Comparison between ATP BioluminescenceTechnique and Traditional Microbiological Method to Detect Contamination within Food Facilities in Saudi Arabia (Jiddah)

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***Abstract*- Food-contact surfaces are potential sources for the transmission of foodborne pathogens. Thus, it is important to eliminate bacteria by using proper sanitizing methods in order to reduce cross-contamination during food preparation and/or consumption. The objective of this study is to determine the level of contamination within certain food facilities in Jiddah, Saudi Arabia, using the traditional microbiological culture (aerobic plate count) and the ATP-bioluminescence assay methods and to establish if any correlation exists between the conventional direct surface plating and an ATP reading. Different samples obtained from food processing surfaces (sampling point) such as a cream mixer, cutting boards, an orange squeezer and knives at the salad section, and also a marble worktop at the pastry site were examined. All samples that were taken from the food processing equipment/surfaces showed high levels of contamination before the cleaning stage, but reduced sharply after cleaning and sanitizing. The correlation coefficient (R) values between the traditional microbiological culture (aerobic plate count) and the ATP-bioluminescence assay methods were in the range of 0.72 - 0.99 after the cleaning stage for all the samples, whereas before the food preparation equipment/surfaces had been cleaned, the R value was very low; this is possibly due to the differences between the two detection methods. The ATP-bioluminescence assay method can detect the presence of food debris, and this was translated to a high number of Relative Light Unit (RLU) indicative of a high level of contamination, whereas the traditional microbiological culture (aerobic plate count) method can only detect microorganisms. Therefore, the correlation coefficient (R) values after the cleaning stage have shown to reach a high value of 0.72-0.99 in all the samples due to the removal of food debris during the cleaning stage. Moreover, the results indicate that the ATP-bioluminescence assay is a good tool for monitoring the cleanliness of surfaces and hygiene practices at food premises.**

Keywords- ATP bioluminescence; plate count method; monitoring methods; food microbiology; Food-contact surfaces; Cleaning and disinfection; Saudi Arabia

I. INTRODUCTION

Food quality and safety at food processing facilities, markets, restaurants and homes are extremely affected by food storage and handling conditions. Food processing plants and restaurants are highly susceptible to contamination [1]. Therefore, monitoring bacterial pathogens and toxic chemicals are vital goals in solving the problems related to food contamination [2].

Developing effective and fast techniques for the detection of food contamination is important to be able to screen microbial organisms in a fast and timely manner. Thus, food processing plants need an efficient control system to prevent contamination in raw food materials as well as in finished products. Using fast-detecting microbiological techniques can help improve food safety measures and can also prevent the costly consequences of food contamination for food companies.

Accordingly, rapid microbial detection techniques that are both sensitive and accurate have become increasingly critical to food processing operations [3]. The implementation of quality management systems such as Hazard Analysis & Critical Control Points (HACCP) and the detection of contamination in food or beverage items are essential [4]. HACCP-based systems comply with the rules of international approved principles and guidelines as outlined by the Codex Alimentarius Commission [5]. Critical Control Points (CCP) refer to the points at which hazards could be controlled during preparing, producing and packaging of the food product. The recognition of these CCPs as well as routine examinations at the critical control points would aid in implementing better plans and actions to acquire safe food [6]. While implementation of the HACCP system remains optional in Saudi Arabia, presently many food producers have opted to adopt the HACCP-based food management system voluntarily. Additionally, more businesses are now asking their food suppliers to adopt the HACCP before they will consider doing business with them. The high number of food contamination incidents that occurred in Saudi Arabia in the past can be attributed to the lack of a centralized agency that is responsible for the food control system. Prior to 2003, different government ministries and agencies were involved in controlling and maintaining food safety measures within food facilities in Saudi Arabia. In 2003, a new agency emerged, the Saudi Food and Drug Authority (SFDA) and was given responsibility for food safety measures [7].

