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Biological Factors Affecting the Durability, Usability and Chemical Composition of Paper Banknotes in Global Circulation

Ahmed Atta Fatouh Elleboudy[1*], Mona Abdelhamed Elagoz[2], George Nubar Simonian[2], and Mohamed Sayed Hasanin[3*]

[1]*Banknotes Printing House, Central Bank of Egypt.*
[2] *Printing, Publishing and Packaging Department- Faculty of Applied Arts, Helwan University.*
[3] *Cellulose and paper department, National Research Centre, Dokki, Giza, Egypt.*

Abstract

Banknotes are widely exchanged for goods and services overall the world, which could play a role in transferring infectious diseases through contact. This study has performed the survey of the microbial contamination in Egyptian paper banknotes and their role on banknotes biodegradation, soiling, dirtiness and deterioration. Twenty four paper currency notes of all available denominations (three samples of each denomination as an example for a different period of use) were collected from different areas in Egypt. All samples were found high contaminated with bacteria except the new 50 piasters note, which was zero bacterial contamination. This study results showed that the paper banknotes can be post coated by varnish (conventional – antibacterial) or converted to using polymer may be effective or long-lasting antibacterial paper as well as in order to reduce the microbial population and exceed the negative effect of the microorganism contaminations. Moreover, many samples were found with high contamination with *E. Coli* which transferred mainly from human feces. Moreover, the high contamination samples were remarked high cellulase enzyme content which affect paper banknotes (cellulose).

Keywords: Banknote; cellulose; antimicrobial; microbial population.

1. Introduction

Paper Banknote is mainly produced from cotton rags and cotton linters fibers due to the fact that these raw materials possess long fibers and are made mainly of cellulose characterized by high Degree of Polymerization. Such properties encourage the use of theses raw materials for production of specialty paper, where permanence and durability are required e.g. security paper, document paper, filter paper etc. [1].

Currency is one of the most frequently circulated items in the world [2]. During its circulation, it can get contaminated and may thus play a role in the transmission of microorganisms and diseases [3]. The hygienic status of banknotes has been a topic of speculation since the late 1800s [4]. Microbial contamination of paper money can occur by money counting machines, atmosphere, dust, soil, storage process, during usage or production process. Contamination during use is most often caused by saliva counting, coughing and sneezing in hands [5]. Reports on defect notes of two paper makers and three central banks [6] reported the soiling level as the most predominant reason for classifying notes as defective. Mechanical defects appear later: notes get dirty first and after soiling the mechanical defects appear. Except for folded corners or dog-ears that appear already on new notes [6, 7]. Since soiling is the main reason for classifying notes as unfit for circulation, soiling reduction should be the first aim in developing more durable banknotes [8]. Many countries raise high requirements for the cleanness and integrity of paper currency, because it represents the country's development level in the economy and the culture [9]. This is not to say that the physical condition and properties of banknotes are unimportant. In highly developed countries, the public interacts on a daily basis with machines that dispense cash or accept cash [10]. A breakdown in the integrity of the banknote, accompanied by a loss in stiffness, can be seen on the note that is otherwise

*Corresponding author e-mail: sido_sci@yahoo.com (**Mohamed Sayed**).; a3ttacbe@yahoo.com (**Ahmed Atta**).
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free of holes, tears, or excessive soiling [11]. The public has an aversion to limp notes, especially when this interferes with the convenience of automated bill acceptance or dispensing. Some data indicate a significant portion of stiffness degradation can occur before elevated soiling levels [12]. This indicates that the substrate itself can be important in optimizing longevity even for banknotes that circulate in mild climates and sophisticated economies [6]. The sources of banknotes wear are both biological and non-biological [13]. People represent the most numerous groups of biological factors. The main factor of banknote soiling is finger contact, which leaves fingerprints that accumulate over time and form a yellow-brown layer of old sebum [13]. Besides, banknotes are affected by microorganisms that use the paper basis of banknotes for their growth and produce various organic acids that cause banknote image fading, pigmentation, and change in chemical composition and structure of the paper [14].

