is also an effective tool for troubleshooting, optimising standards and for the planning phase of the process, where short-run SPC applications could aid keeping the process under control at its infant stage (Pable *et al*., 2010; Paiva, 2013).

The most cited benefits of SPC implementation due to the effective application of control charts is the reduction of process variation; however, application of the remaining SPC tools is rarely discussed in the reviewed articles. This supports the observation that the perception of SPC within the food industry is solely that of control chart application. Second most cited benefits of the application of SPC is the ability to improve food safety control. The review also disclosed that food safety control through SPC implementation can improve the predictability of process behaviour and as well as the feedback systems to avoid occurrences of contamination. Food safety control is improved by the integration of SPC and HACCP, where SPC enhances the HACCP effectiveness for real-time monitoring purposes. Similarly, a study on the implementation of lean manufacturing in the food industry shows that most of its applications focus on addressing food safety issues (Dora *et al*., 2012).

The evolution of quality depicted a paradigm shift in quality control; from the use of inspection to SPC implementation (Dooley, 2000). Yet, based on the review, most of the articles failed to report the reduction of inspection frequency. The minimisation of inspection activities contributes to operational cost savings where the required workforce would be reduced as well. Not surprisingly, such benefits lead to the employees' resistance to change as well as the employees' fear of losing their jobs.

Resistance to change—whether sourced from the shop floor or from the management spheres influences the way in which SPC is perceived, considering it as just another new quality control technique not worth providing the necessary employee time releases and resources for their involvement in the implementation. Compared to the healthcare industry, which faced a similar challenge (Glasgow, Scott-Caziewell, & Kaboli, 2010; Thor *et al*., 2007), the food industry is more known for its conservative nature and resistance to change (Glasgow *et al*., 2010). Fear of the implementation contributed to the resistance against SPC adoption and its rooted in the lack of experience and insufficient employee capability for the implementation (Hung & Sung, 2011). Although there are many food organisations that have implemented SPC, it is regularly applied in its orthodox form of a long-established process with the majority of data available and at their disposal.

Limitations of SPC implementation in the food industry

The list of limitations in this review stressed that the lack of early education on SPC led to other limitations such as the lack of ST culture. ST core elements entail the realisation that all work occurs in interconnected systems, each process has variations and the key to success is to reduce these variations (Hersleth & Bjerke, 2001). ST has a critical role as a platform for the adoption of continuous improvement initiatives such as SPC and Six Sigma in the food industry (Grigg & Walls, 2007a; Srikaeo & Hourigan, 2002). It would also reduce the fear of statistics usage in the food sector and eliminate the perception that SPC is too complex for the users without a solid statistical education background. As a result of lacking ST culture, food industry companies are unable to use statistics-based techniques with maximum effectiveness. This is partly due to lack of pre-requisite knowledge and awareness among managers of the SPC method's real purpose (Snee, 1990).

Grigg and Walls (2007a) and Hersleth and Bjerke (2001) are concerned with the lack of guidelines in SPC implementation within the food industry. A survey of 71 different food processing sites by Grigg (1998) suggested that most of SPC activities in food organisations derived from the Department of Trade and Industry (DTI). The usage is mainly focused on weight and measurement control, where operators, although not statistically trained, are able to simply follow the written procedure. However, although the manual works well for untrained statistical staff on a working level, it falls short of the full set of recommendations within the DTI manual. It is recommended that to establish accurate measures of medium-term process variance, large data sets and longer periods of data collection on an infrequent basis, after significant changes in a process or establishment of new processes are used.

The food industry provides a few numbers of specific existing codes of practice, such as the Codex *Alimentarius Commission* (CAC), the Campden Food and Drink Research Association (CFDRA) and the British Meat Manufacturers' Association (BMMA); however, while quality assurance aspects—such as sanitary hygiene are covered in detail, there is no specific information on SPC tools or methods for their application. In order to achieve ST within the food industry besides having systematic guidelines the organisation must be able to communicate both structural and cultural changes (Grigg & Walls, 2007a).

Conclusions and future research agenda

This paper provides a consolidation the existing knowledge on the SPC implementation in the food industry based on the systematic review and thematic analysis of a sample of 41 articles. The advantages of using systematic review are, the process of the review were structured and transparent for future research in this topic. The theoretical implications of this paper are depicted in Fig. 3, which intends to examine the roots underlying SPC philosophies and their implementation and suggests the future of SPC implementation within the food industry.