SFDA is developing a system of procedures, inspections and regulations to reduce the potential occurrence of the hazards

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that lead to unsafe food processing environments and to ensure the food products are free of potential contaminants. SFDA has been working actively in regulating the food industry and food safety measures in Saudi Arabia. It has many microbiological analysis departments across the county to ensure the implementation of food safety measures and the hygiene standards in food processing plants in Saudi Arabia [7].

There are many food safety challenges in Saudi Arabia. The hot weather in Saudi Arabia is one of the major obstacles for food processing facilities, markets and restaurants as it can trigger bacterial growth. This includes foodborne pathogens when poor hygienic conditions prevail in food storage and handling facilities that are not equipped with an adequate cooling system. Consequently, this kind of environment is ideal for increasing food contamination levels [8].

Almost 80% of the foodborne outbreaks reported can be related to high temperatures (for instance, food is not divided into smaller portions to facilitate cooling or is stored at room temperature for hours or is even placed in hot holding units for reheating), a poor hygienic condition of the person preparing the food, mistreatment of prepared foods, and cross-contamination in the food-service establishments [9]. The existence of food residue is due to the poor cleaning practices that assists in the attachment and survival of microorganisms [10].

Food contamination is a threat to human health as evident by the increasing number of reported food poisoning incidents in Saudi Arabia. The Ministry of Health reported 186 food poisoning incidents in 2000 and 482 in 2001 [11]. In the past 10 years, the number of food poisoning cases has risen to 22,233 according to the Ministry of Health [12]. Food poisoning incidents in Saudi Arabia intensify throughout the summer months and Hajj season [11]. Food safety inspection is important; thus, the lack of food safety measures could lead to death, high medical treatment costs, and high health care costs in controlling diseases that emerge from food contamination. In addition, the frequent occurrences of food contamination could eventually hurt the reputation of companies in the food business as well as negatively affect the national economy.

The workers at food facilities in Saudi Arabia may need both constant and proper training in order to achieve efficient performance since they face many obstacles, such as language and culture barriers that affect their understanding of the rules and regulations imposed by Health authorities [7].

Microbial contamination of food increases the risk of illness and causes severe health consequences for people that could lead to death. Thus, the microbiological evaluation of food contact surfaces is important to assess the efficiency of cleaning systems on surfaces [13].

Cross-contamination of food contact surfaces is the main safety concern for food-service facilities and serve as an indicator of an ineffective cleaning system — such as those making use of reusable wiping cloths that could spread dangerous bacteria and viruses — that creates potential health hazards for consumers [9]. Regular inspection of cleaning practices' effectiveness could prevent possible foodborne outbreaks [14]. Health departments usually conduct a visual examination when inspecting food service operations to evaluate sanitary conditions [15]. Although a visual inspection of a restaurant's kitchen is a key element to decrease the threat of foodborne disease outbreaks, a microbiological assessment of selected kitchen areas is essential to provide further information for fighting outbreaks [15]. A visual assessment for hygiene monitoring is insufficient in determining the possible risk posed by the contaminated food contact surfaces [16]. The existence of foodborne pathogens on the surfaces of food-service establishments and their possibility to spread from surfaces to food are necessary reasons to implement effective cleaning regimes.

Equipment and surfaces that are in contact with food are found to be a favourable environment for bacterial proliferation, facilitate cell attachment and biofilms [17] because of an excessive exposure to liquid, water and humid conditions [18]. Some studies refer to the fact that some bacteria, including *Escherichia coli*, can stay alive on surfaces for hours or days [19] [20], especially in wet environments [21].

Biofilms are ordered structures in which microorganisms are distributed in a polysaccharide matrix [17]. Biofilm formation will complicate the cleaning process and make it difficult for microorganisms to be removed from the surfaces [22], [23].

Improper cleaning measures would result in leaving food residues on surfaces and would induce microorganisms to proliferate at the surface, which could then contaminate any food that subsequently comes into contact with it [24]. Microbial organisms are found to heavily occupy food and beverage areas [25]. These areas require an effective cleaning system in order to prevent cross-contamination; for example, cleaned cloths that are disinfected are found to achieve better results in cleaning food processing equipment than those not disinfected [26]. A combination of cleaning and sanitizing with by suitable cleaning materials with highly effective detergents and disinfectants will improve food safety [24].