There are three types of unwanted microorganisms that can contaminate banknotes. Mould or fungal growth, which can affect their appearance, bacteria and viruses. In the case of mould or fungal growth, fungal spores abound in the atmosphere [15]. Spores on banknotes, when left in an ideal environment for fungal growth, as this is a natural biological process [16]. A difference between bacteria and viruses is that most viruses cause illness, whereas not all bacteria do. Harmful bacteria are usually called pathogenic bacteria because they cause diseases and illnesses like strep throat, staph infections and food poisoning. Some of the most common viral infections include the cold and flu viruses [17]. Two types of bacteria affect banknotes in circulation. Actinobacteria, which proliferate on the substrate and physically degrade it, and those types that merely survive on the substrate but do not proliferate [18]. In addition, the microbial growth may produce enzymes including cellulase enzyme which breaks down cellulose and affects banknote paper mechanical and physical properties [19, 20]. Non-biological sources influence banknote as well. They include sorting equipment, cash machines and coins which come into contact with banknotes during handling [21]. Four mechanisms that contribute to banknotes deterioration were identified [13]. Circulated banknotes commonly show mechanical defects such as folded corners, tears, crumples, holes, abrasion, ink wear and limpness due to facing mechanical influences such as, bending, crumpling, twisting, friction, tearing, denting, creasing and folding [22]. Sunlight is a primary factor of electromagnetic radiation, although artificial light also harms banknotes. Both of these types of light accelerate the aging process of banknote paper, and as a result, paper becomes yellow and brittle and its strength and elasticity are reduced. In addition, the color characteristics of the print change and stains (foxing) appear on banknotes due to local oxidative destruction [13]. It is clear that the influence of the latter factor is more dangerous for a banknote and leads either to its complete destruction due to burning or to local thermal damage [3]. Unfortunately, banknotes could act as a vehicle to spread pathogenic bacteria among individuals of the community. Therefore, this present work is aiming to find alternative technological solutions for reducing dirtiness and soiling that affect banknotes lifetime. It also aims to isolate and identify pathogenic bacteria from banknotes.

2.Materials and Methods

2.1. Materials

2.1.1. Sample collection

Samples were obtained wearing sterile gloves on both hands from different areas in Cairo – Egypt. Paper denominations were randomly collected from markets, bus drivers and shops. Each currency was kept in a separate sterile polyethylene bag and transferred to the laboratory for analysis. Twenty four paper currency of all available denominations were obtained (three samples of each denomination), samples were graded using appearance and degree of dirtiness as new, moderate, old. All Egyptian denominations are 100 % cotton except the 50 piasters notes which use antibacterial 100% cotton paper.

2.2. Methods

2.2.1. Determining the number of colony forming units in a bacterial suspension of paper currency

The Miles and Misra [23] method was carried out to determine the number of colony forming units in a bacterial suspension. The inoculum of suspension was transferred to surface plates of nutrient agar. The surface of the plates was needed to be sufficiently dry to allow a 20µl drop to be absorbed in 15–20 minutes [24-26]. The plates were left upright on the bench to dry before inversion and incubation at 37 °C for 24 hours. Each plate was observed for the growth of colonies. Colonies were counted on the plate. The following equation was used to calculate the number of colony forming units (CFU) per ml from the original aliquot/sample:

CFU per ml =

Average number of colonies for a dilution x 50 x dilution factor.

2.2.2. Qualitative assay for cellulase activity (Paper Banknotes Biodegradation)

Carboxymethyl cellulose (CMC) agar medium was Used to detect the capability of isolates of the eight old samples to biodegrade cellulose. Plates were incubated at 25 ºC for 3 days. After incubation plates were flooded by lugal's iodine reagent (lugal's iodine reagent prepared by 1 gram iodine and 2 grams potassium iodide in 100 ml distilled water). The Appearance of a clear zone around the colony was noted as positive **[19, 20, 27, 28].**

2.2.3. Detection of *E. Coli* pathogenic bacteria

Brilliant Green Bile agar was used as a medium for the detection of *E.Coli* pathogenic bacteria. It was sterilized by autoclave at 121 ºC for 15 min. and poured in Petri dishes, the plates were inoculated by streaking bacteria and incubated at 37 ºC for 3 days and the growth was observed if it had a green color growth its *E. Coli* pathogenic bacteria.

