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A comprehensive risk assessment of toxic elements in international brands of face foundation powders

Basem Shomar*, Sergey N. Rashkeev

Qatar Environment and Energy Research Institute, Hamad Bin Khalifa University, P. O. Box 31110, Doha, Qatar

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ABSTRACT

Despite the COVID-19 pandemic and wearing masks in many countries, women are keen on elegance, beauty and the use of face foundations. Assessment of health risks associated with the regular use of face foundation by females is dynamic due to the emerging products. The most common international 14 brands of face foundation powders were collected and the concentrations of different elements (Ag, Al, As, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Mo, Na, P, Pb, Sb, Se, Sn, V and Zn) in each sample were determined. A combined approach merging the conventional and computational tools was used for investigating the risk of exposure to toxic elements. Monte Carlo simulations were applied to calculate risks associated with twenty elements. We attempted different probability distribution functions for concentrations because the actual distribution functions are not known, and the only data available are the mean value and standard deviation of concentrations obtained from experiment. Our results indicate that the total non-carcinogenic health risk through exposure to different elements (Hazardous Index, HI) does not strongly depend on the choice of the probability distribution function for the concentrations. We also show that taking into account probability distributions of other variables and parameters such as body weight, exposed skin area, skin adhesion, etc. does not significantly change the main result rather just slightly broadening the final Hazardous Index distribution function. We found that calculated HI is well below unity for all considered samples, i.e., the dermal exposure to toxic elements in the considered facial powders is negligible and the considered face foundation powders are quite safe to use.

1. Introduction

Since the dawn of civilization, cosmetics have constituted a part of routine body care not only by the upper strata of society but also by all classes of people (Hall et al., 2007). According to the report of Market (2016), the annual estimated growth rate of the cosmetic market is 4.3% for the period of 2016–2022 and it is anticipated to reach $429.8 billion by 2022. Broad spectra of chemicals have been used in the cosmetics industry worldwide. Cosmetics additives include fragrances, preservatives, surfactants, dye and shine to potentiate their quality, property and shelf life (Bilal et al., 2020).

Bilal et al. (2020) reported the presence and concentrations of toxic ingredients used in formulating cosmetics such as parabens, triclosan, benzalkonium chloride, 1,4-dioxane, plastic microbeads, formaldehyde, diazolidinyl urea, imidazolidinyl urea, sunscreen elements (organic and inorganic UV filters) and trace metals. In addition, several studies investigated the presence of toxic elements in cosmetics (e.g. lip cosmetics and facial foundations) including arsenic, antimony, chromium, cadmium, copper, cobalt, manganese, lead and nickel. Sources of such elements can be the raw materials and additives used in the production of cosmetics (Gao et al., 2018; Lemaire et al., 2013; Nourmoradi et al., 2013).

Prolong using of cosmetics may allow the accumulation of toxic elements in the human body either through adsorption or absorption through the skin and finally entering the blood stream. Examples of such elements are aluminum, lead, cadmium, and mercury (Borowska and Brzóska, 2015; Janicka et al., 2015; Dickenson et al., 2013; Lin et al., 2012). Long-term studies found a correlation between the elevated levels of toxic elements and kidney failure (Soussi et al., 2018), negative impacts on retinal epithelium pigments (Erie et al., 2005; Eichenbaum and Zheng, 2000), cardiovascular and neurologic disorders (Saadatdeh et al., 2019; Hepp et al., 2014), and neurotoxicity and hepatotoxicity (Karri et al., 2016).