High quality food should be free from microbial contamination. Preventing microbial contamination in foods requires following safety measures that start with detecting microbial organisms. Different methods are available to detect pathogenic organisms in foods and to evaluate if the foods are contaminated or not. These methods are under evaluation to assess which is the best.

In the current study, the traditional microbiological culture method (aerobic plate count) and the Adenosine Tri-Phosphate (ATP) bioluminescence assay are evaluated.

The traditional microbiological culture method depends on a visual assessment. It requires a laboratory and 24-48 hours for

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the results to be revealed because it relies on the ability of a microorganism to multiply and form visible colonies that can be counted. The microbial ATP bioluminescence assay depends on the presence of ATP and can be analysed by an instrument. It is a sanitation test and can be done on site within 5 minutes, unlike the traditional plate count method. Bacterial culture medium preparation, inoculation of plates, and colony counting are all time consuming for the person conducting the tests.

Sanitation monitoring is a prerequisite to the HACCP system, which requires that the results are ready quickly for there to be any corrective action implemented in a timely manner [27]. As the ATP technique is a rapid hygiene test, it can better support HACCP implementation as opposed to the conventional culturing methods.

The conventional microbiological method is used to measure sanitation levels. It would require swabbing the surface, followed by plating onto a suitably formulated agar [10]. It is laborious as the incubation period may last for as long as 48 hours; this would place the inspected food products on hold and would not allow their release into the distribution chain. Thus, it is costly for companies operating food business, as they need warehouse space for storage. Traditional microbiological culture methods detect mainly bacterial contamination, whereas an ATP bioluminescence assay can detect both bacterial and non-microbial contamination such as body fluids, milk, soil, organic contamination and food residues [10].

All living cells are found to have intracellular ATP for the regulation of the stored metabolic energy and various cell maintenance functions [28]. ATP is a marker of cellular activity and has been employed as a measure of cell viability and cytotoxicity in research and drug discoveries.

ATP is broken down by autolysis in a few minutes during cell death [29]. Therefore, it is a good target to be used for measuring microbial biomass and, thus, to detect the presence of both somatic cells (like food residues) and microbial contamination. ATP concentration is measured through bioluminescence, in which the light is calculated by a photomultiplier tube detector, and then the signal is converted to Relative Light Units (RLU) [29].

The current work will focus on bioluminescence based on the reaction of the enzyme luciferase — typically extracted from fireflies of the genus *Photinus* with its substrate luciferin. The light emitted during the reaction is directly proportional to the amount of ATP present [30].

The ATP bioluminescence assay detects the presence of food residues on a surface within minutes [31], which significantly speeds up analysis. The presence of microorganisms or food residues on food preparing surfaces can have a negative impact on public health. Nevertheless, since the ATP bioluminescence assay detects ATP driven from both bacteria and food residues, the assay does not sustain a constant correlation between ATP results and bacterial contamination [25]. Moreover, conventional microbiological methods have several constraints in which they rely on a visual assessment to detect microbial contamination and cannot detect all the viral and bacterial contaminants [32].

Conflicting results have been reported concerning the correlation between ATP bioluminescence and the number of bacteria in a sample tested using the total plate counting (TPC) method [16]. For example, many studies reported a high correlation between microbial counts and ATP levels [33].

Using ATP not only works as a marker of cleanliness, since it screens all biological residues, but it also expedites the hygiene monitoring process. Food residue skipped during the cleaning process may not be considered unsafe; however, its presence may supply microorganisms with the nutrients that increase their survival chances [34].

An acceptable level of microbial organisms on food preparation surfaces and utensils is set at less than 80 CFU/cm^2 [35]. These measures will be analysed further in this study.