3. Results and discussion

3.1. Number of colony forming units in a bacterial suspension of paper currency

Table 1 shows that there is a direct relationship between bacterial count and the dirtiness of paper currency, so bacteria is one of the basic reasons for banknotes soiling and dirtiness. Bacterial count increases with the increase of banknotes circulation. Antibacterial banknote paper (50 piasters) has a good resistance against bacteria but it does not last for a long time and loses its properties, so it needs more modifications to be a more highly durable antibacterial banknotes' substrate. Other previous researches [29, 30] showed that lower denominations were found to have the highest level of bacterial contaminants as their turnover was more. This accounts for the fact that these small denominations of currency were frequently used and exchanged more times among all types of people. But it was found that all old and moderate Egyptian denominations have high bacterial contaminates. This indicates that all Egyptian denominations are used frequently for daily activities to purchase goods, and Egypt needs to issue reserve denominations (500 LE – 1000 LE) for the ATMs, high commercial purchase activities and saving money, it also may help in crisis such as Covid-19 pandemic, where it was noted in numerous countries that the higher value notes were in most demand. Possibly this was due to suppressed demand for lower value transactional notes, while social distancing measures meant there was limited chance to spend cash, and/or higher value notes were being used as a store of value. Egyptian currency substrate is not moisture and heat resistant, which helps on bacterial growth, and substrate alternative solutions are needed, such as polymer substrate and banknotes post coatings (conventional – antibacterial).

Table (1): Egyptian currencies colony forming units

denomination	Substrate	colony forming units	dirtiness
50 piasters	100% cotton (Antibacterial paper)	268.000 ±10	Old
		253.000 ±9	Moderate
		zero	New
1 LE	100% cotton	236.800 ±5	Old
		181.000 ±7	Moderate
		19.500 ±5	New
5 LE	100% cotton	344.000 ± 11	Old
		310.000 ±12	Moderate
		75.200 ±6	New
10 LE	100% cotton	298.000 ±11	Old
		260.000 ±8	Moderate
		44.000 ±6	New
20 LE	100% cotton	335.000 ±8	Old
		302.000 ±12	Moderate
		25.000 ±5	New
50 LE	100% cotton	29.800 ±6	Old
		28.000 ±4	Moderate
		6.000 ±6	New
100 LE	100% cotton	252.000 ±8	Old
		216.000 ±13	Moderate
		5.000 ±3	New
200 LE	100% cotton	221.000 ±6	Old
		203.000 ±9	Moderate
		26.000 ±7	New

3.2. Paper Banknotes Biodegradation

Table 2 shows a qualitative assay for cellulose activity that degrades cellulose and breaks down its walls. Data showed that the isolated bacteria of the eight old banknotes (50 piasters, 1 LE, 5 LE, 10 LE, 20 LE, 50 LE, 100 LE, 200 LE) can decompose carboxymethyl cellulose (CMC), so bacteria degrade and weaken paper banknote by breaking down cellulose walls and losing links between paper fibers that decreases banknotes mechanical strength and leads to durability reduction [31]. Previous studies showed that the paper banknotes can be post coated by antibacterial varnish to reduce the microbial population and degradation [32].

Table (2): Egyptian currencies quality assasy for cellulose activity

denomination	Qualitative assay for cellulase activity
50 piasters	Highly effective
1 LE	Highly effective
5 LE	Highly effective
10 LE	Highly effective
20 LE	Highly effective
50 LE	Highly effective
100 LE	Highly effective
200 LE	Highly effective