The USEPA Handbook of 2011 describes the exposure factors to different toxins including heavy metals in cosmetics (USEPA, 2011). On the other hand, the report of the Danish Environmental Protection
Agency (2018) focused on the risk assessment of fluorinated substances in cosmetic product. The United States Environmental Protection Agency released three reports (USEPA, 2004, 2015; 2020); however, a comprehensive database in one entity for all elements is lacking. Generally, facial cosmetics include lipsticks, lip-glosses, face cleansers, face powders, eye shadows, shaving powders, eye pencils, kohl and kajal. Recently, significant concentrations of Cd, Cr, Mn, Ni and Pb were found in the most common cosmetics in Nigeria (UkoNaku et al., 2020). A comprehensive study conducted in China determined the concentrations of As, Cd, Co, Cr, Cu, Ni, Pb, and Zn in face powders (Wang et al., 2020; Rowell et al., 2014). Another indicator is the reference dose (RfD) for dermal exposure where the dermal exposure ($E_d$) can be estimated as the concentration or mass of chemical in the medium contacting the skin (USEPA, 2020). According to the USEPA (2020), dermal exposure occurs when a chemical acts on or is absorbed through the skin to enter the bloodstream. In this work, we focus on metal content of the major international brands of powder face foundation. Such foundations are flesh-tinted cosmetic powder used to improve the appearance of the face by reducing shine and concealing blemishes. Risks of powder face foundation depend on several factors. Major ones are weather conditions, age at first use, skin type and conditions, composition of face foundation, exposure rates, methods of application, and cleaning methods and schemes (USEPA, 2020). Due to the growing market of cosmetics including face foundations, it is very challenging to control, monitor and license all products arriving the different markets of any country. In addition to the inconvenience of skin irritation, chronic contamination can occur with the accidental ingestion of cosmetics. Thus, the control and monitoring of toxic elements in cosmetics are required for consumer protection and sanitary control of these products. Several countries and health entities specify different regulations for cosmetics raw materials. Examples are the EU Article 2 of the Directive 76/768/EEC, and the US- FDA 2013, respectively.

Monte Carlo simulations is one of the powerful tools used in health risk assessment and distribution concerning the exposure to heavy metals (Giri et al., 2020; Rajasekhar et al., 2018; Dimov et al., 2011; Biesiada, 2001). This tool is widely used for modeling natural, social and economic phenomena. In the probabilistic approach, based upon the Monte Carlo techniques, all variables and parameters used could be considered as random variables characterized by their probability distribution functions (Thompson, 1992). The comprehensive health risk assessment depends on many factors. The complete set of variables includes concentrations of different toxic elements in the sample, exposed skin area, skin adhesion factor, dermal absorption fraction, body weight, frequency of exposure, etc. All of these variables are probabilistically distributed and, therefore, one should quantify the uncertainty factor for the risk. During the process of repeated simulations, the estimated quantity (Hazard Quotient or Hazard Index) is calculated many times with randomly chosen values of variables and parameters covering their range of variability and reproducing the distribution density for the calculated variable. The final result is also given in the form of a probability distribution.

The major objectives of this study are: (1) to establish a recent database of trace elements in the major international brands of powder face foundation, and; (2) to conduct risk assessment of toxic elements determined in face foundation powders on human health by simulation tools.

### 2. Materials and methods

#### 2.1. Samples collection

Fourteen samples of the international brands of face foundation powder were purchased from shopping malls in Doha, Qatar. Samples were produced in Canada, France, Italy, Ireland and USA (Table 1). Directly after collection, the samples were stored at room temperature in their original packages inside a clean cupboard until the time of digestion and analysis.

| Nr. | Brand       | Color | Made in | Quantity in pack | Expiry Date Month a | Price (QR) b | Container type | Container Package |
|-----|-------------|-------|---------|------------------|---------------------|--------------|---------------|------------------|
| 1   | Bourjois    | Beige | France  | non              | Non                 | 66           | Plastic       | Plastic          |
| 2   | Giorgio Armani | Beige | France  | 9 g 0.3 OZ       | 24                  | 213          | Plastic       | Paper box        |
| 3   | Lancom      | Beige | France  | 9 g 0.3 OZ       | 26                  | 308          | Plastic       | Paper box        |
| 4   | Dior        | Beige | France  | 10 g 0.35 OZ     | 12                  | 243          | Plastic       | Paper box        |
| 5   | Seifora     | Beige | France  | 10 g 0.35 OZ     | Non                 | 280          | Plastic       | Paper box        |
| 6   | Benefit     | Beige | USA     | 7.0 g 0.25 OZ    | 24                  | 167          | Plastic       | Paper box        |
| 7   | Smashbox    | Beige | USA     | 9.9 g 0.34 OZ    | 25                  | 235          | Plastic       | Paper box        |
| 8   | Este Lauder | Beige | USA     | 12 g 0.42 OZ     | 24                  | 250          | Plastic       | Paper box        |
| 9   | Mac         | Beige | Canada  | 15 g 0.52 OZ     | 24                  | 168          | Plastic       | Paper box        |
| 10  | Too Faced   | Beige | Canada  | 11 g 0.38 OZ     | 12                  | 157          | Plastic       | Paper box        |
| 11  | Maybelline  | Beige | Italy   | 9 g               | 24                  | 190          | Plastic       | Paper box        |
| 12  | Chanel      | Beige | Italy   | 13 g 0.54 OZ     | 18                  | 204          | Plastic       | Paper box        |
| 13  | Max Factor  | Beige | Ireland | 21 g              | 12                  | 24           | Plastic       | Paper box        |
| 14  | Rimmel      | Beige | Ireland | 2.4 OZ 7.0g      | 24                  | 160          | Plastic       | Paper box        |

a Expiry date is number of months after opening.
b Price in Qatari Riyal (1 US$ = 3.45 QR).
### Table 2
Elemental concentrations in the collected samples.