The objective of this current study was to assess the cleanliness level of food contact surfaces using two methods (a) ATP bioluminescence and (b) traditional microbiological swabbing (plating on culture media) and to determine whether these methods were correlated.

II. MATERIALS AND METHODS

A. Sample Collection

Food contamination was assessed in a catering facility that served 350-500 meals daily in Jiddah, Saudi Arabia. The food contamination assessment was conducted on several food processing equipment, items, and surfaces. Samples were taken from each selected food processing equipment item (sampling points), such as a cream mixer, cutting boards at the salad section, a marble worktop at the pastry section, an orange squeezer and knives at the salad section. These five selected sampling points represent the surfaces that had made the most recent contact with foods before they were served and where the foods were not subjected to further cooking beyond these points. Sampling areas approximately covered 100 cm^2 of tested surfaces. The food contamination assessment was subject to the traditional microbiological culture method (aerobic plate count), and the second assessment method was subject to ATP-bioluminescence assay.

For both the aerobic plate count and the ATP bioluminescence assay, a set of 20 samples at each sampling point was taken in parallel, twice per each working day: repeated three times at the start of the day when the surfaces had been cleaned and

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sanitized and at the mid of the day following the use of surfaces but before cleaning so as to compare hygiene conditions before and after the cleaning procedures. A total of 300 bacteriological samples were performed over a period of 3 consecutive weeks as well as 300 samples for ATP assay testing.

B. Bacteriological Sampling and Testing

Sampling, culturing and enumeration methods were adopted after modifying the techniques described by [26]. Swab tubes (*HiMedia* Laboratories Pvt. Ltd, India), prefilled with a sterile saline solution (10 ml) under aseptic conditions, were used to collect samples. Samples were taken from an approximately 10 x 10 cm area (i.e., 100 cm^2) of the desired surfaces. A specially prepared plastic template that had been disinfected was placed on the sampling surface. The area within the template was swabbed by rubbing the swab over the surface for approximately 20 seconds. The surface was aseptically swabbed from side to side (vertically and horizontally) in a zigzag pattern. The swab was then returned to its tube, well shaken to release the bacteria from the bud, and kept chilled below 5℃ until returned to the laboratory within 4 hours. The sample number, date and time information was written on each swab label. The following details were contained in lab submission form: sample number, description, RLU reading, date, time and remarks. In lab, appropriate dilutions were placed on Nutrient Agar Medium (DifcoCatalog # 213000) [36], and they were incubated at 30℃ for 24-48 hrs. The developing colonies were counted using an illuminated magnifying colony counter, and the numbers were expressed as a Colony Forming Unit (CFU)/cm^2 of the food contact surface.

C. ATP Bioluminescence Assay

Ultrasnap ATP swab devices with Hygiena luminometer (*SystemSURE Plus*, Hygiena International, Colne Way Watford, Hertfordshire, UK) were used. The Ultrasnap sampling device was comprised of a clear plastic swab tube and a sterile sampling swab attached to a plastic bulb containing a luciferase/luciferin reagent. The swabs were stored between 2-8 ℃ and were left out at room temperature for 10 minutes immediately prior to use. The swab was pulled out of its tube by twisting and lifting its handle while holding the tube. When possible, an area of approximately 10 x 10 cm (i.e., 100 cm^2) of the desired surface was sampled thoroughly using aseptic techniques. Sampling was carried out by rotating a swab and moving it in a zigzag manner vertically and in the opposite direction to increase sample size. A consistent swabbing technique was used for irregular surfaces. The swab was gently pushed back into the tube and activated by bending the swab bulb forward and backward to break the snap valve. The bulb was squeezed twice to expel all liquid reagents down the swab shaft. The swab was then gently shaken for 5-10 seconds to moisten the bud. The Ultrasnap device was placed into the Hygiena luminometer chamber where the measuring button was pressed, and the RLU reading was recorded.

D. Data Statistical analysis

Statistical analysis of data was carried out using SPSS software version 19. The correlation coefficient between the total bacterial plate count (CFU) and the RLU were determined by Excel to obtain a straight line equation for both techniques.