3.3. Detection of *E. Coli* pathogenic bacteria

Banknotes have mass circulation among the general public, since they are widely used and exchanged for goods and services in Egypt and worldwide. Numerous studies have documented that paper currency could act as a vehicle to spread bacteria among people. Paper banknotes can host a variety of contaminants for a longtime, this may play a role in the transmission of potentiality harmful microorganisms. The first time the presence of bacteria on the surface of banknotes was identified in 1972 by the American Medical Association [33]. Then in 2001, a study by the Institute of Biomedical Studies in Rio de Janeiro found that eight different types of microorganisms could commonly be found on paper and plastic banknotes. In 2010 [34], a study was conducted by the Institute of Food and Science, seven species of organisms were detected from which 169 bacterial isolates were recovered. The study suggested that Bangladesh paper currencies are contaminated, and may play a significant role in the transmission of harmful microorganisms such as cholera, diarrhea, and skin infections. The conclusion was that great care should be taken during the handling of money and food to avoid cross-contamination. A similar conclusion was drawn in a paper entitled 'Dirty Money – An Investigation into the Hygiene Status of Some of the World's Currencies as Obtained from Food Outlets' [35] by the Institute of Crop and Food Science, the University of Ballarat, Victoria, Australia, A total of 1,280 banknotes were obtained from food outlets in 10 different countries (Australia, Burkina Faso, China, Ireland, the Netherlands, New Zealand, Nigeria, Mexico, the UK and US) were examined for their bacterial content. Other study reported that *S. Aureus* contaminating paper currencies, which were collected from a wide variety of places, including shops, hospitals and restaurants and showed that the bacteria could survive for up to eight days on the money [30]. Studies also performed in U.S.A, Hong Kong, China, India, Pakistan, Cambodia and the Philippines revealed that these contaminants include potential pathogens that may cause diseases in a healthy individual such as *Staphylococcus aureus, Escherichia coli, Pseudomonas aeruginosa, Klebsiella pneumonae, Proteus spp, Shigella flixneri* as well as *Enterobacter* and *Enterococcus spp* [36]. This concern is not new, even during the 'black death' -the bubonic and pneumonic plague pandemics in Europe in the 13th Century, historical reports showed that money was strongly believed to transmit fatal infections [23]. Table 3 shows the presence of *E. Coli* on eight moderate banknotes (50 piasters, 1 LE, 5 LE, 10 LE, 20 LE, 50 LE, 100 LE, 200 LE) that have good mechanical strength and may last for a long period on circulation. Table 3 shows that two of the eight notes have *E. Coli* that may transfer to persons during circulation from hand to hand and cause disease such as urinary tract infections including cystitis, pyelitis, and pyelonephritis. It also may cause wound infections, appendicitis, peritonitis, infection of the gall bladder, bacteremia, and meningitis especially of the new born.

Table (3): Presence of *E. Coli* on Egyptian currency denominations

Denomination	Presence of *E.Coli*
50 piasters	Negative
1 LE	Positive
5 LE	Negative
10 LE	Positive
20 LE	Negative
50 LE	Negative
100 LE	Negative
200 LE	Negative

Conclusion

The present study revealed that Egyptian paper banknotes are contaminated with bacteria and their substrates are not moisture and heat resistant, which helps on bacterial growth, and substrate alternative solutions are needed, such as polymer substrate or paper banknotes post coatings (using conventional

varnish or antibacterial varnishes which combines the advantages of conventional varnish and antibacterial banknote papers), and antibacterial paper substrate needs more modifications for long lasting. Bacteria is one of the basic reasons for banknotes soiling and dirtiness, it also degrades and weakens paper banknotes by breaking down cellulose walls, losing links between paper fibers and decreasing banknotes' mechanical strength which leads to durability reduction and deterioration. All Egyptian denominations are used frequently for daily activities for purchasing goods, and Egypt needs to issue reserve denominations (500 LE – 1000 LE) for ATMs, high commercial purchase activities and saving money. Egyptian paper currencies are commonly contaminated with pathogenic bacteria such as *E. Coli* that may play a role in the transmission of various diseases, so people have to improve their health awareness by washing hands after handling banknotes, taking no food after touching currencies, avoiding using saliva during the counting of paper money notes and using for cleaning of ears.

Conflict of Interests

The authors declare that they have no conflict of interests.

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