The development of systematic reviews in various areas, notably in medical field results from the difficulty to find related articles, usually scattered through various journals in different areas that few managers have time to read. Thus, the main findings in this review able to provide answers to the most common questions posed by the managers: What are the common reasons that spark the intention to apply SPC? What type of benefits can be expected from SPC implementation? And what are the challenges and limitation, expected from the SPC implementation?

This review found that, SPC implementation in the food industry is mainly motivated by the conformance of food laws and regulations. Food quality attributes are developed through a network of rules and legislation from government bodies, as well as safety requirements such as Food Safety Act (1990) and consumer preference. However, in these recent years, more SPC implementations concentrate on process improvement purposes. The rising application of structured methodologies such as Six Sigma and Lean Six Sigma have sparked the awareness that process improvement initiatives have a significant and strong impact on quality and operational performance (Sousa & Voss, 2002).

This review disclosed that the most cited challenges for the food manufacturers to implement SPC are the resistance to adopt SPC by various levels of the organisation, insufficient statistical knowledge and the lack of top management commitment. Such challenges can be addressed through continuous training, increasing the awareness and knowledge related to SPC implementation and subsequently, reducing the resistance to the implementation. Despite the list of challenges listed in the empirical studies, compared to previous articles, this review identified that the SPC application manages to improve food process performance whilst being indirectly beneficial to the business and management aspects too. The most cited benefit reported is process variation reduction and followed by food safety control improvement.

This review suggests that incorporating SPC to the other quality control programme such as HACCP could strengthen its application, given that most articles suggested that food safety control is improved with the integration of SPC and HACCP. Notwithstanding all the benefits, there are limitations to the implementation of SPC in the food industry, which has caused the low penetration of SPC application in the food industry. The most cited limitations include: the lack of statistical thinking in the food industry, the lack of practical SPC guidelines customised for the food industry, and the perception that SPC is too advanced to be applied. It is the identification of these limitations that have opened a window of opportunity to draw the agenda for future research.

This review discovered that the current research on *what to do* has provided only a static view of the implementation, offering only an indication of how the end results should look like especially in most of empirical study. Yet, research has failed to produce the guidelines on which factors should be emphasized at different stages of SPC implementation or SPC maturity and what is the best SPC implementation sequence to reach the target/end result? There is no practical guideline for the food producers to embark on an SPC journey and there exists a limited discussion on the method for its implementation. A guideline for SPC implementation can prove of invaluable help, especially for food industry SMEs who face issues such as insufficient resources and budget for consultation, and the fact that statistical techniques like SPC are still unfamiliar to this industry. The development of a systematic step-by-step roadmap of SPC implementation, customised for the food industry, would serve to overcome the lack of awareness and lack of knowledge of the implementation, as repeatedly highlighted in this review.

Although this review suggests that SPC is a powerful technique when implemented in a food industry setting, the true impact of this technique to the business is difficult to judge, mainly due to the lack of rigorous evaluations supporting its role in the food process improvement and business excellence. For this reason, there is still a need for future work to improve the evidence base or performance measurement to confirm the success of SPC implementation in the food industry; and, subsequently to enable further understanding of how SPC implementation can meet the desired quality improvements. Equally important are the attainable benefits of SPC implementation on other business units apart from production. The success of Six Sigma application for continuous improvement in several different business units is evidence of the practicality of the SPC application in other food business units as SPC is one of the underlying techniques of Six Sigma.

Up until now, very little research examining how to improve the current education modules to prepare the graduates with, at least, basic awareness of continuous improvement within the industrial setting. Arguments have been made that knowledge of quality improvement and statistics could reduce the challenges faced within the SPC implementation. The education on quality improvement in food industry management should start within tertiary education to develop early awareness in quality. The courses should cover quality assurance and SPC tools at least at an introductory level. Such skills are considered as the most desirable qualities in new graduates in the food industry.

The limitation of this review is the focus of the study—only on the SPC implementation within the food manufacturing industry while the other context of the food industry such as food service and food supply chain were not considered as the methodology of SPC implementation may differ on each context of the food industry. However, future research is suggested to address SPC implementation in the aforementioned context of the food industry.

This review concludes that the food companies implementing SPC have attained significant benefits in terms of continuous process control and process improvement activities. SPC is a powerful technique for managing quality in the food industry provided that its adoption is greatly facilitated and correctly implemented.

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