III. RESULTS

CFU counts for the traditional microbiological culture method (aerobic plate count) were detected in all the examined food processing equipment and surfaces, cream mixer, marble worktop at pastry section, cutting boards, orange squeezer and knives at salad section. Contamination present before cleaning was detected with both methods: traditional microbiological culture method (aerobic plate count) and ATP-bioluminescence assay. The traditional microbiological culture method detected a high level of CFU as an indication of contamination, unlike the ATP-bioluminescence assay (Table 1). The average number of CFU before the cleaning stage for all food preparation surfaces and equipment being tested were found to have a higher number than the RLU reflecting a high level of contamination (Table 1).

TABLE 1 COMPARISON BETWEEN THE TRADITIONAL MICROBIOLOGICAL METHOD, IDENTIFIED AS COLONY FORMING UNIT (CFU), AND THE ATP BIOLUMINESCENCE TECHNIQUE, THAT CAN DETECT BACTERIA AND LIVING ORGANISMS AS RELATIVE LIGHT UNIT (RLU), TO DETECT CONTAMINATION BEFORE AND AFTER CLEANING OF THE FOOD PROCESSING EQUIPMENT

*TREATMENTS	CFUB1	CFUB2	CFUB3	CFUA1	CFUA2	CFUA3	RLUB1	RLUB2	RLUB3	RLUA1	RLUA2	RLUA 3
CREAM MIXER	148 b	27 b	507 b	25 b	1 b	27 b	4 c	2 b	263 ab	9 b	1 b	51 b
CUTTING BOARDS/SALAD SECTION	1229 a	589 b	100 b	12 b	100 ab	2 b	155 c	70 b	65 bc	7 b	110 b	4 b
MARBLE WORKTOP/PASTRY SECTION	429 b	8010 a	856 b	136 a	1 b	2 b	42 c	377 a	403 a	9 b	2 b	7 b
ORANGE SQUEEZER	1629 a	2264 b	182 b	174 a	131 ab	3 b	304 b	538 a	2 c	245 a	20 b	0 b
KNIFE/SALAD SECTION	155 b	4145 ab	1752 a	14 b	268 a	161 a	606 a	411 a	157 bc	27 b	417 a	232 a

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*Numbers followed by the same letter indicate no significant difference, and the opposite is true where letters are different. For examples, (a) differs from (b) or (c) whereas (a) does not differ from (ab), and likewise, (b) and (ab) are not different. CFUB1 Cream Mixer when compared to RLUB1 Cream Mixer would represent a statistically significant result when comparing these two groups, whereas CFUA1 Cream Mixer compared to RLUA1 Cream Mixer would not represent a statistically significant result when comparing these two groups.

CFUB1	Before cleaning for 1st week	RLUB1	Before cleaning for 1st week
CFUB2	Before cleaning for 2nd week	RLUB2	Before cleaning for 2nd week
CFUB3	Before cleaning for 3rd week	RLUB3	Before cleaning for 3rd week
CFUA1	After cleaning for 1st week	RLUA1	After cleaning for 1st week
CFUA2	After cleaning for 2nd week	RLUA2	After cleaning for 2nd week
CFUA3	After cleaning for 3rd week	RLUA3	After cleaning for 3rd week

The highest average number of RLU before the cleaning stage was on the surfaces of the knife/salad section and the orange squeezer, whereas the cream mixer was found to have the lowest number of RLU. The average number of CFU after the cleaning stage reached a low level in each of the following: the cream mixer, the cutting boards at the salad section, the marble worktop at the pastry section, and the orange squeezer and knives at the salad section (Figure 1). The average number of RLU obtained by the ATP-bioluminescence assay after the cleaning stage remained high in regards to the orange squeezer and the knives at the salad section, while the other food processing equipment reached a very low level (Figure 2). Moreover, the knives at the salad section under the ATP-bioluminescence assay were highly contaminated both before and after cleaning. The comparison between the traditional microbiological culture method (aerobic plate count) (CFU) and the ATP-bioluminescence assay (RLU) for the detection of food surfaces contamination— in terms of the correlation coefficient (R) values for all the stages before and after cleaning — were shown to be very low, 0.001 – 0.600 before cleaning. After the cleaning stage the correlation coefficient increased to 0.720-0.990.