| Sample Nr | Ag/µg/kg | Al/µg/kg | As/µg/kg | Ba/µg/kg | Be/µg/kg | Ca/µg/kg | Cd/µg/kg | Co/µg/kg | Cr/µg/kg | Cu/µg/kg | Fe/µg/kg | Hg/µg/kg |
|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 1         | 3.31 ± 1.9 | 1.84 ± 0.9 | 0.3 ± 0.8 | 0.11 ± 0.5 | 0.09 ± 0.7 | 0.1 ± 0.9 | 0.3 ± 0.7 | 0.1 ± 0.5 | 0.1 ± 0.6 | 0.1 ± 0.5 | 0.1 ± 0.4 | 0.1 ± 0.3 |
| 2         | 1.94 ± 0.9 | 1.84 ± 0.9 | 0.3 ± 0.8 | 0.11 ± 0.5 | 0.09 ± 0.7 | 0.1 ± 0.9 | 0.3 ± 0.7 | 0.1 ± 0.5 | 0.1 ± 0.6 | 0.1 ± 0.5 | 0.1 ± 0.4 | 0.1 ± 0.3 |
| 3         | 6.26 ± 3.5 | 5.47 ± 3.0 | 0.35 ± 1.1 | 0.8 ± 1.2 | 0.7 ± 1.1 | 0.8 ± 1.2 | 0.7 ± 1.1 | 0.8 ± 1.2 | 0.7 ± 1.1 | 0.8 ± 1.2 | 0.7 ± 1.1 | 0.8 ± 1.2 |
| 4         | 1.30 ± 0.8 | 1.23 ± 0.7 | 0.6 ± 0.9 | 0.9 ± 1.0 | 0.9 ± 1.0 | 0.9 ± 1.0 | 0.9 ± 1.0 | 0.9 ± 1.0 | 0.9 ± 1.0 | 0.9 ± 1.0 | 0.9 ± 1.0 | 0.9 ± 1.0 |
| 5         | 4.13 ± 1.8 | 3.54 ± 1.8 | 0.36 ± 1.0 | 0.8 ± 1.0 | 0.7 ± 1.0 | 0.8 ± 1.0 | 0.7 ± 1.0 | 0.8 ± 1.0 | 0.7 ± 1.0 | 0.8 ± 1.0 | 0.7 ± 1.0 | 0.8 ± 1.0 |
| 6         | 1.88 ± 0.8 | 1.66 ± 0.8 | 0.6 ± 0.9 | 0.9 ± 1.0 | 0.9 ± 1.0 | 0.9 ± 1.0 | 0.9 ± 1.0 | 0.9 ± 1.0 | 0.9 ± 1.0 | 0.9 ± 1.0 | 0.9 ± 1.0 | 0.9 ± 1.0 |
| 7         | 0.86 ± 0.6 | 0.66 ± 0.6 | 0.3 ± 0.5 | 0.4 ± 0.5 | 0.4 ± 0.5 | 0.4 ± 0.5 | 0.4 ± 0.5 | 0.4 ± 0.5 | 0.4 ± 0.5 | 0.4 ± 0.5 | 0.4 ± 0.5 | 0.4 ± 0.5 |
| 8         | 7.42 ± 4.0 | 6.13 ± 4.0 | 0.2 ± 0.3 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 |
| 9         | 3.98 ± 1.8 | 3.73 ± 1.8 | 0.2 ± 0.3 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 |
| 10        | 6.28 ± 3.1 | 5.90 ± 3.1 | 0.3 ± 0.3 | 0.4 ± 0.4 | 0.4 ± 0.4 | 0.4 ± 0.4 | 0.4 ± 0.4 | 0.4 ± 0.4 | 0.4 ± 0.4 | 0.4 ± 0.4 | 0.4 ± 0.4 | 0.4 ± 0.4 |
| 11        | 12.56 ± 7.2 | 11.86 ± 7.2 | 0.3 ± 0.3 | 0.4 ± 0.4 | 0.4 ± 0.4 | 0.4 ± 0.4 | 0.4 ± 0.4 | 0.4 ± 0.4 | 0.4 ± 0.4 | 0.4 ± 0.4 | 0.4 ± 0.4 | 0.4 ± 0.4 |
| 12        | 3.20 ± 1.6 | 2.86 ± 1.6 | 0.2 ± 0.3 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 |
| 13        | 9.52 ± 4.8 | 8.73 ± 4.8 | 0.3 ± 0.3 | 0.4 ± 0.4 | 0.4 ± 0.4 | 0.4 ± 0.4 | 0.4 ± 0.4 | 0.4 ± 0.4 | 0.4 ± 0.4 | 0.4 ± 0.4 | 0.4 ± 0.4 | 0.4 ± 0.4 |
| 14        | 5.36 ± 1.9 | 4.70 ± 1.9 | 0.2 ± 0.3 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 | 0.3 ± 0.4 |