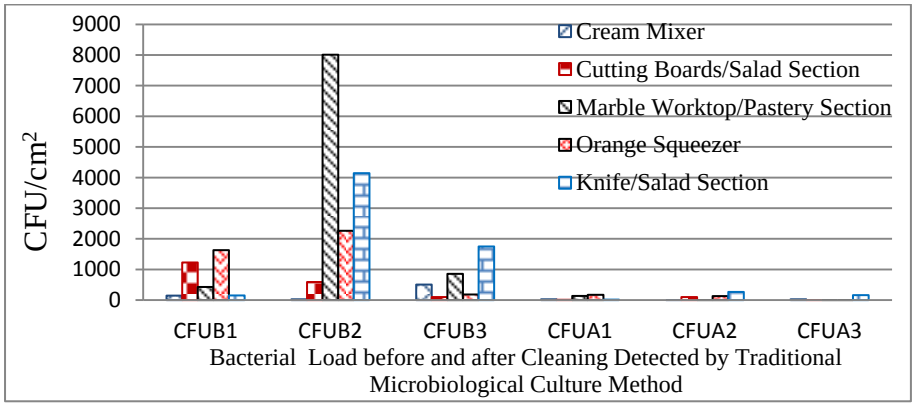

Fig. 1 Bacterial load detected by (aerobic plate count) as Colony Forming Unit (CFU) before (CFUB) and after (CFUA) cleaning.

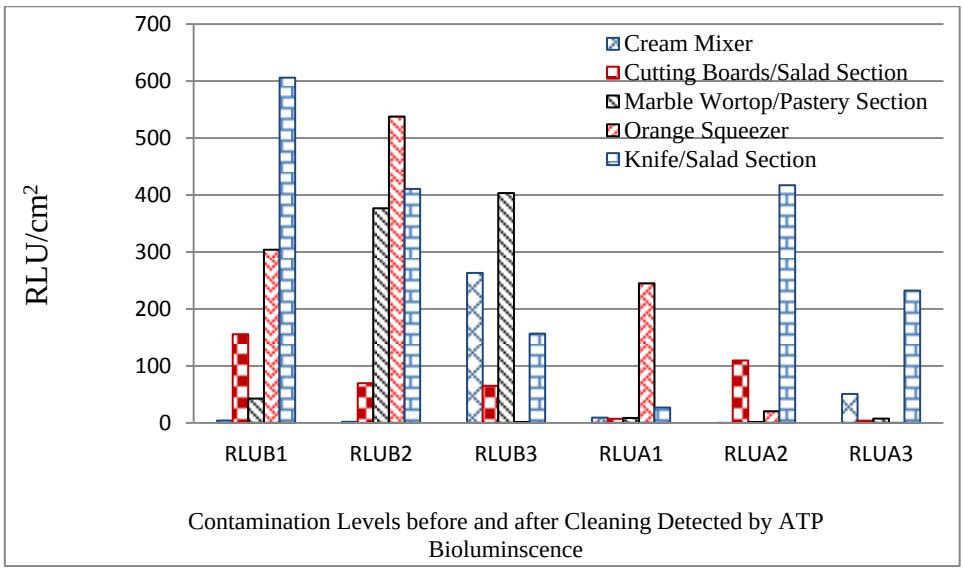

Fig. 2 Contamination levels of various food surfaces as detected by the ATP-bioluminescence assay, expressed as Relative Light Unit (RUL) before (RULB) and after (RULA) cleaning.

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TABLE 2 CORRELATION COEFFICIENT (R) BETWEEN THE BACTERIAL DETECTION METHOD (AEROBIC PLATE COUNT), EXPRESSED AS COLONY FORMING UNIT (CFU), AND THE ATP-BIOLUMINESCENCE ASSAY, THAT CAN DETECT BACTERIA AND LIVING ORGANISMS AS RELATIVE LIGHT UNIT (RLU), BEFORE AND AFTER CLEANING OF THE FOOD PROCESSING EQUIPMENT.

	CFUB1	CFUB2	CFUB3	CFUA1	CFUA2	CFUA3
	RLUB1	RLUB2	RLUB3	RLUA1	RLUA2	RLUA3
R between CFU and RLU	0.001	0.600	0.360	0.720	0.900	0.990

IV. DISCUSSION

The outcome of this study indicates the overall performance of both the traditional microbiological culture (aerobic plate count) and the ATP-bioluminescence assay methods in detecting food contamination within a food facility. No clear relationship was established between the number of ATP bioluminescence units RLU and traditional microbiological culture CFU on food processing surfaces before cleaning.

This lack of correlation before cleaning could be related to many factors, including the different amounts of ATP present in microorganisms, which relies on the type of microorganisms and their physiological condition [10]; types of cleaning procedures in place; type of food preparation surfaces (stainless steel or plastic) used; or the sensitivity of the ATP detection system [10]. Discrepancies between the two methods may also be related to the location of the swabs' sites. In spite of the swabs being taken from adjacent sites, they may have contained different levels of microbial contaminants according to the spot of contamination.

The results for both detection methods showed a tremendous decrease in the microorganisms' numbers after cleaning the food processing equipment. After the cleaning stage, the detection performed by the ATP-bioluminescence assay revealed a higher number of RLU than before the cleaning stage. It is highly anticipated that the reason behind this is the presence of bacteria or organic debris left on the food processing equipment after cleaning (Table 2), particularly since the ATP-bioluminescence assay can detect both bacteria and remaining food. The surfaces that had been cleaned and sanitized might have contained some organic debris from the foods being in contact with the food processing equipment. The ATP bioluminescence assay detected a high number of RLU at the knife/salad section; this could be due to the remaining organic matter from chopped foods (salad) on knives and residues that were not removed by cleaning procedures.

The results of this study showed a high number of RLU even after the cleaning stage was performed with the knife/salad section and the orange squeezer. This result can be attributed to the resistance of food debris to cleaning and their attachment to knives/salad prepared surfaces and the orange squeezer equipment. Also, some bacteria might possess a resistance to sanitization, which kept them alive and therefore detectable as RLU by the ATP-bioluminescence assay [13], [23]. Some bacteria secrete a polysaccharide as an element of their membranes. These elements, referred to as biofilm, are very sticky and, thus, attach tightly to metal surfaces [13], [23].The acceptable number of RLU for the food to be considered uncontaminated is below 50 RLU [37].These results demonstrate what good and poor cleaning means in terms of both CFU and RLU, so we could say we measure "microbiologically clean" and "clean from product residues."

The main purpose of cleaning is to remove product residues so that subsequent disinfectants can function optimally. Food residues provide an environment to protect bacteria from disinfectants and also provide a food source for microbes to survive and grow. If there are no product residues, then microbes do not survive for very long, and the disinfectants produce their maximum effect. Some RLU results that appear low before cleaning are probably due to the presence of too much contamination, such as excess food debris that can block the transmission of light to the detector, e.g. cream and pastry, and/or some food residue that will interfere with the luciferase activity, resulting in a lower RLU.

Food contacts surfaces — as in the case of cream mixers — are considered contaminated if they have higher than 50 RLU [38]. The Public Health Laboratory Service (PHLS) in the United Kingdom (replaced by the Health Protection Agency in 2003) recommended that cleaned ready-to-use surfaces should contain no more than 80 CFU/cm^2 [35]. According to this guideline, the results obtained after the cleaning stage for knives from the salad section and the orange squeezer were considered unsatisfactory, as they contained more than 80 CFU/cm^2. The high number of CFU accrued after the cleaning stage for the knives at the salad preparation section and the orange squeezer are highly expected to be due to insufficient cleaning of this equipment. Thus, more attention to detail, thoroughness and consistency in cleaning would be a big improvement for hygiene and safety. Regular monitoring of cleanliness with ATP provides objective feedback information for the environmental health practitioner and caterers pertaining to inadequate hygiene practices, therefore allowing rapid, corrective action as part of the Good Manufacturing Practices. Visually clean is no guarantee of safety.