**Sample Nr** refers to the sample number, **K mg/kg** to potassium, **Li mg/kg** to lithium, **Mg mg/kg** to magnesium, **Mn mg/kg** to manganese, **Mo µg/kg** to molybdenum, **Na µg/kg** to sodium, **P mg/kg** to phosphorus, **Pb µg/kg** to lead, **Sb µg/kg** to antimony, **Sr µg/kg** to strontium, **Sn µg/kg** to tin, **V µg/kg** to vanadium, and **Zn mg/kg** to zinc.

**BDL**: Below Detection Limit.

### 2.3. Samples treatment and analysis

One to 2 g of each sample were dried in an oven at 45 °C for 48 h then using a clean spatula ground into soft homogeneous powder. About 200 mg of the powder were weighed accurately to the nearest 0.1 mg and placed inside a 20-mL polytetrafluoroethylene digestion vessel. To each vessel, 9.9 mL HCl and 3.3 mL HNO₃ were added and the vessels were sealed. A starting pressure of 50 bar (with Ar) was applied to each vessel before applying microwave power. Heating was continued for 76 min, where the temperature rose to about 240 °C and the pressure to about 120 bars. The microwave power was stopped and the vessels were allowed to cool at room temperatures for about 90 min before opening the vessels. Colorless, homogeneous digestion solutions were obtained, indicating efficient destruction of the organic matter. The contents of the digestion vessels were quantitatively transferred into graduated 15-mL polypropylene tubes and diluted to the mark with dH₂O. A laboratory blank and SRM were included with each batch of 10 samples. All samples solutions, SRM, and blank solutions were filtered through 0.45 µm filters.
and microsyringe filters before being analyzed using the ICP-MS; details on the quality control/quality assurance (QC/QA) can be found in the study of Nriagu et al. (2018).

2.4. Risk assessment by simulation tools

Trace elements in different media can enter the human body through three main exposure routes, namely, ingestion, inhalation and dermal contact, which brings both carcinogenic and non-carcinogenic health risks. For the assessment of health risks associated with the regular use of face powder by females, we considered the exposure route related to the dermal contact only. Also, we treated the considered trace elements as non-carcinogenic elements.

The average daily exposure for i-th given heavy metal via dermal contact $ADD_{derm,i}$ (in milligrams per kilogram of human weight per day, mg/(kg-day)) is given by

$$ADD_{derm,i} = \frac{C_i \cdot SA \cdot CF \cdot SL \cdot ABS \cdot ED \cdot AT}{BW}$$

where $C_i$ is the concentration of the i-th chemical element in face powder (mg/kg); $SA$ is the exposed skin area, (cm$^2$); $CF = 10^{-6}$ (mg/kg) is the conversion factor; $SL$ is skin adhesion (mg/cm$^2$-day); $ABS$ is the dermal absorption fraction for a given element (dimensionless); $ED = 2.365 = 730$ (day/annos) is the exposure frequency (here we suggested that face powder is used twice a day); $AT = ED = 365$ is the average exposure time to different elements (USEPA, 2004).

A non-carcinogenic Hazard Quotient ($HQ_i$) is calculated as

$$HQ_i = \frac{ADD_{derm,i}}{RfD_{derm,i}},$$

where $RfD_{derm,i}$ is absorbed reference dose (for dermal exposure, mg/(kg-day)). Its value could be calculated from the value of oral reference dose, $RfD_{oral}$ using the following relation

$$RfD_{derm,i} = RfD_{oral} \cdot ABS_{G1/F} \cdot$$

where $ABS_{G1/F}$ is the fraction of contaminant absorbed in gastrointestinal tract (dimensionless) in the critical toxicity study. The values of $RfD_{oral}$ and $ABS_{G1/F}$ for most of the trace elements could be found in the database (USEPA, 2020).