The detection methods for food surface contamination applied in this study [traditional microbiological culture (aerobic plate count) and ATP-bioluminescence assay methods] were shown to be correlated after the cleaning stage. The correlation coefficient (R) values, after the cleaning stage, reached a high correlation level, 0.72-0.99 for all samples; whereas before the food processing equipment had been cleaned, the R values were low. This result could be due to the differences in the two detection methods. The ATP-bioluminescence assay method, which can detect both microorganisms and food debris, translated to a high number of RLU mark measured by ATP luminometer, indicative of a high level of contamination, whereas the

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traditional microbiological culture (aerobic plate count) method can only detect microorganisms. Therefore, the correlation coefficient (R) values after the cleaning stage reached a high value of 0.72-0.99 in all samples due to the removal of food debris during the cleaning stage. Murphy et al. and Aycicek et al. found a good correlation between the ATP-bioluminescence assay and the traditional microbiological culture (aerobic plate count) in detecting food contamination [39], [25]. This study is also in agreement with the previous findings as both methods detected a low level of food contamination after cleaning the food processing equipment and showed a high correlation of coefficient (R) values.

This study revealed the necessity to improve the hygienic standards for food facilities for the location in which the study was carried out, Jiddah, Saudi Arabia. Special attention should be given for choosing the materials of cleaning cloths since they are naturally different. It is advised to use cleaning cloths that are designed to detach food contaminants from food-contact surfaces by attaching the food residues to the cloths as well as designed to remove the food debris and microorganisms [23]. The ATP measuring technique has an additional advantage over the conventional method in that it does not require a laboratory and specialized staff, and thus, it reduces the potential of human error during the applications. The ATP-bioluminescence assay could reveal food-surfaces contamination in a short time and on site, unlike the traditional microbiological culture (aerobic plate count), and this would be highly recommended since the correlation coefficient (R) values after cleaning were shown to be highly correlated with the traditional microbiological culture method. These systems can be efficiently applied throughout the different steps of food processing. Moreover, the study's results would assist regulatory agencies to implement new food safety measures and guidelines so as to achieve a higher level of sanitation and hygiene within food premises. Examples would include encouraging national food producers to integrate ATP rapid testing and similar technologies into the Food Safety Management Systems as part of the Good Manufacturing Practices (GMPs) as well as improving food handlers' training by utilizing such techniques as educational tools that emphasise the importance of good cleaning and sanitation in food safety. Similarly, this study would help local food safety authorities to enhance current measures and procedures of inspecting food premises. Furthermore, the study's outcome would help food establishments achieve a higher level of food safety by introducing verification steps to the HACCP programs, such as the rapid testing techniques (i.e. ATP luminometer) in order to ensure sanitary conditions are always maintained at high standards.

V. CONCLUSION

Contamination has always been a threat to public health, but the traditional testing methods have several drawbacks. It can be concluded that the implementation of the ATP-bioluminescence assay within food facilities is a reliable yet rapid detection technique for monitoring the cleanliness of surfaces and hygiene practices. The ATP monitoring system helps to quickly identify contaminated areas so that corrective actions can be taken in a timely manner. Accordingly, this method can effectively enhance the assessment of sanitary conditions and, therefore, would support cleaning and sanitizing needs, assure safe operations and reduce interruption of processes. The traditional microbiological culture (aerobic plate count) can be performed to monitor/verify the effectiveness of cleaning practices, taking into consideration the laboratory and time requirements for the results. Therefore, choosing a method can be influenced by the availability of time and laboratory support.

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