The total health risk through exposure to different elements (Hazardous Index, $HI$) should be calculated as

$$HI = \sum_{i=1}^{N} HQ_i,$$

where $N$ is the number of different elements that are present in a given powder.

In general, the health risk assessment procedure provides a clear and systematic form of quantitative description of environmental health impact. Several variables included in the right hand side of Eq. (1) (concentration of a given metal, exposed skin area, skin adhesion, dermal absorption fraction, body weight, etc.) exhibit uncertainties of different origin and nature. In other words, each of these variables is probabilistically distributed within a specific range. A widely used tool for the assessment of risk which provides a methodology of describing the sensitivity with respect to different exposure factors and evaluating different intervention scenarios is the Monte Carlo simulation technique. In this probabilistic approach all variables and parameters used in risk assessment may be considered as probabilistically distributed. The values of these variables and parameters are randomly chosen, the estimated quantity is calculated many times, and finally its probabilistic density is found. In this work, we employed Monte Carlo simulation technique to calculate Hazard Quotients (HQ) and Hazardous Index (HI) for all cosmetic powder samples and all different metals present in these samples (see next section).

3. Results and discussion

3.1. Elemental analysis of the collected samples

The comprehensive analyses of the collected samples covered 26 elements (Table 2), few of them are known to be toxic and the rest were considered as a baseline for comparison with other studies. Generally, the targeted elements were detected in the 14 samples; however, Fe, Al and Mg were below the instrumental detection limit in few samples. Moreover, the targeted elements, Al, Ba, Ca, K, Li, Mg, Mn and Zn were found at concentrations of mg/kg compared to the rest, which were found at μg/kg. The four producing countries of face foundation powders did not show major differences in the concentration of the elements. The products of the same country did not show common agreement among elemental concentrations. The price of the brand does not mean less content of the toxic elements (Tables 1 and 2). The expiry date (6 months–36 months) has nothing to do with the concentrations of the elements in all samples. Finally, the label of each container did not give any scientific information about the real content of elements especially the toxic ones.

We tried to select the most common international brands of cosmetics; however, the available studies including the recent ones focused mainly on the local produced cosmetics (e.g. Japan, China, Nigeria). Comparing the maximum concentrations of different elements measured in this study with the two recent studies revealed that there is a very good qualitative agreement (Table 3). It is important to mention that the face foundation products in the developing countries (e.g. Nigeria and India) are not of less quality in terms of elemental contents. Additionally, the studies of different consumer group colors (e.g. China, India, Nigeria, USA and Qatar) confirmed that the elemental concentrations in the available face foundation powders are very similar (Aldayel et al., 2018; Iwegbue et al., 2016).

| Element | Max. conc. | Our Study | Aldayel et al. (2018) | Iwegbue et al. (2016) |
|---------|-----------|-----------|----------------------|----------------------|
| Pb      | 912       | 7710      | 326,000              |                      |
| Sn      | 791       | 6510      |                      |                      |
| V       | 1457      | 15,700    |                      |                      |
| Zn      | 8,909,200 | 24,400,000| 325,000              |                      |
3.2. Calculation of exposure

First, we calculate the exposure related to the dermal contact using Eq. (1) and assuming that all 20 considered elements are non-carcinogenic elements. For the concentrations $C_i$ we use the mean values from Table 2. We took the value of $SL = 0.07$ mg/(cm$^2$day) for the skin adhesion (Alam, 2019); SA = 565 cm$^2$ for the average exposed facial skin area (SciComm, 2012); and $BW = 62.8$ kg for the average body weight (Jiang, 2020). Metal dependent parameters $RD_{des}, ABS_{cl}$, $RD_{dern}$, and $ABS$ are shown in Table 4.

Table 5 shows Hazard Quotients (HQ) for all 14 samples and all 20 considered heavy metal elements calculated by using Eqs. (1) and (2).

In general, all of these parameters are quite small which is a positive characteristic of all considered cosmetic powders. When the value of HQ is less than 1, the exposed consumers are considered to be safe. If HQ is equal to or higher than 1, the substance is considered as not safe for human health. Therefore potential health risk occurs, so related protective measurements should be taken.

To estimate the risk to human health due to the exposure to the twenty elements, the Hazardous Index (HI) has been developed. For each sample, the Hazardous Index is calculated as the sum of the hazard quotients for all elements (Eq. (4), Table 6). This Table shows that calculated HI are also well below unity, i.e., the dermal exposure to trace elements in the considered facial powders is negligible, i.e., the

Table 5 shows Hazard Quotients (HQ) for all 14 samples and all 20 considered elements.
cosmetics is quite safe.

3.3. Risk assessment

The comprehensive health risk assessment requires a quantitative analysis of the dermal absorption of trace elements. The risk assessment (HI) calculated above is based on mean (single) values of all variables, i.e., it should be considered as an estimate. As already mentioned, the complete set of variables should include concentrations of a different chemical elements in the sample, exposed skin area, skin adhesion factor, dermal absorption fraction, body weight, frequency of exposure, etc. In general, all of these variables are probabilistically distributed and, therefore, one should quantify the uncertainty factor for the risk. Monte Carlo simulations, a widely used techniques for modeling natural, social or economic phenomena helps to solve this problem. Also, this method is widely used in risk assessment. In the probabilistic approach, based upon the Monte Carlo techniques, all variables and parameters used in risk assessment could be considered as random variables characterized by probability distribution functions (Thompson, 1992). During the process of repeated simulations, the estimated quantity (a risk or hazard quotient) is calculated many times (1,000,000 for each simulation in this work) with randomly chosen values of variables and parameters covering their range of variability and reproducing the distribution density for the calculated variable. The final result is given in the form of a probability distribution. This is inherently a more informative way of presenting the results allowing to capture rigorously the uncertainties related to interpersonal variability in chemical and biological factors related to the process of interest.

For the purpose of Monte Carlo simulations, concentrations $C_i$ of twenty elements were modeled using two different distributions: (i) log-normal distributions; (ii) normal distributions. In both cases, the mean values and standard deviations were the same and taken from the experiment (Table 2). We tried two different distributions because the actual distribution functions are not known and the only data available are the mean value and the standard deviation of a given variable. First, we kept all other parameters in Eqs. (1)–(4) fixed, their values were given in the previous subsection. Fig. 1(a) and (b) show Probability Distribution Functions (PDF) for the Hazardous Index (HI) for one of the samples (Sample 2). As we can see, the result does not depend strongly on the choice of the distribution for metal concentrations. This is not surprising because HI is a sum of 20 $HQ_i$ variables for each sample, and the central limit theorem (which establishes that when independent random variables are added, their properly normalized sum tends to a normal distribution even if the original variables themselves are not normally distributed) starts to work. Fig. 1(c) and (d) used the same concentration distributions as Fig. 1(a) and (b) but we assumed that the body weight (BW) variable is normally distributed with standard deviation of 8 kg. As we see, the two distributions in Fig. 1(c) and (d) are also nearly identical but just a bit broadened as compared with Fig. 1(a) and (b).

The results of the Monte Carlo simulations for all 14 samples are shown in Fig. 2. Log-normal distribution for each metal concentration was assumed, and all other parameters in Eq. (1)–(4) were kept fixed. First, we notice that the shape of all HI distributions is close to normal distribution which is a consequence of central limit theorem. The PDFs have different mean values and standard deviations but all HI distributions are well below unity, i.e., the exposure to trace elements in using the considered cosmetic facial powders is negligible.

4. Conclusions

The total 14 samples of face foundation powders produced in five
western countries (France, USA, Italy, Canada and Ireland) show significant concentrations of all analyzed elements. For health risk assessment, we considered only the dermal contact with toxic elements and ignored the indigestion and inhalation related toxicity (which is reasonable for face foundation powders). The maximum concentrations of tested elements were similar to their concentrations in products of other countries (China, India and Nigeria). Price, packaging and expiry dates did not play significant role on the concentrations of the tested elements.

We employed Monte Carlo simulations to calculate risks associated with twenty trace elements. Our results indicate that the total non-carcinogenic health risk through exposure to different elements (Hazardous Index) does not strongly depend on the choice of the probability distribution function for the concentrations. We also show that taking into account probability distributions of other variables and parameters such as body weight, exposed skin area, skin adhesion, etc. does not significantly change the main result just slightly broadening the final Hazardous Index distribution function. We found that calculated Hazardous Index is well below unity for all considered samples, i.e., the dermal exposure to trace elements in the considered facial powders is negligible and the considered face foundation powders are quite safe to use.

**Credit author statement**

Basem Shomar, was leading the research project on quality of cosmetics. He secured the internal funds from Qatar Foundation, performed the lab experiments and obtained the needed basic data. Sergey Rashkeev, performed calculations, analyzed the data and interpretation. Both authors prepared and finalized the manuscript.

**Declaration of competing interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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